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# ARC FLASH IN SINGLE-PHASE ELECTRICAL SYSTEMS

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# ARC FLASH IN SINGLE-PHASE ELECTRICAL SYSTEMS

A Dissertation Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

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December 2020

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*This work is dedicated to those who have come before*
*and*
*those who encourage and inspire now*

*but most especially to my wife and my family*

*"We stand on the shoulders of giants."*

*- Isaac Newton*

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## Disclaimer

This work explores the history of arc flash investigations and the basis for IEEE 1584 calculations and presents the results of experiments addressing one gap in that Standard. These experiments and the conclusions drawn are the work of the author and do not reflect the work of the IEEE 1584 Working Group nor are they part of the IEEE 1584 Standard.

Findings are intended to contribute to the base of knowledge and inspire further exploration. The author assumes no responsibility for any safety-related decisions, or the consequences thereof, based on this work.

# ABSTRACT

Arc flash and blast are hazards unique to electrical installations. Such events can start fires, destroy equipment, and severely injure or kill workers. NFPA 70E and IEEE 1584 are defining standards for arc flash hazard analysis used during system design, construction, and maintenance. Both focus on three-phase faults for calculations since three-phase power distribution is predominant in utility and industrial applications. However, discussion of arc flash in single-phase systems prevalent in residential and commercial facilities is excluded. Single-phase faults can also occur in a variety of industrial and utility circumstances.

This dissertation explores historic background and treatment of arc flash and foundation phenomena, considers IEEE results as published in the 1584-2018 standard, and documents the author's work with single-phase arc flash.

Experiments were performed at the Schneider Electric facility, High Power Lab #3 in Cedar Rapids, Iowa in June and September 2020. This facility provided a test article; a full suite of voltage, current, and temperature instrumentation; high-speed video recording; and interface for a blast pressure transducer provided by the principal investigator. Test plan development used a template provided by Schneider. Scenarios were peer-reviewed in advance.

Experimental work revealed very low levels of heat released for most single-phase arc fault events at 434 volts and below though there was still blast, flash, and splatter of molten wire residue. In contrast, single-phase events at 460

volts and above produced sustained arcs, orders of magnitude more heat, and dangerously high levels of blast pressure.

Conclusions drawn are that low energy single-phase systems may be at low or very low risk of yielding arc flash burn-related injuries resulting from accidental short circuits.  However, single-phase faults in systems with open circuit voltage at 460 volts or greater can produce significant levels of incident heat energy, flash, and blast pressure even at moderate levels of available fault current.

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# LIST OF ATTACHMENTS

All attached data files are identified by Oscillogram Number.

Raw Voltage / Current Data Files and Spreadsheets (ZIP File)

Raw Calorimeter Data Files and Spreadsheets (ZIP File)

30044 Video (MOV File)

34451 Video (MOV File)

Oscillogram PDFs (ZIP File)

High Speed Video & data files (ZIP File) - requires VLC Player or similar

# Chapter One : Introduction

Since the advent of electricity as a harnessed power source, its potential for causing harm and death has been well-understood. The lethal nature of electric shock was already recognized at the beginning of the competitive race to commercialize electricity [1, 2]. For the next 100 years, the focus of electrical safety was on shock hazards and the potential for faulty electrical systems to cause structural fires [3, 4]. A significant example was the demand for inspection of the electric power and light exhibit at the 1893 Columbian Exposition (Chicago World's Fair) following a July fire, attributed to faulty sign wiring, that resulted in the deaths of twelve firefighters and four bystanders [5]. This awareness subsequently led to the formation of both Underwriters Laboratories and the National Fire Protection Association (NFPA) [3, 6].

The dangerous phenomenon identified as arc flash, or high energy arc fault, began rising in industry's awareness in the early 1960s even though 480-volt three-phase systems (which are at increased risk for such events) had been in commercial use since the 1930s [7]. Following several injury incidents at DuPont facilities, Ralph Lee published a 1982 paper [8] suggesting that heat from arc flash events could be predicted mathematically. In 1987, Lee offered additional work [9] attempting to explain the explosive nature of arc flash events including expulsion of molten material and debris from the locus of the event.

Four years later, the Occupational Health and Safety Administration (OSHA) [10] documented recognition of arc flash as a unique cause for concern. At OSHA's prompting, NFPA created a new standards committee to address the concern for worker electrical safety. The first edition of the workplace electrical safety standard NFPA 70E [11] was published in 1979. However, arc flash would not appear in 70E until 1995 [12].

Increasing awareness of and interest in understanding arc flash events, as a specific aspect of arcing faults, and their potential to cause life-threatening burns and to start fires led several teams to investigate both arc flash incident energy predictions and personal protective equipment (PPE) selection [13]. These investigations culminated in the development of the first edition of IEEE Standard 1584, *IEEE Guide for Performing Arc-Flash Hazard Calculations*, in 2002. Additional experimental investigations [14] added data to the collection. Knowledge arising from these investigations drove significant revision to the 1584 Standard [15] and led to an increased understanding of the phenomenon, methods for reducing the occurrence of arc flash, and improved PPE specifications.

One of the bounding conditions for the application of both NFPA 70E and IEEE 1584 calculations is the assumption of a three-phase fault. This assumption addresses common utility and industrial circumstances. However, neither speaks adequately to single-phase faults or lower energy, single-phase systems. This is tacitly recognized in 1584 Section 4.11, with acknowledgment that suggests the calculation method may yield overly cautious results. In certain cases, this approach does not provide reasonable guidance for PPE selection or arc flash mitigation erring on the side of excessive PPE.

This dissertation further investigates single-phase arc flash.

- Literature review documents past works with arcing faults and arc flash; foundation theory of electric arcs; basis for medical assessments of injury due to burn, blast, and ultraviolet (UV) exposure. Selected case studies of arc flash as well as blast injuries and fatalities resulting from such exposure, establish relevance.
- Experimental work investigates the vertical conductors in a box with open ends (VCB) electrode configuration common to residential circuit breaker panels. This configuration may also be encountered in industrial applications.
- The results section presents data from the experimental work, mathematical analysis, and connects results to representative past works. This is followed by interpretation and conclusions.

The objective of this work is to contribute to the subject knowledgebase and inspire additional work in an area directly related to electrical worker and facility owner safety.

# Chapter Two :
# Literature Review - Arc Flash

## Early Work on Arcing Faults

Since the late 1800s, arcing faults have been a subject of interest and concern. *American Electrician Magazine*, first published in January 1887, was a safety-oriented and skill-of-craft periodical that regularly included articles describing the prevention of arcs. The predominant interest of the electrical safety community in the 19th and early 20th century was fire, equipment and facility damage, and shock risk, consistent with the focus of the National Electrical Code.

Wagner and Fountain published “Arcing Fault Currents in Low Voltage AC Circuits” [16] in 1948. The investigators’ interest was arcing and bolted faults in metal-clad switchgear. Their observations on experimental results were frequently confirmed by succeeding investigators. These observations included the assertion that arc currents and voltage drop values demonstrate significant instability even in highly controlled experimental environments. They also observed that voltage developed across an arc tends to fall in the range of 40% to 60% of line voltage. The authors remarked that as a result of induced arc faults, “The [bus] bars were thrown from their positions violently.” Since arc flash and arc blast were not yet topics of consideration, they did not comment on the nature of the forces that could have caused this violent deformation.

Francis Shields’ 1967 paper used the term “burndown” to describe equipment damage due to persistent, arcing faults [17]. He went on to emphasize improved sensing and protection. This treatise, like others of the time, detailed physical equipment destruction including several dramatic case vignettes. It is noteworthy that Shields acknowledged the very rapid generation and release of large amounts of heat during such an event. This heat would later come to be recognized as a hallmark of arc flash.

What would become OSHA General Industry Safety Standard 29 CFR Part 1910 Subpart S (1910.301 - 1910.399) came into existence in 1970 and complemented Subpart R (1910.269) that covered protective equipment. Initially, OSHA focused solely on the electrical safety topics and installation requirements identified in the National Electrical Code (NFPA 70) including shock hazard and faulty electrical systems causing fires [4] and combustion burns. Arc flash, as a topic of awareness and concern, was not mentioned.

J.R. Dunki-Jacobs published several articles beginning in 1972 [18] detailing the nature of system damage and failure due to arcing ground faults. Early in the 1972 paper, the author identified the change from three-phase delta to three-phase 4-wire WYE distribution systems as a significant contributing factor to an increased incidence of burndowns at that time. More significant was his assertion that “Due to increasing load density requirements, an increase in voltage to 480Y277V became an economical necessity…” since “Research has shown that at the lower voltage, the arcing line-to-ground fault is essentially self-extinguishing…”. In his 1986 paper, the author developed an analysis of arcing ground faults describing how single-phase faults escalated to three-phase faults [19], asserting that arcs to ground may generally self-extinguish.

In 1974, H.I. Stanback, with Square D, performed a series of tests [20] on a representative 277-volt single-phase test article resembling one corner of a motor control center bus section.  This structure was chosen to contain arcs and sustain them rather than allowing them to blow off the ends or edges of rods or open-end buses.  The intention was to identify a bracketing approximation that could be used in system modeling.  The author's experiments identified bus bar burning rate ***Y*** (a measure of arcing energy) having the following relationship to arcing current ***i***:

$$Y \propto i^{1.5} \qquad (1)$$

While this experiment series again reflected the interest of the day, i.e. equipment damage, it also discussed results showing the self-extinguishing character of arcing faults at around 6 cycles (0.1s) in the 277-volt single-phase regime.

By the early 1980s, the nature of electrical arcs as an ignition source was well-established.  It was known that, while an electrical short-circuit would yield nearly immediate overcurrent protective device activation, an arc through air would not necessarily do so and could potentially burn for several seconds and yield considerable heat.  Two articles by Beland [21, 22] illustrate this understanding. These articles included calculations and experimental results showing energy yield from an arc in a 30A residential circuit potentially as great as 19,000 joules.  The high voltage developed across an air gap, equal to the phase-to-phase voltage for the low voltage system Beland considers, maximized the heat produced by the arc in this case.

## Initial Consideration of Arc Flash

As early as 1968, Dow Chemical had introduced an arc flash PPE program though there was not yet a way to determine how much PPE was adequate. In the early 1980s, DuPont Chemical began their own PPE program. While at DuPont, Ralph Lee became involved with arc flash injury prevention. His 1982 paper used cable failure data in a novel attempt to show how electric arcs could be a source of significant radiated heat [8]. His calculations suggest 10s or 100s of MW of heat energy, depending on plasma sphere diameter, including arc events with duration as short as 0.1s (six cycles of 60c/s AC). Lee's references to the surface temperature of the sun were overly dramatic. Nevertheless, they emphasized the unexpected and extraordinarily high levels of energy released in an arc flash event when compared to the burning arc faults that researchers and experimenters had been concerned with up to that time. With this sobering data, he then cited medical thresholds [23] for what he referred to as curable, i.e., second degree and non-curable skin burns. He linked heat exposure and duration to arc energy. This paper brought into focus industry's awakening to an emergent truth: heat from arc flash events represents a significant source of risk for personnel injury and death with lethal exposures possible at three feet from the event and significant injury still possible at ten feet.

In 1987, Lee further developed ideas about hazards associated with arc events by correlating arc current and distance to pressure wave magnitude. Lee's 1987 article included four examples [9] that focus on the mechanical aspects of a blast. The phenomena he calls attention to are hearing damage and the propulsion of personnel away from the event. Two of the examples identified a developing awareness of another previously unexplored consequence of arc flash and attendant blast: expulsion of molten metal droplets and their propensity for causing severe burns and starting fires. Others' work had attributed mechanical damage and deformation to magnetic effects, those forces being undeniably extreme. However, Lee concluded that arc flash is an explosive event that, apart from blasting heat, causes a powerful destructive shock.

In a 1994 industry article [24], Heberlein et al. summarized Lee's work on arc flash and arc blast and then documented a testing survey in Allen Bradley motor control center (MCC) equipment. The article begins with précises of two events where an arc and explosion occurred during maintenance work on MCCs. The objective of the ten experimental tests was to develop a body of information regarding the containment of arc blast inside an MCC compartment. A variety of conditions were explored including use of current-limiting fuses. The article also identified several circumstances under which the arc was self-extinguishing. Since the authors were Allen Bradley employees, it is understandable that the results focused on the confirmation of the MCC compartment doors' ability to contain an over-pressure due to arc blast.

## Development of Basis for Protective Equipment Selection

In a series of articles and papers [25-27] written between 1996 and 1999, Neal, Bingham, Doughty and their colleagues at DuPont further developed basis information for PPE selection for protection from electrical arcs, recognizing that by then NFPA 70E-1995 identified flash flame as an injury risk. This basis rose from an extensive experimental testing and modeling program, investigating arcs in 600V – 2400V open-air and enclosed systems. The results of these tests conceptually supported Lee's 1982 hypothesis and empirically yielded incident energy values at several distances from arc flash events. The authors connected their results to those of Stoll and Chianta [28] to establish relationships of incident energy to skin burn, including the now-familiar threshold 1.2 cal/cm$^2$ at 18 inches. Their 1997 article [27] detailed additional testing to establish the relationships between arc power, incident energy, conductor spacing, and, among other things, open versus enclosed arcs.

In 1990, Stokes and Oppenlander performed a series of experiments collecting data on vertical and horizontal arcs burning in open air [29] and compared the results to those predicted by mathematical theory previously developed by Lowke [30]. The data concentrated on the voltage and current of arcs burning between electrodes with separations varying from 5mm to 500mm and measured for up to 0.5 sec (30 cycles of alternating current). Of interest in the field of arc flash study were Stokes' results for gaps in the range 20mm to 100mm. These gaps aligned with the 1-inch to 4-inch spacings encountered in many types of commercially manufactured electrical distribution equipment. While at odds with the character of theoretical values predicted by Lowke (Figure 1, page 270), Stokes' data revealed arc energies in generally the same range: as high as 2MW to 8MW [29] for these spacings with burning temperatures in the vicinity of 6700°C. Stokes' later work supported the measured levels of heat energy.

## Recent Work

In the late 1990s and early 2000s, a flurry of work was published that explored and expanded knowledge about arc flash and arcing faults.

Jones, Liggett, Capelli-Schellpfeffer, et al. performed a series of 38 experimental tests in 1996 [31]. Seeking to represent conditions either known to cause arcing faults or known from prior case studies to contribute to injuries, test configurations simulated foreign objects and debris (misplaced tools) and open cabinet doors.

Jones' tests recorded temperatures, sound pressure, and photographic images of the induced arc flash events in 480-volt three-phase equipment. Like Neal et al. [25], they found real-world simulations produced results with high variability in likelihood, energy yield, duration, and arc propagation.

Building on their earlier work, in 1999, Doughty, Neal, and Floyd continued collecting test data. Their subsequent paper [32] offered the following important conclusions about arc flash events:

- Arc flash incident energy is directly proportional to the time duration of the arc.
- Transfer of radiated heat is also a function of arc current, electrode configuration, and environment (enclosed or open-air).
- Incident energy tends to peak at arc lengths greater than that where maximum arc power develops.

Their tests of 600V three-phase arcs at 6 cycles duration (0.1s) yielded arc energies between 5MW and 23MW, with maximum incident energies varying between 1 cal/cm$^2$ and 12.5 cal/cm$^2$ (Figure 2, page 270). Incident energy in test runs correlated closely with bolted fault current and revealed that an enclosure will contain and focus heat in one direction such that effective incident energy on the discharging face can be as much as three times higher than a comparable arc flash in open air.

*IEEE 1584 - IEEE Guide for Performing Arc-Flash Hazard Calculations* [15] was initially published in 2002 and was the first standard recognized by many industries and countries (though not all) as providing empirical underpinnings that extended previous knowledge. The arc flash incident energy predictions were based on data collected from hundreds of experimental runs. Das [33] was critical of this approach devoting an entire chapter of his 2012 book, *Arc Flash Analysis and Mitigation* to it. Nevertheless, the 2002 edition would prove to be only a beginning.

Wilkins, Allison, and Lang proposed a time-domain calculation model for arc flash, claiming a better representation of experimental conditions than IEEE 1584 [34, 35]. Furthermore, the authors cited anomalies resulting from the differences in piecewise 1584 calculation methods for high voltage and lower voltage systems that their unified expression approach did not exhibit. Their modeling method employed non-linear resistances and first-order differential equations derived from straightforward node analysis and described, though did not detail, a computational approach to deriving arcing behavior for both three-phase and single-phase systems.

In 2003, 2004 and again in 2006 Stokes and Sweeting [36-38] raised concerns that IEEE 1584 incident energy predictions were low for systems under 1kV because the 1584 premise was solely based on radiated heat, and because calorimeter placement in the standard experimental setup biased results. The authors conducted several experimental tests with bus rods in a horizontal configuration (as opposed to the conventional IEEE vertical configuration), with calorimeters measuring energy delivered from the axial ends as well as normal to the rods' axes and, like Jones, they incorporated high-speed photography to capture images of developing and collapsing arc plasma flares and clouds. The authors asserted that the plasma cloud originating from an arc event was a significant source of convective heat transmission that was not being measured by others.

Eblen and Short ran a series of 45 tests, described in their 2012 article [39]. They were concerned with protecting utility workers from arc flash events in 480-volt three-phase meter bases and panels. These tests dramatically supported the assertions made by Stokes and Sweeting concerning plasma clouds. Figure 3, page 271, illustrates the arc flash plasma plume ejected from a three-phase meter base during one of these tests.

Eblen and Short also compared their measurements to energies predicted by IEEE 1584. Their findings tended to run contrary to the concerns expressed by Stokes. In all cases, the authors' measured heat and calculated incident energy values were lower than what was predicted by 1584 calculations.

The authors also considered single-phase and phase-to-phase faults in transformers. Like Jones, Liggett, et al. they simulated a misplaced tool as the shorting mechanism for initiating a flash. They found that in the configurations explored, a single-phase arc flash generally escalated to fully involve all three phases within ½ cycle.

In 2013, Smoak and Keeth conducted a short series of 13 tests [40] simulating arcing faults in residential metering installations. The test setup consisted of a 7.2kV to 240/120V utility transformer with primary fuse, a secondary power pedestal, and a meter socket with a bypass handle. Electrodes were constructed of large gauge direct burial service entrance (URD) cable; size in the range of 4/0 was likely. The authors precisely controlled the gap distance between the electrodes from as little as 1/24 inch up to 1 inch. Fuse wires (the authors called them teaser filaments) initiated the arcs. Measured values were arc current and clearing time in 60Hz cycles. Fault currents ran as low as 1446A and as high as 12120A.

# Chapter Three :
# Analyses of Selected Works

## Lee’s Initial Work

Ralph Lee’s 1982 article documented a theoretical exercise that combined arc information from a cable insulation failure study performed at the University of Minnesota with data from skin burns to synthesize a thesis that arc flash events generate enough heat to radiate at a level that can cause serious or life-threatening injury. While not a new idea, this article was the first to clearly offer a suggested prediction calculation.

Lee calculated arc energy based on the assumption that the arc path through air is purely resistive. Using the RMS formula:

$$i_{RMS} = {i_{PEAK}}/{\sqrt{2}} \qquad (2)$$

to determine arc wattage based on AC current, Lee concluded that the maximum wattage possible for any value of arc path resistance R is calculated:

$$Watts_{MAX} = i_{RMS}^2 \times R \qquad (3)$$

Lee thus concluded that maximum arc power is delivered at one half the available bolted fault current. Lee tabulated maximum power transfer values as shown in Table 1, page 301.

Lee’s calculations are based on several simplifying assumptions and yielded maximum values based on theoretical circumstances. A key point to note is that several subsequent investigators determined that arc currents are highly unstable, and that arc behavior is non-linear. This instability and non-linearity undermine the validity of Lee’s assumptions. Additionally, Lee’s calculations are only applicable to three-phase systems and he did not consider systems with phase-to-phase voltage lower than 480 volts.

Lee's simplifying assumptions and calculation methods were implicitly called into question as early as 1995 when medical professionals such as Capelli-Schellpfeffer et al. [41] noted a need for "…reevaluation of the methods by which thermal burn severity is predicted." Lee's approach has also been the subject of withering criticism by more recent investigators, notably such authorities as Stokes and Babrauskas. Nevertheless, Lee's work suggested bracketing extremes that invited future investigations.

## Stanback

Stanback's [20] focus also reflected the concern of the day: equipment damage resulting from arcs inside large gear.

His team had conducted earlier tests in 1970 that simulated induced faults in a large three-phase circuit breaker panel by solidly connecting one phase to the fixture shell and shorting the other two phases to the shell with small-gauge fusing wires. These early tests yielded arcs only between the bus bars and the fixture shell. The arcs did not propagate across phases nor did they consume all three buses. The author concluded that phase-to-phase arcing did not occur because system voltage was 280V and bus gap was 1-3/8 inch. As available fault current increased from 3200A to 6600A, measured arc current as a percentage of available dropped from ~58% to ~41%.

Stanback's 1974 experimental series consisted of 38 total test runs with a key interest in bus and housing destruction due to sustained arcs. Twenty-four percent of these test runs self-extinguished within 1-1/2 cycles (25 ms). The author speculated that increased bus spacing, increased available current, or increased size of the bus (added layers of bus conductor) contributed to a reduction in arc stability. The test series covered two different materials (Cu and Al), a range of spacings (1 inch, 2 inches, 4 inches), several bus configurations (1 bar, 2 bars, 4 bars), and four different available fault current values (5150A, 9900A, 19300A, 36100A). The consequence of this variety was that there were only one or two tests for each combination of the four different parameters being varied. Furthermore, with 54 possible combinations, not all were examined. Additionally, the erratic nature of electric arcs resulted in the authors discarding 10% of the test runs as atypical. Nevertheless, single-phase arcs from bus to ground for gaps of one and two inches were consistently stable. Measured arcing times ranged between 21 cycles (350ms) and 72 cycles (1200ms).

While the investigators did apply computer-based, non-linear regression to yield relationships between arc current and quantity of bus and housing material lost, and expressed those results using statistical terminology, they did not seek to improve the statistical robustness of their results with increased numbers of test runs for each of the 54 possible combinations of material, current, spacing, and conductor mass.

The initially calculated material loss equations derived from the 34 usable test runs yielded the following expressions for Y (material loss in cubit inches) as a function of arc current are as follows:

For Aluminum Bus Bars:

$$Y = 1.979 \times 10^{-6} {I_{arc}}^{1.473} \qquad R^2 = 0.9868, \sigma = 0.2341 \qquad (4)$$

For Copper Bus Bars:

$$Y = 8.168 \times 10^{-6} {I_{arc}}^{1.251} \qquad R^2 = 0.9827, \sigma = 0.1005 \qquad (5)$$

For 0.1” Steel Housing:

$$Y = 8.168 \times 10^{-6} {I_{arc}}^{1.251} \qquad R^2 = 0.9559, \sigma = 0.1151 \qquad (6)$$

The authors went on to arbitrarily select an $I_{arc}$ exponent of 1.5 to “…facilitate practical use of the damage formula concept.” This choice seems unnecessary since pocket calculators were supplanting slide rules by the early 1970s and fractional exponents shouldn’t have presented a calculation difficulty. However, the developed expressions, with coefficients of determination and standard deviation comparing favorably to the basis equations, suggest their choice may have been reasonable at the time.

Stanback offered further observations about the character of the arc current and voltage during the test runs. Measured arc voltage exhibited an approximate square wave behavior due to flattening of sine wave peaks. Though not called out in the paper, this behavior is now understood to arise from the non-linear nature of conduction in plasma.

The author cites a historic principle that 277V single-phase arcs to ground will self-extinguish when arc current is less than 38% of available fault current; however, the author goes on to acknowledge the erratic character of arcs and suggests the doubtful utility of this value.

## Doughty, Neal, Bingham, Floyd

The most common experimental methodology employed by a variety of investigators considered arc flash events induced on vertical copper buses, either in open air or inside an enclosure open on one side. Copper slug calorimeters were, and continue to be, used to make emitted energy measurements normal to the plane of the vertical bars.

In their 2000 paper describing the results of a series of experiments, Doughty, Neal, and Floyd offer a second-order polynomial expression for maximum open arc incident energy as a function of bolted fault current, based on curve-fitting their experimental data. The data set was quite small in this case - four test runs in each of two configurations.

The test setups described in their 1997 paper [27] were identical: vertical buses, open-air and enclosed, with calorimeters perpendicular to the axes of the bus rods. Compared to modern understanding, the test data set was sparse, and the straightforward algebraic expressions for arc power lacked sophistication.

By contrast, Neal, Bingham, and Doughty’s slightly earlier work developing protective clothing guidelines [26, 42] incorporated a testing and data collection sequence using single-phase arcs in the 600V to 2400V regime. Arc events were initiated with electrode gaps varying between 1 and 7 inches. For open-circuit voltage equal to 630V, arc voltages developed in the approximate range of 400V to 450V and measured incident energies ranged between 4.5 cal/cm$^2$ and 8 cal/cm$^2$ (Figure 4, page 271). Tests were limited to six cycles (100ms) to control test setup damage.

While experimenters have suggested that single-phase arcs are difficult to initiate or maintain, this set of experiments and Stanback's work amply demonstrate that single-phase arcs will persist and yield considerable energy.

## ASTM

Coincident to and supported by the work of Neal et al., the American Society for Testing and Materials (ASTM) published tentative test method PS57 for determining flammability of flame retardant (FR) material in PPE. This method, and its current successors F1958 and F1959 [43], used and still use a single-phase arc, generated between two electrodes, spaced 12 inches apart, and initiated with a fuse wire. The fuse wire was, and remains, the method of choice for starting an arc in all controlled experimental environments where system voltage is less than the breakdown potential of air. While the objective of the test method was PPE flammability testing, and the 12-inch gap used in this test was so large as to apply only to utility voltages, this test method demonstrated that single-phase arcs can be established and source enough heat to ignite nearby materials.

## NFPA 70E

The 2015 revision of NFPA 70E requires that risk assessment and mitigation be performed for all electrical work. The procedural content does not dictate the method for conducting arc flash calculations. Various calculation methods are found in Annex D.

Annex D assembles the work of several investigators to date, attempting to cover all situations. The Annex begins with a repetition of Ralph Lee's calculation method directly from his 1982 paper [8] followed by a collection of sample calculations. The method is described as "…conservative over 600V and becomes more conservative as voltage increases." Lee did not consider systems below 480 volts. More recent data show that incident energy results calculated using this method for utility distribution systems are excessive.

The next section repeats the work of Doughty, Neal, and Floyd [32] for arcs in open air and arcs in a box. Calculations are limited to three-phase arc currents between 16kA and 50kA.

The third section repeats the calculations found in IEEE 1584-2002. The general limitations identified are for three-phase systems 208V to 15kV, 0.7kA to 106kA fault currents, and with conductor gaps ½-inch to 6 inches. Arc current and incident energy are determined using first-order polynomials. There are detailed correction factors for fuses, circuit breakers, and enclosures. These formulae are significantly less sophisticated than in the 2018 revision of 1584 and do not have the advantage of a much-enlarged sample set.

## Stokes, Oppenlander, and Sweeting

Stokes and Sweeting [38] continued the earlier work of Stokes and Oppenlander [29], performing additional arc tests on horizontally oriented bus rods with open ends. The authors show that magnetic effects drive arcs in horizontal bus structures to yield higher levels of heat and arc plasma than in vertical configurations on which IEEE 1584-2002 was based. The horizontal-with-open-ends configuration directly reflects the terminal configuration often encountered in ground-mounted utility transformers.

Their more recent work investigated arc plasma as a source of convective heat energy transmission. In their 2003 conference paper, “Electric Arcing Burn Hazards”, the authors expressed concern that IEEE 1584 methods at the time yielded overestimates of heat for high voltage systems and alarming underestimates for systems under 1kV by failing to consider effects of the plasma cloud, particularly for horizontal buses with open ends.

The authors’ high-speed photographs significantly reveal the behavior of arc flares across several milliseconds. These photographs answer an important question that differentiates three-phase arcing systems from single-phase: why are three-phase arcs readily self-sustaining? The answer is apparent in the arc images. Stokes’ and Sweeting’s images (Figure 5, page 272) showed that magnetic effects influence the behavior of arc plumes drawing them closer together or driving them apart. This attraction of plumes could initiate or sustain phase-to-phase flashover in a three-phase system and ultimately result in all three phases becoming fully involved. Note in the photo sequence the back-and-forth movement of the arc plumes between bus rod ends as the plumes develop and decay (images left to right, top to bottom).

Significantly, the magnetic attraction of arc plumes is not a possibility in single-phase arcs, hence the authors observed that “For single-phase open-air arcs at a supply voltage of 415V, self-interruption always occurred in < 10 ms.” Contrary to the authors’ assertions, however, this initial interval was still enough for a single-phase arc to achieve its highest temperatures though the emitted energy from less than one A.C. cycle (1/60 second) is more likely radiant than convective.

Further developing the idea of very high arc flash temperatures theorized or observed by their predecessors, Stokes and Sweeting reported plasma cloud heat values (Figure 6, page 272) that could reach 14,000°C, depending on arc current magnitude, immediately following arc onset.

Ironically, Doughty, Neal, and Floyd pointed toward these very results in their 1999 investigations, noting, “Video observation of the arcs in the box indicated that a significant portion of the increased incident energy was due to increased convective heat energy transfer due to hot gas expansion and projection out the front of the box toward the sensors. This effect visibly and dramatically increased at higher current levels. It appeared that, as the arc current increased, the arc plasma volume increased and the plasma projection out of the box increased.” [32] However, that team immediately settled back into conventional wisdom and asserted that radiant emission was responsible for 90% of arc flash heat transfer [42].

## IEEE 1584

IEEE 1584 was originally issued in 2002 and revised for reissue in 2018 [15]. This later version of the model and calculations is based on a statistical consideration of nearly 2000 experimental test runs, with equations derived from partial regression analysis. These tests were performed over a variety of voltages and available fault currents. Perhaps influenced by work of those such as Stokes, the calculation method was expanded beyond the 2002 models to address various conductor configurations: vertical buses inside a metal box, vertical buses terminated in an insulator and inside a metal box, horizontal buses inside a metal box, vertical in open air, and horizontal in open air. These bus structures are reflected in the standard's Electrode Configuration selections in section 6.6. While Stokes' work was not credited explicitly for influencing the 2018 standard, both open-air arrangements address his objection to the previous version of the standard that asserted end-on arc flash and its attendant plasma cloud had not been considered and are more dangerous than conditions obtained normal to a vertical bus.

The calculation method requires several steps. The equations include terms for electrode configuration, system voltage, enclosure type, and arc gap. The initial calculation for average arcing current is the product of an exponential that accounts for bolted fault current and arc gap, and a $6^{th}$ order polynomial with coefficients selected based on operating voltage and electrode configuration. Criticism of the previous 1584 calculation approach by Das [33] and Wilkins [35] noted the use of Lee's equations for systems above 15kV, and anomalies arising from differing treatment of low voltage versus high voltage. The single series of expressions used throughout the 2018 revision responds to those concerns.

Once intermediate values are determined for arc current and incident energy, several correction factors are then applied that account for arc variation, enclosure size and type. Final values are then calculated. When system voltage is between 208V and 600V, several intermediate steps are skipped.

As noted previously, paragraph 4.11 of the standard is explicitly clear, “This model does not cover single-phase systems.” While identifying a conventional method for applying the calculations to single-phase, 4.11 also advises, “The incident energy result is expected to be conservative.”

The previous version of IEEE 1584 included the assertion[1] that “Equipment below 240V need not be considered unless it involves at least one 125 kVA or larger low-impedance transformer in its immediate power supply.” [44] However, the 2018 revision eliminated this declaration in favor of the more general statement, “Sustainable arcs are possible but are less likely in three-phase systems operating at 240 V nominal or less with an available short circuit current below 2000A” because the exemption’s assertion was contradicted by subsequent testing [45, 46].

## Smoak and Keeth

While Smoak and Keeth’s study [40] was very limited, it explored the regime specifically of interest in this dissertation and makes some useful boundary condition observations.

The test stand reflected a common residential single-phase service. The secondary pedestal located immediately adjacent to the transformer yielded higher available secondary current. The authors observed that under ordinary circumstances the short circuit current at a meter base or distribution panel main breaker would be lower due to impedance in the longer service drop length.

[1] The 240V/125kVA exemption was convenient for residential applications since 125kVA is a conventional size for pad-mounted transformers supplying two 240V 200A breaker panels.

Two of the test runs were bolted fault and two runs were nearly bolted fault, using the meter base bypass handle to create a 240-volt phase-to-phase short circuit. Two sizes of transformers were tested: 50kVA and 167kVA, with results shown in Table 2 and Table 3, starting on page 301. The authors did not comment on transformer impedance or primary side characteristics such as available power or X/R ratio, nor did they offer theoretical bolted-fault short circuit current calculations. Not considering utility characteristics is apparent in the lack of explanation for relatively low, and variable, levels of fault current. While it could be argued this simulates real-world conditions to which utility linemen may be exposed, the objective of such work is most useful when consistently demonstrating worst-case conditions from which electrical workers must be protected.

Unfortunately, Smoak and Keeth's experimental setup did not include heat measurements. They instead relied on IEEE 1584-2002, and NFPA 70E which in 2013 still referred to Lee's equations and the work of Doughty and Floyd. Both calculation approaches were inappropriate for predicting incident energy in most 240-volt systems with fault currents and arc gaps in the range measured. Nevertheless, the authors applied Doughty's calculation method to Test 7, the only one that met the applicability criteria. Based on this single calculation, they asserted that expected incident energies would be "…less than 1 cal/cm$^2$ at a radial distance of 18 inches from the arc." due to the arcs usually self-extinguishing in less than ½ cycle.

## Gaps in Arc Flash Research for Single-Phase Systems

A salient point in Wagner and Fountain's 1948 synopsis [16] relevant to low-energy system arc flash is the conclusion that "On 250-volt and 125-volt a-c circuits, arcing faults are unstable and will extinguish themselves within two cycles or less even when initiated by four number 8 copper wires on a bus with 4-inch spacing." While this would seem to provide very useful guidance in establishing a bounding condition for low-voltage arc situations, the authors go on to say "On buses with less than 4-inch spacing, it would be expected that the arc would have more of a tendency to stabilize itself."; an assertion they posit but did not test. This lack of data overshadows the seeming utility of the 2-cycle apparent limit or the expectation of sustained arcs since energized conductor spacings of less than four inches are quite common in panelboards designed for 240 volts or less.

Stanback, however, did look more closely at 277-volt single-phase-to-ground arcing conditions and determined that, for certain configurations at least, sustained arcing is possible. While this work did not address the condition now identified as arc flash, it demonstrated practical interest in single-phase arcs in electrical equipment.

IEEE 1584, as noted previously, is brief and clear. As single-phase arc flash was not part of the experiment series, single-phase arcs are not supported by the calculations and more research is needed.

Jones, Liggett et al. observed that "The results confirm that single-phase faults are much more difficult to sustain that three-phase faults." [31] Citing previous work by Dunki-Jacobs [19], the authors declared that the plasma collapse every half cycle would cause self-extinguishing. This would be of primary interest to those concerned with fault propagation and arc fault burndown. However, the authors do not speak to the difficulty of initiating an arc flash in a single-phase system. Furthermore, this declaration is contradicted to some extent by the work of Neal et al. in their PPE investigations [26].

Additionally, minimal focus on the initiation of single-phase arc events was implicit in the work of many of Jones' predecessors. Laboratory methods used by Dunki-Jacobs, Stanback, Doughty, Floyd, Eblen, and many others were concerned with three-phase fault conditions because those will verifiably yield flash and blast. Stokes' and Sweeting's later experimental configuration provided for exploration of single-phase arcs, but their most cited article only briefly mentioned results and did not draw conclusions. Neal's thorough treatment of single-phase arcs when developing PPE requirements stands out as a noteworthy exploration of the subject. The test scenario Neal employed is most appropriate for single-phase to earth ground faults such as those a utility line worker might encounter but does not reflect circuit breaker panels or similar enclosed equipment.

Some investigators have been curious about single-phase arc flash, whether at commercial distribution voltage or at utility level voltage. However, the preponderance of work to date has chiefly addressed three-phase systems. The literature does not illuminate why single-phase arc flash seems to be minimally explored.

# Chapter Four :
# Literature Review - Electric Arcs Behavior and Effects

Experimenters' observations of electric arcs reach back to the very beginnings of interest in understanding electricity. Sir Humphrey Davy's development of a rudimentary arc lamp traces to the early 1800s [47]. While shock and burn injuries from electrical exposure were also well-understood, it wasn't until the mid-20$^{th}$ century that physicists and medical professionals worked to quantify the nature of these injuries, and regulatory and standards agencies documented methods of protecting workers [48].

## Physics of Fuse-Wire Initiated Arcs

### *Time to Onset*

For the fine strand (133 conductor) 10 AWG copper wire used in many arc flash experiments, the nominal DC resistance of the wire is 1.1 ohms per 1000 ft and mass is 49 kg/km. Considering an experimental setup with 1.5 inches between electrodes, this yields 0.1375 milli-ohms for the wire with mass 1.8669 grams.

Fusing current for 10 AWG wire is estimated between 333A and 1600A [49-51] depending on time allowed for fusing to occur, with times of one second up to ten seconds being traditional. Stauffacher's expression ([50] pp. 326) is the result of integrating a temperature-dependent expression for resistivity and specific heat of copper and, despite a dubious credit to I. M. Onderdonk, is mathematically valid [52] for short intervals of time. Assuming the moment of failure (fusing) occurs when a copper conductor reaches melting temperature, then Equation (7) can be used to calculate the melting time for a 10 AWG conductor.

$$33 \times \frac{I^2}{A} \times S = \log\left(\frac{t}{274}\right) + 1 \qquad (7)$$

Where:
I – current (A)
A – conductor cross-section (cmil)
S – time current applied (s)
t – temperature rise of the copper conductor (°C)

This method suggests a 10,000-amp current should cause a 10 AWG wire to melt in 9.5 μs.

Babrauskas and Wichman [53] approached the problem of fusing in a rapid heating situation by considering the thermodynamic properties of copper: time to fusing is the sum of time to heat copper from ambient to melting temperature plus the additional time to fully melt the given mass of copper. This is based on several factors including enthalpy of solid relative to 289°K, latent heat of melting, and temperature-dependent resistivity of copper. The equations for these two phases are:

$$\rho V[h_s(T_m) - h_s(T_o)] = t_1 i^2 R \qquad (8)$$

Where:
$\rho$ - 8890 kg/m$^3$ - density of copper
V - volume of copper in m$^3$
$h_s$ - enthalpy of solid relative to 289K
$T_m$ - 1083°C
$T_o$ - given as 40°C
$t_1$ - time to melting temperature
i - current in amperes
R - average resistance of copper over the temperature range

$$\rho V[\Delta h_m] = t_2 i^2 R(T_m) \qquad (9)$$

Where:
$\Delta h_m$ - 2.087x10$^5$
$R(T_m)$ - 8.927x10$^{-8}$
$T_o$ - given as 40°C

$t_2$ - time to molten

Adding these two expressions and substituting all constants yields the expression for rapid temperature rise fusing time:

$$\frac{i^2 t}{A^2} = 9.644 \times 10^4 \qquad (10)$$

Where:
A is cross-sectional area of the conductor in $mm^2$

For a 10-gauge wire with cross-sectional area of $5.37mm^2$ and 10,000-amp available fault current, time to fusing is calculated as 27.8 ms

***Contribution of Metallic Vapor***

While the breakdown potential of dry air is 3MV/m, this has no relevance to arc flash conditions. An arc flash is initiated by a conductive object shorting across two or three phase legs, or one or more phase legs to ground, creating a momentary bolted fault. Once the object or contact points are destroyed by the arc heat, a plasma is created with significant contribution by the metallic vapor. Babich et al. [54] conducted a series of experiments with low current arcs attempting to measure arc temperature, electron concentration, and spectral absorption for 6mm copper rods with gaps 2mm – 8mm. They demonstrated that even a tiny amount of metallic vapor noticeably affects the conductivity of the plasma. They also found arc temperatures as high as 8,500°C that dropped off rapidly as the gap between electrodes increased. Similarly, electron concentration arising from metallic vapor showed a strong correlation with distance. i.e., inversely proportional to the electrode gap.

Babich's results confirmed earlier work by Cheminat and Andanson who found that for low voltage and low current arcs, conductivity in the arc column increases by several orders of magnitude in the presence of copper vapor as shown in **Figure 7**, page 273. Further, Cheminat et al. [55, 56] found that for arcs only in gas, conductivity was greatest near the center of the arc column. However, in argon arcs contaminated by copper vapor, conductivity was greatest at the outer reaches of the arc channel.

***Migration of the Arc***

One of the recognized behaviors of electric arcs is that they migrate away from the source. This is a consequence of the Lorentz Force which is calculated as the cross product of the charge velocity vector and the magnetic field, as below in Equation (11).

$$\vec{F} = q\vec{v} \times \vec{B} \qquad (11)$$

In a system where current is flowing through two fixed, parallel conductors a circulating magnetic field is established perpendicular to the axis of the conductors according to the right-hand rule. Since the conductors are fixed, the developed Lorentz force cannot push them apart. If an arc is struck between the two conductors, with current flowing from Conductor 1 to Conductor 2, the arc becomes an independent current path that produces a separate magnetic field. Since the arc can move, the Lorentz force will push the arc in the direction of current flow in Conductor 1 and away from the source [57] as shown in Figure 8, page 273.

This behavior drives arcs toward and off the ends of bus bars and rods. In pad-mounted transformers, the Lorentz Force causes the behavior Stokes and Sweeting found most alarming - the arc plume and plasma cloud projecting outward from the open ends of horizontal terminals. Additionally, this behavior explains why calculations based on averages of Vertical Conductors in a Box configurations underrepresent maximum radiated heat for horizontal buses.

## Heat and Burns

### *Heat Transport*

Pennes [58] study of heat transfer in human skin resulted in a time-dependent second-order partial differential equation that can be used to determine temperature rise at any skin depth of interest.

$$\rho c \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\delta x_2} - G(\rho_b c_b)(T - T_c) \qquad (12)$$

Where:

| | | | |
|---|---|---|---|
| $x$ | – skin depth (m) | | |
| T | – temperature at skin depth of interest (°C) | | |
| $\rho$ | – density of skin (kg/m$^3$) | 1200 (epidermis, dermis) | |
| $c$ | – specific heat of skin (J·kg·°C) | 3598 (epidermis)<br>3222 (dermis) | *(12)* |
| $k$ | – thermal conductivity of skin (W·m/°C) | 0.255 (epidermis)<br>0.523 (dermis) | [59, 60] |
| $G$ | – blood perfusion rate (m$^3$/s/m$^3$ of tissue) | 0 (epidermis)<br>0.00124 (dermis) | |
| $\rho_b$ | – density of blood (g/l) | 1050 (average) | |
| $c_b$ | – specific heat of blood | 3617 (average) | |
| $T_c$ | – human body core temperature | 37°C | |

While Pennes studied skin thermal behavior at a nominal room temperature range 25°C - 27°C, with induced excursions of up to -5°C (alcohol wipe), his heat transfer equation is accurate for burn conditions as well.

***Structure of Human Skin Related to Burns***

Human skin as shown in Figure 9, page 274 [61] has two major layers of interest: the superficial epidermis and the deeper dermis. The epidermis is divided into four or five layers depending on body location. Beneath the dermis is found the hypodermis or subcutaneous, consisting of connective and fatty tissue. Two layers of key interest in the study of skin burns are the stratum basale or basal layer of the epidermis and the dermis. Second-degree burns result when the boundary between the basal layer and the dermis reaches 44°C. Third-degree burns occur when the base of the dermis reaches 44°C [59].

Skin layers are quite thin, depending on the body region. Various cadaver studies have examined skin thickness with the results listed in Table 4, page 302 [62] being typical for the anterior, or frontal, body surfaces that could be exposed to arc flash. Note that for an adult, the combined thickness of epidermis and dermis on the chest or fronts of the legs is only about 1/6 inch.

***Skin Burn Classification***

There are several systems of burn classification: traditional, Zawacki and Reed, Lawton, and the University of Rochester and as modified by Knox. Table 5, page 302, compares four of these systems. The SFPE Guide [63] asserts "No one method has been shown to be substantially better than the others." and utilizes the traditional classification method. Accepted criteria for second-degree burns are used in this dissertation.

### ***Skin Burn Models***

The most commonly cited sources for burn injury data by prior arc flash investigators are publications from the late 1950s to early 1970s [25-28, 48, 63, 64] by A.M. Stoll, M.A. Chianta, and L. Greene in collaboration with each other and with associates. While the Stoll Curve is straightforward to apply, the authors are clear [64], and others have emphasized [59, 65], that the method is only appropriate for second-degree burns under circumstances closely duplicating the rectangular heat source and heat flux intensities [66] used in their experiments. Heat flux values, times, and configurations outside those examined experimentally require extrapolation and may yield questionable results. Stoll's subjects coincidentally represented those most likely to be burned by arc flash, men and often younger men, and a region of the body most likely to be injured, the inner forearm. However, extension to somewhat thicker skin on the chest and thighs, or to thinner skin on older workers, again requires extrapolation.

Another method for evaluating and predicting skin burns often cited in fire protection studies is derived from the 1947 work of Henriques and Moritz [23] combined with Pennes' equation from page 36. The Henrique Integral is a first-order differential of an Arrhenius temperature-dependent chemical reaction equation [67, 68]. The constants closely parallel those of the heat-induced denaturation of proteins [69], thought to be the operative process in skin damage due to burns. Henrique determined skin damage begins when basal layer temperature reaches 44°C; the degree of damage is a function of temperature and exposure duration; and when skin temperature reaches 72°C, skin destruction is complete without regard for the preceding exposure time.

$$\Omega = P \int_0^t e^{\left(-\frac{\Delta E}{RT}\right)} dt \qquad (13)\ [59]$$

Where:

Ω – quantitative measure of skin damage
P – frequency factor $2.185 \times 10^{124}$
ΔE – activation energy of skin
R – Universal Gas Constant 8.315 *J/kmol °K*
ΔE/R = 93534.9
T – absolute temperature at skin layer of interest, *°K*
t – total time for which T is above 44°C (317.15°K)

Irreversible or second-degree burns occur when the Henrique Integral value Ω ≥ 1 at the basal layer of the epidermis.

Figure 10, page 275, presents data derived from one simulation study, using Henrique's method, identifying the boundary line for deep partial-thickness burns (burn depth to 1mm) between the time/temperature region where such injury will likely occur and that where it likely will not. The vertical axis is temperature at the surface of the skin. The study's simulation interval was up to 50 seconds. Time in Figure 10 is less than one second, an interval appropriate for arc flash had this simulation study been performed with that in mind. The horizontal axis for this derived plot is logarithmic rather than linear to allow clearer visualization of the exponential curve by not compressing the time interval less than six cycles (0.1 seconds).

## Arc Blast

The phenomenon identified as arc blast arises when an electric arc heats the air around it so quickly that a shockwave forms around the expanding plasma cylinder. The best-known example of this is the peal of thunder that accompanies a lightning bolt. However, when a set of switch contacts opens, if there is a spark that produces an abrupt snap or pop sound, then even that is a very tiny instance of such a shock wave.

The blast wave created by an arc flash event is significant and concerning for several reasons: (1) The sudden overpressure is capable of blowing covers off gear and otherwise destroying equipment; (2) It will propel debris away from the event site, including molten metal; and (3) It can cause significant injury like that experienced in the presence of conventional explosives including hurling workers and directly or indirectly causing soft or connective tissue damage.

***Hearing Damage***

A review by Babrauskas [70] collects the results of numerous arc blast studies considering overpressure inside enclosures. Many are based on laboratory conditions inside either small volumes or quite large ones. The most relevant of these studies for industrial electrical equipment[2] is that of Tanaka et al. [71] for a 320 $cm^3$ enclosed volume, AC current, 0.1 second arc.

A 2-cycle arc flash event at 480 volts and 10,000 amps would, according to these results, yield an overpressure of approximately 110kPA. When such events occur close at hand or inside an enclosed space such as a utility substation switchgear compartment, the pressure impulse is more than enough to exceed the 100kPA impulse guaranteed [72] to rupture a worker's eardrums.

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[2] A 200-amp 42-circuit Square D circuit breaker panel shell encloses 123 $cm^3$. A common size Motor Control Center bucket shell encloses 131 $cm^3$, though mounted components usually reduce that internal volume by about half.

In addition to immediate trauma, the force of an arc blast has also been documented as loud enough to cause inner ear damage. This class of explosion injury can result in persistent tinnitus [73] or partial hearing loss.

#### ***Blunt Force Trauma***

The boxing community has determined [74] that a punch with a force of 3.3kN over surface area approximately 24 square inches (0.015$m^2$) [75] poses a 25% possibility of fracturing an average person's ribs. This force translates to 220kPa or 31.9psi. Converted to acoustic pressure, this is 201dBA. Arc blast pressure values have been measured by others as high as 165dBA at six feet [76]. If a worker is located at the 18 inches conventionally used for incident heat effects calculations, the possibility of rib fractures could increase proportionally to the square of the reduced distance.

Beyond the chance of directly causing broken bones, even a 165dBA shockwave is problematic. Converting 165dBA to pounds per square inch yields 0.5 psi. Applied to the same 0.15$m^2$ or 225 square inches of torso, this force yields a pressure roughly equivalent to catching a 90-pound sack of cement. This is more than enough to knock a startled worker completely off balance and into adjacent equipment, causing head injury or indirect blunt force trauma from impact with corners, edges, or protruding sharp objects.

### Arc Flash Light Emission

Although light emission from an arc flash event has been examined, many studies lean heavily on related past work considering arc welding and flash blindness. The emphasis seems to be arriving at a workable spectrophotometer that has broad frequency sensitivity, response speed, and can accurately measure the intensity of light yielded by a flash event.

The Commission Internationale de l'Éclairage introduced a very precise determination of the human eye's response to various frequencies of light at their sixth session in 1926. The graphic representation of this luminosity function curve is known as the V(λ) curve. Prior work has assumed [77] that an arc flash light emission measurement system should duplicate the human eye's response, particularly in the photopic or well-lit region of 380nm to 760nm on the V(λ) curve; however, the necessity for this is not clear. The effects on the human eye are a function of total light energy, and the wavelengths of interest extend into the UV-A (315nm – 400nm) and UV-B (280nm – 315nm) bands. In the UV band, all but the longest wavelengths of UV-A are not visible to humans though emissions in this region are a primary source of eye injury.

There are two areas of concern for vision damage arising from arc flash: the overall intensity of light across all wavelengths which will damage the retina and the intensity of UV light known to cause cataracts and corneal keratitis.

Figure 11, page 275, depicts spectra for nitrogen and oxygen, the predominant components of air. Figure 12, page 276, depicts a similar plot for several metals common in electrical systems [78]. Both charts range from UV-B through visible wavelengths.

Copper is the material of choice in most facility electrical wire. Tin-plated copper is prevalent in electrical equipment such as switchgear, panelboards, and circuit breakers. Aluminum is used in utility aerial cable, large gauge facility wiring, and a frequent choice for transformer windings. Iron appears in the steel from which electrical workers' tools are constructed.

Nitrogen and oxygen have generally low spectral emission intensities although oxygen shows stronger emissions in the region of shorter visible wavelengths and extending into UV. Copper has strong spectral lines in both visible and UV-A wavelengths. Spectral lines from tin in the wavelengths of interest are most strong in UV-B. Aluminum shows strong spectral emissions in UV-B, UV-A, and visible. Iron emissions are all strongest around the UV-A band.

The major contributors to ultraviolet emissions from arc flash events are the metals involved, i.e., the current-carrying conductors which are copper, tin-plated copper, or aluminum; and steel tools. Visible light emissions are dominated by copper, aluminum, and oxygen.

***Vision Damage***

An arc flash event develops within the first few cycles (16ms – 48ms). Even caffeinated college students have an eye-blink delay of as much as 44ms [79] so it seems probable that vision damage from an arc flash event will, like heat incident on the skin, depend on the total intensity of light and the energy in particular bands such as UV and not be affected by protective reflexes. The human blink reflex is simply not fast enough to protect the eyes from arc flash.

Ultraviolet keratitis has been compared to sunburn of the cornea and conjunctiva [80]. Even single exposures to intense UV-A and UV-B will cause ultraviolet keratitis and can be powerful enough to result in cataracts [73]. Repeated exposures will cause or accelerate vision loss.

Experimental work by Shiuan-Hau Rau et al. [81] has shown that three-phase arc flash events can produce on the order of 3 x $10^6$ lux at 3m from an event. They have proposed a predictive model for light intensity based on these results. The calculations for this proposed method are shown in Equation (14).

$$bxcf = K1 \times e^{(K2 \times box\ size)}$$

$$\text{Lux} = bxcf \times 10^{\left(K3 + K4 \times \log\left(I_{bf}\right) + K5 \times \log(Gap) + K6 \times \log(D)\right)} \tag{14}$$

Where:

$I_{bf}$ – Bolted Fault or Available fault current (kA)

Gap – electrode separation (mm)

*box size* – average of height and width in inches

*K1 – K6* – constants based on system voltage and configuration

Consider a sample enclosure 14.75 inches x 12 inches with open-ended electrodes (VCB) separated 1.5 inches; 10,000A available fault current; and a working distance of 18 inches. Using this method yields an overall expected light intensity as follows:

$$bxcf = 0.0939 \times e^{(0.0896 \times 13.375)}$$

$$\text{Lux} = 3.113 \times 10^{(22.472 + 0.35 \log(10000) + 0.384 \log(38) - 4.935 \log(457))}$$

Calculated light intensity is 7x$10^{11}$ lux for a three-phase 10,000-amp flash in this case. Past work on eye sensitivity and injuries arising from bright light lists 6.83 x $10^6$ lux for 100ms as bright enough to cause retinal damage. The calculation Shiuan-Hau Rau et al. have offered suggests a worker standing at a conventional 18 inch working distance from industrial three-phase equipment could be exposed to a flash as much as five orders of magnitude brighter than that required to yield retinal damage.

# Chapter Five : Representative Case Histories of Arc Flash Injuries

Reported statistics on arc flash injuries vary depending on the authority consulted. In any given year, there are between 5 and 10 [82] arc flash incidents per day to as many as 30,000 per year [83]; with 7000 burn injuries; 2000 hospitalizations [48]; and 400 fatalities [84]. The most severe of these circumstances may be underestimated since incidents may not be reported [85] by OSHA as arc flash if there was not a fatality; fewer than three employees required hospitalization; OSHA did not perform an investigation; or the event was reported as another incident type such as electrocution, a fall, or a fire [86].

It is clear from examining case histories of arc flash injuries, fatalities, and losses that these incidents are usually preventable. Injury and fatality events often result from a general deficiency in an organization's safety culture. These deficiencies manifest as lack of knowledge, lack of training, and lack of emphasis on correct work practices.

## Case: Chew et al. v. American Greetings Corp.

**Courts:** United States District Court for the Eastern District of Arkansas, Jonesboro Division [87]
CASE NO. 3:10CV00199 March 5, 2013

United States Court of Appeals, Eighth Circuit [88]
754 F.3d 632 (2014)
Nos. 13-1966, 13-1751 Submitted January 13, 2014

**Facts of the case:**

On Sept 23, 2009, an employee of American Greetings reported a burned electrical cable and a blown fuse between the utility pole and a facility transformer. This was brought to the attention of the Plant Maintenance Manager and the local electric utility was called.

The facility's ground-mounted transformer was equipped with two sets of doors- an exterior weather door and a flash-guard barrier inner door. Both sets of doors were opened in the presence of the utility manager. The transformer nameplate was affixed to the inside of the exterior door initially visible but then obscured after both doors were opened. The transformer nameplate identified the primary voltage as 13,800 volts and the secondary voltage as 4,160 volts. The transformer did not bear exterior labeling at the time of the incident.

The utility manager directed one of the plaintiffs to retrieve a voltmeter to take measurements at the transformer. The plaintiff returned with a voltmeter rated for 1000 volts because he had not looked at the nameplate and believed the transformer had a 480-volt secondary.

When the plaintiffs approached the energized transformer to use the voltmeter, an arc flash ensued that injured plaintiffs.

Plaintiff Duncan, the crew supervisor and the one most injured, had more than 23 years of training and experience.

Plaintiff Chew had worked at the utility for more than ten years.

Plaintiff Hoskins was an apprentice lineman.

**Court opinion:**
The District Court agreed with American Greetings Corp's response that it owed Plaintiffs no duty to warn of special hazards since they were experienced electrical contractors and should have known the dangers of electricity and risk of arc flash.

In summary judgement, based on undisputed material facts, District Court found in favor of Defendant.

This decision was upheld on Appeal.

**Analysis of the case:**
The plaintiffs did not read the transformer nameplate nor did they perform a Pre-Job Hazard Analysis.

One of the plaintiffs had worked at the American Greetings many times, was accustomed to power distribution at 480 volts, and assumed this was again the case. None of the plaintiffs had ever worked on a pad-mounted transformer with secondary rated 4,160 volts.

The investigating forensic engineer [89] observed that the site was supplied by seven (7) pad-mounted transformers: five with secondary voltage 480 volts, two parallel with secondary voltage 4,160 volts. The engineer commented that the 4,160-volt transformer to be tested was not in compliance with NFPA 70 Article 450.8(D) that requires voltage labeling when live parts are exposed. This observation may have been misplaced since secondary terminals were not at risk of being exposed until the weather door was open, thereby revealing the transformer's nameplate.

The 1000 volt rated voltmeter selected would have been appropriate for assumed conditions; however, it was entirely unsuited for actual conditions. Insulation on the meter's leads and internal components would have failed instantly and catastrophically when connected to the much higher system voltage.

No comments were offered in court documents concerning plaintiffs donning Personal Protective Equipment (PPE). However, it seems highly unlikely they did so since PPE selection would have been the result of a Job Hazard Analysis including reading the transformer labeling or system knowledge provided by the facility owner's representative who was on hand. The absence of PPE would have contributed to significant injury from the resulting arc flash.

While the extents of the crew members' injuries were not discussed in case files, none were identified as deceased. However, the crew supervisor's spouse was named as a co-plaintiff, suggesting he was most severely affected; possibly disabled. This is supported by the forensic engineer's mentioning that only this individual as having been burned.

**Conclusions:**

The proximate cause of the arc flash and injuries in this case was the plaintiffs' failure to be guided by their experience and determine actual conditions before beginning work. Rather than consult with the system owner or investigate the equipment to be worked, the senior lineman made a flawed assumption that precipitated an arc flash event at one of the most dangerous of all possible locations, the transformer secondary terminals.

## Case: Khosh vs. Staples Construction Inc.

**Courts:** Court of Appeal of the State of California, Second Appellate District, Division Six.  2d Civil No. B268937  Filed: 10/26/16 [90]

**Facts of the case:**

Plaintiff Khosh was an employee of Myers Power Systems, a subcontractor of DK Electrical Systems, working under contract to Staples Construction.  Staples had been contracted by California State University Channel Islands to install a backup power system.  This installation required construction in, and modifications to, a utility substation.  Myers Power was hired to construct and install switchgear.

In preparation for completion of the installation, Myers Power advised they would need three days to complete their installation work.  A campus-wide electrical shutdown was scheduled so Myers could have the required time to perform its last task.

Khosh arrived on-site 2-1/2 hours ahead of the scheduled shutdown.  The University's project manager allowed Khosh and a helper to enter the substation.

Khosh performed work on energized equipment.  An arc flash ensued 30 minutes before the scheduled outage and Khosh was seriously injured.

**Court opinion:**

Even though Staples Construction had a contractual requirement from the University to be responsible for worksite safety, the court found for the Defendant because Staples Construction did not participate in the substation construction, and did not have a representative on-site when Khosh was injured. [91]

**Analysis of the case:**

The nature of the final installation activities was well-understood.  Myers Power had communicated their requirements through Staples to the University.  The University had gone to the trouble of scheduling a campus-wide power outage.

Scheduling such work is a large undertaking. It would have required a work plan, including coordination with the electric utility, to perform the Lockout-Tagout at the substation.

**Conclusions:**

Khosh deviated significantly from the planned schedule by arriving on-site far in advance of the agreed time.

Khosh further deviated from accepted work practice by unnecessarily interacting with energized equipment in a utility substation when there was no reason to do so. An outage had already been arranged, three days were planned, and the added two hours would not have appreciably accelerated the work.

## Case: Gerasi v. Gilbane Building Co.

**Courts:** Cook County Circuit Court No. 08-L-7258
Illinois Appellate Court, First District, Second Division
No. 1-13-3000 Filed: 05/14/2017 [92]

**Facts of the case:**

Gilbane was contracted by AT&T to replace air conditioning equipment at a Chicago facility. This was not the first time Gilbane had done work for this client in this facility. Gilbane hired a subcontractor to perform electrical work. Gilbane had a standing relationship with this subcontractor, who had performed electrical work at that facility for many years.

Detailed plans were prepared for each phase of work both to maintain service continuity and to ensure worker and facility safety.

The electrical subcontractor was responsible for reporting any equipment they identified as requiring de-energize and lockout/tagout before performing work. The electrical subcontractor had not identified any equipment believed to need deactivation before work could begin, nor did they have in place any detailed work plans for performing temporary equipment connections.

The electrical subcontractor was charged with providing personal protective equipment (PPE). Such equipment was provided and stored in a designated location. Any worker needing PPE was free to use it.

Throughout the course of the contract, several temporary electrical power feeds were required to supply the subcontractor's equipment and tools. These temporary connections were made at an existing Motor Control Center (MCC). AT&T had specifically prohibited pulling MCC buckets while the entire MCC was energized. While the electrical subcontractor could deactivate and connect spare MCC breakers, only the building manager was permitted to authorize shutting down an entire MCC.

At the time of the incident, one member of the electrical subcontractor's team was connecting a temporary power feed to a deactivated bucket when he was called away. Plaintiff continued the connection activity. Plaintiff was not wearing any electrical PPE, and the plaintiff's co-workers were also not in the habit of wearing PPE for work inside deactivated buckets.

Plaintiff encountered a difficulty tightening one breaker connection, gripped the breaker with one hand while tightening with the other, and the breaker failed internally causing an arc flash that injured the plaintiff seriously.

**Court opinion:**

Summary judgement was granted because there was no dispute about material facts. Gilbane was not required to, and did not, have a full-time Safety Supervisor on site to oversee all subcontractors' activities. Each subcontractor was required to provide and adhere to a rigorous safety plan.

The trial court found in favor of Defendant Gilbane – they were not materially responsible for Plaintiff's injuries. This finding was upheld on appeal.

**Analysis of the case:**

Arc flash was first introduced into NFPA 70E in 1995. Guidance evolved and matured with each successive revision to the document. Electricians in the mid-2000s should have been familiar with 70E including the specifics of Approach Boundaries and associated PPE.

It was noted that neither the Plaintiff nor his co-workers were in the habit of wearing electrical PPE while working inside a deactivated Motor Control Center bucket even though the line side of the bucket breaker was still energized. This is a common behavior among old-line electricians who either do not understand or choose to ignore arc flash hazards.

NFPA 70E identifies the Restricted Approach Boundary for exposed components energized to 480 volts to be 12 inches. Inside this boundary, an electrical worker must have and work to the requirements of an Energized Equipment Work

Permit.  Outside this boundary, to a distance usually 42 inches from the exposed equipment, a worker must be guided by an Electrical Job Hazard Analysis which will include required PPE.

The electrical sub-contractor did not have any detailed work plans for temporary connections, no mention was made of Electrical Job Hazard Analysis documents, and it was specifically noted that Plaintiff was not wearing PPE. Working inside a de-activated Motor Control Center bucket will occur outside the 12" boundary if in the bottom right corner, or inside the 12" boundary if on the breaker itself.  Plaintiff was working inside the 12" boundary.

**Conclusions:**
As evidenced by the explicit declaration that they had been performing such work, in the same way, for years without incident, the cause of this incident was a pronounced safety culture deficiency within the entire electrical subcontractor team. This dangerous work practice would have repeatedly exposed members of the team and those working in the immediate vicinity to unnecessary risk of severe arc flash injury.

While the best circumstance is to perform electrical work on completely de-energized systems, it is possible for well-trained and experienced electricians to safely conduct work near active equipment.  It was possible that even if the work had been done with the entire MCC turned off, the failed circuit breaker could still have exploded when connected and re-energized.  However, with the door of the energized bucket open, and no PPE, the plaintiff had no barriers between him and the arc flash that injured him.

## Case: Arc Flash Accident - LANL TA-53

**Facility:** Los Alamos National Lab, Technical Area 53 Substation 0070

**Facts of the case:**

Early May 2015, maintenance workers were simultaneously executing two separate work orders to perform Preventive Maintenance (PM) on switchgear and air-break circuit breakers in the TA-53-0070 13,800-volt substation.

The maintenance crew consisted of members with various levels of experience, with one member available to perform zero-voltage checks and to attach grounding cables (a utility work convention).

Maintenance and cleaning activities were completed on two of three compartments on the first day of work. These compartments were re-energized to restore power to parts of the facility. Appropriate markings were put in place to identify the boundary between de-energized and energized compartments.

Workers returned the next day to resume. A pre-job briefing was conducted including a detailed review of hazards and personnel safety requirements. The energized compartments were specifically called out, tags confirmed to be in place, and grounding cables still secure. Work commenced.

At the time of the incident, the worker, designated W1 in the report [93], walked past tags and entered one of the energized compartments. W1 was wearing nitrile gloves, an arc-rated long-sleeve shirt with sleeves rolled up, non-arc-rated coveralls, and a baseball cap. W1 removed the protective covers from the bus bars and then commenced a cleaning operation, spraying commercial cleaner into the space between the bus bars energized at 13,800 volts. An arc flash ensued that ignited W1's clothing. The pressure wave from the arc blast ejected W1 from the compartment and threw him to the floor. W1's co-workers extinguished the burning garments, summoned assistance, and was evacuated W1 in critical condition to the regional burn center. Forensic analysis of W1's charred garments yielded an estimated heat exposure of 20 to 25 cal/cm2 [94].

**Investigating team's analysis and determinations:**

The Investigating Team considered three primary topic areas: 1) past experience guiding the work at hand, 2) safety management, work planning and control, and 3) human performance.

Past experience was recognized. Subject matter experts were consulted to correctly identify the scope and complexity of the PM tasks. However, work tasks for substation PMs had historically been described in broad terms and not down to the specific task level. As a result, hazards of working in the substation were not fully identified.

Work scope description was deficient. Planning failed to account for performing two PM activities at the same time, workplace clutter and crowding, changing the work area configuration in the middle of the job, and the possibility of human error. The pre-job brief on the second morning did not anticipate the possibility of a worker entering an energized compartment.

Enforcement of personnel protection was lacking. PM work packages required hard hat, safety glasses, arc-rated long sleeve shirt, and leather gloves. W1 was allowed to work in nitrile gloves and roll up shirt sleeves. Zero voltage checks were not performed in the compartment W1 was working: there was no physical barrier installed to block access to the energized buses.

The work evolution was scheduled across a weekend with workers putting in as much as 28 hours of overtime on top of the previous 40-hour workweek. Human Performance and prevention of fatigue-induced errors were not adequately addressed with detailed work package steps. The method of identifying work progress was inadequate and not well- understood by all members of the work team.

**Conclusions:**

The proximate cause of W1's injuries was his walking past identifying tags; entering a substation compartment energized at 13,800 volts; removing covers and spraying conductive cleaner into the exposed buses causing an arc flash and blast.

The investigating team determined that the root cause factors were failing to rigorously implement zero-voltage checks before every work step and failing to implement physical barriers around energized equipment.

The stress, fatigue, crowded conditions, clutter, and sense of urgency to complete the work evolution and outage over a weekend were also factors. Under these circumstances, it would have been easy to make or allow poor choices.

Additionally, changing the configuration of the substation by re-energizing part of it amid the workflow may have been desirable and viewed as an accommodation to end-users; however, it introduced an unnecessary hazard that could have proved fatal.

## Case: Electrical Arc Injury - Stanford Linear Accelerator Center

**Facility:** Stanford Linear Accelerator Center (SLAC), Menlo Park, CA

**Facts of the case:**

Bay Span was an electrical maintenance firm providing construction and labor services to SLAC and other northern California industrial companies. On the morning of October 11, 2004, a SLAC supervisor instructed a Bay Span electrician, designated BSE-1 in the incident report, to install a new circuit breaker in an existing panel. The panel was 480-volt and energized.

BSE-1 was wearing a cotton/polyester shirt with short sleeves, electrical gloves, safety glasses, and a hard hat. None of BSE-1's garments were arc flash rated. He was using a standard, uninsulated screwdriver. BSE-1 was kneeling on a rubber insulating mat at the time of the incident.

The SLAC supervisory provided the new circuit breaker. The breaker and panel were manufactured by General Electric. The breaker was mechanically mounted by screws at the load-lug end of the breaker and electrically connected by bolts through wells on the supply side of the breaker into threaded holes in the bus bars. The panel bus bars were constructed: they were fully exposed when the dead-front panel cover was removed.

Starting with the electrical connection, BSE-1 attempted to mount the breaker. Phase C (bottom) was secured and then Phase B (middle). BSE-1 was trying to secure the Phase A screw (top) when the arc flash occurred.

Based on photographs and forensic analysis of the burned bus bars, the investigating team determined that BSE-1 was struggling to tighten the Phase A bus screw. There are several possible explanations - thread damage to the bolt or bus bar hole, or misalignment. When BSE-1 applied additional force with the screwdriver to the bolt, it compressed insulating material between Phase A and Phase B bus bars, weakening it and allowing an arc to occur.

BSE-1 was burned third-degree on his face, chest, and legs; and second-degree on his arms.  This involved about half of his body surface.  The attending laborer was knocked off his feet by the force of the pressure wave, resulting in soreness in his back but was otherwise he was uninjured. [95]

**Investigating team's analysis and determinations:**
The investigating team identified several key work execution and worker safety deficiencies.

Neither Bay Span nor SLAC had conducted a Pre-Work Hazard Analysis, nor had they prepared an Energized Equipment Work Permit identifying appropriate PPE.  There was no identified justification for why the work was conducted on an energized panel rather than waiting for a convenient time when it could be de-energized.

BSE-1 failed to stop work when unexpected difficulties arose.  None of the Bay Span personnel working in the area exercised their authority to stop work in the face of hazardous conditions.

Violating OSHA's standards for worker protection in multi-employer workplaces, SLAC's provisions for worker safety only covered SLAC employees not contractors.

There was a complete breakdown of responsibility in the worker oversight chain. The SLAC supervisor failed to conduct a pre-job brief and advise BSE-1 of the hazards and failed to insist on appropriate PPE. Bay Span's oversight failed to identify and correct BSE-1's marked nonconformity with its contractual safety requirements.  SLAC's electrical safety oversight did not detect and correct organizational and contractor failures.  DOE's safety office did not identify and issue corrective requirements for SLAC's failure to provide uniform safety protections as required by OSHA.  All organizations involved with planning the work had failed to take advantage of the wealth of OPEX Lessons Learned from similar work.

**Conclusions:**

As in Gerasi v. Gilbane, there was no defensible reason why the Bay Span electrician was working inside the Restricted Boundary in an energized 480-volt 3-phase panel without arc flash rated PPE.

This worker was woefully unprepared for the work environment. He should have been wearing a full complement of PPE including 8 $cal/cm^2$ rated coveralls over cotton garments, a rated face shield and hood with safety glasses and hard hat, gloves, boots, and hearing protection.

Systemic failures in safety culture extended from Department of Energy oversight down to contract workers. The Stanford Linear Accelerator Center management team had abrogated their direct safety supervision responsibility by failing to treat contract personnel with the same care as SLAC employees. This failure in leadership unintentionally influenced front line workers' behavior and manifested as both ignoring safety requirements and workers' failing to look out for each other.

## Case: Arc Flash - PM of Vacuum Circuit Breakers

**Facility:** Idaho National Laboratory, Central Facilities Area (CFA) Substation

**Facts of the case:**

During the fourth week of April 2015, three Idaho National Lab linemen were performing preventive maintenance on vacuum breakers. The equipment being worked on was connected to a 12,500-volt bus.

During work on the final breaker, one of the linemen attempted to move a grounding cable from Phase A of the breaker to another phase. The cable became hung on a corner of the vacuum breaker cabinet. The worker was handling the ground cable with an insulated lineman's hot stick. He attempted to dislodge the cable several times by flipping it, eventually succeeding but unintentionally causing the cable to rise and contact an energized, overhead cable above an adjacent breaker. The free end of the grounding cable contacting the energized overhead cable caused an arc flash.

No one was injured and there was no reportable damage to equipment or loss of power. [96]

**Investigating team's analysis and determinations:**

Work package planning failed to develop any mitigations for possible hazards associated with the energized overhead cables even though they were specifically called out: minimum separation distance was clearly identified.

The hazard of working close to energized equipment was discussed during the pre-job brief; however, workers did not request additional hazard controls. Additionally, they were overly focused on keeping power on and accepted increased risk to achieve this.

The lineman performing the grounding cable relocation lost overall situational awareness when he became focused on dealing with dislodging the hung-up cable.  The lineman acting as designated spotter failed to remain vigilant and ensure minimum separation distance was maintained.

**Conclusions:**

While this incident did not result in worker injury, power outage, or facility damage, it easily could have.  Splatter from the arc flash could have caused serious burns.  A severe arc event could have severed the overhead cable.

Lineman's grounding cables are commonly between 6' and 10' long.  That a free end could contact an overhead cable suggests work was being conducted inside the recommended 10-foot separation from 12.5 kV lines.  It would have been prudent, and not difficult, for the linemen to have set conventional insulating line hoses on the overhead cables before starting work on the vacuum breakers.

## Case: Arc Flash - Locked Out 3.3-kV Fused Contactor

**Facility:** Hot Rolling Steel Mill

**Facts of the case:**

On 19 May 2014, a 3300-volt fused contactor had been disengaged (racked out) of associated switchgear to support planned maintenance of the supplied equipment, a water pump. Maintenance activities had concluded. The facility was being returned to service.

The contactor cubicle was designed so that when racked out, the internal electrical components were rotated to disengage with switchgear buses and press fuse phase terminals against grounding straps.

When the water pump was wanted, a member of the plant staff removed the padlock from the contactor cubicle's racking handle and attempted to re-engage the contactor cubicle in the switchgear. The cubicle did correctly re-engage; therefore, the worker reapplied the padlock and reported the issue.

After making observations in the plant control room, the staff member returned later with senior workers including a senior electrician. With the two other staff members attending, the senior electrician opened the front of the cubicle to inspect. The electrician observed a broken pin in the racking mechanism and discussed that finding with attending staff while still kneeling in front of the open gear cubicle.

During the discussion, while the electrician was facing the cubicle, an arc flash occurred that severely injured the senior electrician.

At the time of the incident, all staff members were wearing company-issued cotton jackets and trousers, personal shirts, safety glasses, leather safety shoes, and hard hats.

Maintenance workers lacked manufacturer's support documentation for the contactor cubicle and had incorrectly adjusted the positions of the internal grounding straps.  This resulted in the grounding straps potentially contacting fuse phase terminals during both rack-in and rack-out operations.

At the time of the incident, the phase terminals were still engaged with the grounding straps and the broken mechanical linkage allowed the contactor's terminals to fall into and re-engage with the switchgear bus bars.

**Investigating team's analysis and determinations:**
The investigating team determined the arc flash was comprised of two events. The first occurred when the contactor cubicles phase terminals neared the switchgear bus bars.  This arc was extinguished when the terminals made solid contact with the bus bars.  A second and much more powerful arc flash then occurred where the cubicle fuses phase terminals contacted the grounding straps.  This arc flash vaporized the grounding straps.

The staff member who removed the contactor cubicle and attempted to re-engage it erred when reapplying the padlock.  At that point, an unknown condition existed and the presence of the padlock unintentionally communicated a safe condition.  A new and separate work activity should have been initiated to troubleshoot the malfunctioning cubicle.

The senior electrician assumed the safe state of the contactor cubicle and opened the front cover.  He compounded this error by failing to don electrical PPE.  The investigating team identified an organizational safety culture deficiency that resulted in failures to correctly identify and respond to potential workplace hazards.

Maintenance personnel were not provided proper manufacturer documentation or detailed work instructions describing correct adjustments to the contactor cubicle's internal grounding straps.  As a result, these straps were forced into the wrong positions over time and created the possibility of a short-circuit which, in this case, resulted in an arc flash.

Maintenance personnel had grown complacent about the condition of the compartment's mechanical linkage. The linkage failure observed had occurred on previous occasions. The failed component had been replaced but never reported.

**Conclusions:**

While the staff member who originally attempted to return the contactor to service is to be commended for stopping work in the face of uncertainty, his choice to reapply the padlock unintentionally communicated a safe condition that did not exist. A better choice might have been leaving the lock off and setting up cones and warning tape.

The senior electrician failed to exhibit a questioning attitude when confronted with an unknown condition and then compounded that error by assuming a safe state rather than starting with the assumption of greatest danger until proven otherwise. He paid for this lack of judgment with 24 months away from work.

Organizational lack of support and complacence, coupled with a likely emphasis on getting it done quickly, led to the mechanics and technicians causing damage to the cubicle assembly and putting it outside the manufacturer's safe operating envelope.

Safety culture deficiencies were also apparent from the normal sequence of events that allowed a staff member who was not an electrically qualified person to perform a cubicle rack in operation on 3300-volt switchgear. This is considered by some to be energized work. As such, it would require an Energized Equipment Work Permit with attendant hazard analysis and appropriate PPE, none of which were in evidence or noted by the investigators.

# Chapter Six :
# Experimental Materials and Methods

Exploring some of the assertions about arc flash in single-phase systems invited experimental investigation. Conventional wisdom, as embodied in the 2002 release of IEEE 1584, stated that 240-volt single-phase systems with available energy below some threshold did not yield risk for arc flash and thus did not require analysis. However, lacking supporting data, this assertion was removed. With this as a starting point, the initial hypothesis for this series of tests was **"Single-phase arc flash energy yield is expected to be less than that predicted for three-phase at equivalent voltage and available current."** Thus, a conventional test article and calorimeter configuration was deemed appropriate.

This experimental series sought to focus directly on installations found in residential, commercial, and light industrial applications. In these types of facilities, single-phase power distribution is common.

## Terminology

Definition of terms used in this section:

- **Cycle**. This test series used 60 Hz alternating current prevalent in the United States. One cycle is defined as 1/60 second or 16.67ms for a full 360-degree sine wave.
- **Available Fault Current**. The maximum short-circuit current that the test cell can deliver to the fixture, based on its configuration. This was determined by the arrangement of resistors and inductors in a network ahead of the cell's step-down transformer. The Schneider one-line diagram is presented in Figure 13, page 277.

- **Open Circuit Voltage (Voc)**. The nominal secondary voltage delivered to the test cell, based on its configuration. This is determined by the arrangement of primary side resistors and inductors, and the position of the transformer primary taps.
- **Arc Flash**. The intense light and heat radiated by an arcing fault. This is separate from arc blast, the supersonic shockwave that often arises from the same fault that produces arc flash.
- **Arc Blast**. The pressure wave created by the rapid expansion of the plasma column and surrounding air during an arc flash event.

The combination of direct connection to the public utility and a very large step-down transformer yielded what is referred to as a stiff system; that is: the test cell could deliver very high currents without exhibiting appreciable sag in delivered voltage. The fault currents chosen for this series of tests were low enough that no secondary voltage sag was expected.

## Test Fixture

The conventional test article for IEEE arc flash experiments aka arc in a box consists of parallel copper rods mounted at the rear of a 20 x 20 x 20 inch steel box, open on one side. Rods may extend down to insulating material at the bottom of the enclosure yielding a Vertical Conductors in a Box with Barrier (VCBB) configuration or they may end in open air yielding the more common Vertical Conductors in a Box (VCB) configuration (Figure 14, page 278). These arrangements were used in the late 1990s for three-phase arc tests by Doughty and others [27] and saw continued use through 2014 in data collection for the latest edition of IEEE 1584.

While the single-phase arrangement used by Neal [42, 97] (Figure 15, page 278) is still employed for ASTM fire retardant clothing testing, it does not represent the Vertical Conductors in a Box (VCB) conditions found inside a circuit breaker panel or contactor enclosure.

For this reason, a variant of the IEEE configuration was used for this investigation: a smaller enclosure with two parallel electrodes as shown in Figure 16, page 279. The shell is 14.75 inches high, 12 inches wide, and 7.5 inches deep. Electrodes are 3/4-inch diameter, separated by a nominal 1-1/2-inch gap braced by four phenolic blocks as shown. Vertical position is maintained by set screws in each support block. Connections at the top are made with rod clamps.

## Sensors

### ***Calorimeters***

The facility provided the copper slug calorimeters used for this test series. These are the same type of thermal capacitance sensors commonly employed in arc flash and ASTM 1959 clothing testing for the last 20 years - an 18g electrical grade copper disk, 4cm in diameter, with a Type J thermocouple spot-welded to the back. The assembly is mounted in an insulating carrier, in this case ceramic-based, and supported on a structural arm. See Figure 17, page 279, for arrangement and Figure 18, page 280, for a simplified cross section. The composition of the support arm, conductive or non-conductive, does not influence the thermocouple.

Arrangement of the calorimeters bounds a hexagonal region 15 inches wide and 15 inches tall. This area approximates that of the front center of an adult torso from chin to navel [98].

The rated temperature range for Type J (iron / copper-nickel) thermocouples is 0°C to 750°C with a commonly published upper limit of 1190°C. Other experimenters investigating catastrophic high energy arc faults [14] have employed Type K thermocouples (nickel-chromium / nickel-aluminum), with range up to 1250°C, bonded to Inconel® slugs, to improve sensor survival and response time.

Calorimeters and the ambient temperature probe were connected to a standalone HBM Genesis 3i High-Speed Data Recorder. This unit provided the required electrical isolation noted by Zhang [99].

***Voltage and Current***

Phase current to the test fixture was measured with Rogowski coil transducers. Ground current (fixture shell to earth ground) was measured with a current transformer (CT) during the first group of 43 tests. The maximum secondary voltage attainable in the Number 3 test cell is 726 volts RMS so bus voltage was measured by direct connection through 100-to-1 high-impedance test probes. Current and voltage measurements were fed directly to an HBM data acquisition system Genesis 3t unit connected to the test cell control station. Since this test series used one phase pair of the source, only one phase voltage and one phase current measurement were logged.

### ***Pressure Sensor***

The author provided a PCB Piezotronics 102B04 high frequency ICP® dynamic pressure sensor for test series #2. This type of device measures impulses to 1000 psi and has a response time ≤ 1 millisecond. The pressure sensor was connected to a 482C four channel signal conditioner provided by the lab. Signal conditioner output was connected as an input to the HBM data acquisition system Genesis 3t. Pressure values are reported as the third channel on oscillograms for series #2 tests 1 through 110.

The blast pressure sensor was mounted 18 inches above the midline of the center-middle calorimeter to approximate the position of a worker's ears. A support arm was constructed from the same extruded aluminum members as the calorimeter frame, with an angle bracket drilled and tapped to accept the sensor's threaded front end. A curtain of rubber sheet was hung below the sensor to protect the cable from flash spray and the plasma cloud. See Figure 19 on page 280.

## Test Cell Configuration

Initial configuration for the test cell had the calorimeters spaced a conventional 18 inches back from the near surfaces of the vertical bus rods. A high-speed digital video camera was located approximately ten feet away, behind a debris screen as shown in Figure 20, page 281. Two of three available phases sourced power via 750kcmil cables, restrained with rope to prevent movement from magnetic forces.

An arc between the electrode rods was initiated with a piece of 10AWG bare fine-stranded, tinned copper fuse wire tied to secure by friction onto each rod as shown in Figure 21, page 281. The fuse wire was typically located between 1/2 inch and 1-1/2 inches above the ends of the rods.

The rods were cleaned with Scotch-Brite™ between test runs to remove oxidation and maintain uniform conductivity. When wire remnants were welded to the electrodes by a test, these were removed with a small flat file.

## Test Scenarios

Four nominal test scenarios were planned for the first test series that reflect standard breaker panel voltages and low to medium fault currents: two groups at 240 volts and two at 480 volts. Considering past investigators' observations that arc events can be erratic, each test scenario included 10 runs at the selected voltage and fault current to secure a reasonable minimum number of samples for statistical treatment.

Scenarios for the second test series were chosen to fill in the gaps between 240 volts and 600 volts, to investigate the validity of using simple geometry for correcting data collected with calorimeters at 12 inches, and to determine whether painting calorimeter surfaces flat black would affect measured heat. Selected scenarios were based on available test cell configurations.

## Adjustments to Configuration

The first test run in the 240V @ 10kA configuration produced almost no measurable heat in the calorimeters. The calorimeters were moved from 18 inches to 12 inches for the remainder of the first test series in the interest of intercepting more radiated energy as shown in Figure 22, page 282. This closer configuration was also used for selected runs in the second test series.

Two sound pressure measurements were attempted at the beginning of the first 480-volt test group. A handheld sound pressure meter was secured just to the left of the test fixture as shown in Figure 23, page 282. This location was chosen to approximate an electrical worker's position and simulate sound pressure to which they might be exposed. In both cases, the developed sound pressure exceeded the device's 130dB upper limit. In the interest of avoiding damage to the instrument, no additional measurements were attempted during the remaining 28 tests in this series. A high-pressure blast sensor was added to the setup at the beginning of test series #2.

# Chapter Seven : Results

## Test Run Numbers & Configurations

Raw data files for voltage, current, pressures; calorimeter measurements; oscillograms; high-speed camera sequences; and calculation spreadsheets are included with this dissertation as file attachments. Measurement and video files are identified by oscillogram number. Test run identifiers and configurations are listed in Table 6 through Table 9, beginning on page 303.

## Analysis of Measured Currents

Figure 24, page 283, shows probability distribution histograms of measured current values for series #1 test runs 2 through 11 and test runs 12 through 21. Test run 1 values are calculated but not used initially because the calorimeters were spaced 18 inches; all other series #1 runs were at 12 inches. Figure 25, page 283, shows probability distribution histograms of measured current values for test runs 22 through 31 and test runs 32 through 41. Series #1 test runs 42 and 43 are not used here because they were performed for video capture only.

The probability distributions for 10kA and 12kA test runs show little discernable character other than directing attention to most or all maximum current values being at least 10% greater than the target available fault current. 23kA and 21.5kA test runs show a strong tendency toward Uniform Distribution with mean values 7% and 14% higher than target values.

Coefficients of variation are all less than 10% - 9.3%, 8%, 9.4%, and 9%. All collected arc current values are within 2$\sigma$ of respective data set Mean values.

Analyzing the values from 40 test runs in series #1 suggests the test cell consistently sources higher than predicted available currents for 23kA and less, and that arc current would continue to fall in the same ranges for each of the four test configurations.

## Calculated Incident Heat

Heat energy imparted to each calorimeter is calculated as follows:

$$q = m \cdot \Delta T \cdot c \tag{15}$$

Where

- q : calculated heat energy in joules
- m : mass in grams
- ΔT : temperature change in degrees Celsius
- c : specific heat

Electrolytic tough pitch (ETP) copper [100] used in most electrical applications is 99.9% pure. Pure copper has a specific heat of $0.386\ J/(g\ ℃)$ at 37°C. For an 18g copper slug the conversion equation is then:

$$q = 18 \cdot \Delta T \cdot 0.386 \tag{16}$$

For 4cm diameter calorimeters, heat is calculated:

$$q(J/cm^2) = 0.5529 \cdot \Delta T \tag{17}$$

Arc flash calculations continue to carry the influence of medical research into skin burns. In this arena, thermochemical calories are more common as measures of heat energy. Joules and thermochemical calories are directly related by the expression $1\ cal\ =\ 4.184\ J$.

This yields the equivalent expression for incident heat energy

$$q(cal/cm^2) = 0.132 \cdot \Delta T \tag{18}$$

Values for specific heat of copper vary across sources. Physical properties of copper have been studied for many years and the temperature-dependent nature of this parameter is well understood [101]. The conversion constant for 18g copper slug calorimeters used by ASTM and others [102] is 0.135 to allow for repeated testing with initially very hot calorimeters. This conventional value will be used in this dissertation.

## Tabulated Heat Results

Table 10 through Table 24, starting on page 305, list test runs' maximum currents scaled to RMS for convenient comparison with expected fault current, arc event durations, and calculated incident energy values for each calorimeter. Arc durations vary depending on conditions of individual tests. For safety reasons, the test cell was configured to limit arcing time. Time limits varied according to the judgement of the facility manager. For some tests, the limit was 150ms, for others 350ms. Controlled termination of an arc, rather than allow it to self-extinguish, does not negate the validity of measurement. Radiated heat is a function of arc duration, especially for persistent arcs.

Tests performed at low anticipated incident energy had calorimeters positioned at 12 inches from the electrode rods. Series #2 tests where higher incident heat values were expected had the calorimeters placed at a conventional 18 inches from the electrodes. Incident energy values' table cells are color-coded according to NFPA 70E injury thresholds as follows

| | | |
|---|---|---|
| <1.2 *cal/cm²* | 1.2 → 4.0 *cal/cm²* | > 4.0 *cal/cm²* |

As described previously, for series #1 runs 1 through 43 the shell of the test fixture was connected to earth ground and the grounding cable passed through a CT. Measurements of ground current were collected for each test run and included on respective oscillograms. Several oscillograms have ground current scaled where impulses are observable.

For all series #1 runs, ground current impulses were approximately 100A peak. This value is less than, or much less than, 1% of full scale for currents measured. Furthermore, unlike Stanback's experiments, there was no erosion of the grounded metal shell. This leads to the observation that greater than 99% of arc current passed between the electrode rods and that phase-to-ground arc current was a minute contributor to overall arc energy.

For purposes of comparison, total heat exposure across the sensor array is determined from the arithmetic average of each group of seven incident heat values. This methodology is consistent with the work of Lee, Gammon, et al. [48]. Average heat, maximum heat, and arc duration are plotted against arc current in Figure 26 through Figure 40, beginning on page 284.

Comparing results from 240-volt runs shown in **Figure 26** to those of Smoak and Keeth (**Table 2** and Table 3) testing meter bases, their conclusion that arc flash incident energy would be quite low is born out. Had they measured heat for runs with fault currents as low as 1500A, the values in Table 10 suggest their results would have shown heat exposure much less than 0.1cal/cm$^2$.

With one exception, results depicted in Figure 26 and Figure 28 appear to support assertions by Wagner and Fountain [16], Stanback [20], and Jones, Liggett, et al. [31] that arcs in a 240-volt single-phase system will self-extinguish in two cycles or less. For arc events with enough available energy, the maximum emitted heat correlates with arc duration. This relationship has been understood for many years.

Coefficients of correlation are calculated for average radiated heat versus arc duration in the 40 series #1 events.

- The 10kA fusing events captured in Figure 26 all emitted less than 0.1 cal/cm$^2$. The coefficient of correlation for these 2.4MVA events is -0.13, reflecting the erratic nature of low energy arc flash events.
- While the heat energy releases for 240V @ 23kA (2.9MVA) runs were all 0.22 cal/cm$^2$ or less, Figure 28 still shows fair correlation with duration: a coefficient of 0.45.
- Figure 27 and Figure 29 show very good or fair correlation between arc duration and maximum emitted heat energy for 5.8MVA and 10.3MVA 480-volt scenarios. Correlation coefficients are 0.98 for Runs 12 through 21 and 0.5 for Runs 32 through 41.

As open circuit voltage increased and greater fault current was made available, arc duration, and thus incident heat, increased though not in a straight line. Measured incident heat remained below 0.1 cal/cm$^2$ at all tested currents for open circuit voltages 260V, 285V, 354V, and 434V. Only at 460 volts did average incident heat approach 0.5 cal/cm$^2$.

## Voltage Across the Arc

Once an arc channel is open, the plasma will conduct as much charge flow as the source system can deliver with little increase in arc voltage above some threshold. This behavior is highly non-linear and a topic of study to itself. What is significant in the area of arc flash is the evidence provided by real-time voltage measurements that a plasma conduit is created for an event. This is apparent on oscillograms where the arc persists for several cycles. The voltage waveform is truncated at the breakdown potential for the plasma column created by the vaporized copper. This behavior has been observed by many including Stanback who commented on the “square wave” nature of the clipped arc voltage plots. Illustrative examples can be found throughout Appendix A beginning on page 132.

## Copper Loss

Across the course of the series #1 480-volt total test runs, four inches of each 3/4-inch copper rod was consumed or an average of approximately 0.2 inches of each rod (~26gm) was lost to vapor or molten spray during each test.

Applying Stanback’s estimation method for copper loss to the second set of ten 480-volt runs, using measured arc currents and durations, yields a predicted total loss of 4.54 cu. in. The actual copper loss for these ten runs is $\left(\frac{0.75}{2}\right)^2 \times \pi \times 4 \times 2 = 3.53\ cu.in.$ This suggests Stanback’s method applies best to the single-bus or multiple-flat-buses configuration he was testing.

## Tabulated Arc Blast Pressure Results

Arc blast pressure measurements were collected with the calorimeter cart located at 12 inches from the electrodes and at 18 inches. With the pressure transducer mounted 18 inches above the center calorimeter, this corresponds to distances from the arc of 21.6 inches and 25.4 inches. Measured values of maximum arc blast pressure, normalized to 18-inch calorimeter spacing, varied from 1.2 psi (8.4kPa) to 223 psi (1539.6kPa). This corresponds to pressure wave intensities of 172.5dBA up to 217.7dBA. Distance corrected values are collected in Table 25 beginning on page 312 and shown graphically in Figure 44 on page 293. The red line in the figure identifies the guaranteed eardrum rupture threshold. 41% of the values in the series #2 tests evaluated exceed this threshold.

## Post-Run Snapshots

Snapshots were taken at several times during the testing sequence to capture results of special interest.

Figure 46, page 295, shows snapshots following 240-volt, 10,000-amp test runs #1, #2, and #9. Copper spray behind the right-most rod after Run #2 is evident. Considering the absence of rod erosion at this point, the somewhat straight line of spray resulted from the melted and splattered copper fuse wire.

Contrasted with the 240-volt runs, the deposition of copper vapor on the back panel from rod erosion after just three 480 volt runs and pronounced by Run #34 is apparent as shown in Figure 47, page 295. The shape and direction of the deposition patterns reflect the photographs of Stokes' arc flares shown in Figure 5.

It is also apparent from the angular shape of the rod ends and the position of the fuse wire remnants that, once initiated, the arc migrated away from the point of initiation and then burned at the rod ends and flared outward as the arc evolved. This is a graphic demonstration of the Lorentz Force, described in "Migration of the Arc" on page 35. It may explain why incident energy values in series #1 test runs 32 through 41, show calorimeters 6 and 7 at the bottom of the array exposed to the greatest heat.

Figure 48 shows the condition of the test fixture following series #2 test 76. By this time, the interior of the fixture shell was heavily coated with copper slag primarily due to the preceding 604V @ 14.6kA tests. Also conspicuous is heat damage of fixture finish on the lower rear sides due to arc flares.

Figure 49 on page 296 focuses on the interior of the fixture at the conclusion of series #2. The ends of the copper electrode rods have been burned down to two inches after having been moved down twice during preceding tests. There is heavy accumulation of copper vapor deposited on the backplate bottom corners, and a heavy overall buildup of molten copper splatter and slag.

## High Speed Video

High-speed video revealed two characteristic sequences of events for the cases in this investigation:

**Sequence 1** – example shown in Figure 50, page 297

1. Destruction of the fuse wire, with ejection of molten material, varying levels of blast, and minor flash.

**Sequence 2** - example shown in Figure 51, page 297

1. Initial destruction of the fuse wire, with ejection of molten material followed by a short delay
2. Significant flash and blast event – higher available current extends the flash event
3. Generation of a plasma cloud

Tests at voltages below 460 volts exhibited both sequences though any flash or blast was usually brief. Evidence of fuse wire welding at tie points and observations of behavior in such high-speed videos as 27878, 27880, 27883 shows the fuse wire tended to heat uniformly and then melt at one or both ends, often with a withered remnant of the fuse wire falling away as the arc flash developed.

By contrast, all test runs at 480 volts or greater exhibited all three stages listed above for Sequence 2: fusing event with a short delay corresponding to the current waveform rising to its peak, flash extending across multiple cycles, and plasma cloud and molten spray. An example from series #1 run 35 is shown in Figure 52, page 298.

High speed video was reconfigured during test series #2 to capture only the arcs and flares present during the flash event. This required reducing the framerate from 5000 frames/sec to 2000, increasing the shutter speed to its maximum value, and adjusting aperture f-stop to its highest setting. This produced small, lower resolution images but does allow direct observation of arc and flare behavior, especially the ebb and flow of flares at the rod ends as current cycled positive and negative.

Recalling Stokes' high-speed still images (Figure 5), the clip sequence in Figure 53 shows a short, one-cycle fuse and flash sequence that yielded very little heat. Figure 54 shows the multiple cycle 604V event for series #2 run 68, video file 34405. This illustrates arcing events between electrodes and aggressive flares at rods ends.

## Sources of Error

### ***Calorimeter Surface Treatment***

Mary Stoll's method of collecting heat injury data required blackening the target skin area with India ink. Lee, Gammon, Mandal and Song [103], and others painted calorimeter surfaces with flat black paint. The U.S. Naval Radiological Defense Laboratory (USNRDL) treated calorimeters and radiometers with either platinum black plating or 3M Velvet Black paint [104]. Winkler and Sheldahl [105] showed calorimeter surface treatment can affect measured temperature for gas streams by as much as 20%.

For series #1 runs 1 through 43 and series #2 runs 1 through 90, the calorimeters were left unpainted. This could have reduced the thermal absorption of the calorimeter faces yielding lower heat rise value. USNRDL results suggest heat could have been under-measured by a factor as great as 2.5.

Series #2 test runs 91 through 110 were executed to provide a basis for directly comparing painted versus unpainted calorimeters. Tests 91 through 100 measured incident heat for 460 volts at 20.66kA with calorimeters spaced 18 inches from the electrodes. Copper dust on calorimeter faces from previous runs was not removed before executing this test sequence. Tests 101 through 110 measured incident heat for the same configuration except that calorimeter faces were burnished with Scotch-Brite® and coated with Rustoleum® high heat 2000°F flat black spray paint. Calorimeter faces were repainted every other test.

Series #2 tests 91 through 95 exhibited unexpectedly low arc durations in contrast to the rest of this group so, for purposes of direct comparison, these values will not be considered.

The average of series #2 tests 96 through 100 heat values for unpainted, uncleaned calorimeters is 2.42 cal/cm$^2$. The average maximum heat is 4.08 cal/cm$^2$. By comparison, the average heat for tests 101 through 110 is 2.48 cal/cm$^2$ and the average maximum is 3.69 cal/cm$^2$. An increase in average accumulated heat of only two percent paired with a decrease in average maximum value shows the emissivity difference between unpainted and painted calorimeters was insignificant. An explanation for this can be deduced by examining the calorimeter faces in Figure 48, page 296. The copper discs are all covered with a uniform brown haze. Since nothing flammable existed inside the test fixture it can be reasonably assumed this was copper dust or black copper oxide. The emissivity values of copper oxide and copper powder have been measured as 0.76 - 0.8 [106]. While less than the 0.91 emissivity of 3M Velvet Black paint [107] used in others' tests, it is equivalent to the 0.81 – 0.88 exhibited by textiles [108] used in flame retardant garments.

The bright copper of new calorimeter faces would have exhibited emissivity less than 0.1 and so would have been less sensitive to incident heat; however, once the first few test runs had been executed, they were covered with metallic haze. This haze would have increased the emissivity of the calorimeter faces and aligned the measurements from following tests with others' findings, making paint application unnecessary.

***Calorimeter Placement***

During series #1 tests and for some series #2 tests, calorimeters were deliberately moved closer to the test fixture to intercept more emitted heat. This relocation, from 18 inches to 12 inches, does not permit direct comparison with past work by others who conventionally chose an 18-inch separation.

For the sake of completeness and accuracy, an arc must be considered as a line or column source of radiant heat. However, for purposes of this discussion arcs will be approximated by a point source. Correcting for difference in configuration geometry from a point source leads to the following:

- For the centermost calorimeter, the diameter of a 4 cm disc at 12 inches projected to 18 inches is 6 cm. This yields a correction factor of $\pi\left(\frac{4}{2}\right)^2/\pi\left(\frac{6}{2}\right)^2 \; or \; {}^{1}/_{2.25}$ for this one calorimeter.
- Accounting for horizontal angular difference and thus greater distance, the correction factor for the other two center row calorimeters is $0.707/2.25$.

- Similarly, for the top and bottom row devices, the correction factor is $0.716/2.25$, again due to combined angles and increased distance.

Series #2 tests 33 through 52 were executed to check the suggested geometric corrections and determine their validity. Runs 33 through 42 were configured 488 volts at 14.3kA with calorimeters located at 12 inches from the electrodes. Runs 43 through 52 were the same configuration but with the calorimeters moved back to 18 inches. Table 21 and Figure 33 show values for the 12-inch setup. Table 22 and Figure 34 show values collected at 18 inches. Figure 33 and Figure 34 show probability distributions for these two data sets. Distribution of data collected at 12 inches is skewed high and distribution of data collected at 18 inches is skewed low. Deriving an overall correction factor requires choosing values to represent these two data sets. Arithmetic average is appropriate in this case because averages are influenced by skew where median values are not. The ratio of average values yields a correction factor of 0.233; smaller than the straight ratios developed based on geometry which range between 0.314 and 0.444.

***Data Recording Truncation***

The test cell controller was configured to open the source bus contacts at a predetermined time. During series #1 and some series #2 tests, this was one cycle past 150 ms. For all other tests in series #2, this time was 350ms or 500ms. Events that could have persisted beyond ~167ms but were terminated by the test cell would have produced less measured heat, so the reported incident heat values for these tests will be low.

Test series #2 data recording was typically terminated at 500ms. For some instances, the blast pressure wave had not fully developed by this point so blast pressure is underreported in these cases.

***Loss of Resolution***

Producing an engineering model for any physical system requires developing acceptable approximations. In the case of arc flash data, one approximation is the arithmetic average of incident heat values over the array of seven calorimeters. While such averages will be influenced by hot spots, the effects of high temperatures at one or two calorimeters can be reduced by much lower ones at others.

The tradeoff for collecting data into an overall average is the loss of accounting for hot spots. For example, arcs driven down to the ends of the rods in series #1 tests 32 through 41 increased the measured heat at the bottom two calorimeters to greater than 1.2 $cal/cm^2$ yet all the averages were 0.88 or less. Series #2 tests 32 through 52 exhibited increased heat about the left-center and center calorimeters but generally lower heat energies on the right.

Another potential loss of data occurs with a standard seven-element calorimeter array set at the conventional 18 inches back from the test fixture. The conspicuous difference in probability distribution skew between the 488V tests at 12 inches and at 18 inches illustrates how the six additional inches moved calorimeters such that they intercept less of the arc plume. When values are averaged, this results in underestimating exposure of the lower or upper body.

***Parameter Sensitivity***

The specific heat of copper varies with temperature. One historic source shows it increasing from a value of 0.3805 at 0°C to 0.3885 at 50°C [101]. Other sources list copper specific heat as 0.385 at 20°C [109] for the alloy identified as electrolytic tough pitch. For an 18g copper slug calorimeter that is 4cm in diameter, this variation causes the temperature-to-energy conversion multiplier to vary from 0.130 to 0.133. The conventional multiplier for calorimeters constructed according to ASTM specifications is 0.135. This value is 3.8% greater than that at 0°C and 2.4% greater than that at 20°C. Examining the Henrique integral on page 35, the temperature term is in the denominator of a negative exponent of *e*. Varying the temperature term by 2.4% yields an approximately 2% effect on the resulting value of the boundary parameter Ω. For very high energy arc flash events, using a constant conversion value of 0.135 could result in minor observable variation in predicted degree of skin damage, usually erring in the direction of over-estimating heat. For arc flash events in the energy range explored in this dissertation, a 2% difference is insignificant.

By contrast, the effect of distance and distance correction is pronounced. Increasing distance from the origin of the arc flash event by six inches reduces incident heat by a factor of at least two and as high as four. For purposes of standard calculations, this distance is controllable. However, in day-to-day working conditions it may not be. Prudent caution would be required when basing protective equipment selection on assumed working distances since workers' hands and lower forearms are likely to be closer to an arc flash origin than the conventional 18 inches.

## Data Correction

Empirical evidence in this dissertation's experiments showed that calorimeter surface treatment is not a factor for arc flash tests in the configuration used so no correction is required.

Experimental findings for heat reduction in 12-inch versus 18-inch calorimeter spacing yielded a correction multiplier of 0.233 or $1/4.3$. For purposes of this treatise, the corrections based on geometry will be used instead because the resulting heat values are greater; that is: the reduction multiplier is lower. This is a more cautious approach. Heat values for all test runs at or normalized to 18 inches are presented in Table 26 starting on page 316. Color codes shown on page 77 are again used to identify calorimeter readings that do, or do not, show dangerous levels of incident heat.

Blast pressure values were collected with the sensor array at both 12 inches and 18 inches from the electrodes. Since the blast sensor was mounted 18 inches above the center calorimeter, this corresponds to 21.6 and 25.4 inches respectively. Sound pressure has an inverse reciprocal relationship to radial distance. Pressure values at 12-inch cart spacing were reduced by a factor of 1.178 to normalize them to 18-inch sensor cart spacing.

## Comparing Single-Phase Values to IEEE 1584

In the absence of an accepted standard method, design engineers or system owners may be tempted to apply IEEE 1584-2018 calculations to single-phase equipment. This approach yields questionable results since low fault energies can precipitate overcurrent device trip times exceeding 900 seconds in modeling software and may result in very large incident heat values of hundreds with arc flash boundaries in hundreds of feet. As stated previously, IEEE is clear the 1584 method is intended for use only when analyzing three-phase systems.

As a demonstration comparison, the system configuration and measured values are processed through the IEEE 1584-2018 calculation method for open-circuit voltages $208V \leq V_{OC} < 600V$, with incident energy results compared to those obtained experimentally. Results are shown graphically in Figure 43 on page 292. The ratios of IEEE predicted values divided by respective measured average heat values are plotted by voltage test group. Nearly all the ratios are greater than 1.0 with most much greater than 1.0. This demonstrates that the IEEE 1584 calculation method overestimates incident heat for single phase systems and serves to reinforce the IEEE's admonition that the 2018 calculation method should not be used for any configuration other than three-phase.

# Chapter Eight : Conclusions

The terms arc flash, arc blast, and high energy arc fault describe an event that can start fires, damage or destroy equipment and surrounding structures, and severely injure or kill personnel. These dangerous conditions arise when a short circuit is introduced into an electrical system with the following results:

- Very high fault current – thousands of amps
- Intense radiated heat and light
- Arc plasma, flares, and plume
- Explosive sound pressure
- Molten metal ejecta

Although three-phase arc flash events have received the most research attention, single-phase events should be researched further as they can occur in a variety of commercial, industrial, and utility circumstances. Experimental work for this dissertation explored one single-phase electrical configuration and revealed both a lower threshold of concern for that configuration and that severe burns are probable above that threshold. Ear and eye injuries are possible or likely for any of events in this investigation.

## Observations and Interpretation

### ***Low Heat Events***

The first and most conspicuous finding apparent from the series #1 and #2 data and plots is that for open circuit voltage 434 volts and below, for any current tested, all but three arc events self-extinguished at less than 50 milliseconds or three 60Hz AC cycles. The incident energy values were all at least one order of magnitude less than the 1.2 cal/cm$^2$ threshold for second-degree skin burn. This is consistent with others' findings and with intuition that while short duration arc flash events may be hot enough at the event site to melt the initiating conductor, they do not exist long enough to radiate much heat or generate a pronounced convective plasma cloud.

This shows that circuit breaker panels in common residential and light commercial applications do not represent a risk of burns from arc flash during an accident. However, this observation must be heavily qualified. For example, high-speed videos 27881 (series #1 run 7), 27882 (series #1 run 8), and 27883 (series #1 run 9) show that a short duration plasma plume can be created, that there can be a flash event, and that a spray of molten particles from the object causing the fault can be ejected from the arc site. This will produce localized burns, especially to delicate tissues of the face and thinner skin on the forearms. Furthermore, there is still a risk of eye damage due to bright light.

While arc events at 260 volts did not develop pressure approaching the 14.5 psi guaranteed eardrum rupture threshold, they did produce blast waves as high as 5 to 7 psi. This translates to as much as 1500 pounds force on an adult – enough to assuredly knock a worker off their feet.

***High Heat Events***

Where lower energy arcs generally self-extinguished in a few cycles, most arc events at 460 volts and higher persisted for much longer. This finding contradicts assertions made by Jones, Liggett, et al. but aligns with Stanback’s results. The longer arc durations yielded predictably higher measured incident energies, e.g., ten times greater than 240-volt events with similar fault current. This greater heat production was enough to raise the temperature of the test fixture to levels where the electrodes could not be safely handled immediately following any of the 480-volt or higher test runs.

Experimenter and test cell operators agreed the subjective description of series #1 480-volt events' acoustic intensity was equivalent to a shotgun blast, even behind protective windows and door. Greater than 130dB from the two sound pressure measurements suggests this description was entirely reasonable. This impression was confirmed by series #2 blast pressure measurements which revealed dangerous high-pressure impulses. Elevated heat and sound pressure impulses exceeding safe limits are both evidence that single-phase arc flash events in systems 460 volts and higher with 1.5-inch gap distance are a likely source of severe injury and equipment damage.

Plotting incident energy values versus open circuit voltage and available fault current for the 1.5-inch arc, and connecting the mean values for the voltage-specific data sets, more clearly reveals a relationship as shown in Figure 45, page 294. Average data values for 240, 260, 385, and 434-volt sets all clustered at less than 0.1 cal/cm$^2$ incident energy, essentially independent of arc current or duration. At 460 volts and greater, enough power is delivered to the arcs that incident energy greater than 1.2 cal/cm$^2$ becomes possible.

Plotting and joining median values, and interpolating where reasonable, yields a family of curves that suggest a prediction of incident heat should be possible based on open circuit voltage and available fault current. Experimental data reveal times for arcs to self-extinguish that should be used as an upper limit in a predictive calculation when a shorter interruption time is not introduced by a fast-acting overcurrent protective device.

Because the blast wave is a result of rapid thermally driven expansion within and around the arc column, Figure 44 plots maximum pressure against corresponding arc current and duration calculated as $i^2t$. The value of $i^2t$ expresses available thermal energy in an electrical system and is commonly used in sizing overcurrent protection devices. The trend line added to the plot suggests the possibility that blast pressure may be predicted. As detailed in Chapter Four : Arc Blast, the threshold for guaranteed eardrum rupture is 100kPA or 14.5 psi. 40 of the 98 values in Table 25 exceed this threshold; some by an order of magnitude.

As described in Blunt Force Trauma on page 41, an impact of 220kPa blast wave to the chest will result in a 25% chance of fracturing ribs. The most extreme of the arc flash events could yield a momentary force of more than 1500kPa. While ribs in a living person are quite flexible [110], and total power of the blast wave must be evaluated, this level of impulse seems likely to result in severe physical injury.

## Summary

This dissertation explores the history of arc flash investigations and the basis for IEEE 1584 calculations. It presents the results of experiments addressing one gap in that Standard. The initial hypothesis for this work was **"Single-phase arc flash energy yield is expected to be less than that predicted for three-phase at equivalent voltage and available current."**

- This conjecture was shown to be true and supported by empirical data.

Incident heat results are presented in a family of curves that suggest the possibility of predicting heat for arc flash in single-phase systems. This would be useful for the following reasons:

- incident heat values for single-phase arc flash events in systems 460 volts and greater are high enough to risk potentially severe burn injury
- incident heat values in systems 434 volts and lower appear to pose little or no risk of burn injury in the configuration investigated

Blast pressure data were collected, tabulated, and plotted. Results show high risk of hearing damage and potential for significant blunt force trauma when a worker is within 18 inches of an energetic event.

## Recommendations for Additional Work

This dissertation's experimental series investigated one bus configuration, Vertical Conductors in a Box, with copper electrode rods spaced a nominal 1.5 inches, and collected data allowing determination of risk for burn injury and hearing loss or blunt force trauma. In order to provide a complete basis for arc flash calculations commensurate with the IEEE 1584 standard, additional scenarios should be evaluated.

### *Voltages and Currents*

While the results in this dissertation show little or no risk of arc flash burn injury for 240 volts at 22kA and as high as 434 volts at 10.9kA, the same may not be true for other configurations. Lower threshold voltages or currents may exist depending on the test fixture arrangement.

Single-phase faults to ground or to an adjacent phase are a likely occurrence in utility installations. Exploring the range of industrial and utility medium voltages from 601 volts to 15kV would add to the knowledge basis for protective equipment research and the ASTM method based on T. E. Neal's work.

### *Bus Configurations*

All five IEEE 1584 configurations may be found in single-phase applications and should be fully investigated. Experimental work for this dissertation explored Vertical Conductors in a Box (VCB); however, additional work is needed. The other four IEEE 1584 configurations that should be examined are:

- Vertical Conductors in a Box with Barrier (VCBB)
- Horizontal Conductors in a Box (HCB)
- Vertical Conductors in Open Air (VOA)
- Horizontal Conductors in Open Air (HOA)

***Conductor Gaps***

A variety of separation distances exist in all electrical equipment. These spacings should be investigated. IEEE 1584 section 4.2 identifies ranges for conductor gaps as follows:

- 208 volts to 600 volts – 0.25 inches to 3.0 inches
- 601 volts to 15kV – 0.75 inches to 10.0 inches

***Eye Injury***

As shown in Chapter Four : Vision Damage, arc flash injury to the eye has been explored to varying degrees in the recent past. Experimenters' interests focused on measurement technology and quantifying the relationship between incident energy and type or extent of injury. Significant additional engineering and biomedical cross-discipline collaboration is needed in this arena to:

- further characterize the wavelengths and energies associated with specific types of eye injury (cornea, lens, retina), including validation against biological specimens
- develop and standardize instrumentation for accurately measuring short duration impulses of injurious wavelengths and energies
- extend previous work to offer a predictive algorithm for identifying light output from three-phase and single-phase arc flash events.

### ***Hearing Damage and Blunt Force Trauma***

Pressure measurements collected during test series #2 revealed the possibility of dangerously powerful pressure waves at 12 to 18 inch working distances. Blast pressure measurements should be included as a routine part of all future arc flash testing experimental set-ups, with data collection allowed to run past the point of maximum blast wave pressure - likely about one second. Additional research and analysis of the underlying phenomena, and further data collection, are needed to develop and validate an accurate predictive model for arc blast wave intensity.

### ***Arc Column Temperature***

A variety of methods have been employed over the years to measure the temperature of the arc column during a flash event. These have included such techniques as inferred values from radiant heat and temperatures calculated from sound velocity changes. One method that offers promise is direct measurement by passive microwave. This approach allows measurements at microsecond speeds, unimpaired by obscuring soot or debris. The effect of conductive vapor in the plasma column must be investigated.

### ***Electrode Materials***

This investigator initially supposed that the melting and vaporization temperatures of aluminum being lower than copper would lead to arc flash events with significantly greater incident heat energy. However, discussion with the Schneider Electric engineering manager revealed their experience pointed in the opposite direction. While the melting temperature of aluminum is much lower than for copper, the vaporization temperature is only slightly lower.  The engineering manager reported previous tests in their facility showed that, rather than vaporizing and increasing the conductivity of the plasma column, the aluminum melted so rapidly that it simply fell away and puddled in the bottoms of test fixtures.  For this reason, investigating arc flash incident heat for aluminum conductors as a contrast to copper is <u>not</u> expected to be fruitful.

### ***Calorimeter Surface Treatment***

The sample set of comparable values based on arc duration turned out to be quite small, however the results are consistent with the experience of the laboratory operators.  Accumulation of metallic dust on the faces of the calorimeters verifiably increased emissivity to the level achieved by using flat black paint.  For this reason, further data collection to compare unpainted versus painted calorimeters is <u>not</u> expected to improve these findings.

## Recommendations to Industry

Consistent with the approach taken in NFPA Standard 70E, recommendations for worker protection from possible single-phase arc flash events are divided by system voltage.

Approach boundaries for electric shock protection as detailed in 70E article 130.4 must be observed as written for both single-phase and three-phase installations for all system voltages.

***Single-Phase 50 – 277 Volts***

The arc flash risk from single-phase events up to 277 volts and 22,000 amps bolted fault current, where there is no possibility of involving three phases, is very low. Maximum incident heat protection required is 0.2 cal/cm$^2$. This can be accomplished with the flame-resistant garments required for all electrical work. Additionally, a face shield, hard hat, and hearing protection are required. Ear plugs must be non-flammable foam with 22dB noise reduction ratio or greater.

Equipment labeling in this voltage and current group shall be as required in 70E article 130.5 with the incident heat value set at 0.2 cal/cm$^2$ and no PPE category identified. This includes residential circuit breaker panels for 230-volt and 240-volt installations.

***Single-Phase 277 – 434 Volts***

The arc flash risk from single-phase events between 277 volts and 434 volts and up to 22,000 amps bolted fault current, where there is no possibility of involving three phases, is moderate. Incident heat protection shall be based on a possible 1.2 cal/cm$^2$ exposure and shall be selected in accordance with 70E article 130.5. This must include all listed gear including face, head, eye, and ear protection. Ear plugs must be non-flammable foam with 31dB noise reduction ratio.

Equipment labeling in this voltage and current group shall be as required in 70E article 130.5 with the incident heat value set at 1.2 cal/cm$^2$.

***Single-Phase 434 – 600 Volts***

The arc flash risk from single-phase events between 434 volts and 600 volts and up to 15,000 amps bolted fault current, where there is no possibility of involving three phases, is high. Incident heat protection shall be based on a possible 8 cal/cm$^2$ exposure and shall be selected in accordance with 70E article 130.5. This must include all listed gear including face, head, eye, and ear protection. Hearing protection must include both non-flammable foam ear plugs with 31dB noise reduction ratio and earmuffs with 34dB noise reduction ratio or better.

Research and empirical data show high levels of risk for cataracts and retinal damage from arc flash in systems 460 volts phase-to-phase and higher. Where electrical work must be performed on energized equipment of this type, ultraviolet and bright light protection, such as auto-darkening welder's glasses, are strongly recommended.

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# APPENDICES

# APPENDIX A : OSCILLOGRAMS

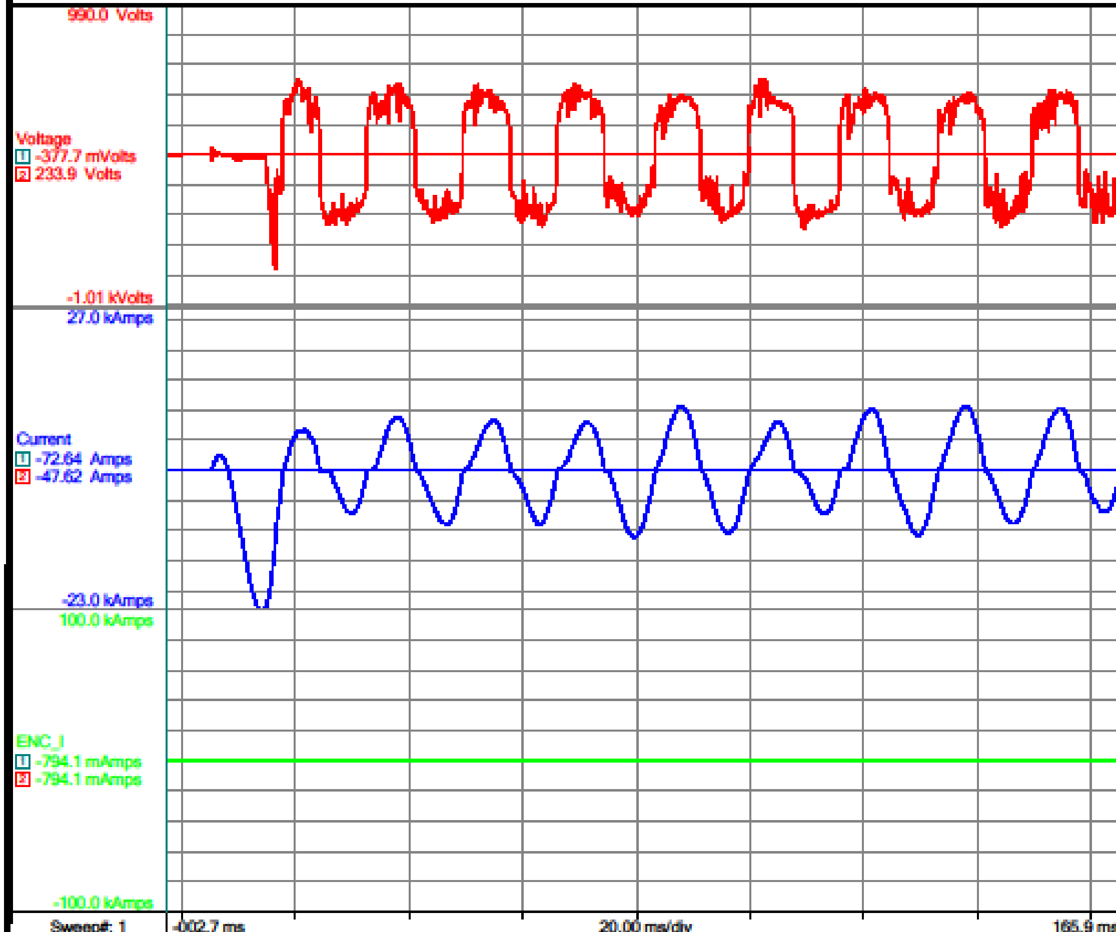
Oscillogram No.: HPL3-30027 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 10:50:28 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 14




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 284 Deg |
| Closing time (V0)+ | 16.87 m Sec |
| Peak Current (Ip) | -23.38 k Amperes |
| Time to Ip | 8.799 m Sec. |
| I²t | 7.820 M Amp^2sec |
| I Duration | 152.6 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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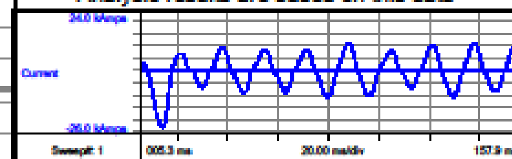
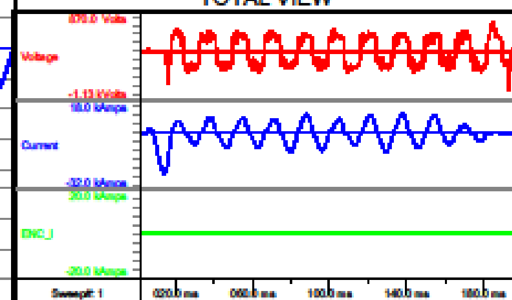
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE:HPL3 [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-30027**

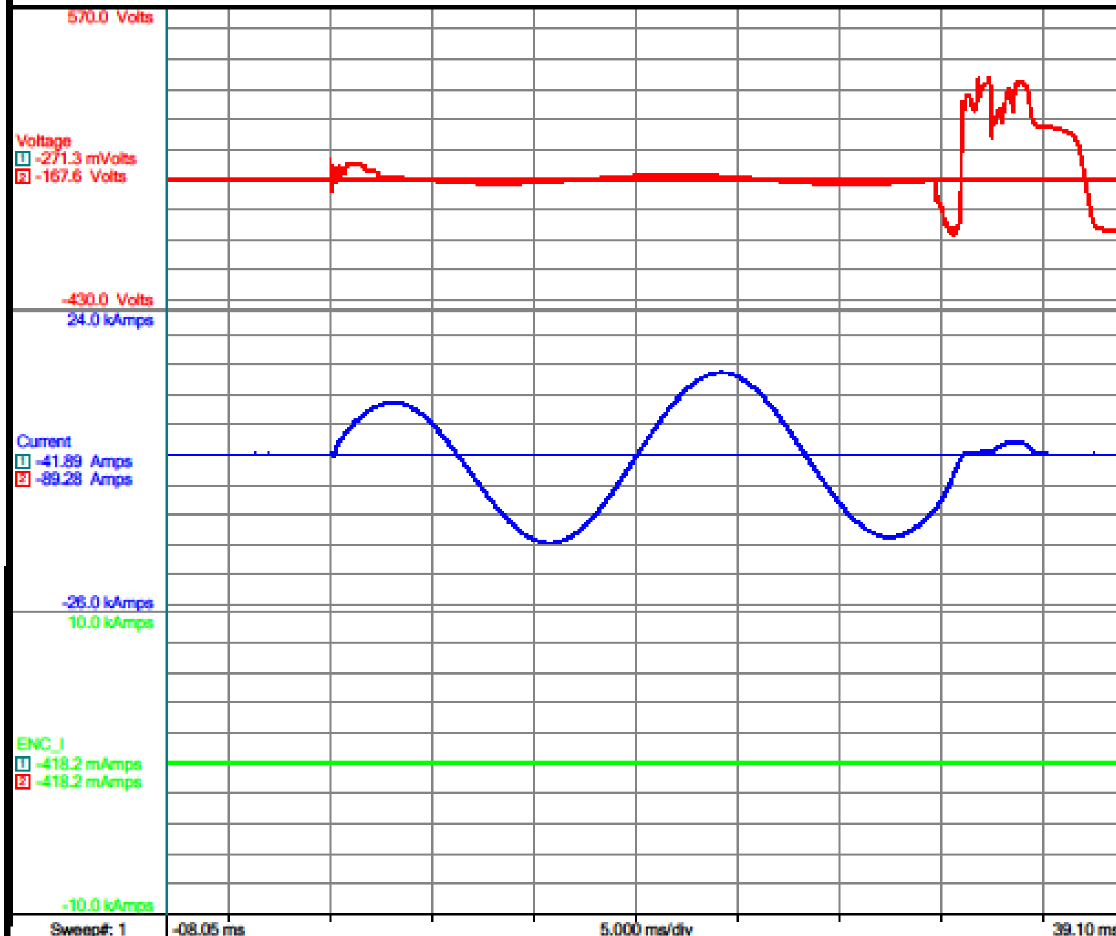
Oscillogram No.: HPL3-27875 OCV = 241 V
Date of Test: 6/9/2020 Time of Test: 8:14:51 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30017 Calibration Date: 5/05/2020
OCV = 240 V Rms Sym Current = 10.01 kA
Power Factor = 47%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 1




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 95 Deg |
| Closing time (V0)+ | 4.417 m Sec |
| Peak Current (Ip) | -14.75 k Amperes |
| Time to Ip | 10.81 m Sec. |
| I²t | 2.719 M Amp^2sec |
| I Duration | 31.14 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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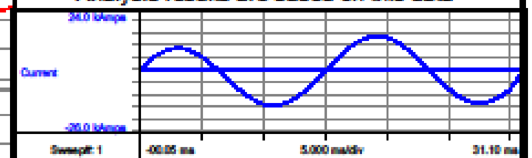
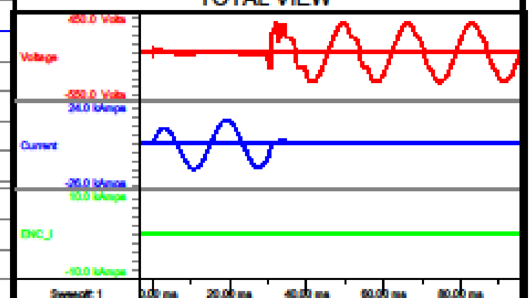
## Analysis results are based on this data




## TOTAL VIEW



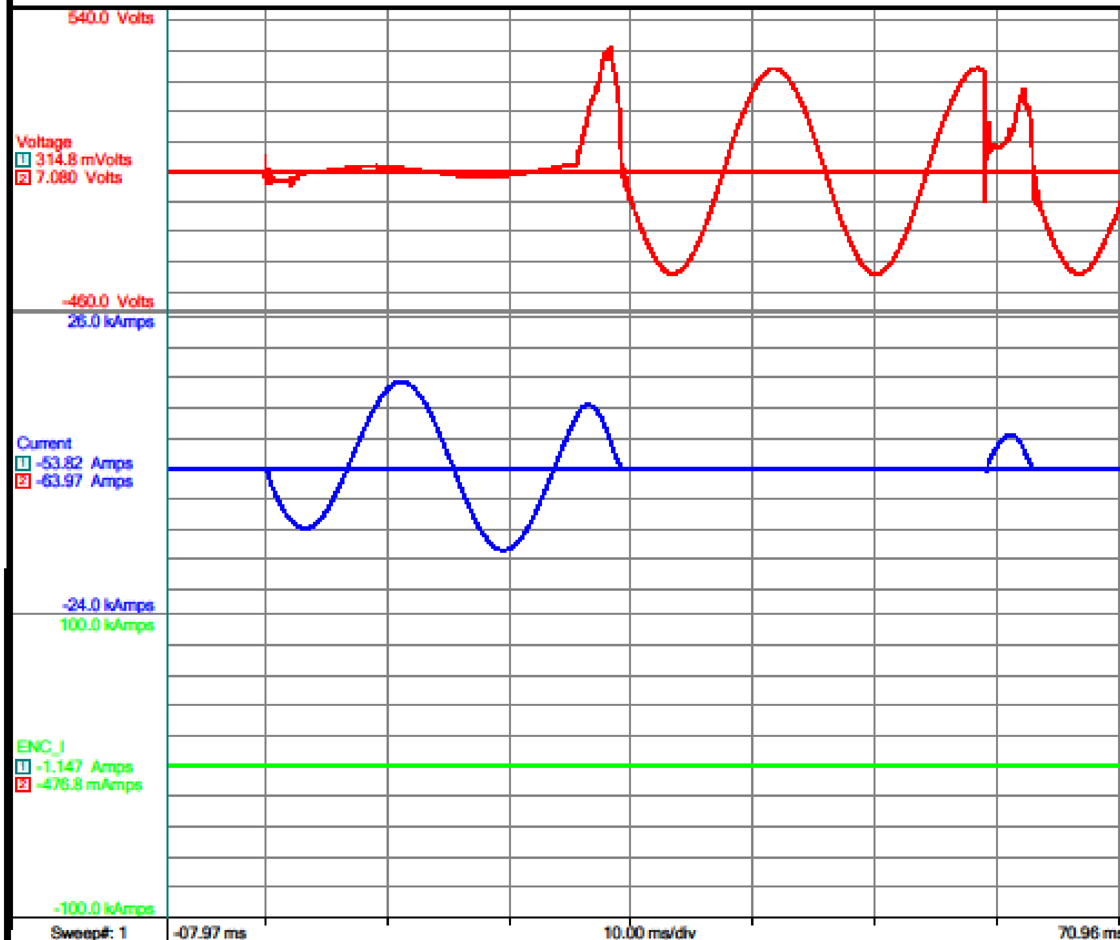

## INSTRUMENTATION DATA

Data Recording System:HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-008, 1% PLOT FILE:HPL3 CR_I_W
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-443
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-27875

| | |
|---|---|
| Oscillogram No.: HPL3-27876 OCV = 241 V<br>Date of Test: 6/9/2020 Time of Test: 8:33:57 AM | **Schneider Electric**<br>High Power Laboratory, HPL3 Facility<br>Cedar Rapids, Iowa, USA |
| AVAILABLE CIRCUIT CHARACTERISTICS:<br>Osc. No: 30017 Calibration Date: 5/05/2020<br>OCV = 240 V Rms Sym Current = 10.01 kA<br>Power Factor = 47% | |

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 2




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 269 Deg |
| Closing time (V0)+ | 12.44 m Sec |
| Peak Current (Ip) | 14.43 k Amperes |
| Time to Ip | 11.14 m Sec. |
| I²t | 2.332 M Amp^2sec |
| I Duration | 62.92 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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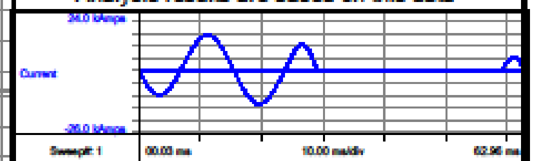
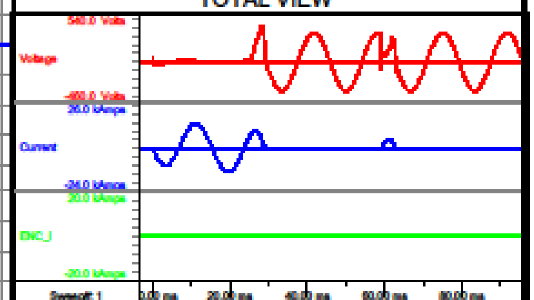
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN3T CAl 063-173
VOLTAGE 100X Scope Probe, CAl 131-505, 1% PLOT FILE HPL3 CR_I_III
VOLTAGE 100X Scope Probe, CAl 131-504, 1%
CURRENT ROGOWSKI COIL, CAl 048-445
NOTE: Channel offset removed for analysis,
but not for display.

**OSC. NO.: HPL3-27876**

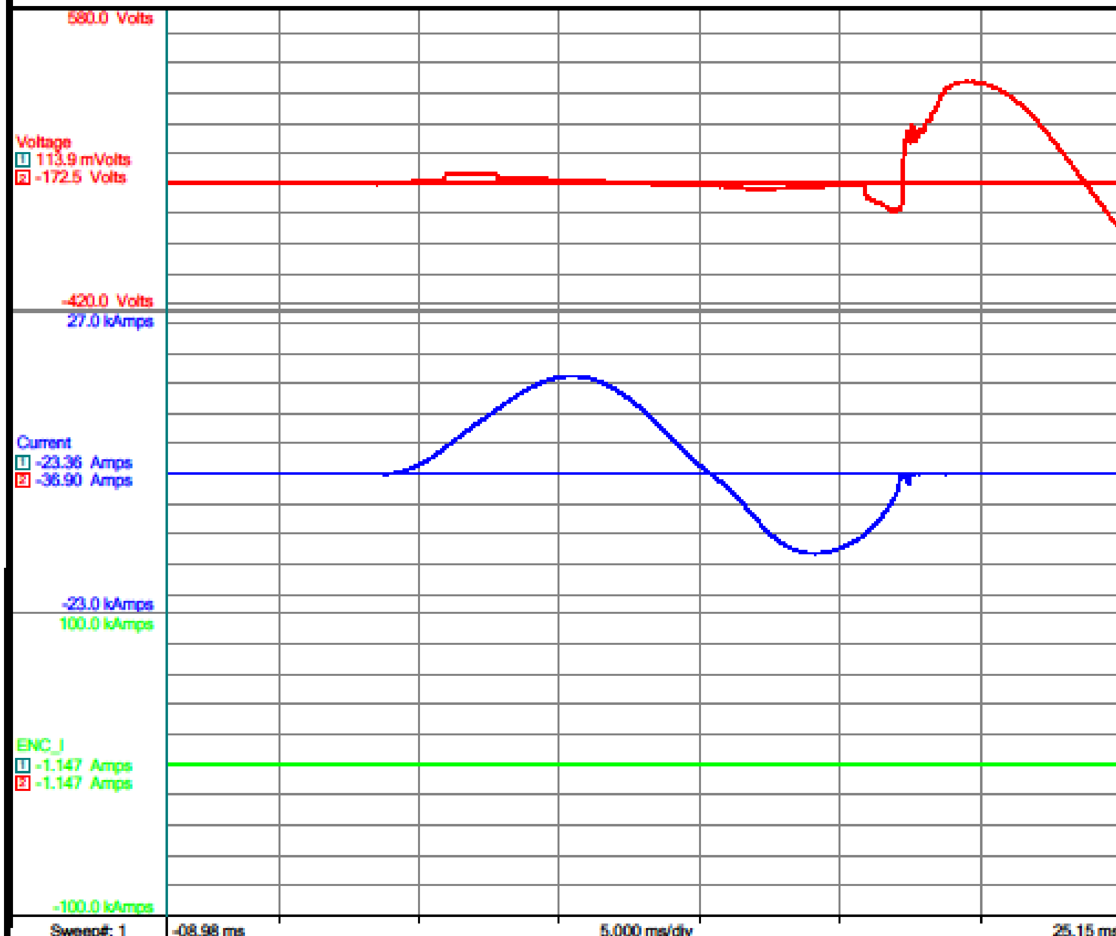
Oscillogram No.: HPL3-27877 OCV = 241 V
Date of Test: 6/9/2020 Time of Test: 8:47:21 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30017 Calibration Date: 5/05/2020
OCV = 240 V Rms Sym Current = 10.01 kA
Power Factor = 47%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 3




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 6 Deg |
| Closing time (V0)+ | 282.0 µ Sec |
| Peak Current (Ip) | 16.22 k Amperes |
| Time to Ip | 6.447 m Sec. |
| I²t | 1.912 M Amp^2sec |
| I Duration | 18.13 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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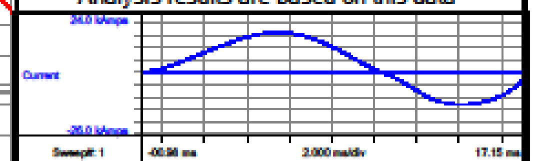
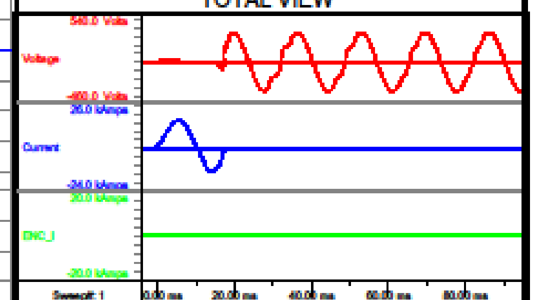
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System:HBM GEN7T CAI 000-173
VOLTAGE 1000X Bruger Probe, CAI 131-000, 1%
VOLTAGE 1000X Bruger Probe, CAI 131-004, 1%
CURRENT ROGOWSKI COIL, CAI 040-443
NOTE: Channel offset removed for analysis
but not for display.

PLOT FILE:HPL3 CR_I_M

**OSC. NO.: HPL3-27877**

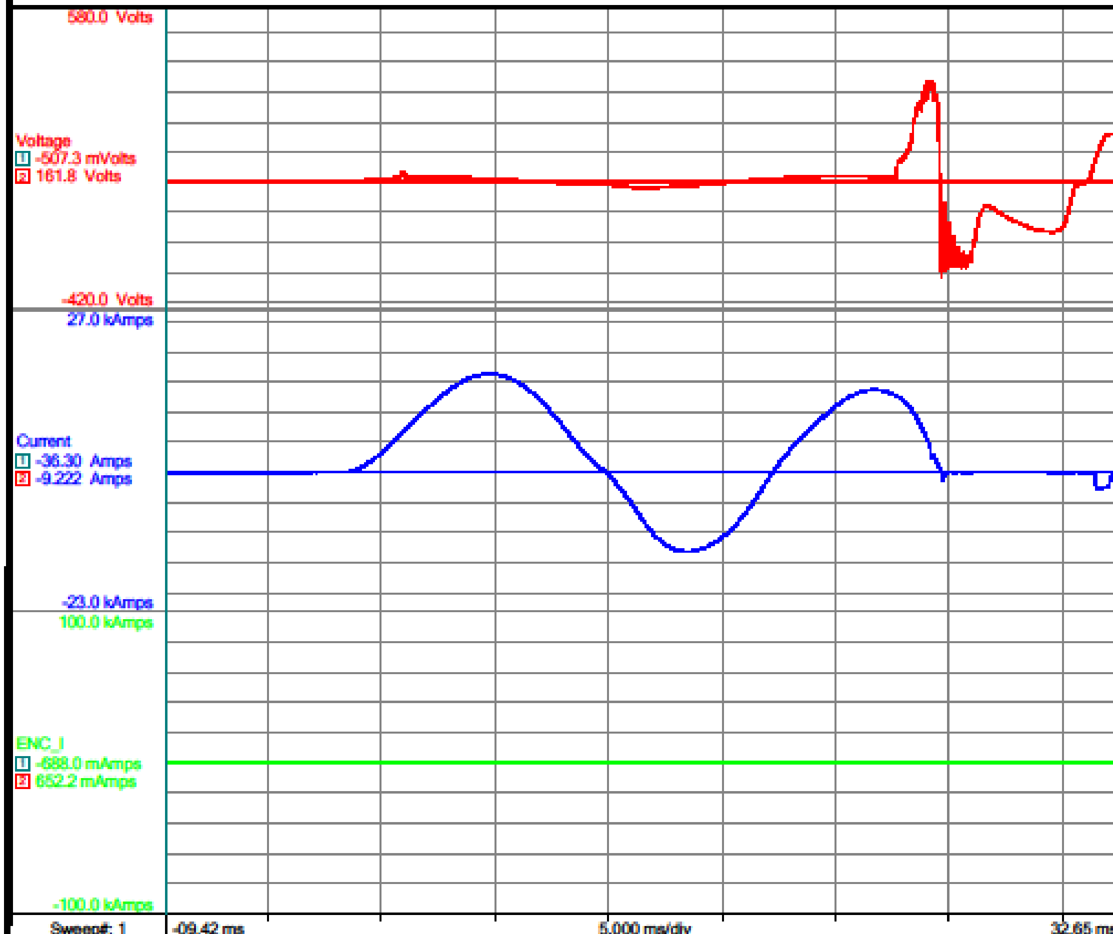
Oscillogram No.: HPL3-27878 OCV = 241 V
Date of Test: 6/9/2020 Time of Test: 8:55:17 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30017 Calibration Date: 5/05/2020
OCV = 240 V Rms Sym Current = 10.01 kA
Power Factor = 47%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 4




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 9 Deg |
| Closing time (V0)+ | 438.0 µ Sec |
| Peak Current (Ip) | 16.38 k Amperes |
| Time to Ip | 6.228 m Sec. |
| I²t | 2.888 M Amp^2sec |
| I Duration | 26.07 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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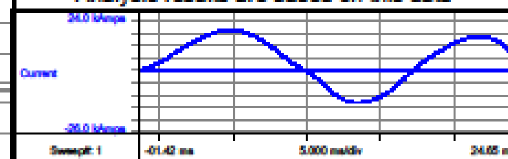
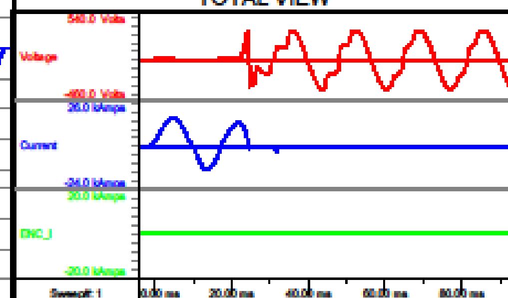
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System: HBM GEN7T C/N [illegible]
VOLTAGE 1000X Scope Probe, C/N [illegible], 1% PLOT FILE HPL3 [illegible]
VOLTAGE 1000X Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-27878

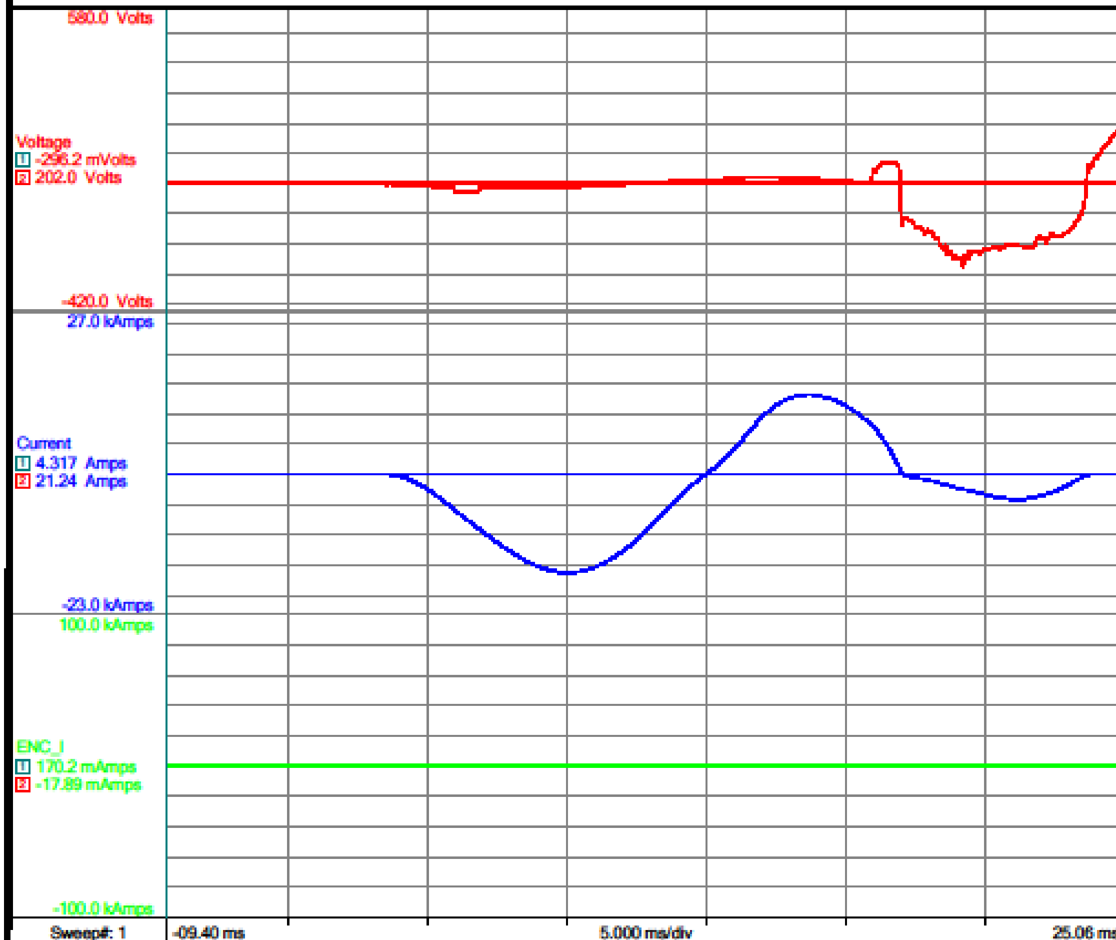
Oscillogram No.: HPL3-27879 OCV = 241 V
Date of Test: 6/9/2020 Time of Test: 9:02:31 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30017 Calibration Date: 5/05/2020
OCV = 240 V Rms Sym Current = 10.01 kA
Power Factor = 47%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 5




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 188 Deg |
| Closing time (V0)+ | 8.602 m Sec |
| Peak Current (Ip) | -16.34 k Amperes |
| Time to Ip | 6.434 m Sec. |
| I²t | 1.932 M Amp^2sec |
| I Duration | 18.46 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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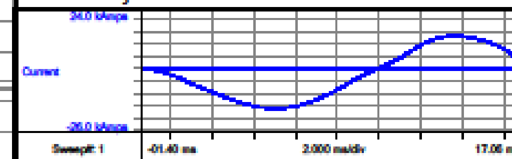
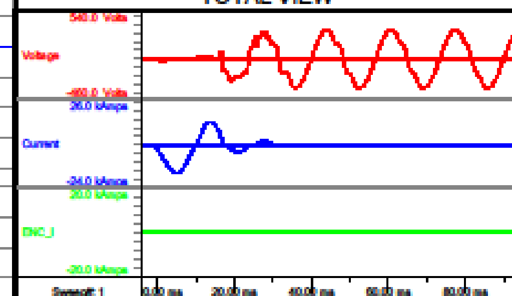
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 1000X Bogus Probe, C/N 131-008, 1% PLOT FILE HPL3 CR_I_V
VOLTAGE 1000X Bogus Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 048-445
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-27879**

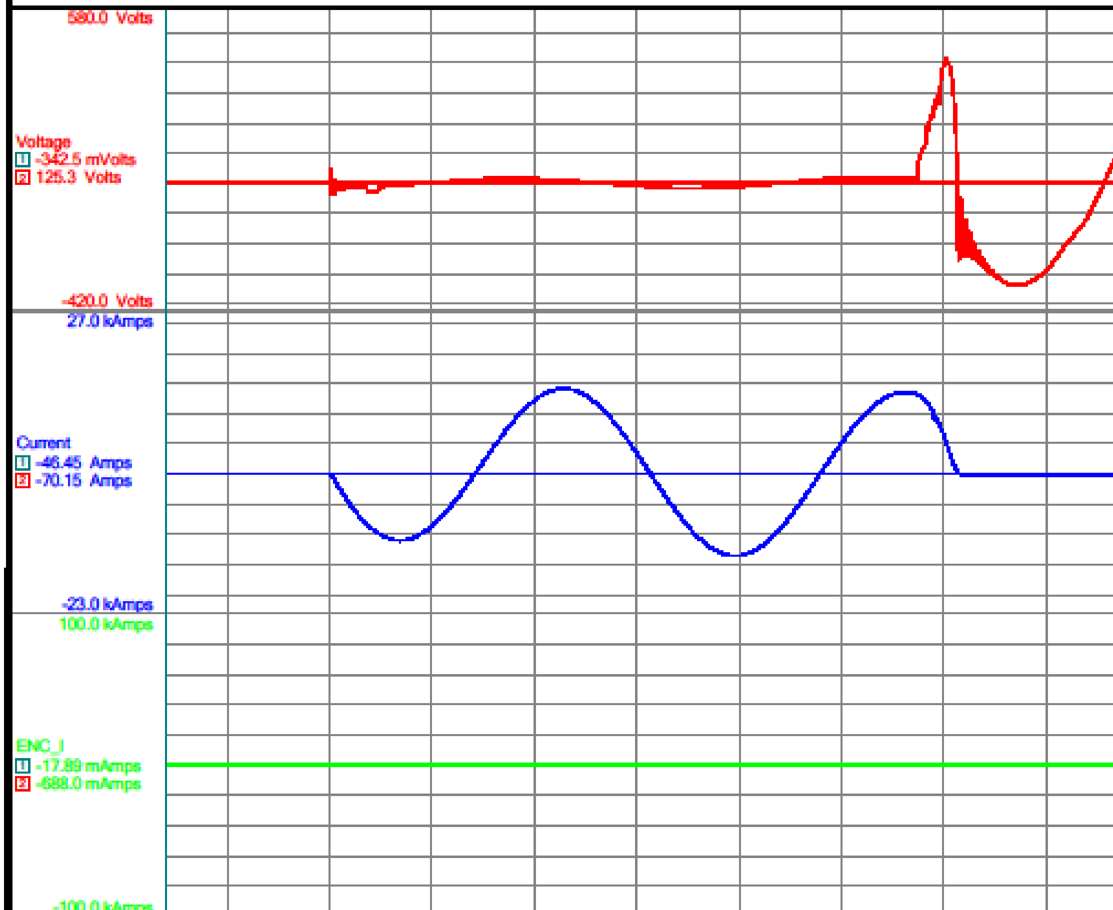
Oscillogram No.: HPL3-27880 OCV = 241 V
Date of Test: 6/9/2020 Time of Test: 9:11:21 AM

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30017 Calibration Date: 5/05/2020
OCV = 240 V Rms Sym Current = 10.01 kA
Power Factor = 47%

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 6




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 284 Deg |
| Closing time (V0)+ | 12.23 m Sec |
| Peak Current (Ip) | 14.22 k Amperes |
| Time to Ip | 11.40 m Sec. |
| I²t | 2.705 M Amp^2sec |
| I Duration | 30.68 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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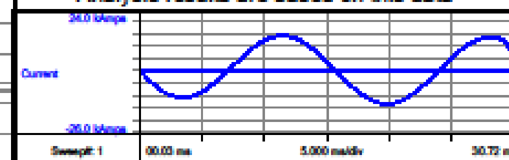
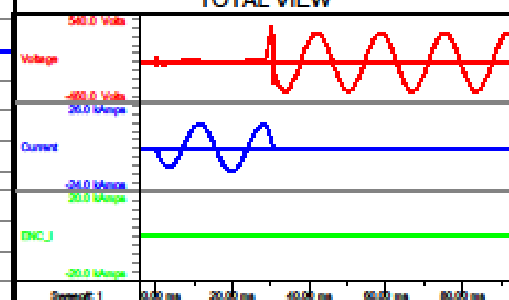
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1% PLOT FILE [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis,
but not for display.

**OSC. NO.: HPL3-27880**

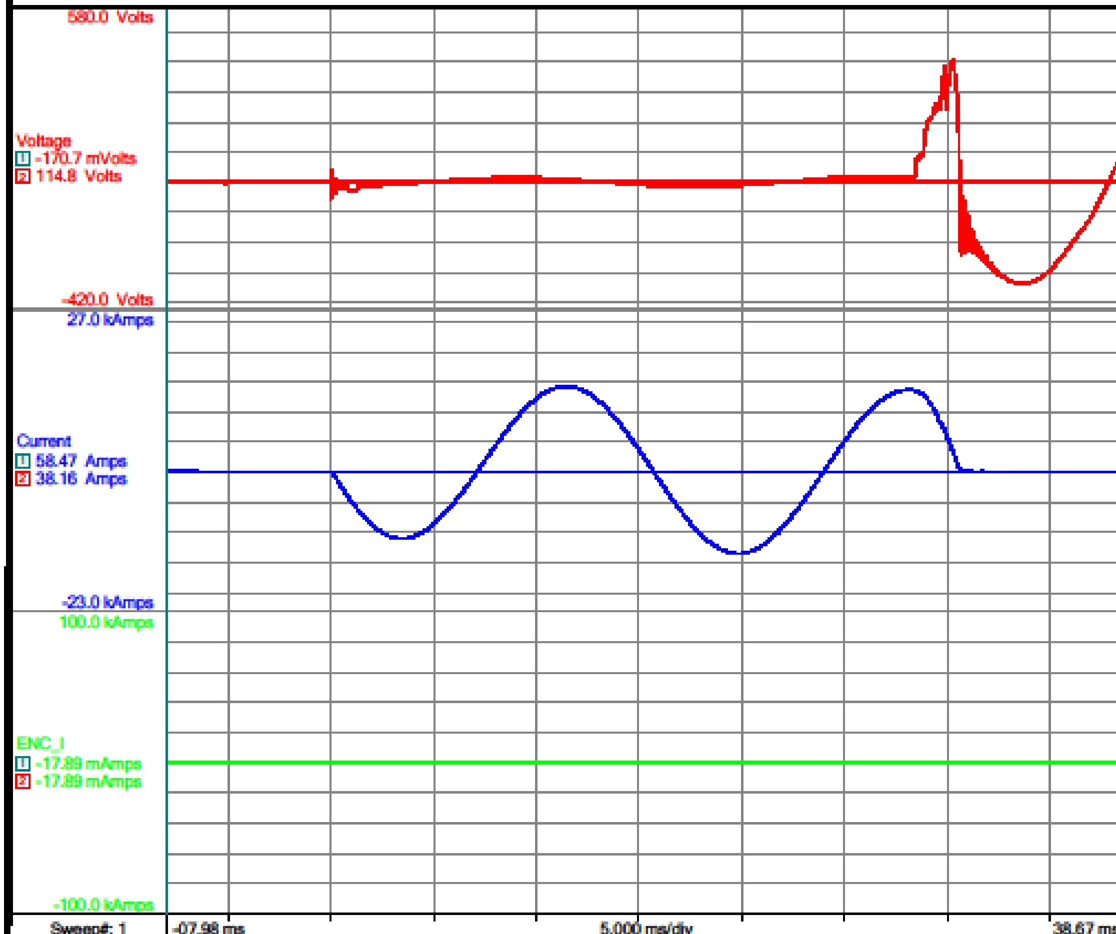
Oscillogram No.: HPL3-27881 OCV = 241 V
Date of Test: 6/9/2020 Time of Test: 9:18:25 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30017 Calibration Date: 5/05/2020
OCV = 240 V Rms Sym Current = 10.01 kA
Power Factor = 47%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 7




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 284 Deg |
| Closing time (V0)+ | 12.22 m Sec |
| Peak Current (Ip) | 14.22 k Amperes |
| Time to Ip | 11.43 m Sec. |
| I²t | 2.695 M Amp^2sec |
| I Duration | 30.65 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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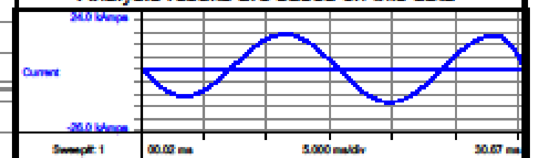
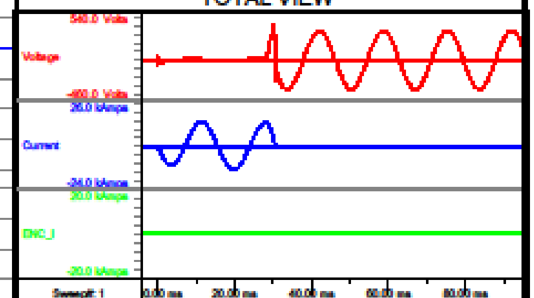
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE 1000X Scope Probe, CAL [illegible], 1% PLOT FILE [illegible]
VOLTAGE 1000X Scope Probe, CAL [illegible], 1%
CURRENT ROGOWSKI COIL, CAL [illegible]
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-27881**

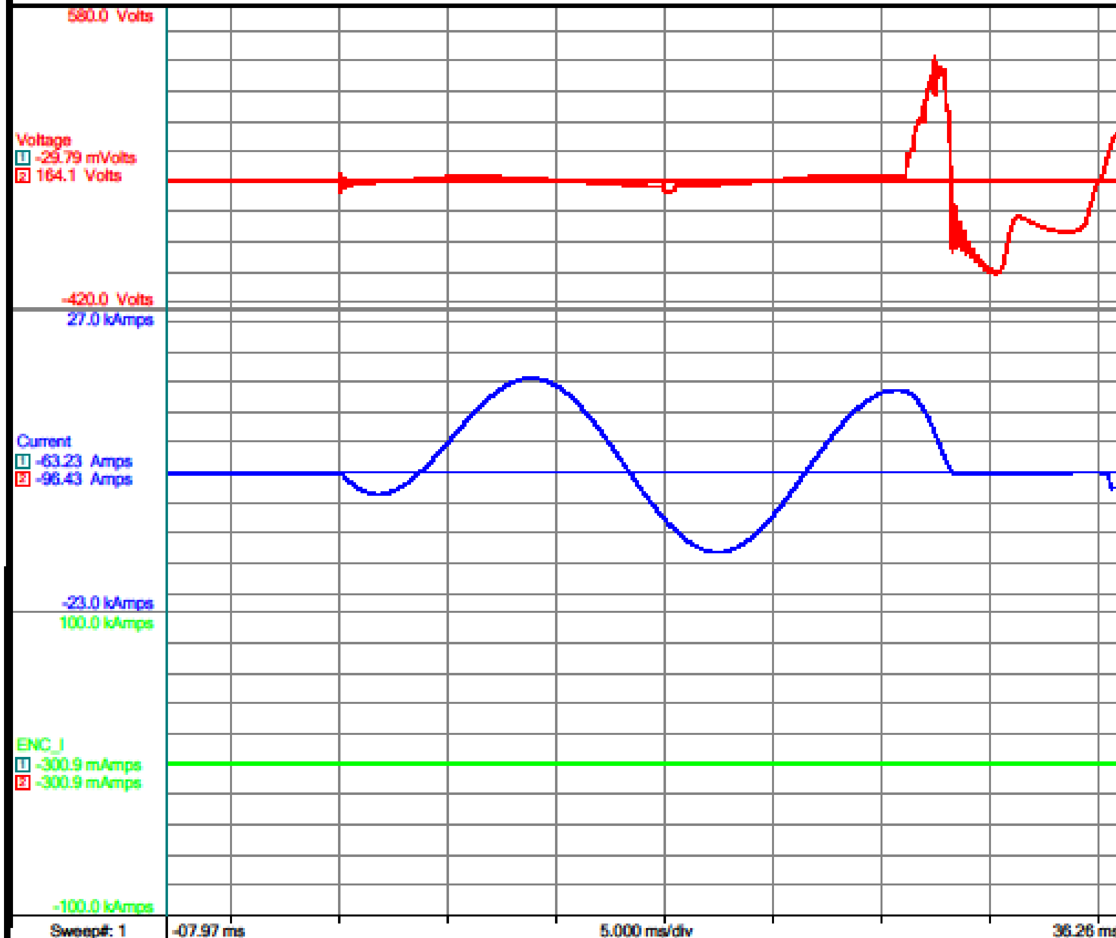
Oscillogram No.: HPL3-27882 OCV = 241 V
Date of Test: 6/9/2020 Time of Test: 9:24:10 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30017 Calibration Date: 5/05/2020
OCV = 240 V Rms Sym Current = 10.01 kA
Power Factor = 47%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 8




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 315 Deg |
| Closing time (V0)+ | 14.60 m Sec |
| Peak Current (Ip) | 15.68 k Amperes |
| Time to Ip | 8.798 m Sec. |
| $I^2t$ | 2.510 M Amp^2sec |
| I Duration | 28.23 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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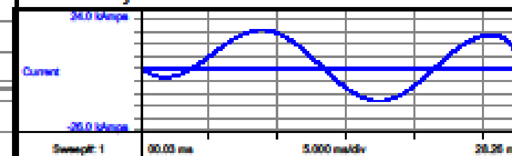
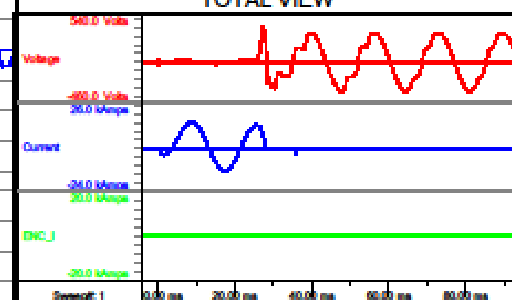
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE: [illegible] Probe, C/N [illegible], 1% PLOT FILE:HPL3 [illegible]
VOLTAGE: [illegible] Probe, C/N [illegible], 1%
CURRENT: [illegible] COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-27882

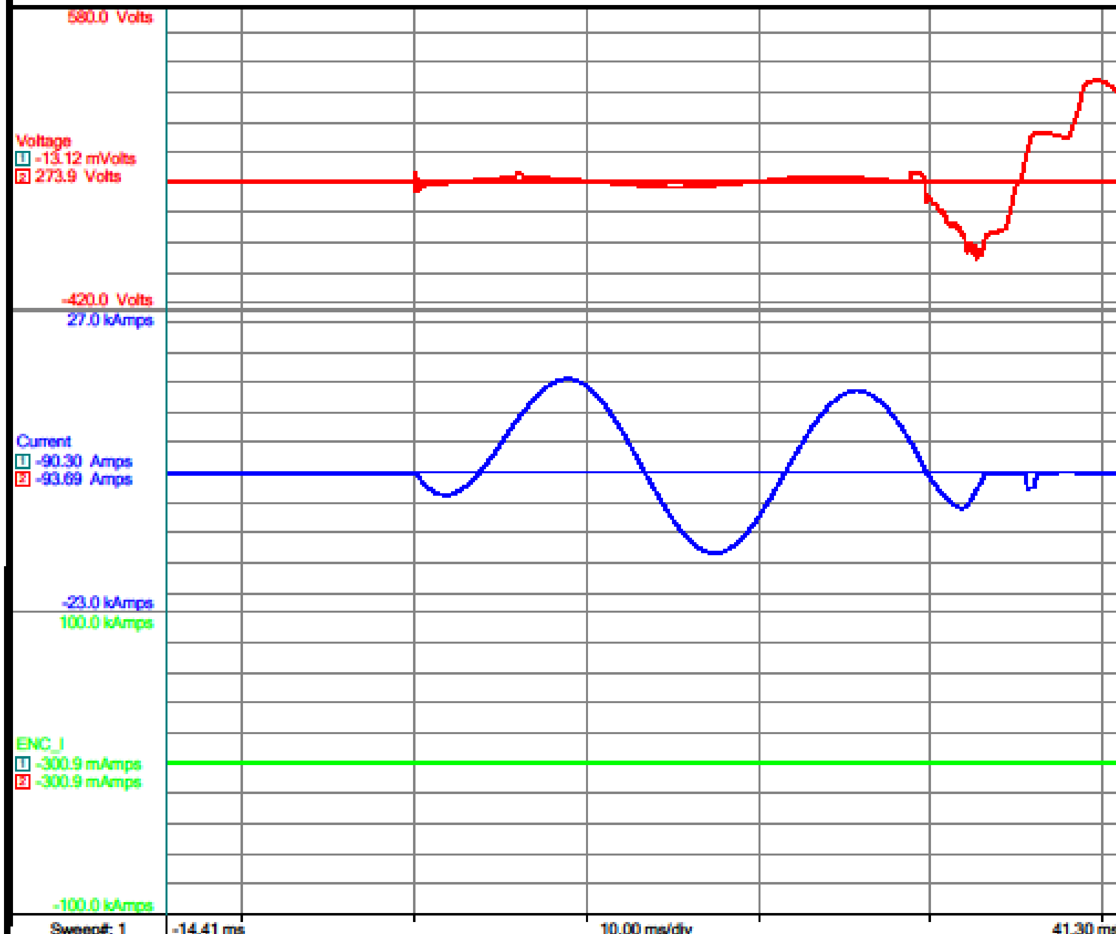
Oscillogram No.: HPL3-27883 OCV = 241 V
Date of Test: 6/9/2020 Time of Test: 9:32:55 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30017 Calibration Date: 5/05/2020
OCV = 240 V Rms Sym Current = 10.01 kA
Power Factor = 47%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 9




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 173 Deg |
| Closing time (V0)+ | 8.003 m Sec |
| Peak Current (Ip) | 15.63 k Amperes |
| Time to Ip | 15.30 m Sec. |
| I²t | 2.698 M Amp^2sec |
| I Duration | 39.71 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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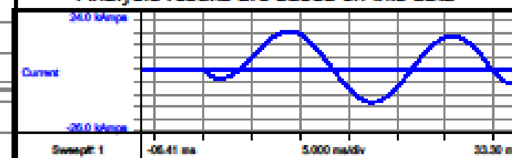
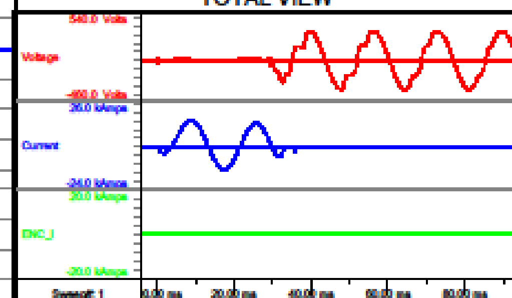
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN3T C/N 003-173
VOLTAGE 1000X Scope Probe, C/N 131-000, 1% PLOT FILE HPL3 CR_I_M
VOLTAGE 1000X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 040-443
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-27883**

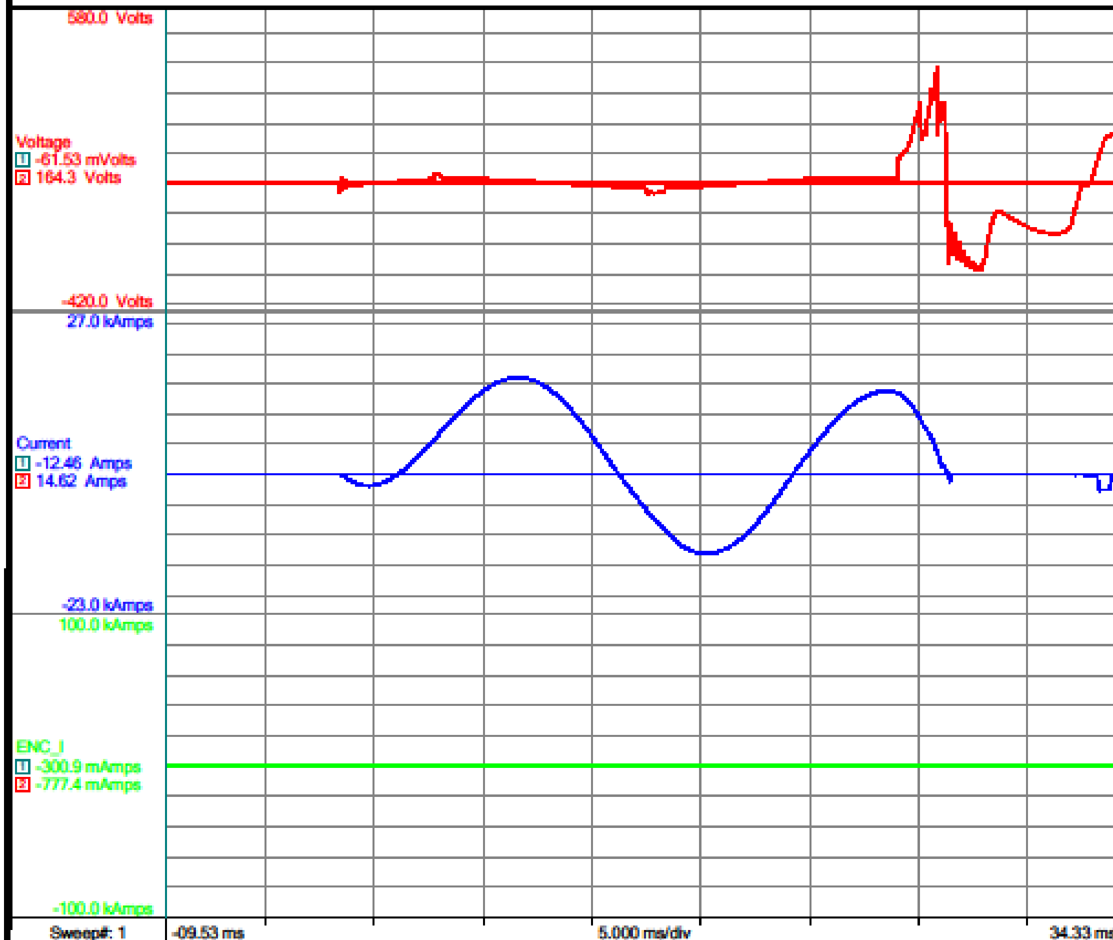
Oscillogram No.: HPL3-27884 OCV = 241 V
Date of Test: 6/9/2020 Time of Test: 9:38:52 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30017 Calibration Date: 5/05/2020
OCV = 240 V Rms Sym Current = 10.01 kA
Power Factor = 47%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 10




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 329 Deg |
| Closing time (V0)+ | 15.24 m Sec |
| Peak Current (Ip) | 16.07 k Amperes |
| Time to Ip | 8.144 m Sec. |
| I²t | 2.592 M Amp^2sec |
| I Duration | 27.88 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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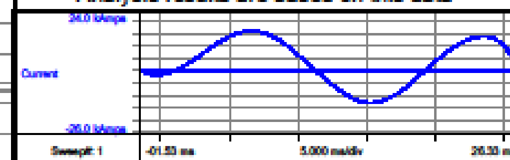
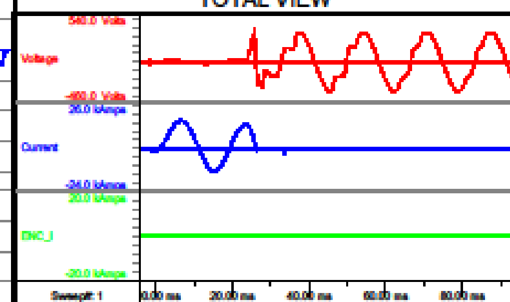
## Analysis results are based on this data




## TOTAL VIEW



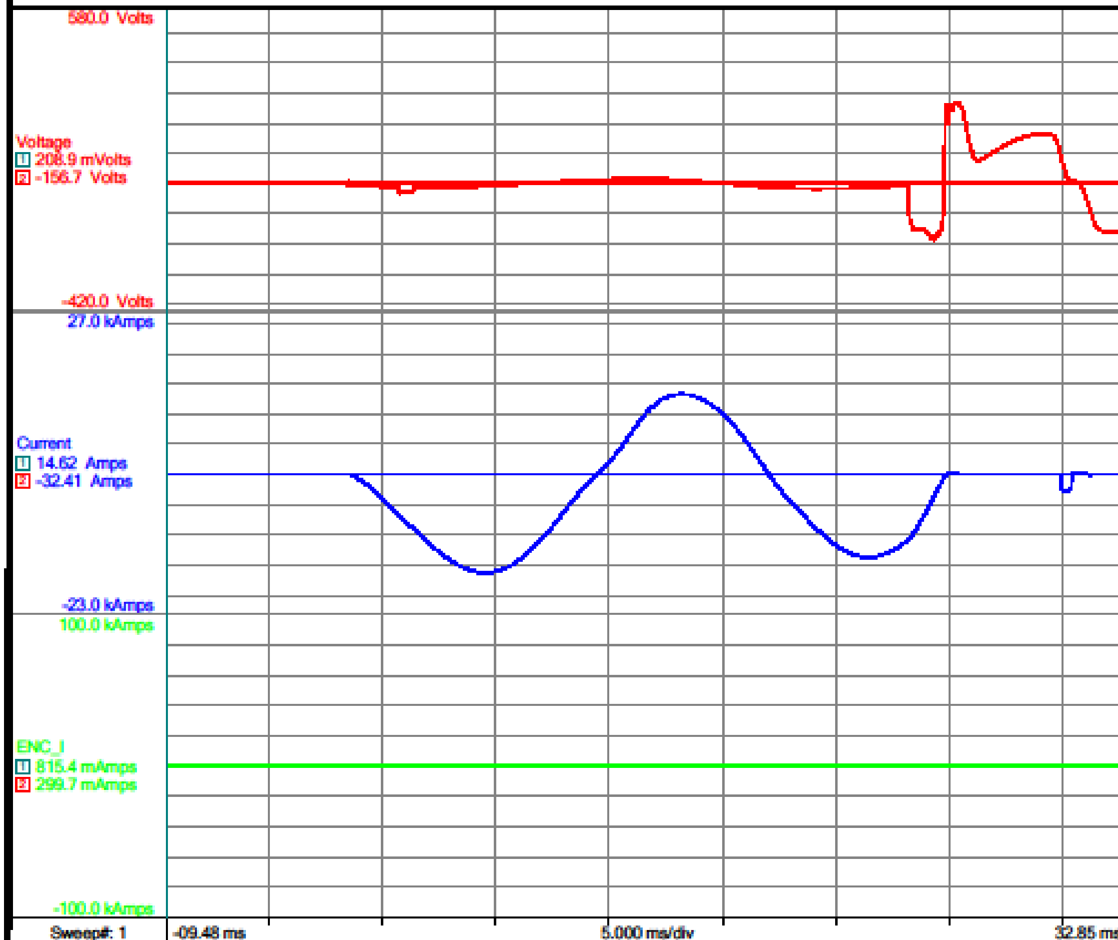

## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-27884**

| | |
|---|---|
| Oscillogram No.: HPL3-27885 OCV = 241 V<br>Date of Test: 6/9/2020 Time of Test: 9:46:40 AM | Schneider Electric<br>High Power Laboratory, HPL3 Facility<br>Cedar Rapids, Iowa, USA |
| AVAILABLE CIRCUIT CHARACTERISTICS:<br>Osc. No: 30017 Calibration Date: 5/05/2020<br>OCV = 240 V Rms Sym Current = 10.01 kA<br>Power Factor = 47% | |

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 11




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 195 Deg |
| Closing time (V0)+ | 9.026 m Sec |
| Peak Current (Ip) | -16.35 k Amperes |
| Time to Ip | 6.013 m Sec. |
| I²t | 2.717 M Amp^2sec |
| I Duration | 26.33 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

### Comment Section

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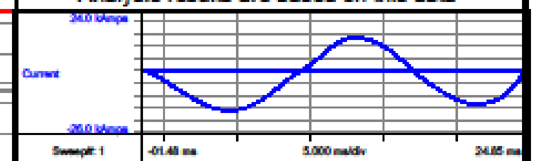
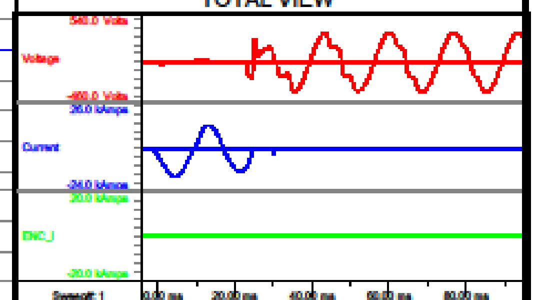
### Analysis results are based on this data




### TOTAL VIEW




### INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis,
but not for display.

**OSC. NO.: HPL3-27885**

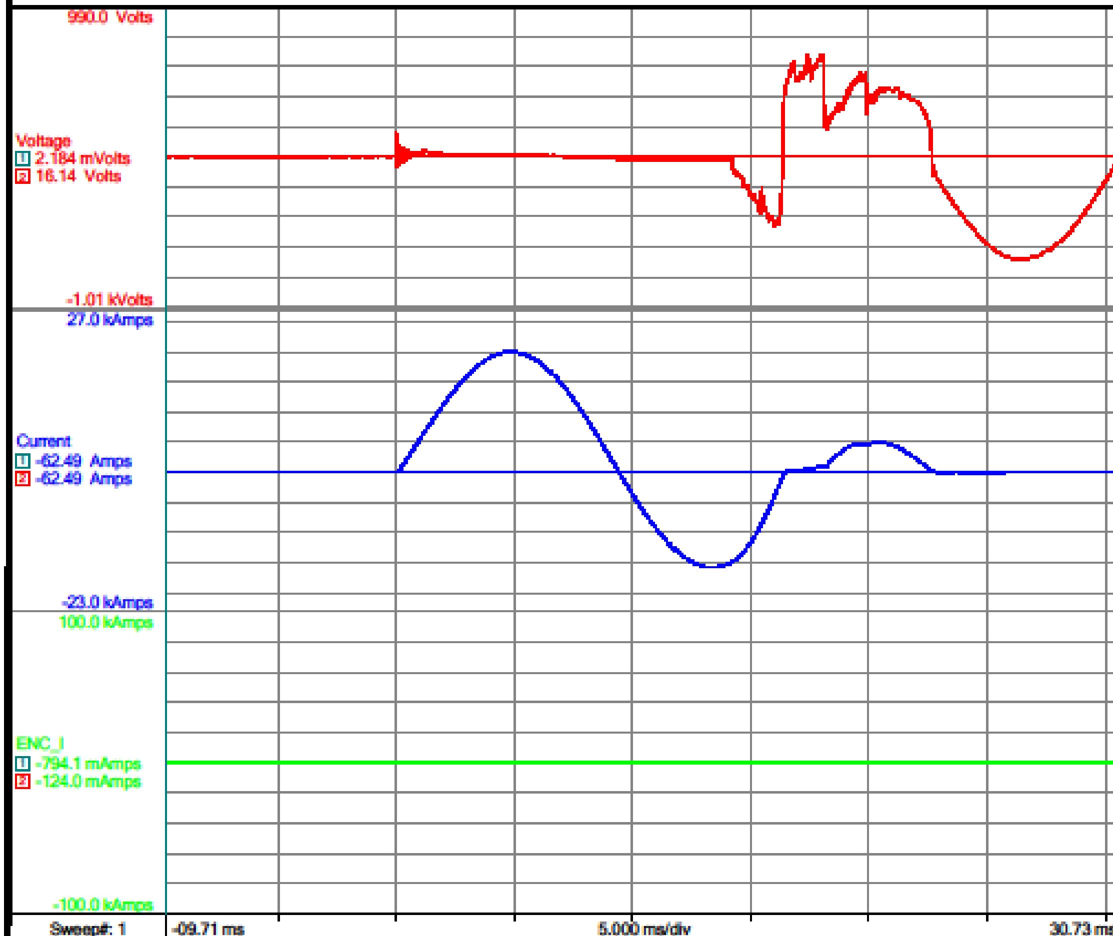
Oscillogram No.: HPL3-30025 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 10:34:07 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 12




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 60 Deg |
| Closing time (V0)+ | 2.798 m Sec |
| Peak Current (Ip) | 20.05 k Amperes |
| Time to Ip | 4.775 m Sec. |
| I²t | 2.817 M Amp^2sec |
| I Duration | 22.62 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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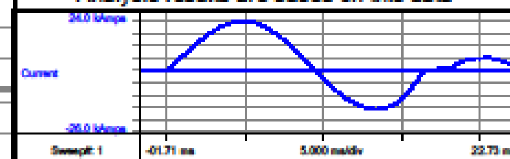
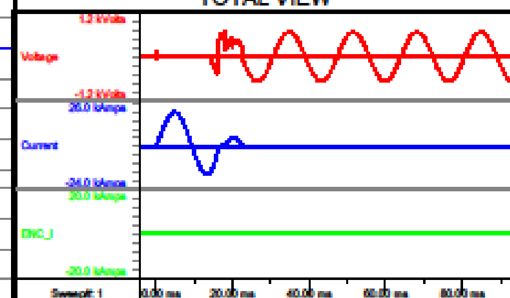
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE 1000X [illegible] Probe, [illegible], 1% PLOT FILE [illegible]
VOLTAGE 1000X [illegible] Probe, [illegible], 1%
CURRENT ROGOWSKI COIL, [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30025

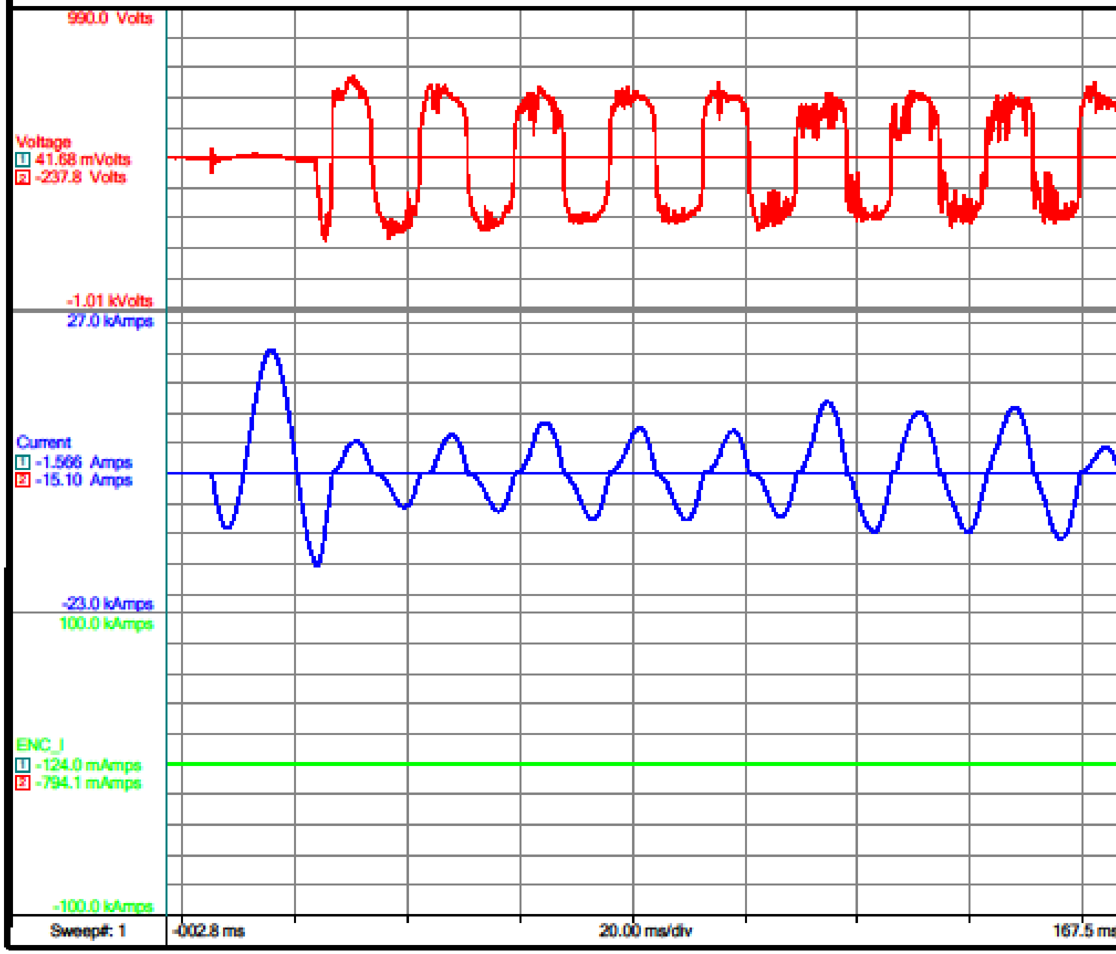
Oscillogram No.: HPL3-30026 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 10:41:56 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 13




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 194 Deg |
| Closing time (V0)+ | 18.43 m Sec |
| Peak Current (Ip) | 20.52 k Amperes |
| Time to Ip | 10.59 m Sec. |
| I²t | 7.100 M Amp^2sec |
| I Duration | 154.3 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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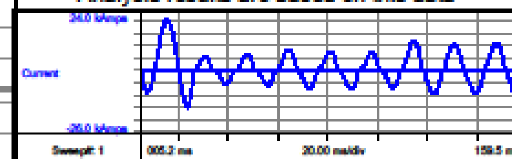
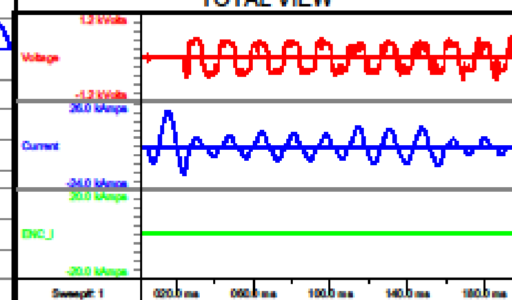
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 383-173
VOLTAGE 100X Scope Probe, C/N 131-600, 1% PLOT FILE HPL3 CR_I_M
VOLTAGE 100X Scope Probe, C/N 131-604, 1%
CURRENT ROGOWSKI COIL, C/N 040-443
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30026

Oscillogram No.: HPL3-30028 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 10:56:49 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

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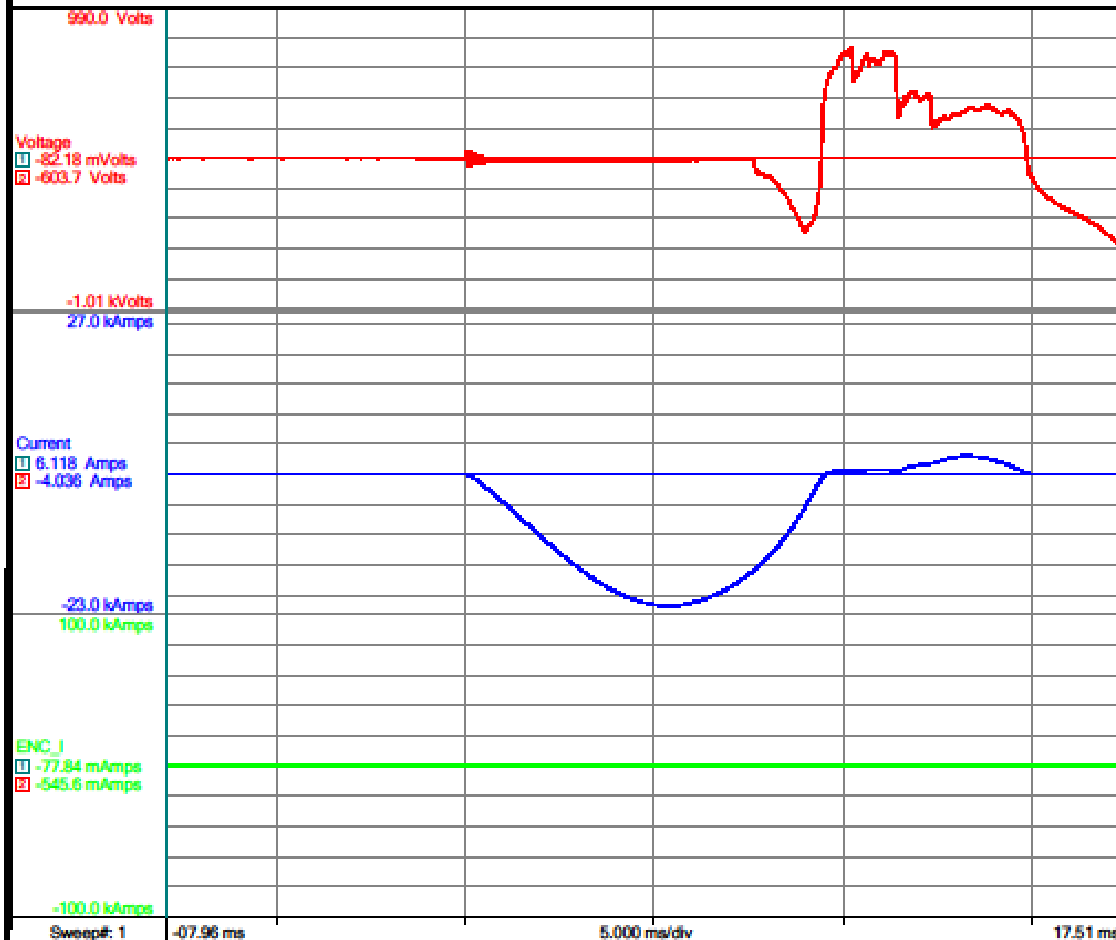
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 15




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 228 Deg |
| Closing time (V0)+ | 10.46 m Sec |
| Peak Current (Ip) | -21.88 k Amperes |
| Time to Ip | 5.348 m Sec. |
| I²t | 2.260 M Amp^2sec |
| I Duration | 9.470 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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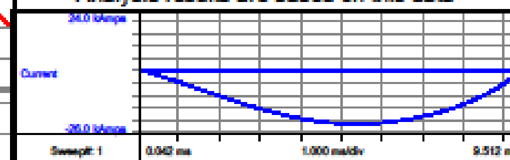
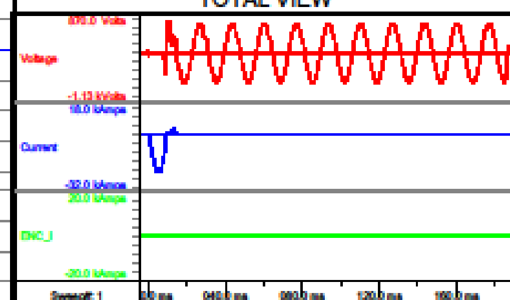
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 383-173
VOLTAGE 1000X Bogue Probe, C/N 131-668, 1% PLOT FILE HPL3 CR_I_M
VOLTAGE 1000X Bogue Probe, C/N 131-664, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-30028**

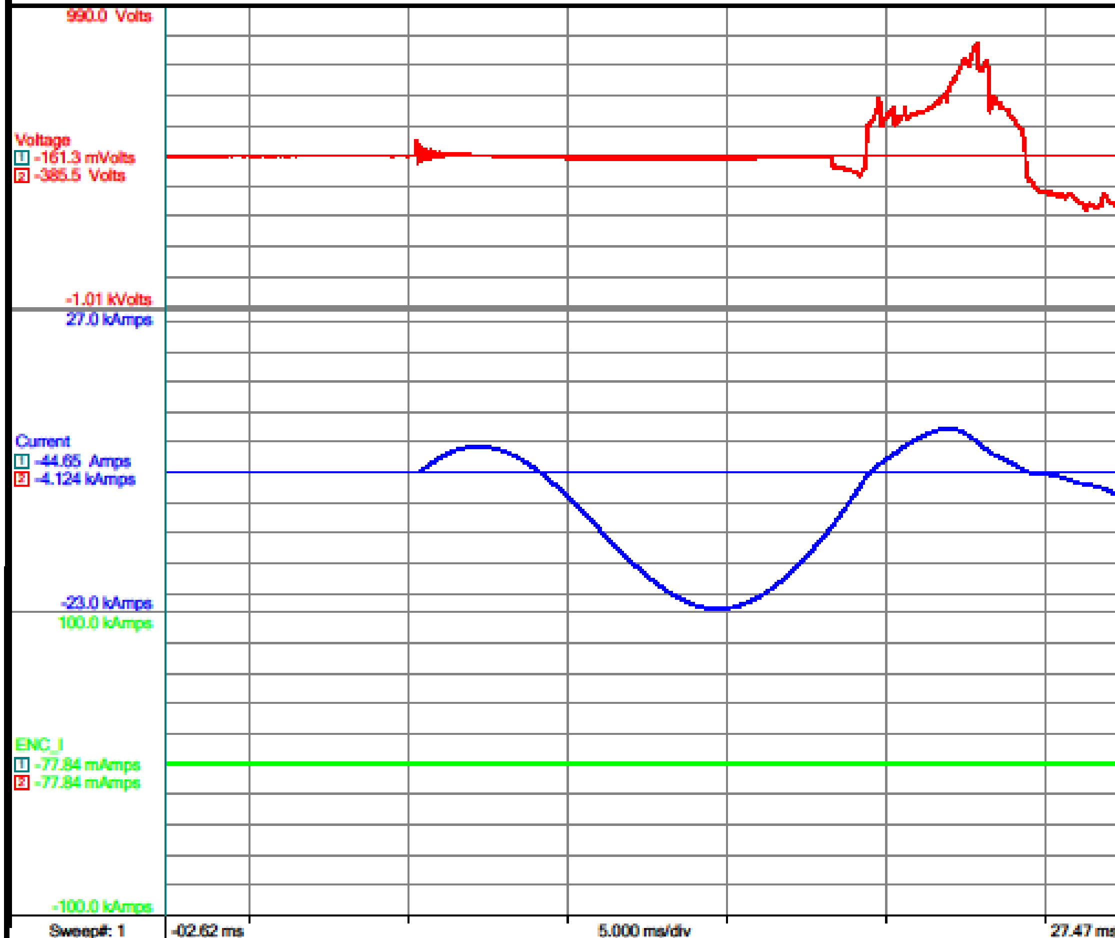
Oscillogram No.: HPL3-30029 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 11:01:41 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 16




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 138 Deg |
| Closing time (V0)+ | 6.404 m Sec |
| Peak Current (Ip) | -22.65 k Amperes |
| Time to Ip | 9.380 m Sec. |
| I²t | 2.567 M Amp^2sec |
| I Duration | 14.09 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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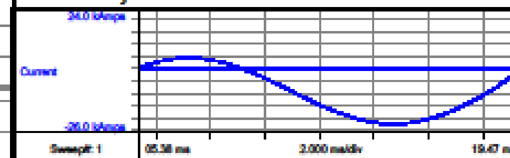
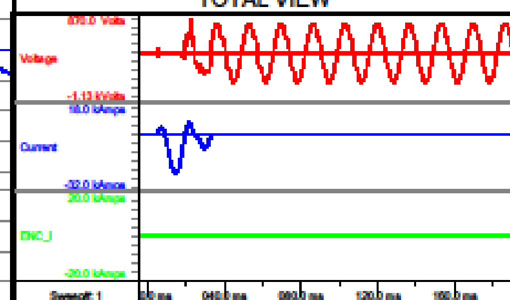
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

OSC. NO.: HPL3-30029

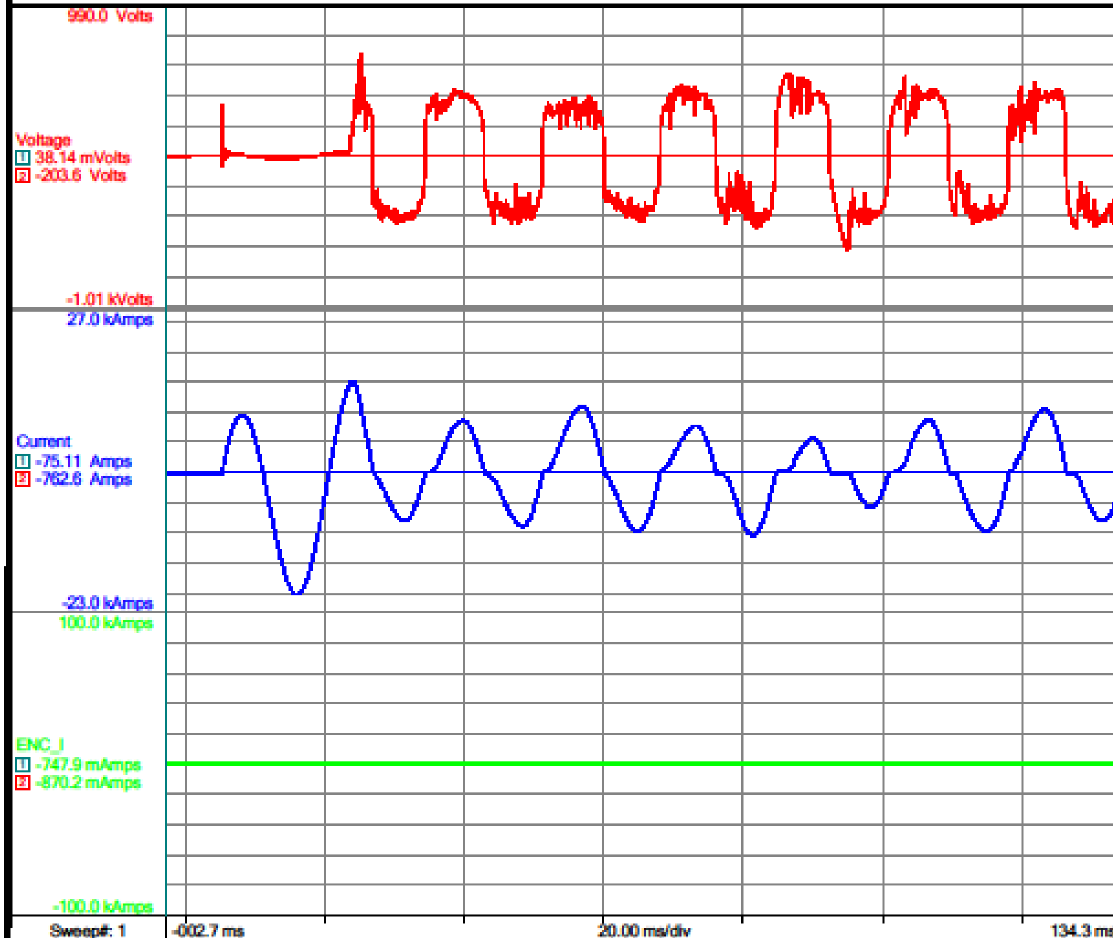
Oscillogram No.: HPL3-30030 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 11:07:07 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 17




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 62 Deg |
| Closing time (V0)+ | 2.636 m Sec |
| Peak Current (Ip) | -20.23 k Amperes |
| Time to Ip | 10.72 m Sec. |
| I²t | 6.183 M Amp^2sec |
| I Duration | 121.0 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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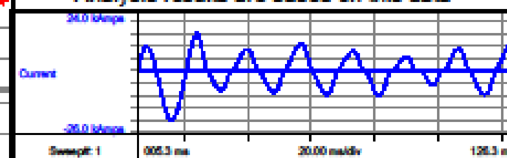
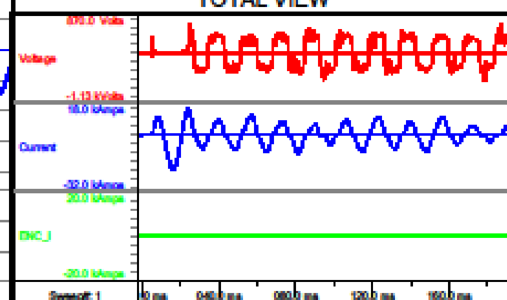
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 303-173
VOLTAGE 100X Scope Probe, C/N 131-000, 1% PLOT FILE HPL3 CR_1_W
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30030

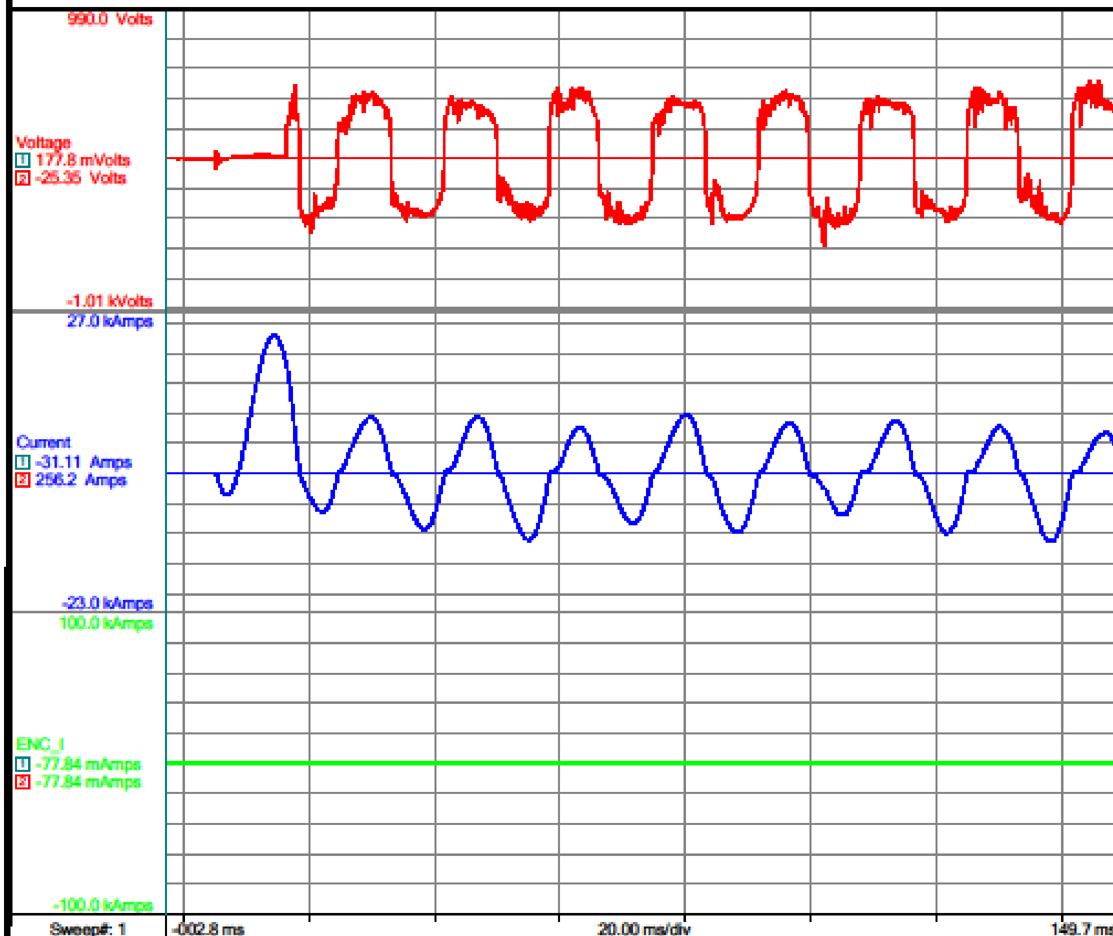
Oscillogram No.: HPL3-30031 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 11:14:46 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 18




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 322 Deg |
| Closing time (V0)+ | 14.90 m Sec |
| Peak Current (Ip) | 22.99 k Amperes |
| Time to Ip | 9.168 m Sec. |
| I²t | 7.057 M Amp^2sec |
| I Duration | 136.4 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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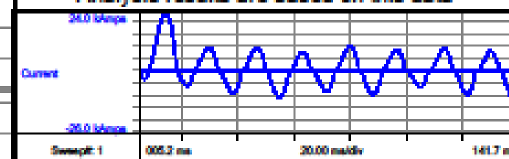
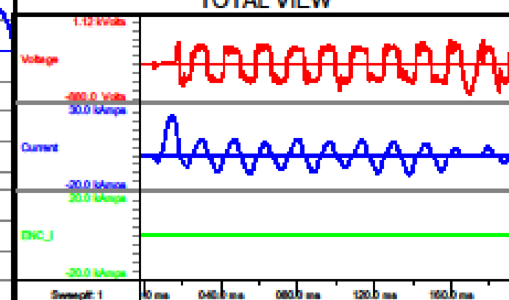
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 383-173
VOLTAGE 100X Scope Probe, C/N 131-888, 1%    PLOT FILE HPL3 CR_1_B
VOLTAGE 100X Scope Probe, C/N 131-894, 1%
CURRENT ROGOWSKI COIL, C/N 048-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30031

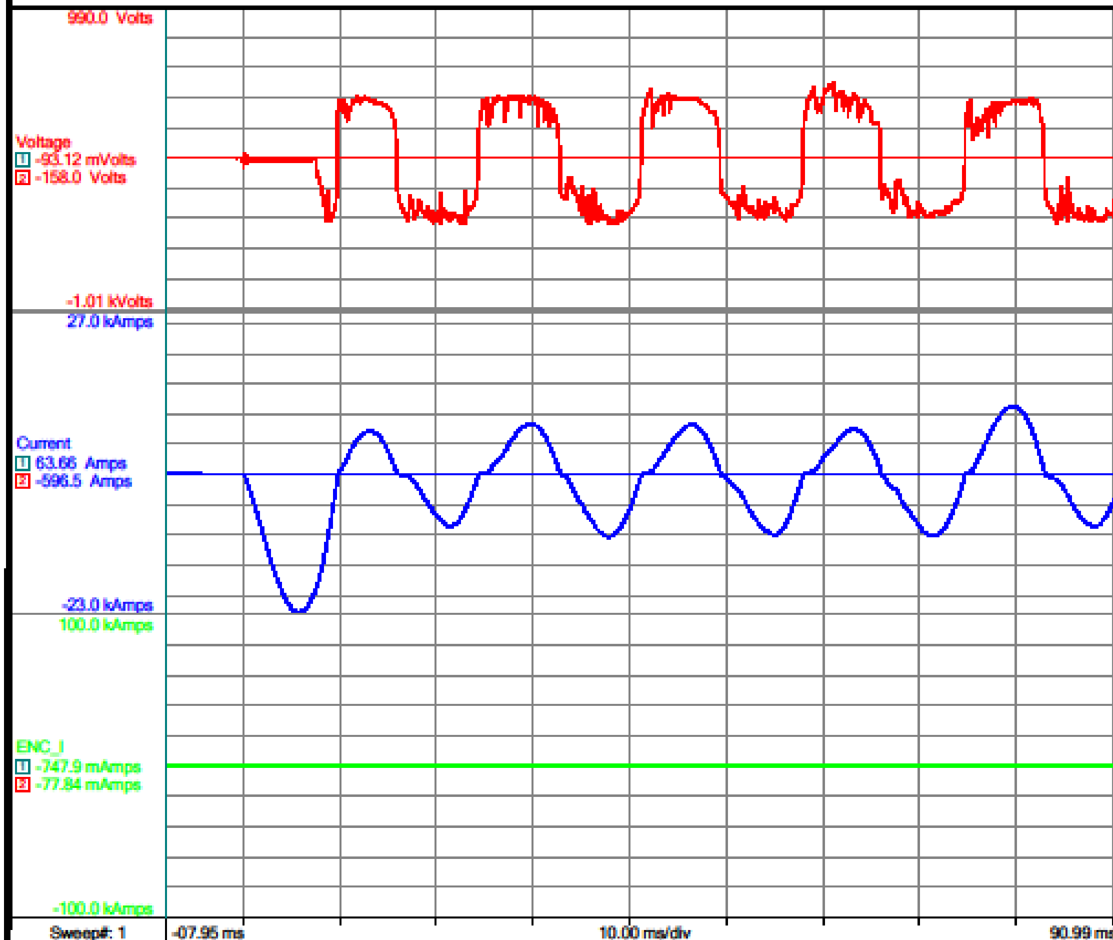
Oscillogram No.: HPL3-30032 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 11:20:42 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 19




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 231 Deg |
| Closing time (V0)+ | 10.84 m Sec |
| Peak Current (Ip) | -22.93 k Amperes |
| Time to Ip | 5.697 m Sec. |
| I²t | 5.264 M Amp^2sec |
| I Duration | 82.94 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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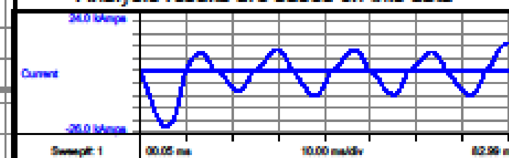
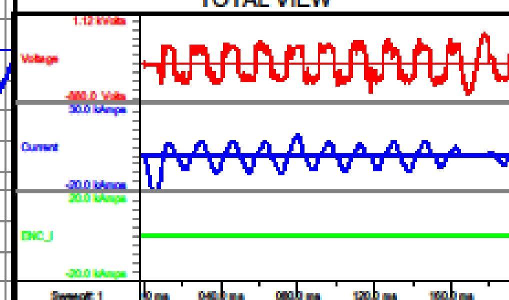
Analysis results are based on this data




TOTAL VIEW




## INSTRUMENTATION DATA

OSC. NO.: HPL3-30032

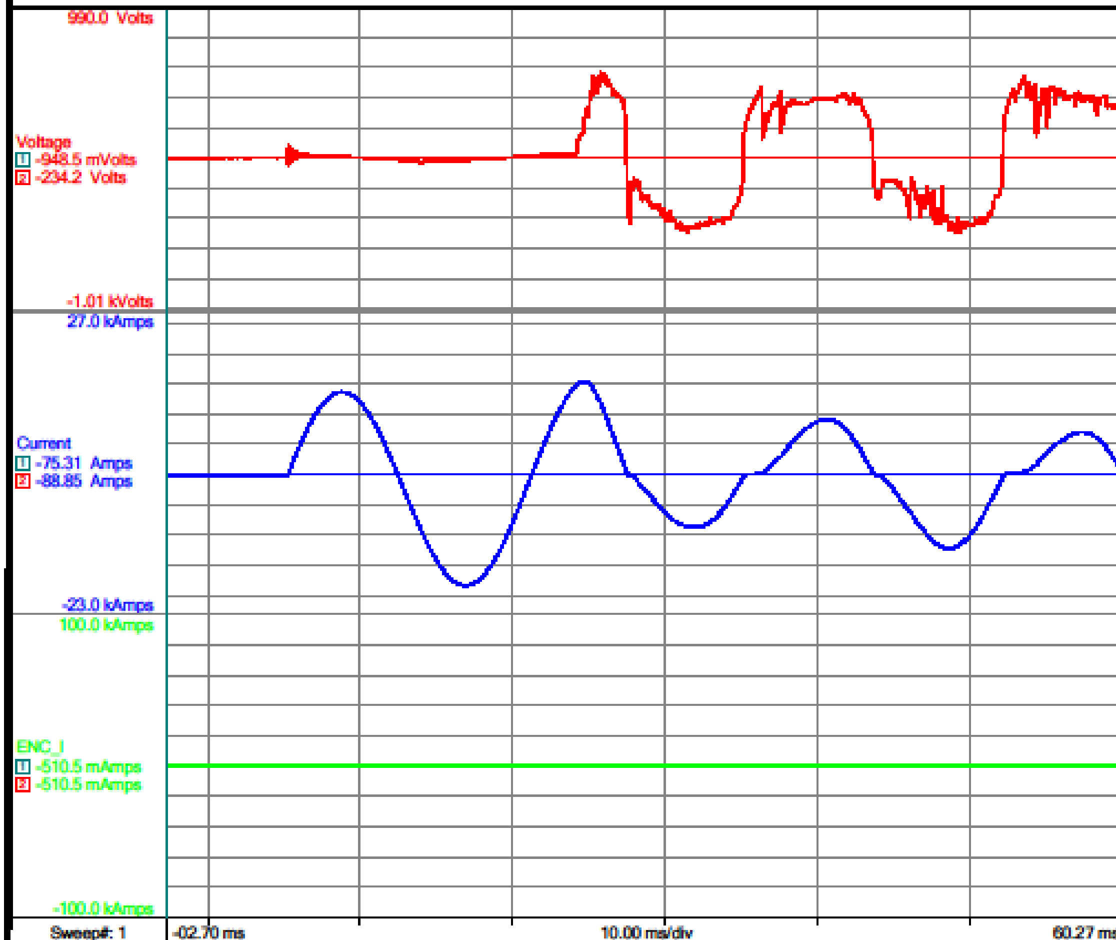
Oscillogram No.: HPL3-30033 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 11:25:19 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 20




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 94 Deg |
| Closing time (V0)+ | 4.332 m Sec |
| Peak Current (Ip) | -18.43 k Amperes |
| Time to Ip | 11.62 m Sec. |
| I²t | 3.989 M Amp^2sec |
| I Duration | 46.98 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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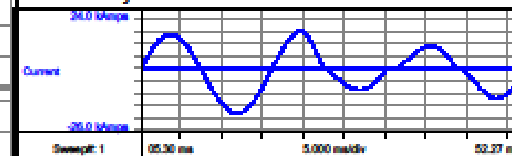
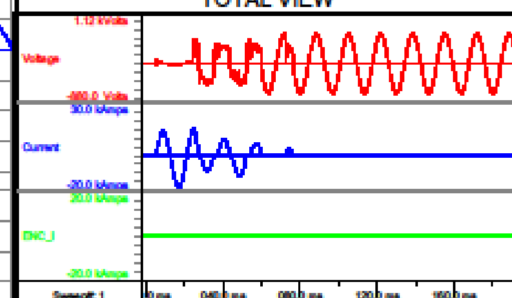
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

OSC. NO.: HPL3-30033

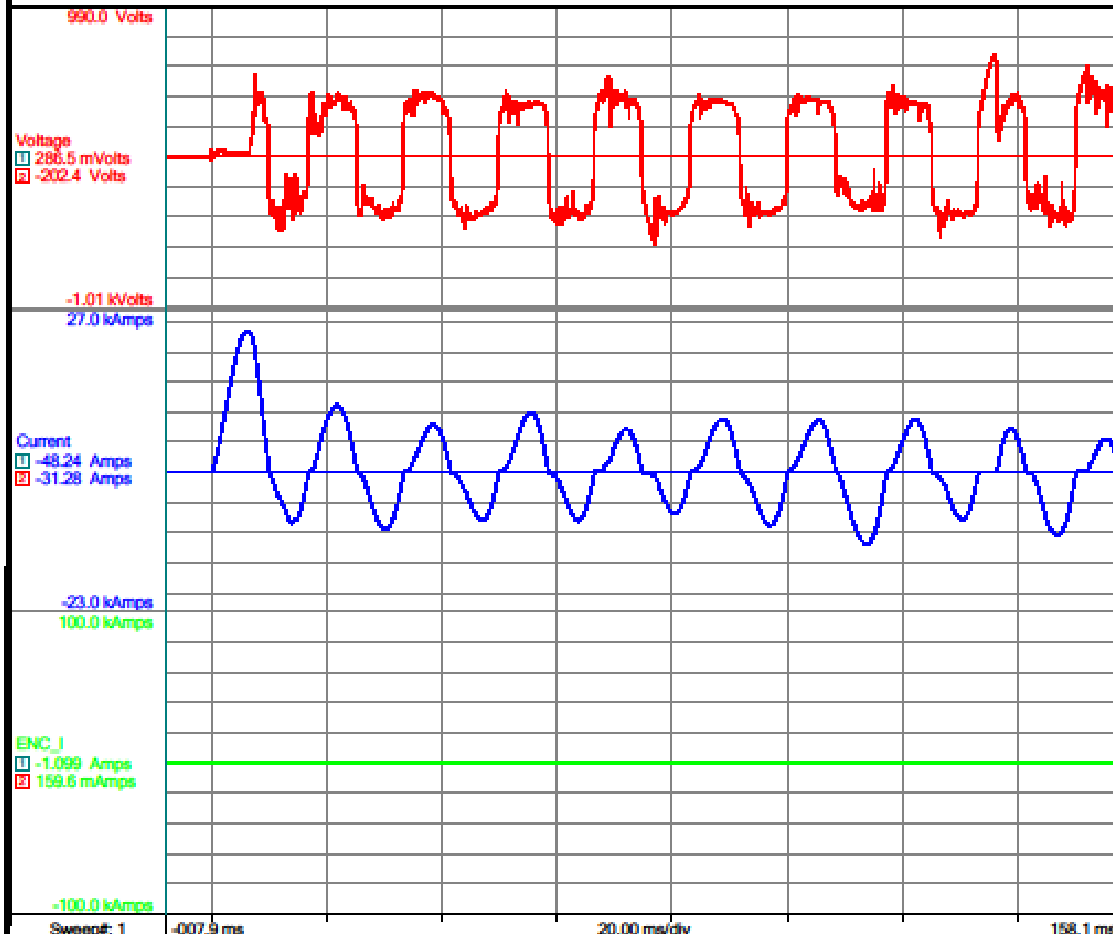
Oscillogram No.: HPL3-30034 OCV = 486 V
Date of Test: 6/9/2020 Time of Test: 11:30:05 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 5/12/2020
OCV = 487 V Rms Sym Current = 12.314 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 21




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 40 Deg |
| Closing time (V0)+ | 935.0 µ Sec |
| Peak Current (Ip) | 23.53 k Amperes |
| Time to Ip | 6.138 m Sec. |
| I²t | 7.221 M Amp^2sec |
| I Duration | 150.0 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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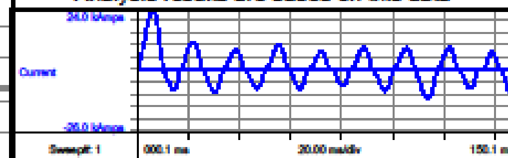
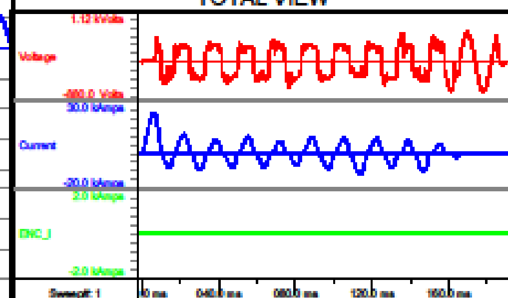
## Analysis results are based on this data



## TOTAL VIEW



## INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis,
but not for display.

**OSC. NO.: HPL3-30034**

Oscillogram No.: HPL3-30035 OCV = 240 V
Date of Test: 6/9/2020 Time of Test: 12:41:23 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 26037 Calibration Date: 2/11/2020
OCV = 243 V Rms Sym Current = 22.87 kA
Power Factor = 19%

Schneider Electric

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Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 22

| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 84 Deg |
| Closing time (V0)+ | 3.889 m Sec |
| Peak Current (Ip) | 29.12 k Amperes |
| Time to Ip | 3.970 m Sec. |
| I²t | 2.381 M Amp^2sec |
| I Duration | 6.109 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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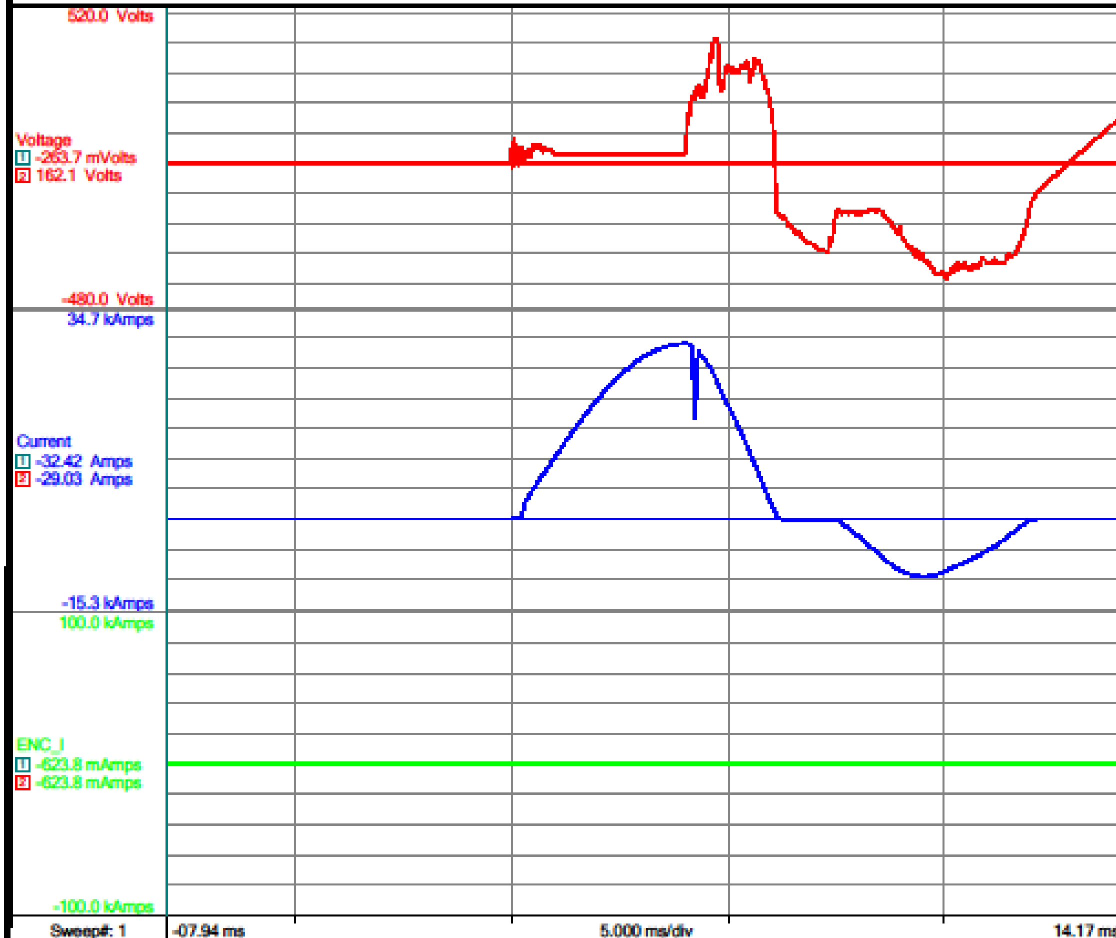
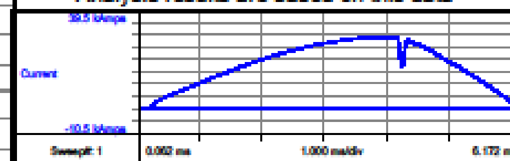
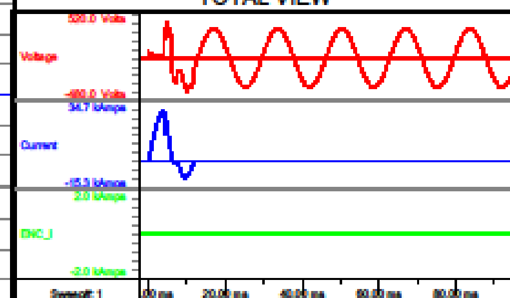



Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 360-173
VOLTAGE 100X Bogus Probe, C/N 131-866, 1%
VOLTAGE 100X Bogus Probe, C/N 131-864, 1%
CURRENT ROGOWSKI COIL, C/N 048-445
NOTE: Channel offset removed for analysis
but not for display.
PLOT FILE HPL3 CR_I_M

OSC. NO.: HPL3-30035

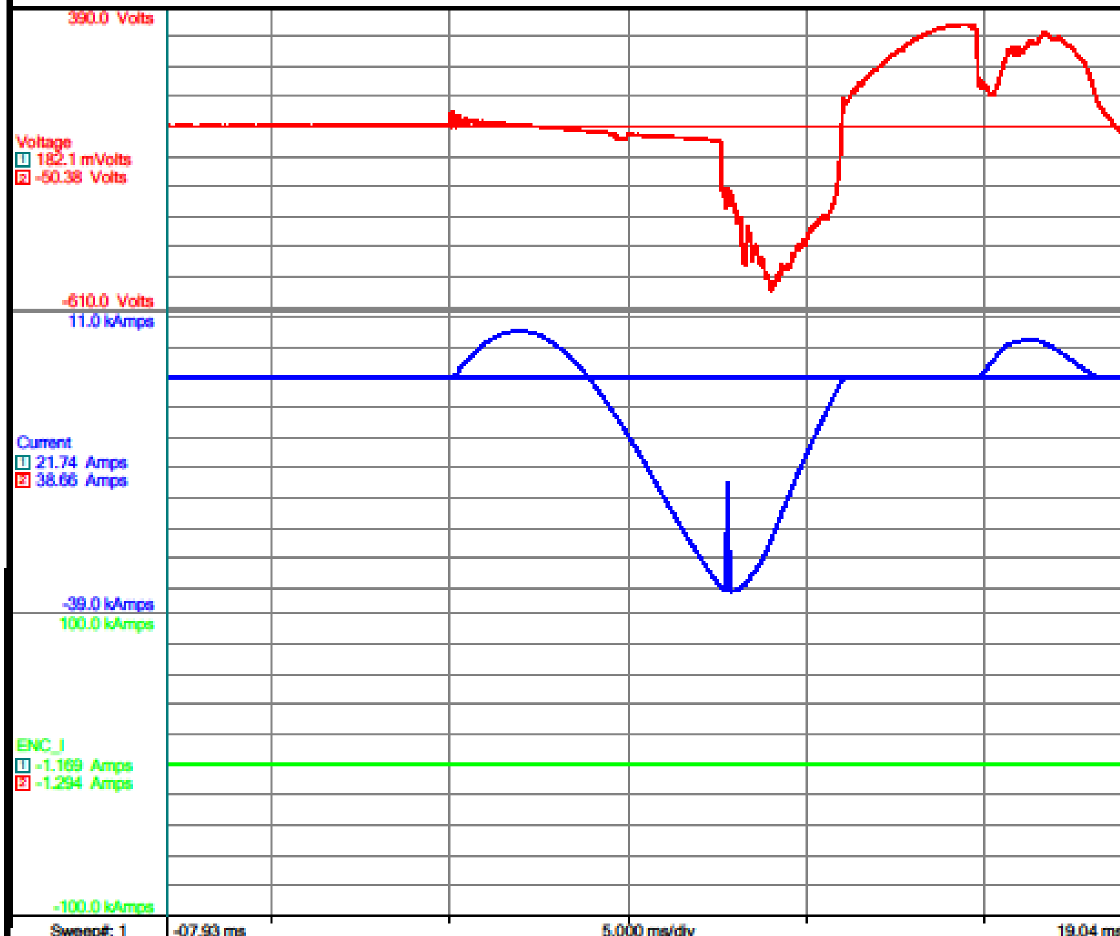
Oscillogram No.: HPL3-30036 OCV = 240 V
Date of Test: 6/9/2020 Time of Test: 12:47:23 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 26037 Calibration Date: 2/11/2020
OCV = 243 V Rms Sym Current = 22.87 kA
Power Factor = 19%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 23




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 138 Deg |
| Closing time (V0)+ | 6.411 m Sec |
| Peak Current (Ip) | -35.74 k Amperes |
| Time to Ip | 7.818 m Sec. |
| I²t | 3.592 M Amp^2sec |
| I Duration | 10.97 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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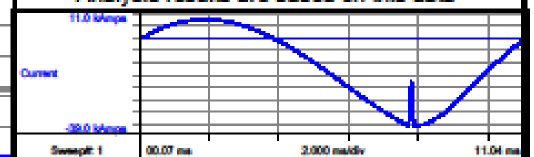
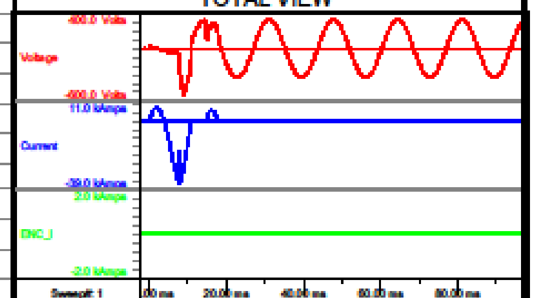
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

[illegible]
[illegible]
[illegible]
[illegible]
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-30036

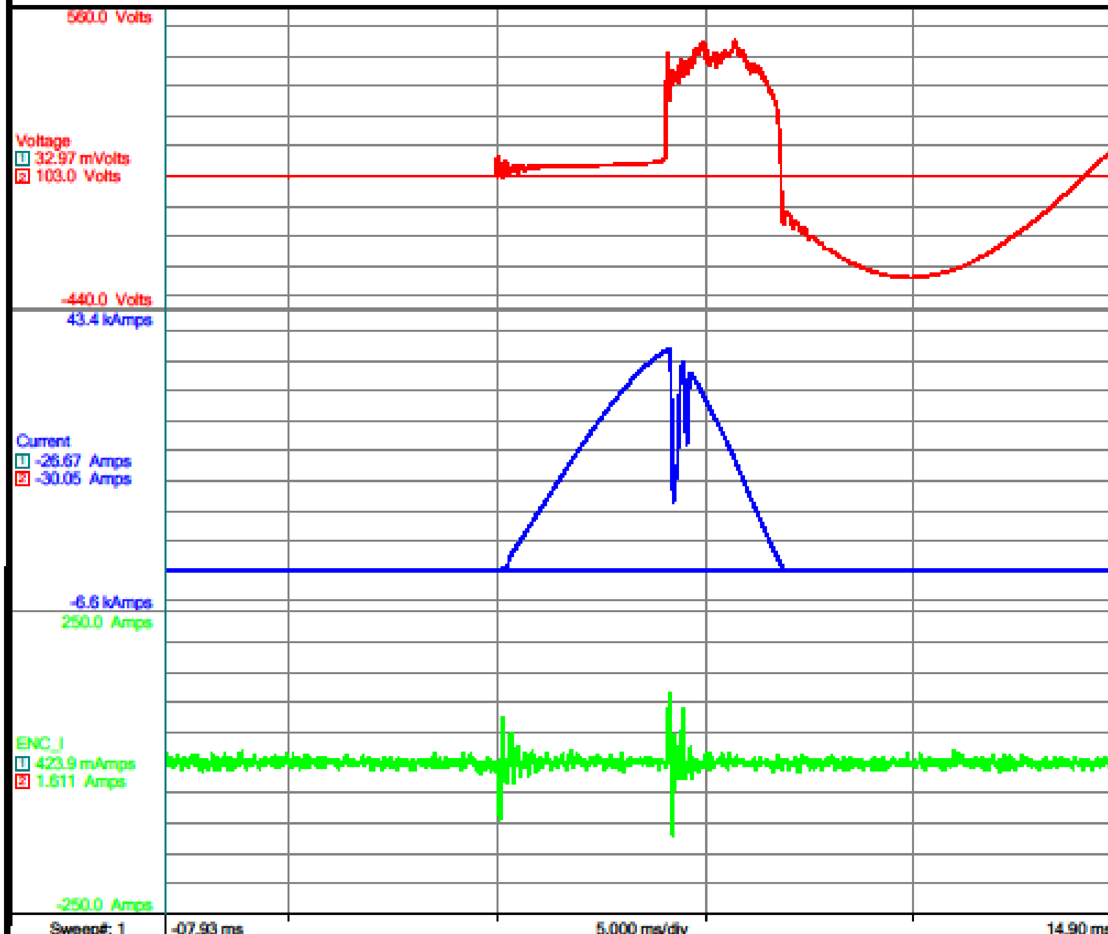
Oscillogram No.: HPL3-30037 OCV = 240 V
Date of Test: 6/9/2020 Time of Test: 1:04:57 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 26037 Calibration Date: 2/11/2020
OCV = 243 V Rms Sym Current = 22.87 kA
Power Factor = 19%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 24




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 57 Deg |
| Closing time (V0)+ | 2.847 m Sec |
| Peak Current (Ip) | 36.88 k Amperes |
| Time to Ip | 4.058 m Sec. |
| I²t | 3.455 M Amp^2sec |
| I Duration | 6.828 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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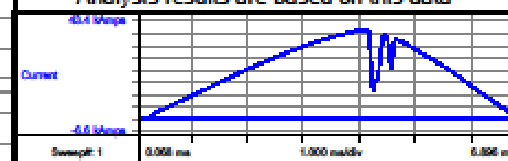
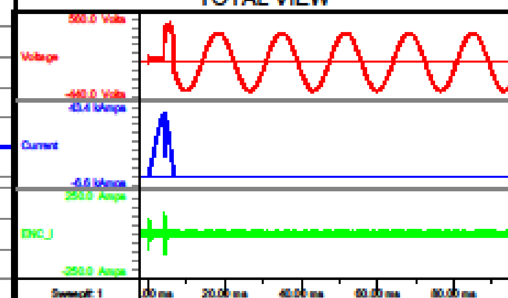
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System:HBM GEN7T C/N 063-173
VOLTAGE 100X Scope Probe, C/N 131-008, 1% PLOT FILE:HPL3 CR_I_H
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 046-440
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30037

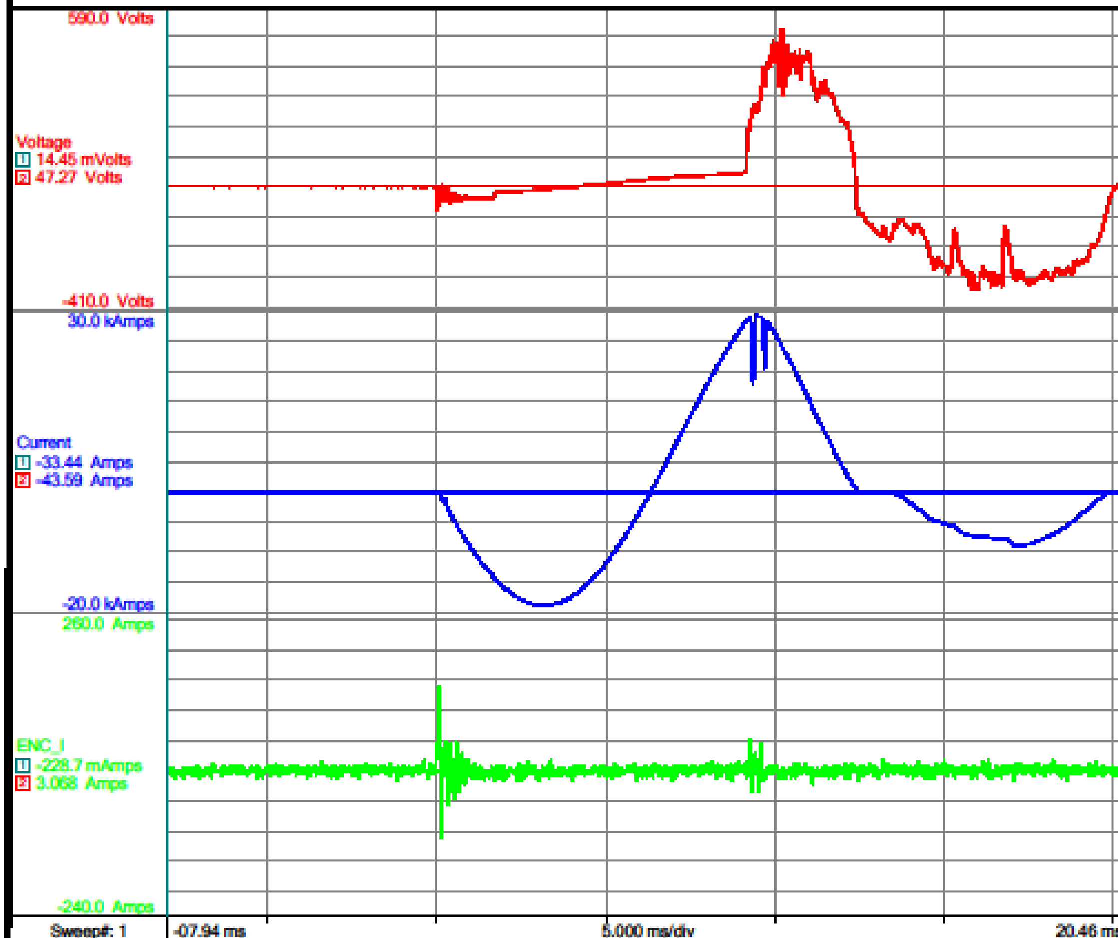
Oscillogram No.: HPL3-30038 OCV = 240 V
Date of Test: 6/9/2020 Time of Test: 1:12:44 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 26037 Calibration Date: 2/11/2020
OCV = 243 V Rms Sym Current = 22.87 kA
Power Factor = 19%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 25




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 288 Deg |
| Closing time (V0)+ | 13.34 m Sec |
| Peak Current (Ip) | 29.40 k Amperes |
| Time to Ip | 9.405 m Sec. |
| I²t | 3.153 M Amp^2sec |
| I Duration | 12.40 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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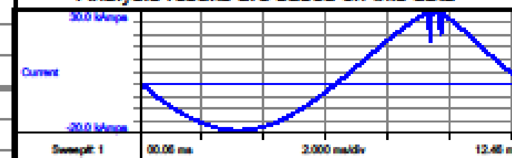
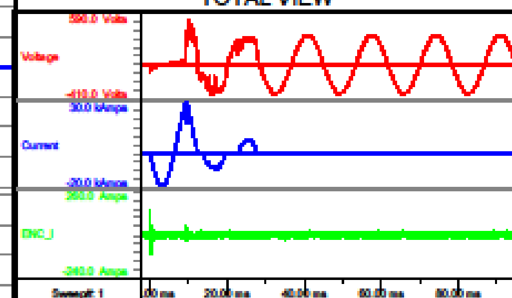
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

[illegible]

[illegible] PLOT FILE: [illegible]

[illegible]

[illegible]

NOTE: Channel offset removed for analysis

but not for display.

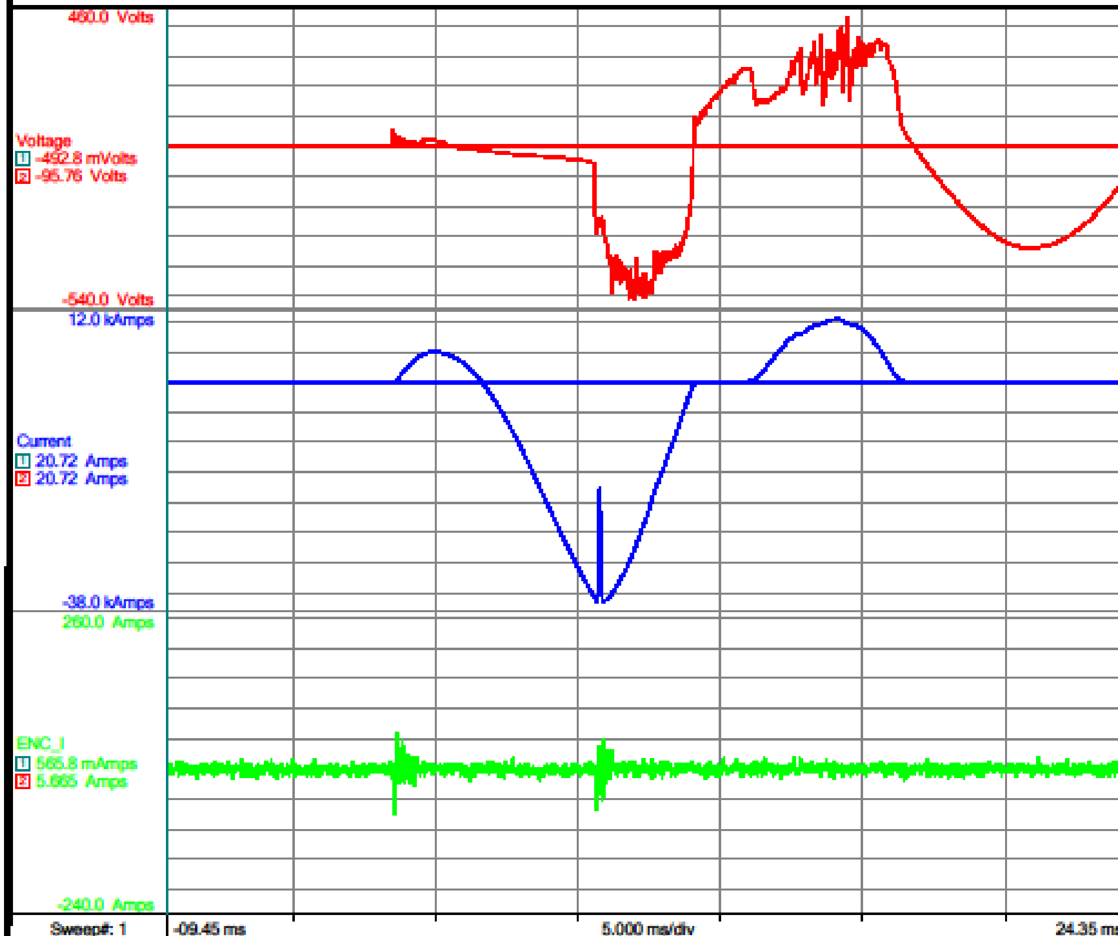
**OSC. NO.: HPL3-30038**

Oscillogram No.: HPL3-30039 OCV = 240 V
Date of Test: 6/9/2020 Time of Test: 1:18:07 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28037 Calibration Date: 2/11/2020
OCV = 243 V Rms Sym Current = 22.87 kA
Power Factor = 19%

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 26




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 147 Deg |
| Closing time (V0)+ | 6.807 m Sec |
| Peak Current (Ip) | -36.57 k Amperes |
| Time to Ip | 7.289 m Sec. |
| I²t | 4.063 M Amp^2sec |
| I Duration | 17.80 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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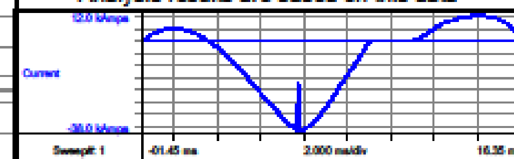
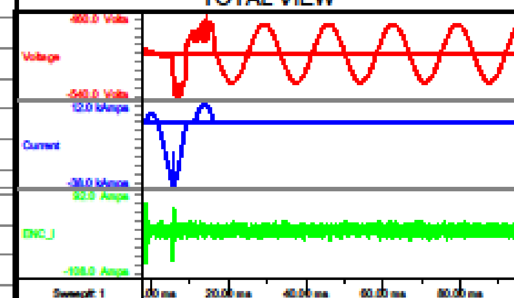
Analysis results are based on this data




TOTAL VIEW



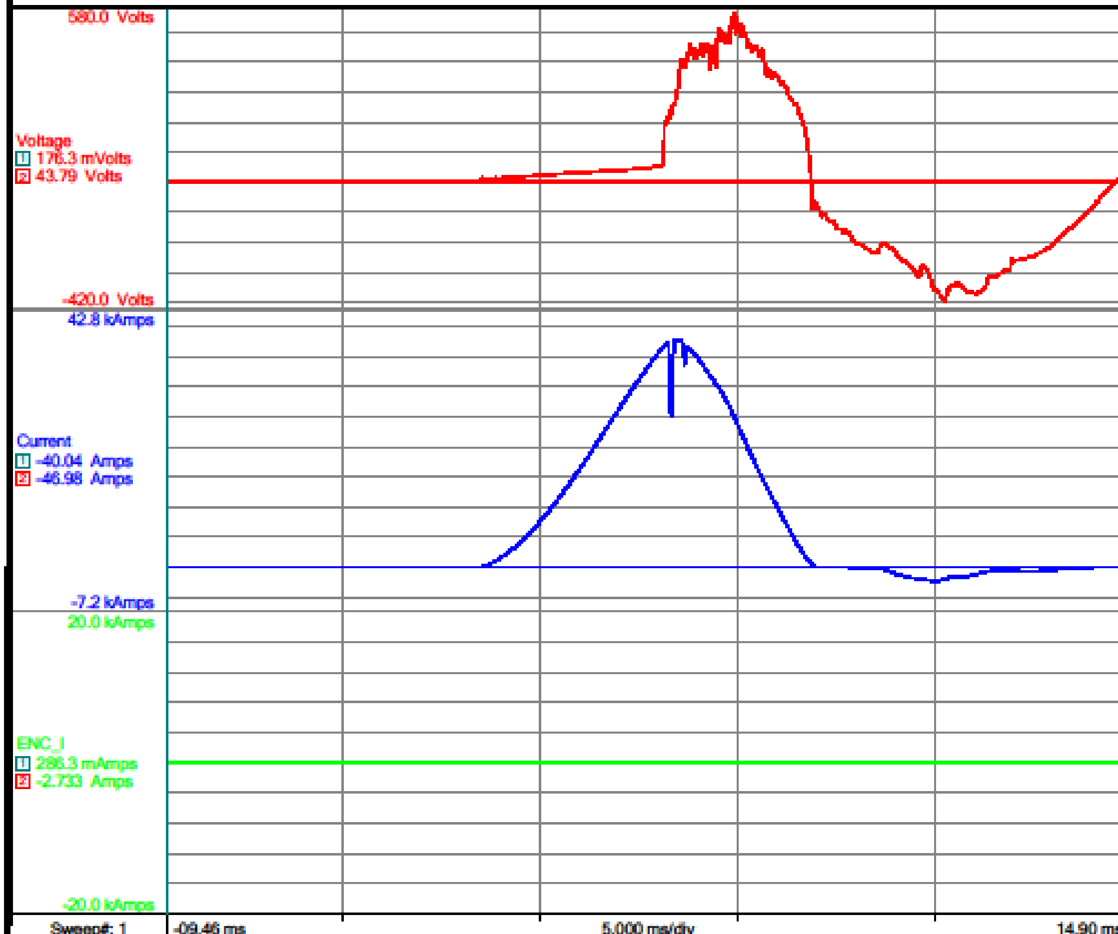

## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173
VOLTAGE 100X Scope Probe, C/N 131-608, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 100X Scope Probe, C/N 131-604, 1%
CURRENT ROGOWSKI COIL, C/N 045-443
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30039

| Oscillogram No.: HPL3-30040 OCV = 240 V<br>Date of Test: 6/9/2020 Time of Test: 1:22:21 PM | **Schneider Electric**<br><br>High Power Laboratory, HPL3 Facility<br>Cedar Rapids, Iowa, USA |
|---|---|
| AVAILABLE CIRCUIT CHARACTERISTICS:<br>Osc. No: 26037 Calibration Date: 2/11/2020<br>OCV = 243 V Rms Sym Current = 22.87 kA<br>Power Factor = 19% | |

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 27




**ANALYSIS RESULTS TABLE**

| | |
|---|---|
| Closing Angle | 14 Deg |
| Closing time (V0)+ | 632.1 μ Sec |
| Peak Current (Ip) | 37.99 k Amperes |
| Time to Ip | 4.859 m Sec. |
| I²t | 4.110 M Amp^2sec |
| I Duration | 8.362 m Sec. |

**Performance Observations**

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

**Comment Section**

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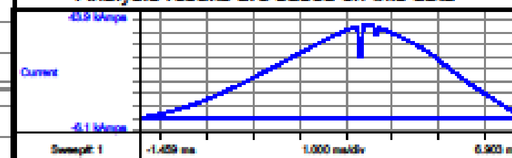
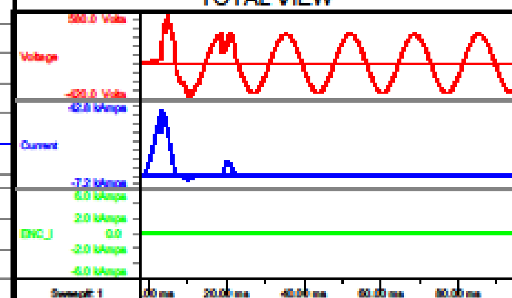
Analysis results are based on this data




TOTAL VIEW




**INSTRUMENTATION DATA**

Data Recording System HBM GEN7T C/N 383-179
VOLTAGE 100X Scope Probe, C/N 131-880, 1%   PLOT FILE HPL3 CR_I_II
VOLTAGE 100X Scope Probe, C/N 131-884, 1%
CURRENT ROGOWSKI COIL, C/N 048-445
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-30040**

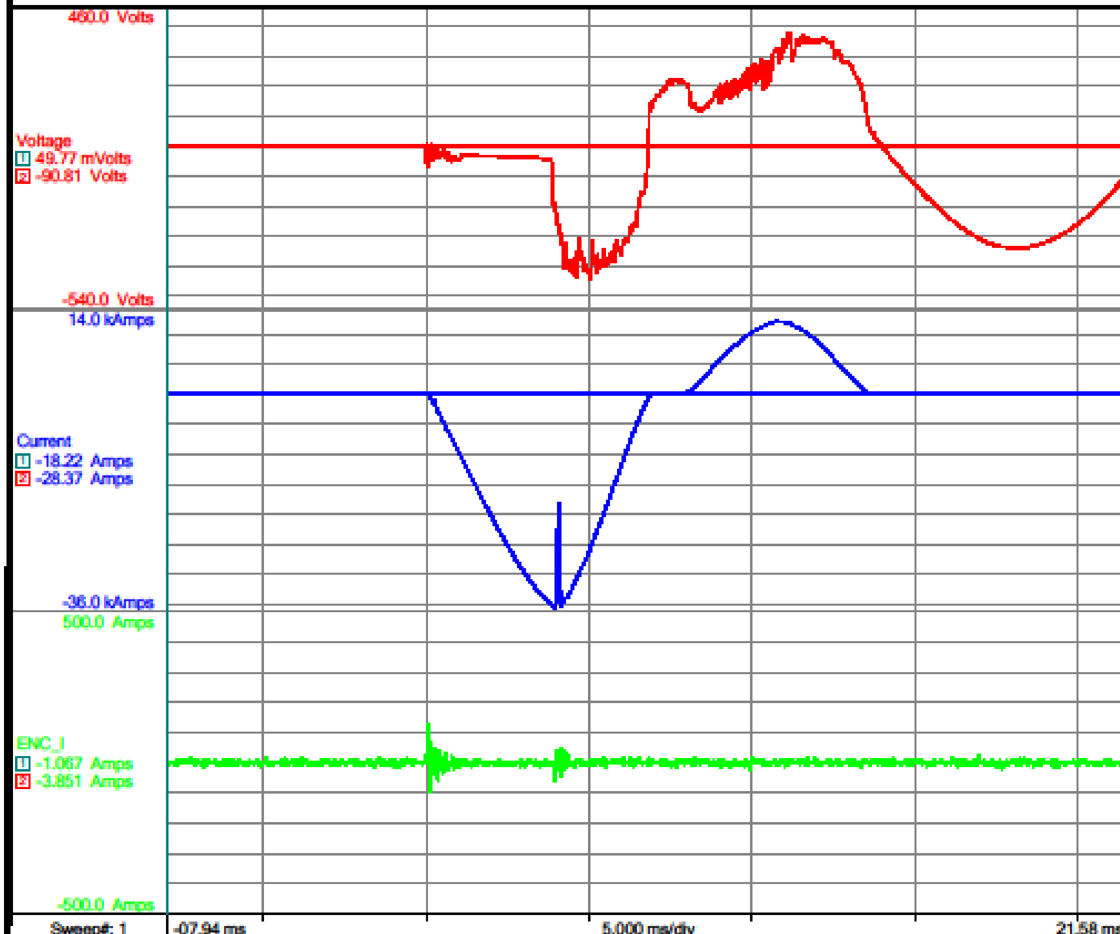
Oscillogram No.: HPL3-30041 OCV = 240 V
Date of Test: 6/9/2020 Time of Test: 1:27:47 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 26037 Calibration Date: 2/11/2020
OCV = 243 V Rms Sym Current = 22.87 kA
Power Factor = 19%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 28




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 240 Deg |
| Closing time (V0)+ | 11.11 m Sec |
| Peak Current (Ip) | -35.58 k Amperes |
| Time to Ip | 3.908 m Sec. |
| I²t | 3.721 M Amp^2sec |
| I Duration | 13.52 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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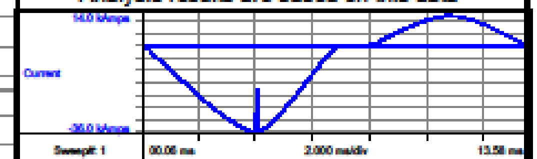
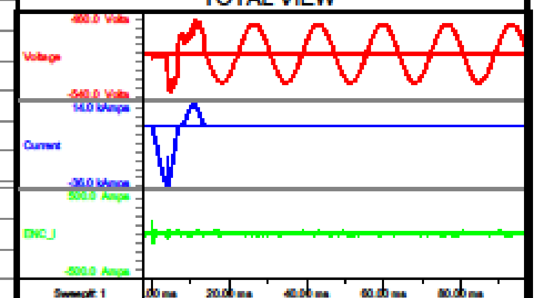
Analysis results are based on this data



TOTAL VIEW



INSTRUMENTATION DATA

OSC. NO.: HPL3-30041

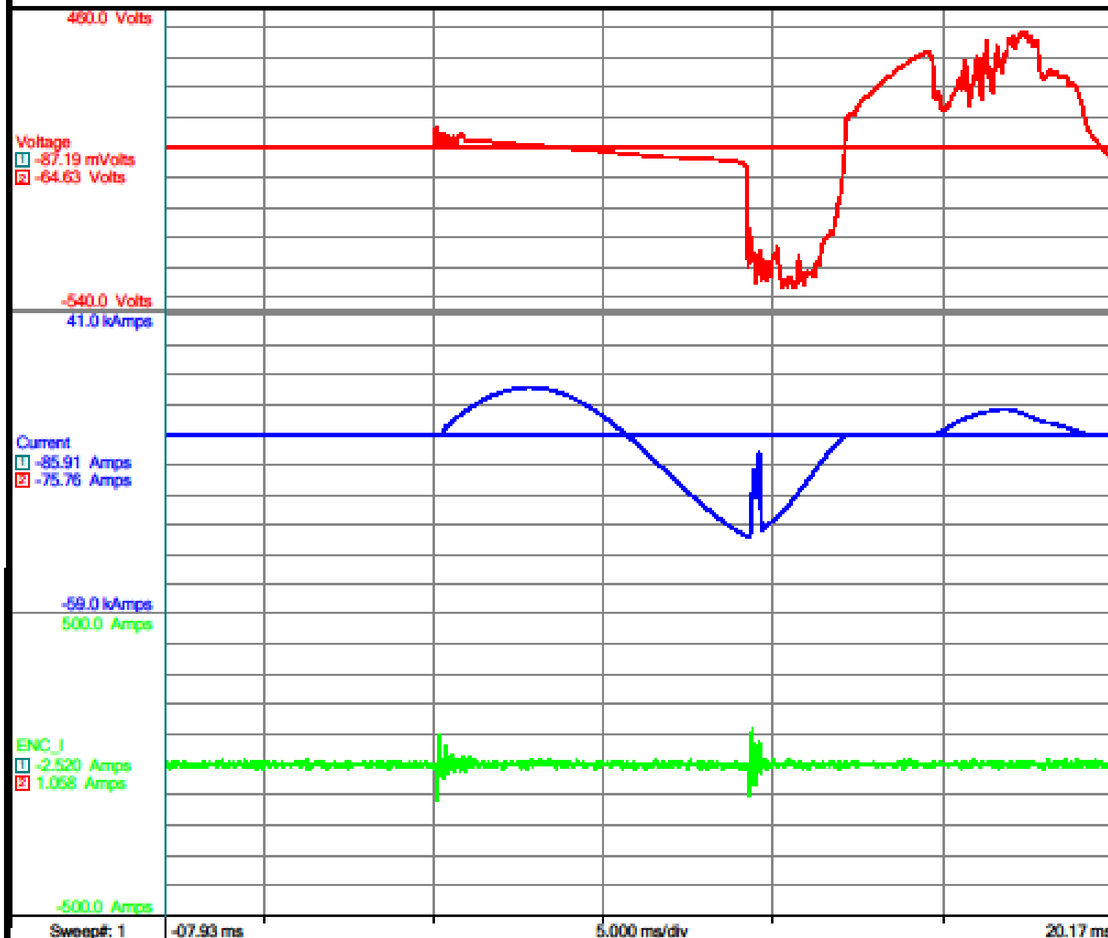
Oscillogram No.: HPL3-30042 OCV = 240 V
Date of Test: 6/9/2020 Time of Test: 1:32:22 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 26037 Calibration Date: 2/11/2020
OCV = 243 V Rms Sym Current = 22.87 kA
Power Factor = 19%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 29




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 117 Deg |
| Closing time (V0)+ | 5.429 m Sec |
| Peak Current (Ip) | -34.18 k Amperes |
| Time to Ip | 9.239 m Sec. |
| I²t | 3.401 M Amp^2sec |
| I Duration | 12.11 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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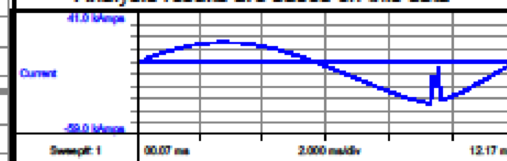
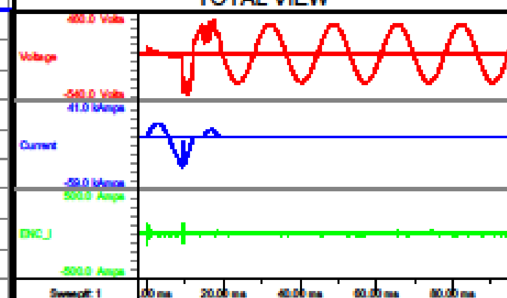
Analysis results are based on this data




TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T CAl 003-173
VOLTAGE 100X Scope Probe, CAl 131-808, 1% PLOT FILE HPL3 CR_I_M
VOLTAGE 100X Scope Probe, CAl 131-804, 1%
CURRENT ROGOWSKI COIL, CAl 045-448
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-30042**

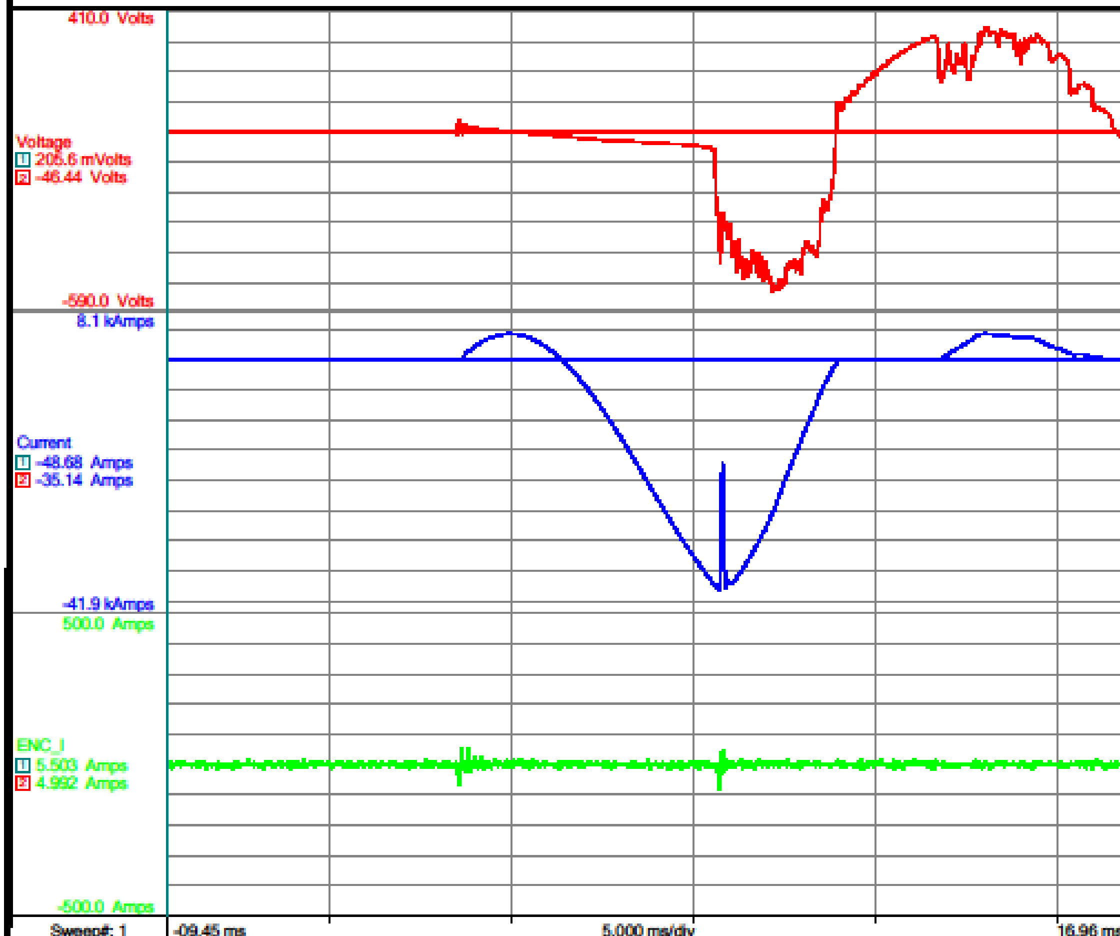
Oscillogram No.: HPL3-30043  OCV = 240 V
Date of Test: 6/9/2020  Time of Test: 1:37:47 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 26037  Calibration Date: 2/11/2020
OCV = 243 V  Rms Sym Current = 22.87 kA
Power Factor = 19%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332  TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 30




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 150 Deg |
| Closing time (V0)+ | 6.933 m Sec |
| Peak Current (Ip) | -38.09 k Amperes |
| Time to Ip | 7.139 m Sec. |
| I²t | 4.013 M Amp^2sec |
| I Duration | 10.42 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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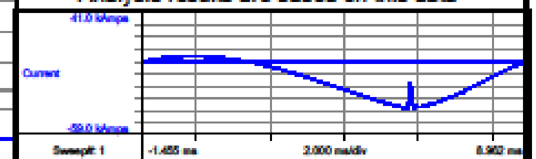
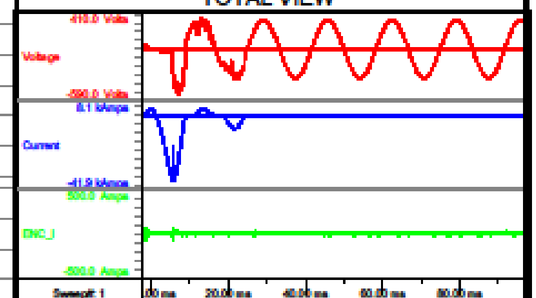
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-000, 1%  PLOT FILE HPL3 CR_1_M
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30043

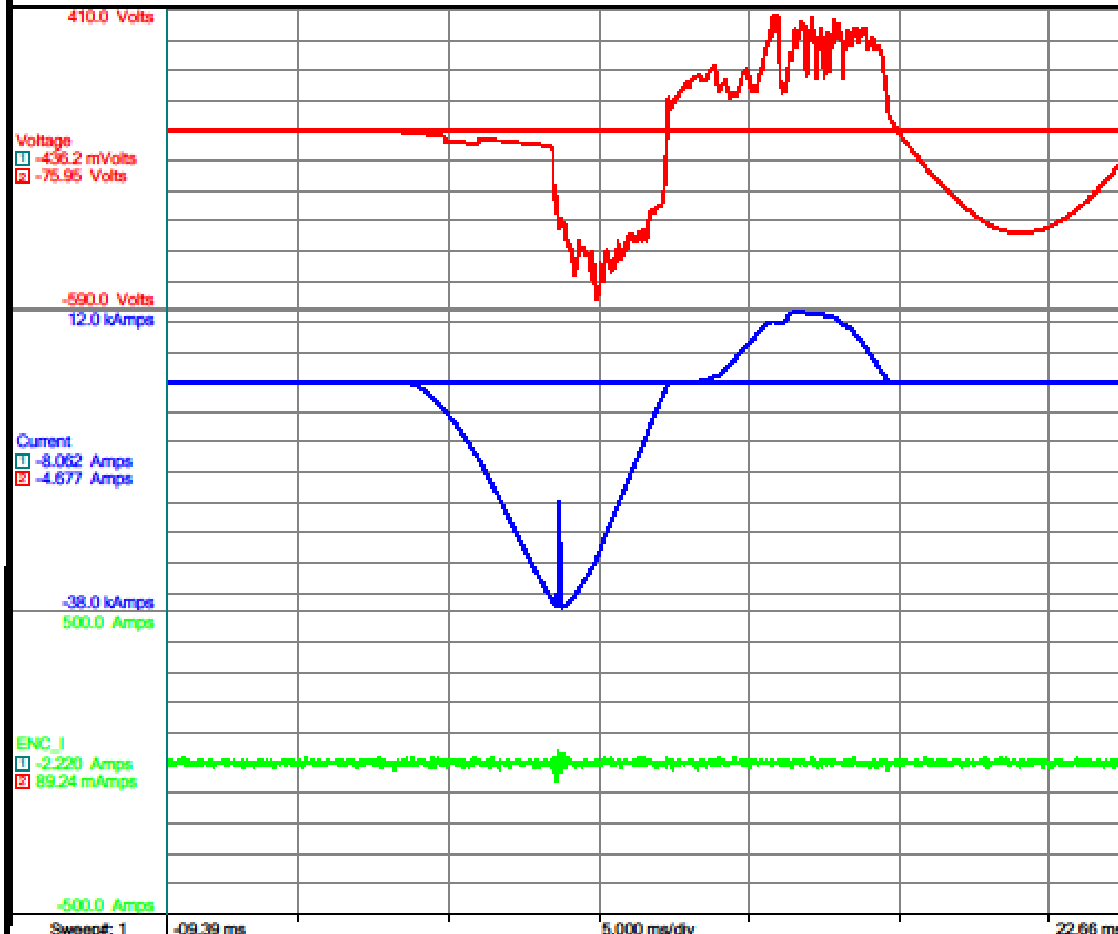
Oscillogram No.: HPL3-30044 OCV = 240 V
Date of Test: 6/9/2020 Time of Test: 1:42:59 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 26037 Calibration Date: 2/11/2020
OCV = 243 V Rms Sym Current = 22.87 kA
Power Factor = 19%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 31




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 188 Deg |
| Closing time (V0)+ | 8.700 m Sec |
| Peak Current (Ip) | -37.54 k Amperes |
| Time to Ip | 5.157 m Sec. |
| I²t | 4.532 M Amp^2sec |
| I Duration | 18.05 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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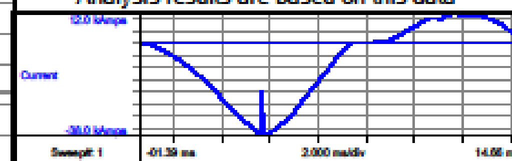
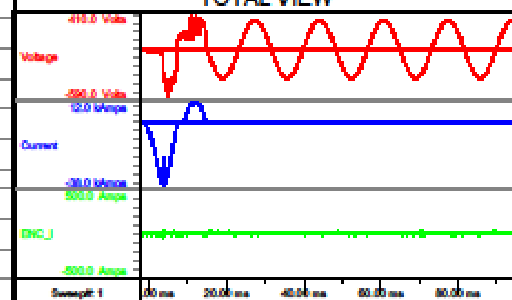
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

OSC. NO.: HPL3-30044

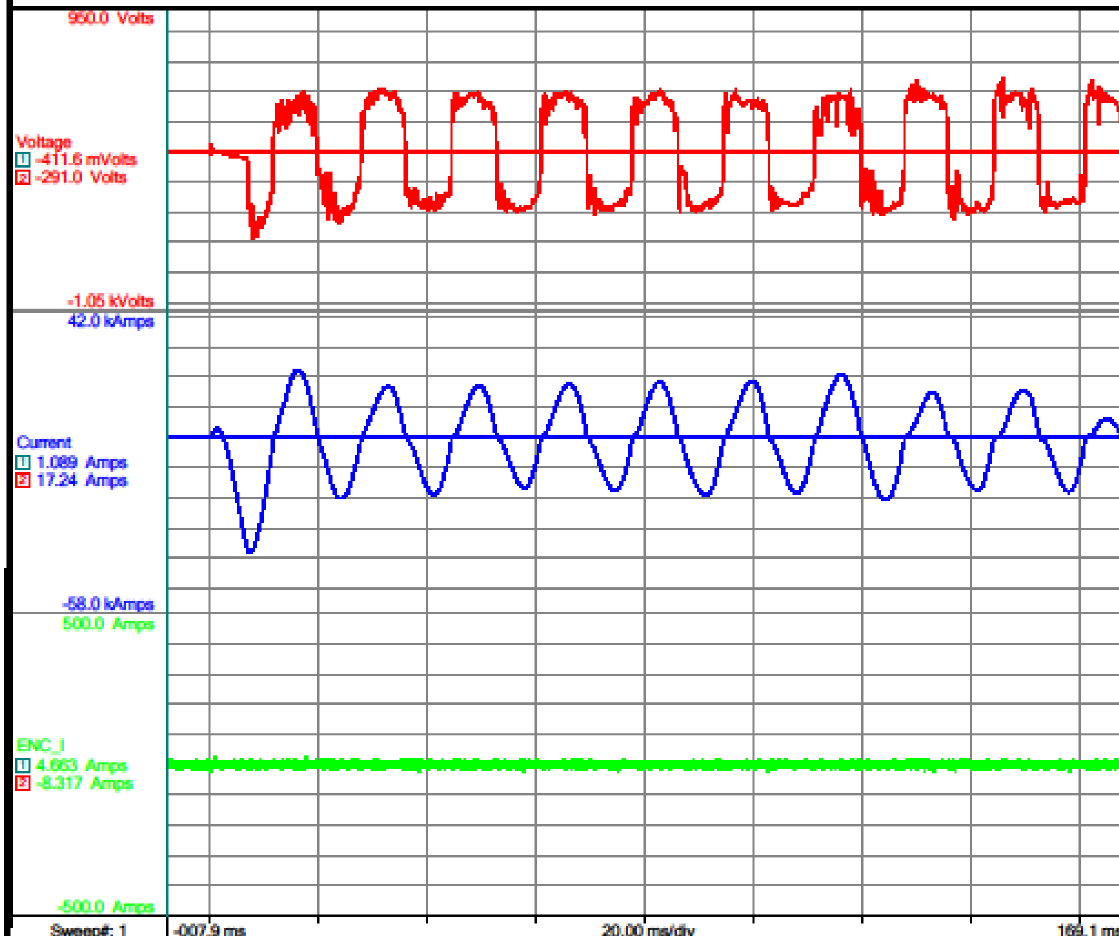
Oscillogram No.: HPL3-30045 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 2:21:16 PM

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 32




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 179 Deg |
| Closing time (V0)+ | 23.40 μ Sec |
| Peak Current (Ip) | -38.50 k Amperes |
| Time to Ip | 7.255 m Sec. |
| I²t | 29.09 M Amp^2sec |
| I Duration | 161.0 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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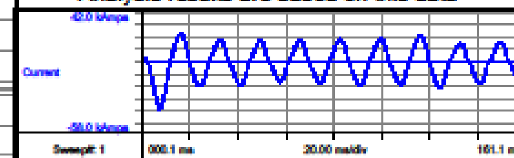
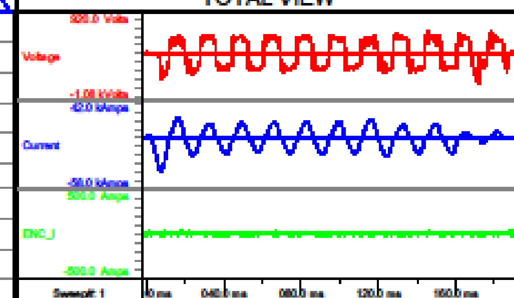
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

[illegible]

OSC. NO.: HPL3-30045

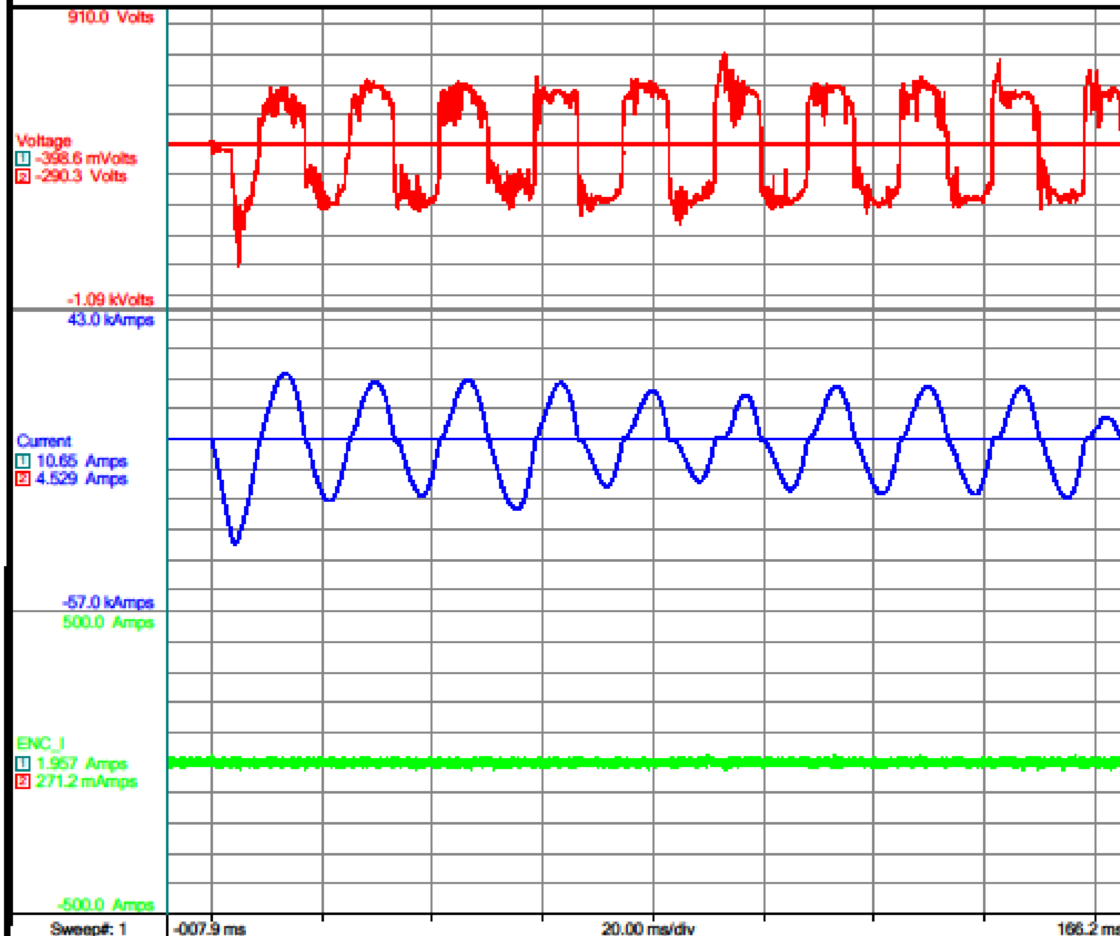
Oscillogram No.: HPL3-30046 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 2:27:59 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 33




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 254 Deg |
| Closing time (V0)+ | 198.3 µ Sec |
| Peak Current (Ip) | -34.90 k Amperes |
| Time to Ip | 4.274 m Sec. |
| I²t | 27.44 M Amp^2sec |
| I Duration | 158.1 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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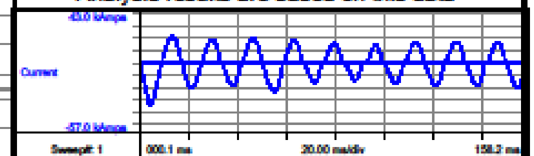
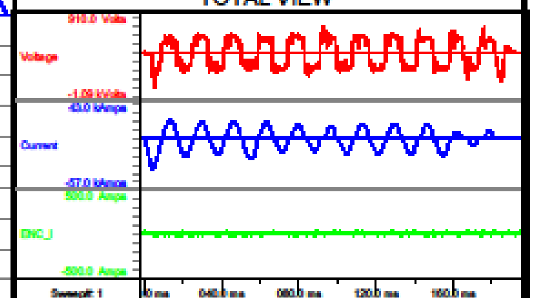
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173
VOLTAGE 100X Scope Probe, C/N 131-000, 1% PLOT FILE:HPL3 CR_1_B
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-30046

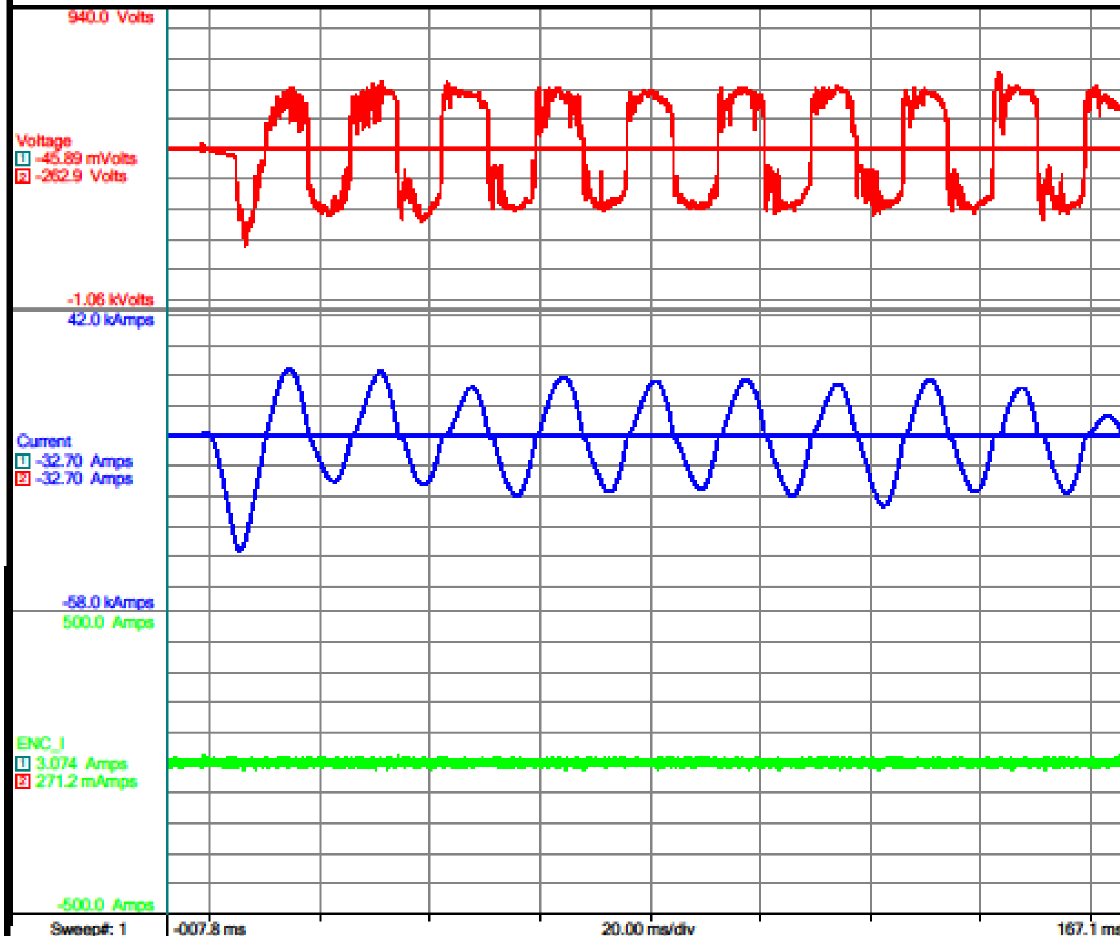
| |
|---|
| Oscillogram No.: HPL3-30047  OCV = 484 V |
| Date of Test: 6/9/2020  Time of Test: 2:34:39 PM |

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776  Calibration Date: 9/06/2019
OCV = 485 V  Rms Sym Current = 21.5 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332  TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 34




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 285 Deg |
| Closing time (V0)+ | 714.0 µ Sec |
| Peak Current (Ip) | -37.97 k Amperes |
| Time to Ip | 5.080 m Sec. |
| I²t | 30.03 M Amp^2sec |
| I Duration | 158.9 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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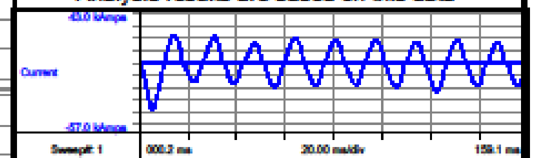
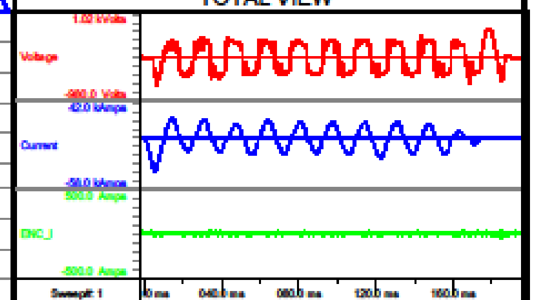
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 100X Scope Probe, C/N 131-888, 1%  PLOT FILE:HPL3 CR_1_R
VOLTAGE 100X Scope Probe, C/N 131-894, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-30047**

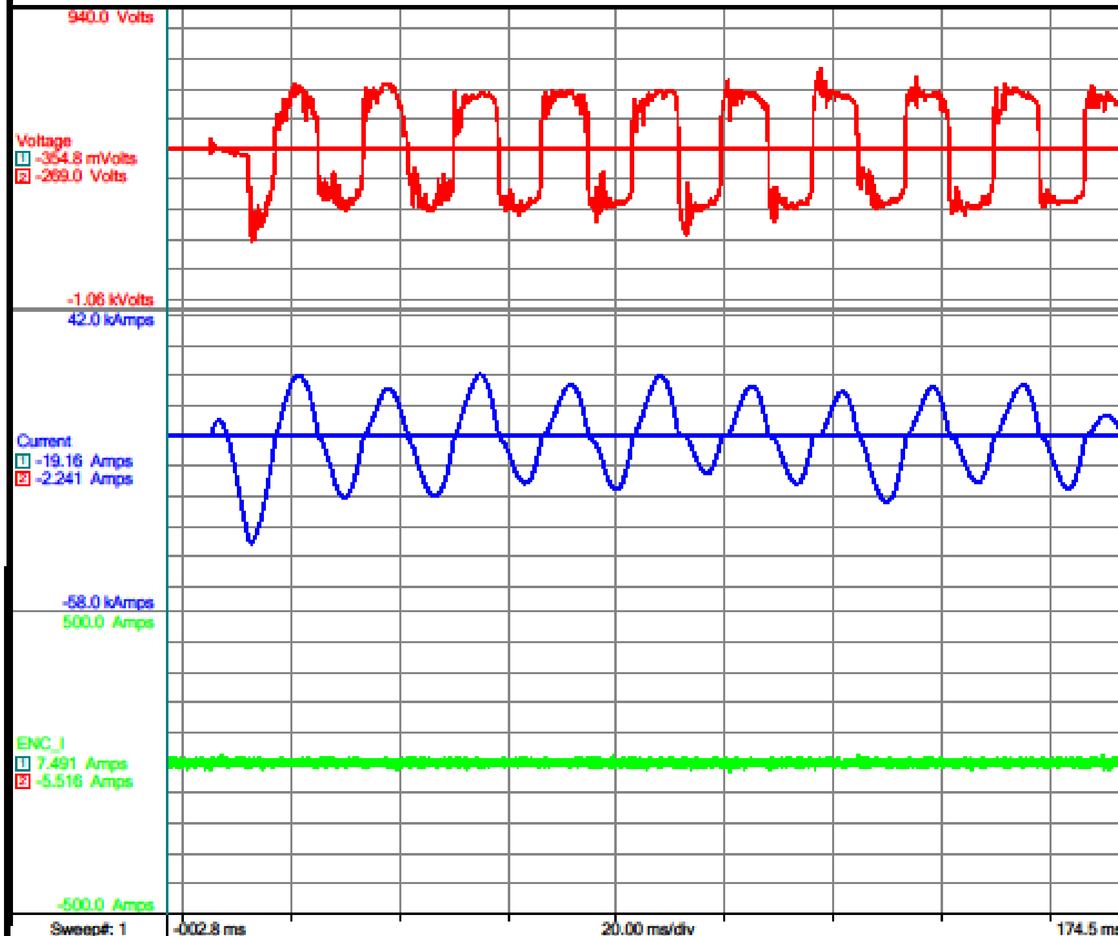
Oscillogram No.: HPL3-30048 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 2:42:32 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 35




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 325 Deg |
| Closing time (V0)+ | 248.2 µ Sec |
| Peak Current (Ip) | -35.71 k Amperes |
| Time to Ip | 7.487 m Sec. |
| I²t | 25.91 M Amp^2sec |
| I Duration | 161.3 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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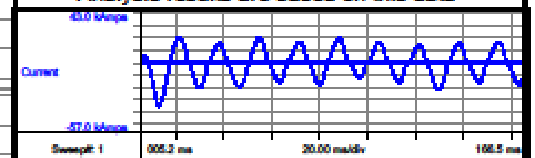
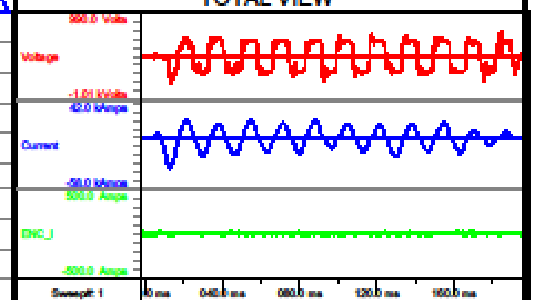
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 093-173
VOLTAGE 1000X Scope Probe, C/N 131-688, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 1000X Scope Probe, C/N 131-604, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30048

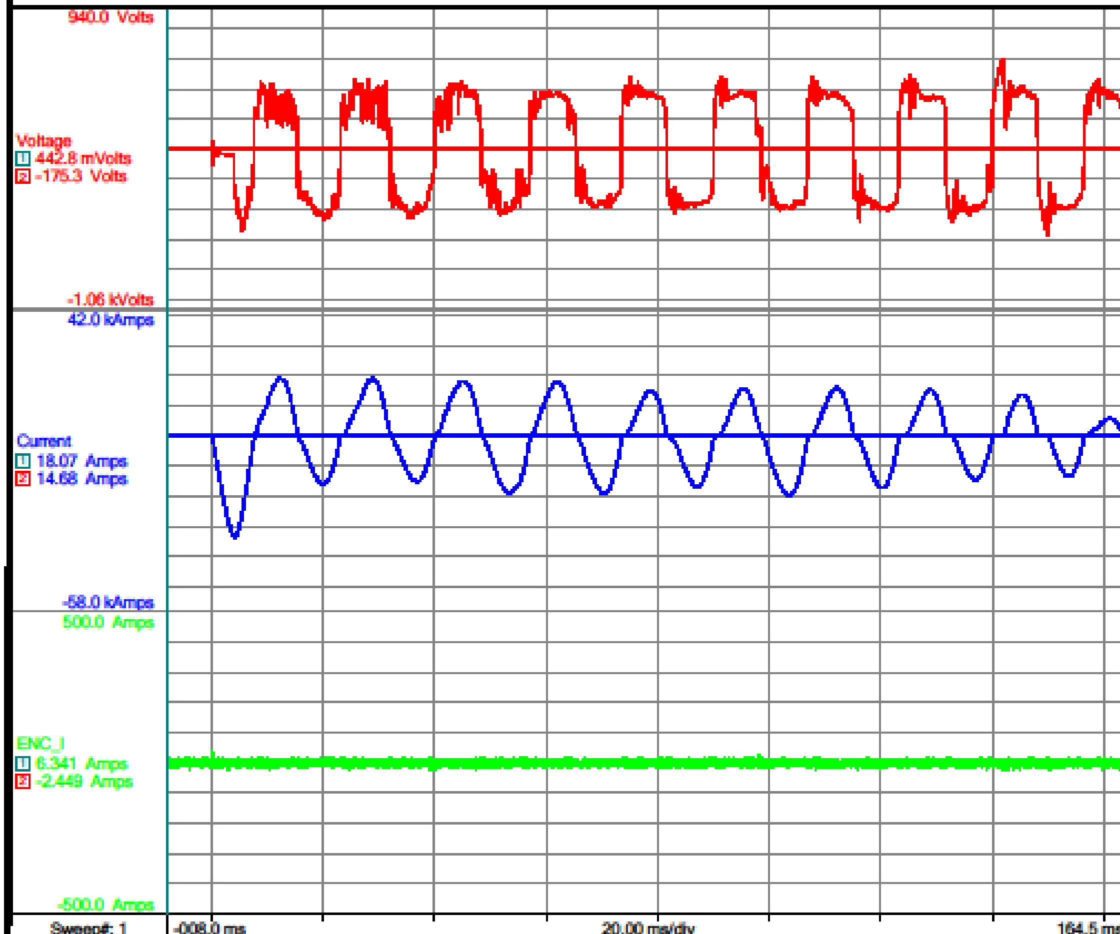
Oscillogram No.: HPL3-30049 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 2:48:39 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 36




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 148 Deg |
| Closing time (V0)+ | 3.378 m Sec |
| Peak Current (Ip) | -34.03 k Amperes |
| Time to Ip | 4.071 m Sec. |
| I²t | 22.54 M Amp^2sec |
| I Duration | 156.5 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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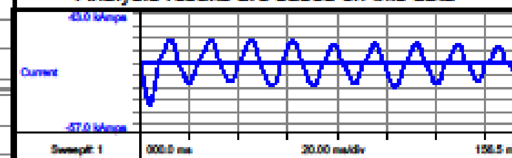
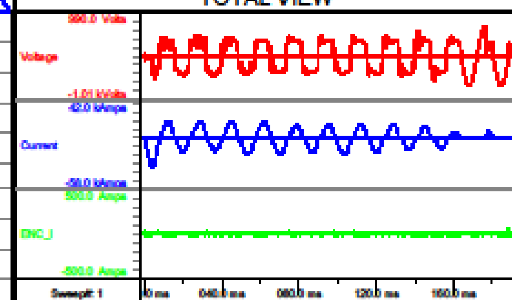
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

[illegible]

[illegible]

[illegible]

[illegible]

NOTE: Channel offset removed for analysis,

[illegible]

OSC. NO.: HPL3-30049

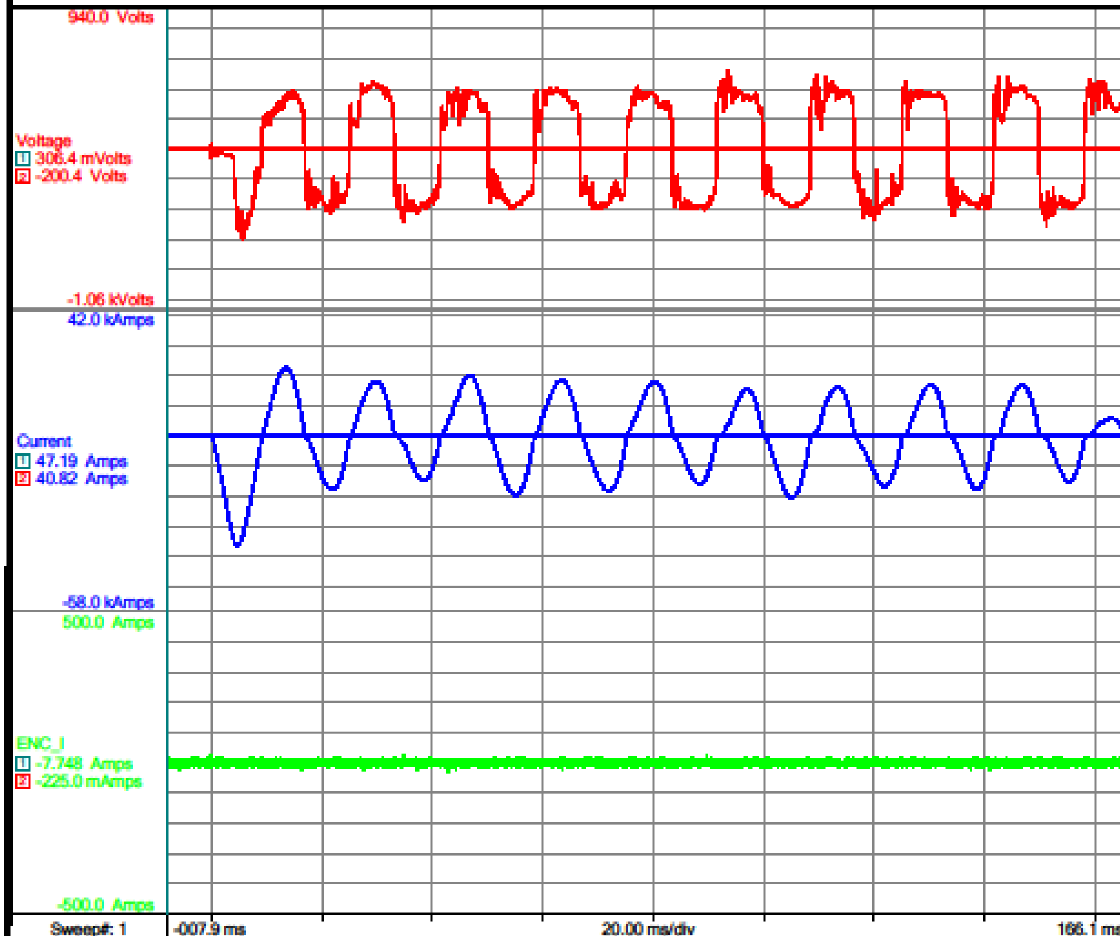
Oscillogram No.: HPL3-30050 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 2:56:01 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 37




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 199 Deg |
| Closing time (V0)+ | 14.12 m Sec |
| Peak Current (Ip) | -36.70 k Amperes |
| Time to Ip | 4.592 m Sec. |
| I²t | 26.87 M Amp^2sec |
| I Duration | 158.1 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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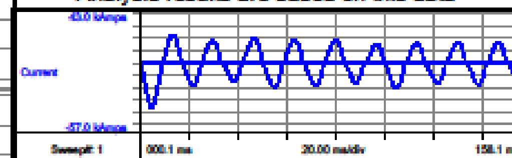
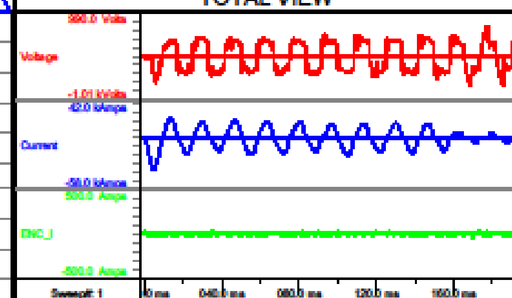
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173
VOLTAGE 100X Scope Probe, C/N 131-808, 1% PLOT FILE HPL3 CR_1_M
VOLTAGE 100X Scope Probe, C/N 131-804, 1%
CURRENT ROGOWSKI COIL, C/N 048-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30050

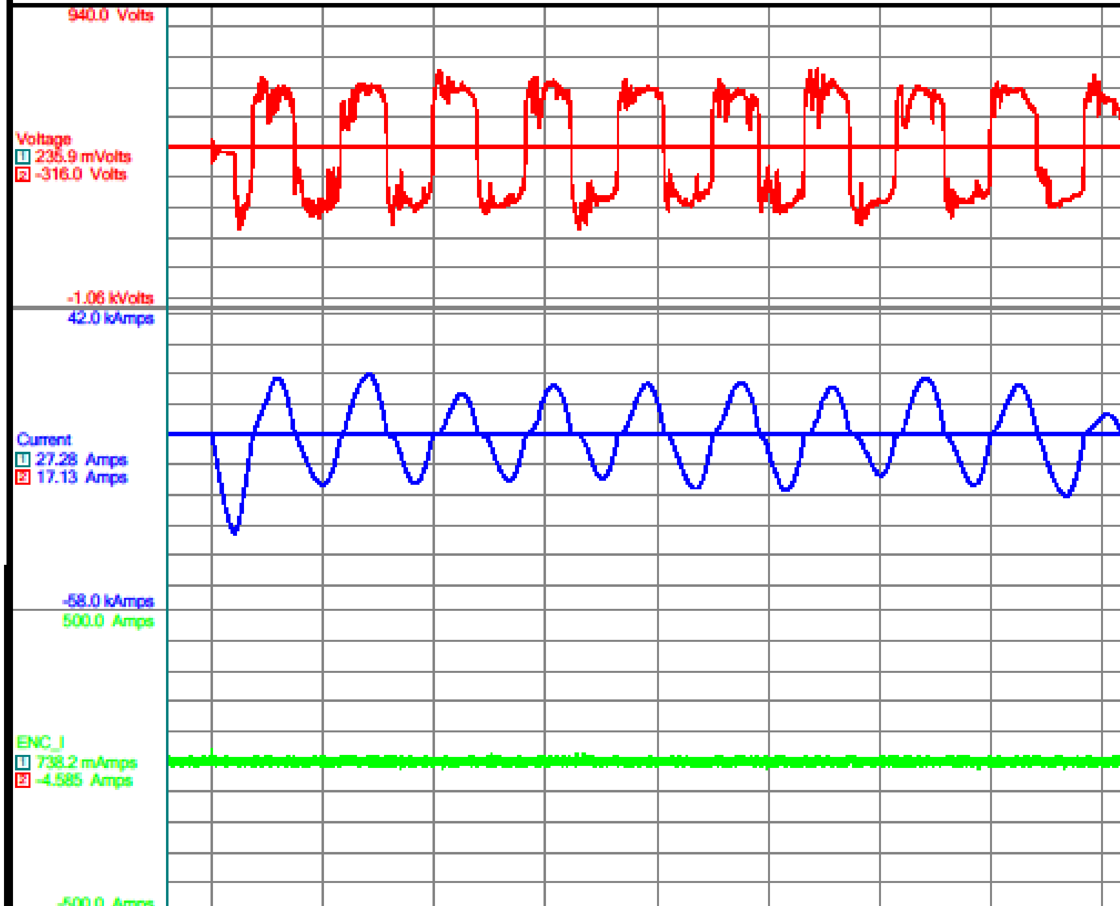
Oscillogram No.: HPL3-30051 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 3:00:53 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 38




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 238 Deg |
| Closing time (V0)+ | 55.08 µ Sec |
| Peak Current (Ip) | -32.83 k Amperes |
| Time to Ip | 4.175 m Sec. |
| I²t | 22.44 M Amp^2sec |
| I Duration | 156.8 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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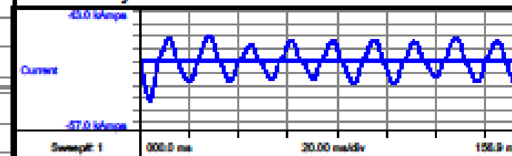
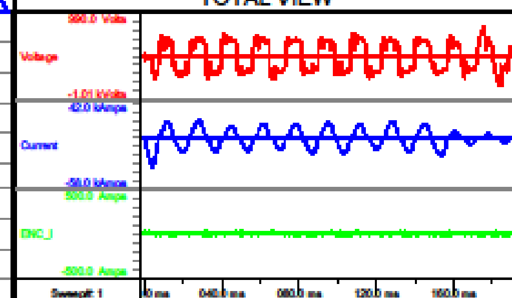
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-000, 1% PLOT FILE HPL3 CR_1_M
VOLTAGE 100X Scope Probe, C/N 131-604, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-30051**

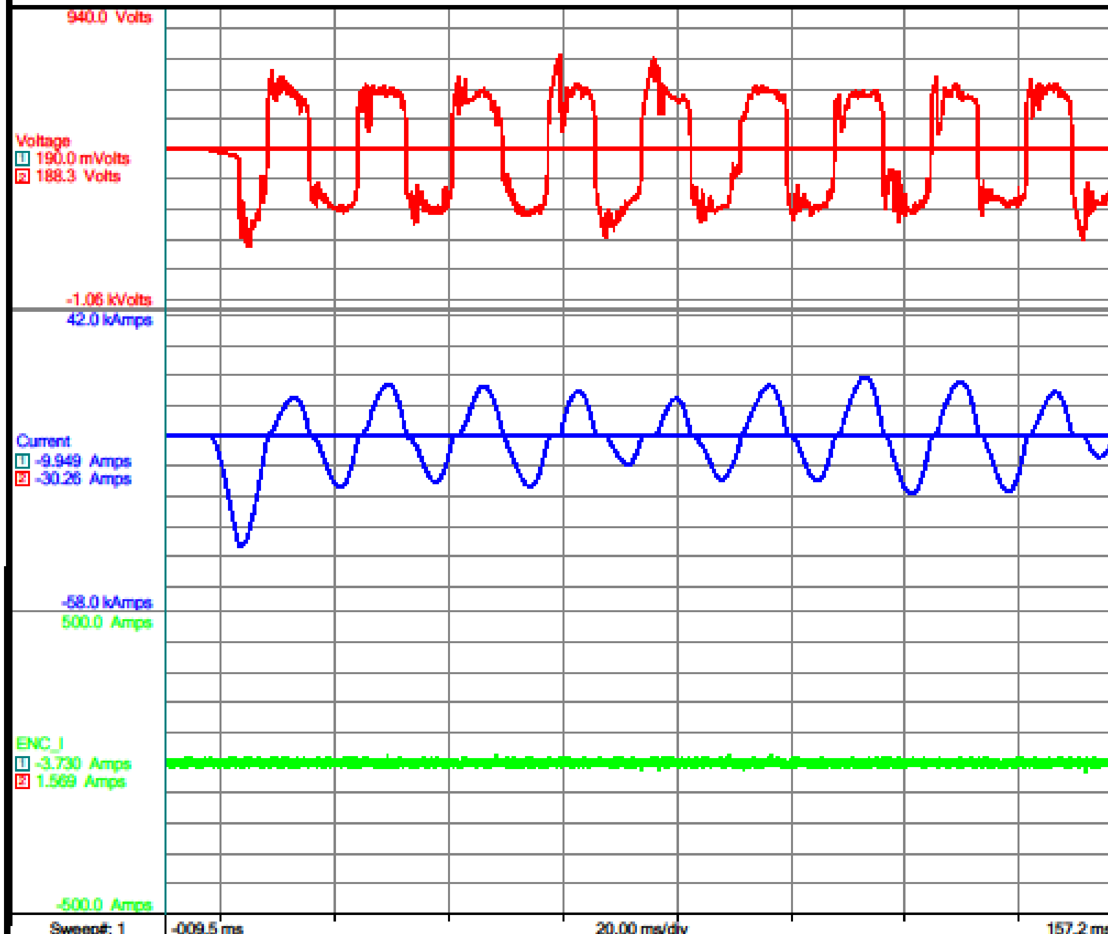
Oscillogram No.: HPL3-30052 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 3:07:40 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 39




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 288 Deg |
| Closing time (V0)+ | 19.09 m Sec |
| Peak Current (Ip) | -38.88 k Amperes |
| Time to Ip | 5.127 m Sec. |
| I²t | 21.10 M Amp^2sec |
| I Duration | 150.7 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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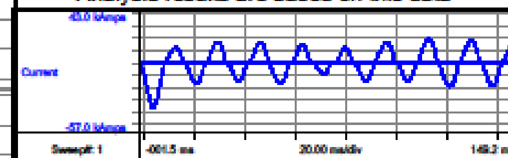
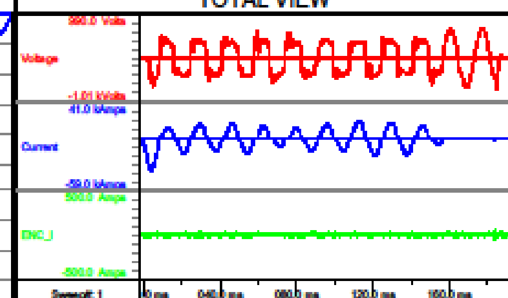
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis but not for display.

OSC. NO.: HPL3-30052

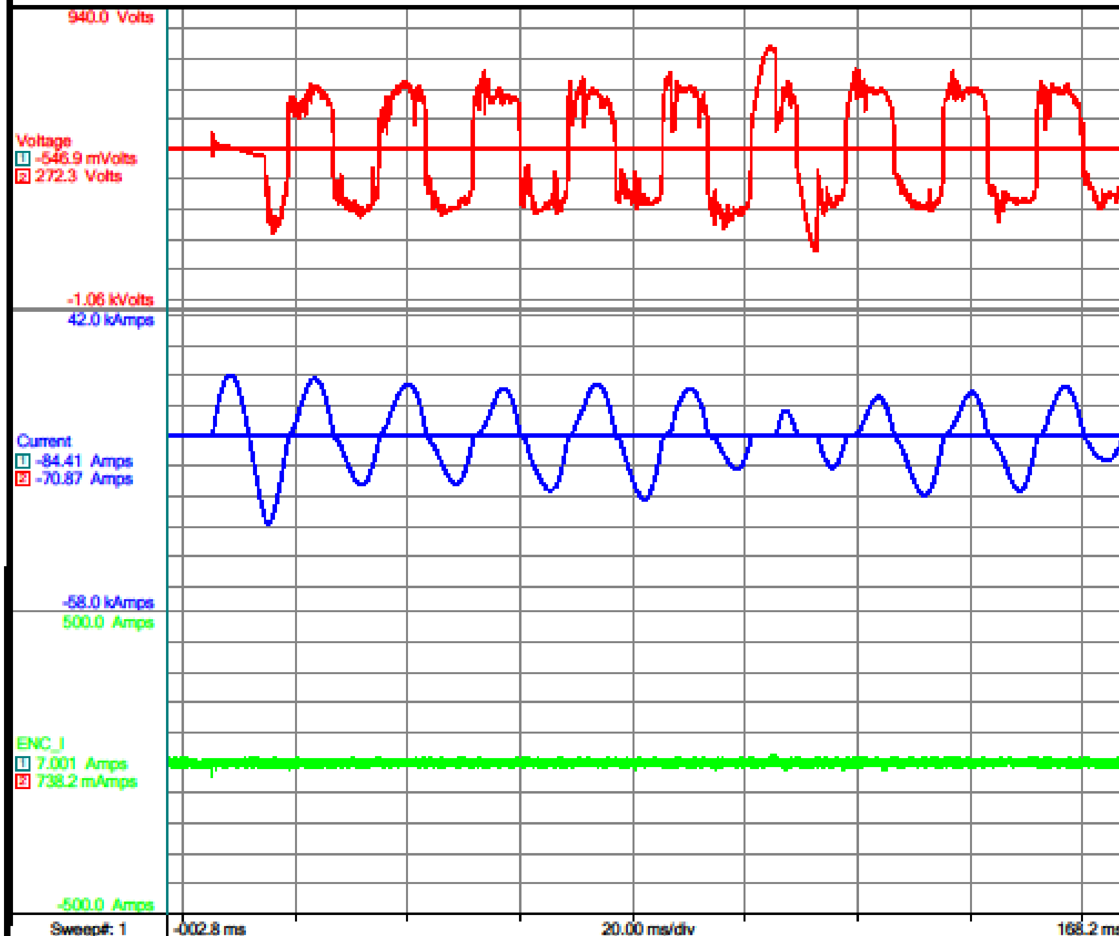
Oscillogram No.: HPL3-30053 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 3:13:28 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 40




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 128 Deg |
| Closing time (V0)+ | 5.353 m Sec |
| Peak Current (Ip) | -29.09 k Amperes |
| Time to Ip | 9.914 m Sec. |
| I²t | 20.23 M Amp^2sec |
| I Duration | 155.0 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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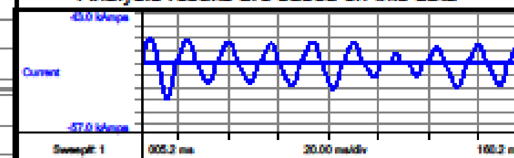
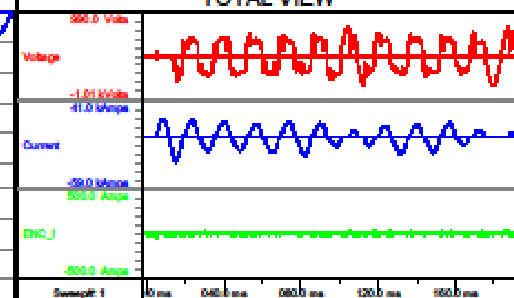
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 100X Scope Probe, C/N 131-000, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30053

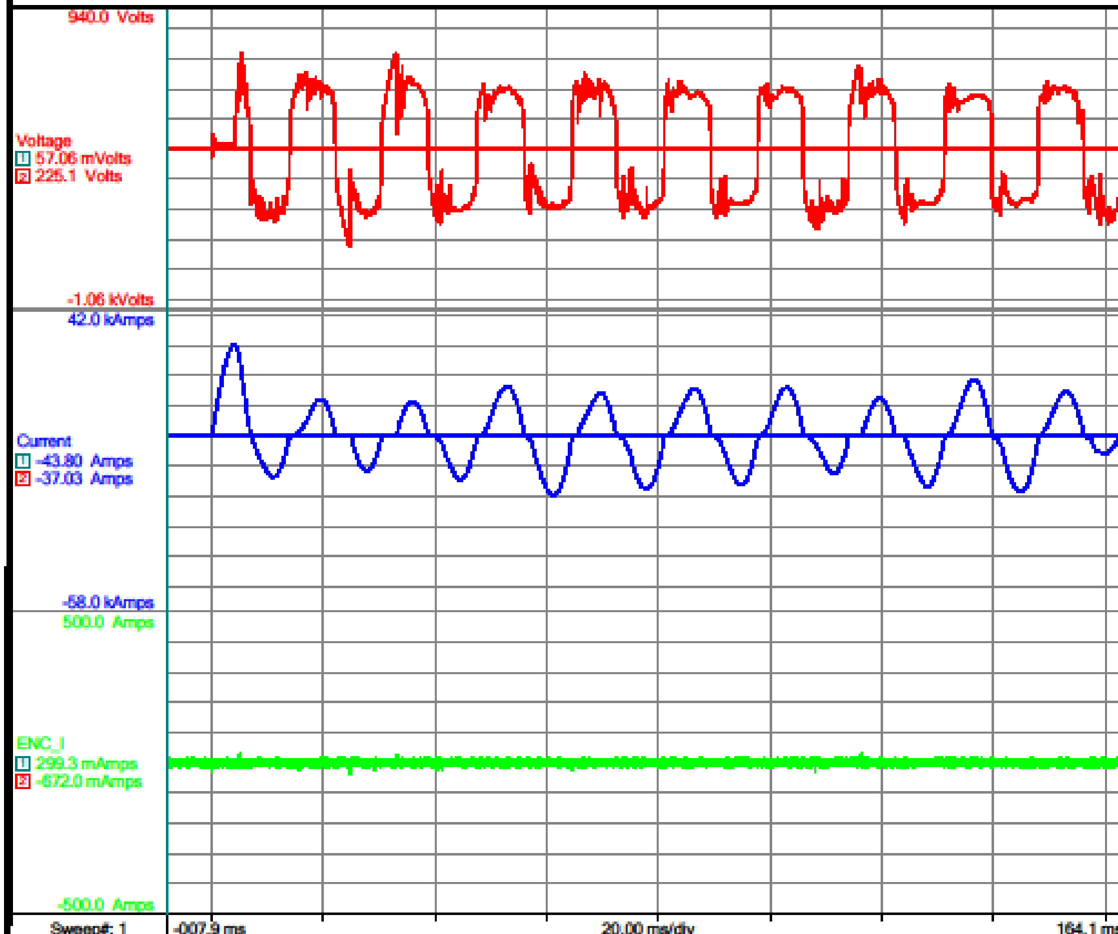
Oscillogram No.: HPL3-30054 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 3:18:28 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 41




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 353 Deg |
| Closing time (V0)+ | 3.125 m Sec |
| Peak Current (Ip) | 30.50 k Amperes |
| Time to Ip | 4.128 m Sec. |
| I²t | 17.84 M Amp^2sec |
| I Duration | 156.0 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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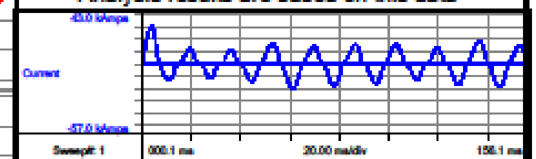
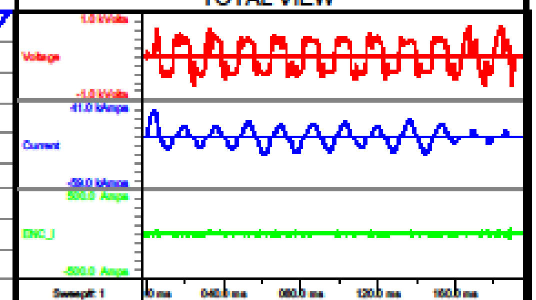
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1% PLOT FILE HPL3 CR_1_B
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30054

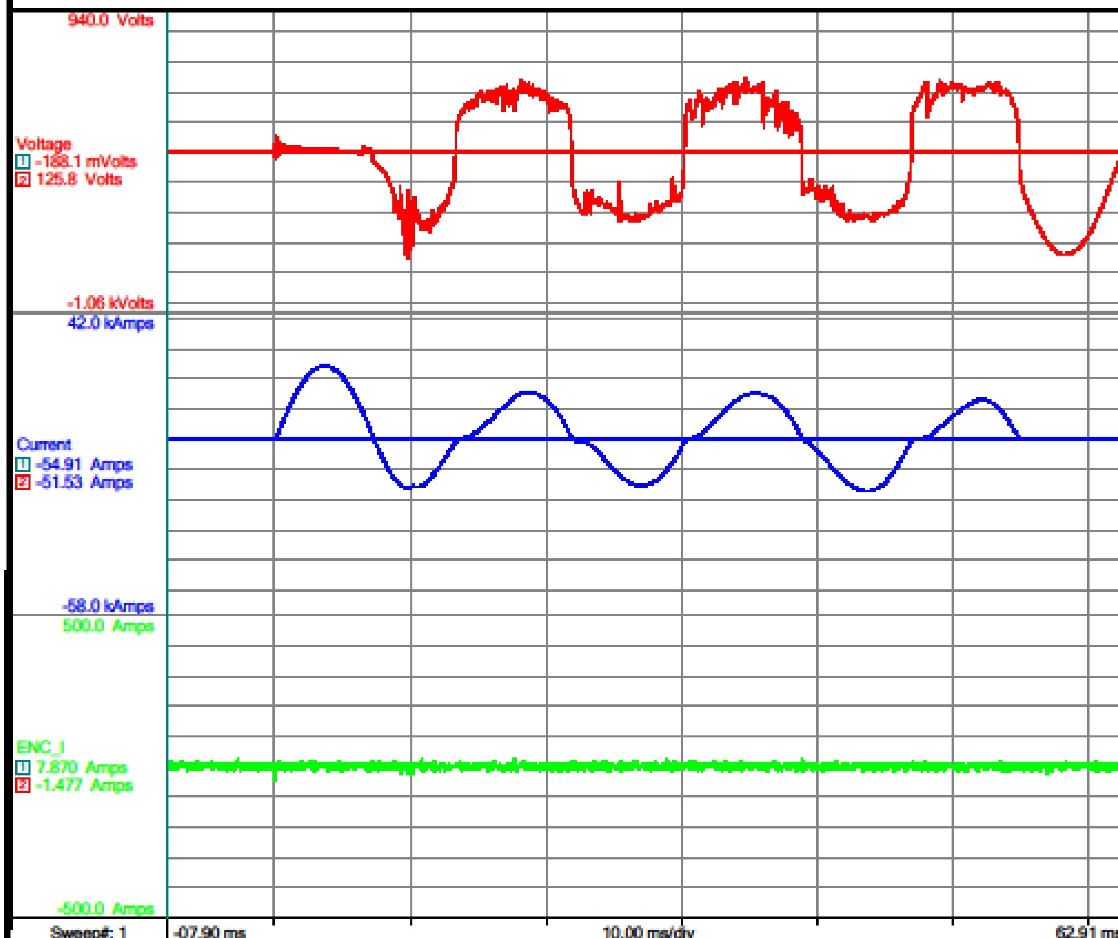
Oscillogram No.: HPL3-30055 OCV = 484 V
Date of Test: 6/9/2020 Time of Test: 3:25:12 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 9/06/2019
OCV = 485 V Rms Sym Current = 21.5 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 42




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 94 Deg |
| Closing time (V0)+ | 4.378 m Sec |
| Peak Current (Ip) | 24.52 k Amperes |
| Time to Ip | 3.588 m Sec. |
| I²t | 7.385 M Amp^2sec |
| I Duration | 54.81 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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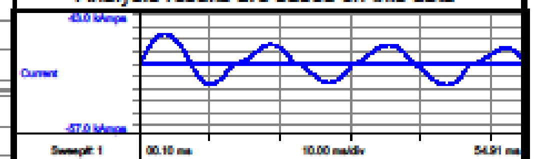
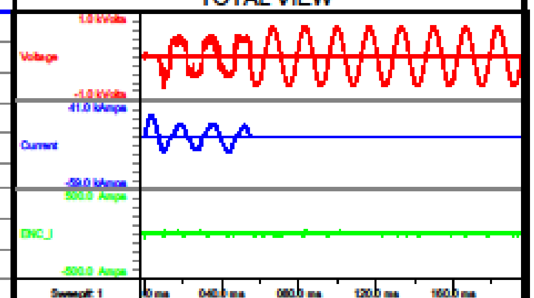
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 100X Beige Probe, C/N 131-505, 1% PLOT FILE HPL3 CR_1_B
VOLTAGE 100X Beige Probe, C/N 131-504, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30055

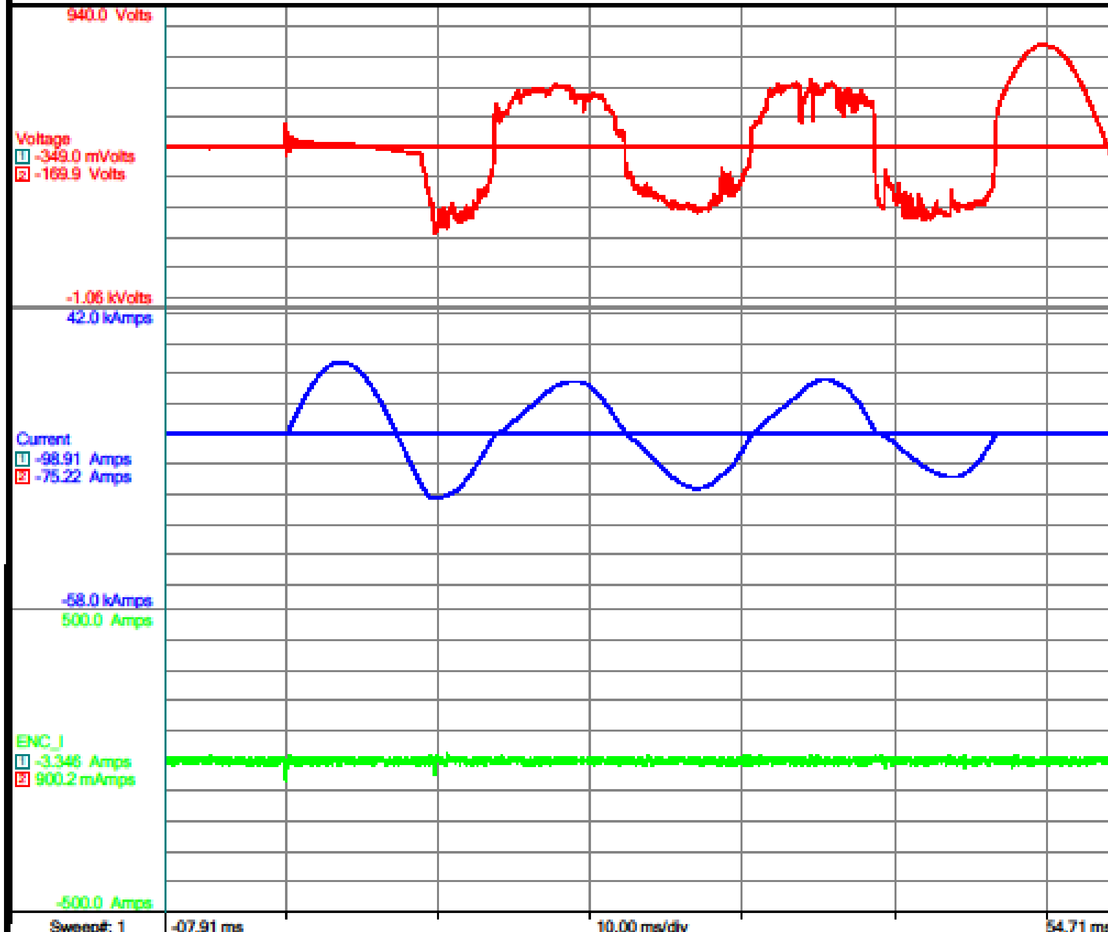
Oscillogram No.: HPL3-30056  OCV = 484 V
Date of Test: 6/9/2020  Time of Test: 3:32:34 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776  Calibration Date: 9/06/2019
OCV = 485 V  Rms Sym Current = 21.5 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332  TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 43




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 95 Deg |
| Closing time (V0)+ | 4.420 m Sec |
| Peak Current (Ip) | 24.05 k Amperes |
| Time to Ip | 3.558 m Sec. |
| I²t | 6.040 M Amp^2sec |
| I Duration | 46.61 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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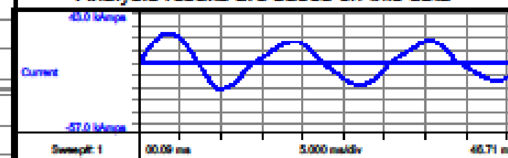
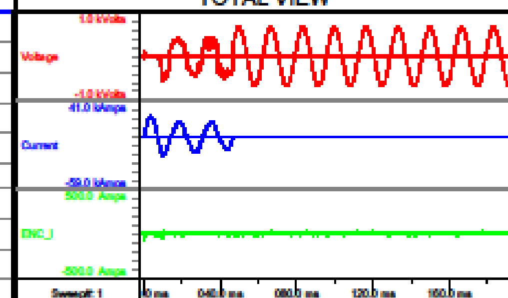
## Analysis results are based on this data



## TOTAL VIEW



## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173
VOLTAGE 100X Scope Probe, C/N 131-588, 1%  PLOT FILE HPL3 CR_I_W
VOLTAGE 100X Scope Probe, C/N 131-604, 1%
CURRENT ROGOWSKI COIL, C/N 048-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-30056

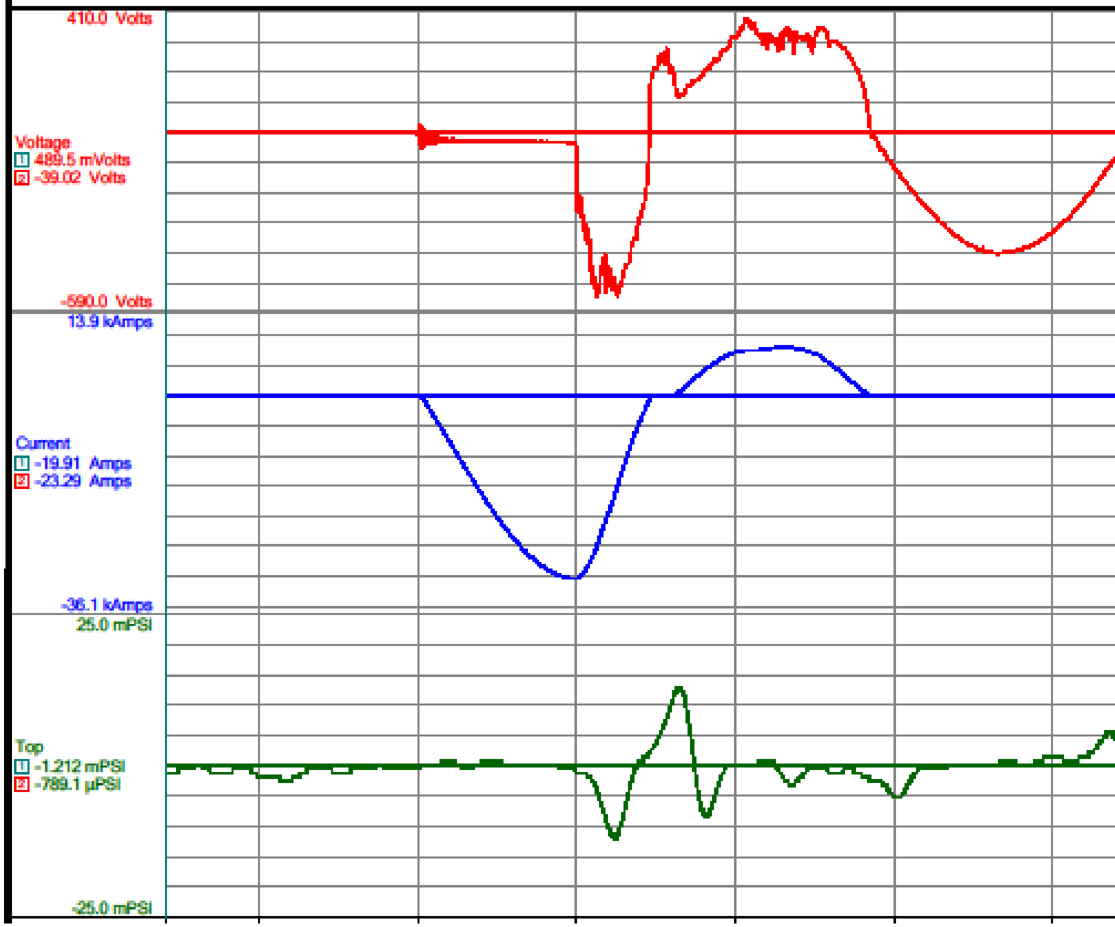
Oscillogram No.: HPL3-34315 OCV = 285 V
Date of Test: 9/28/2020 Time of Test: 10:12:01 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474 Calibration Date: 07/13/20
OCV = 278 V Rms Sym Current = 18.29 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 1




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 234 Deg |
| Closing time (V0)+ | 10.83 m Sec |
| Peak Current (Ip) | -30.38 k Amperes |
| Time to Ip | 4.880 m Sec. |
| I²t | 3.240 M Amp^2sec |
| I Duration | 14.25 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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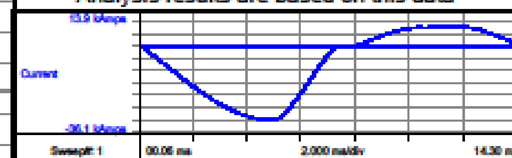
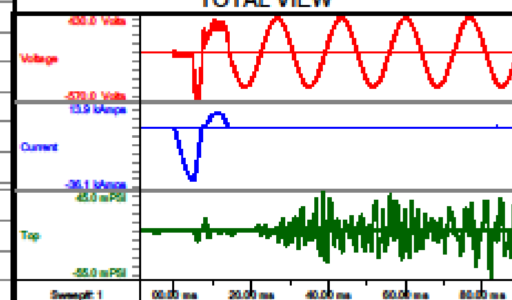
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System:HBM GEN7T CAL 083-173
VOLTAGE 1000X Scope Probe, CAL 131-006, 1% PLOT FILE:HPL3 CR_1_W
VOLTAGE 1000X Scope Probe, CAL 131-004, 1%
CURRENT ROGOWSKI COIL, CAL 046-445
NOTE: Channel offset removed for analysis,
but not for display.

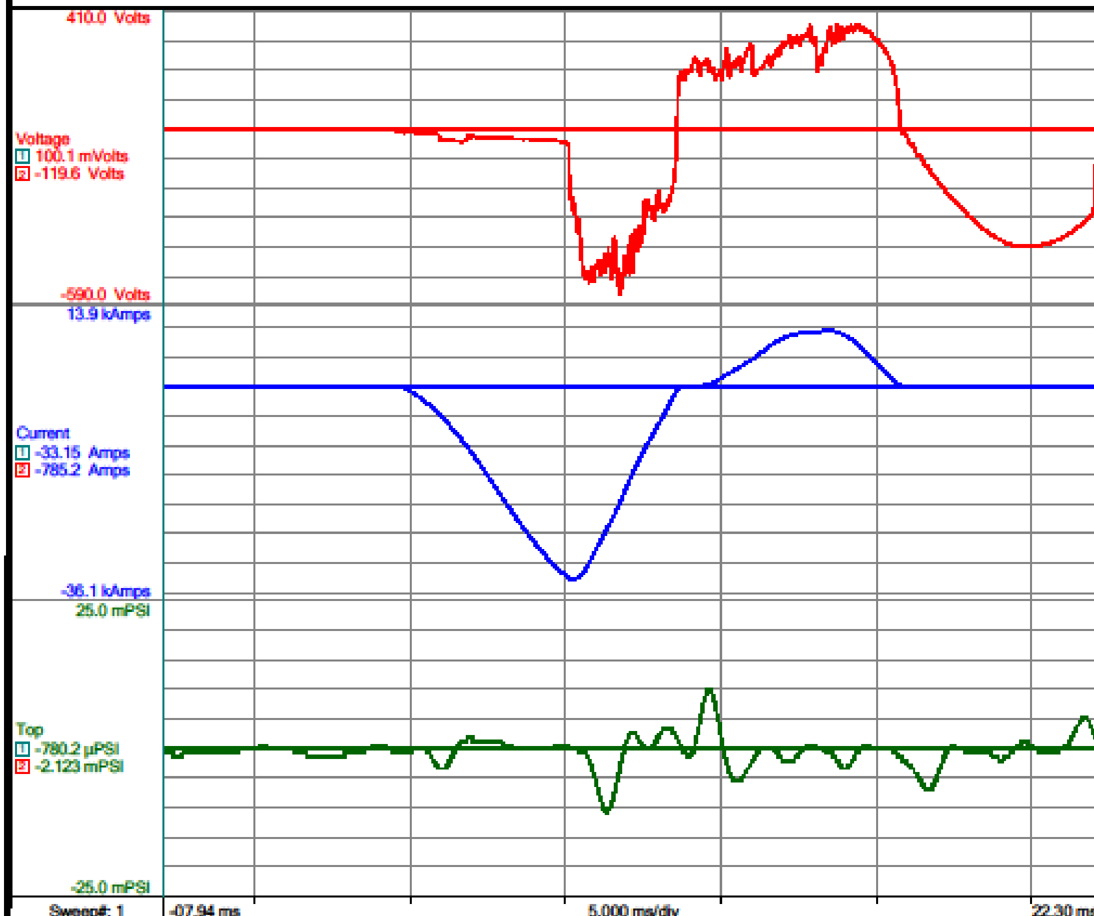
Oscillogram No.: HPL3-34316 OCV = 285 V
Date of Test: 9/28/2020 Time of Test: 10:23:07 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474 Calibration Date: 07/13/20
OCV = 278 V Rms Sym Current = 18.29 kA
Power Factor = 29%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 2




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 191 Deg |
| Closing time (V0)+ | 8.862 m Sec |
| Peak Current (Ip) | -32.83 k Amperes |
| Time to Ip | 5.573 m Sec. |
| I²t | 3.822 M Amp^2sec |
| I Duration | 16.19 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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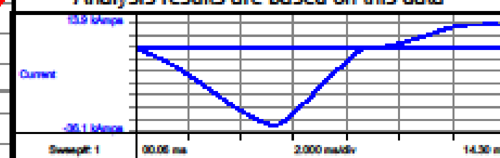
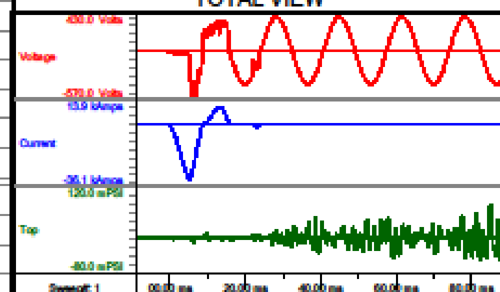
Analysis results are based on this data




TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 1000X Bugs Probe, C/N 131-006, 1% PLOT FILE HPL3 CR_1_B
VOLTAGE 1000X Bugs Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 040-443
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34316

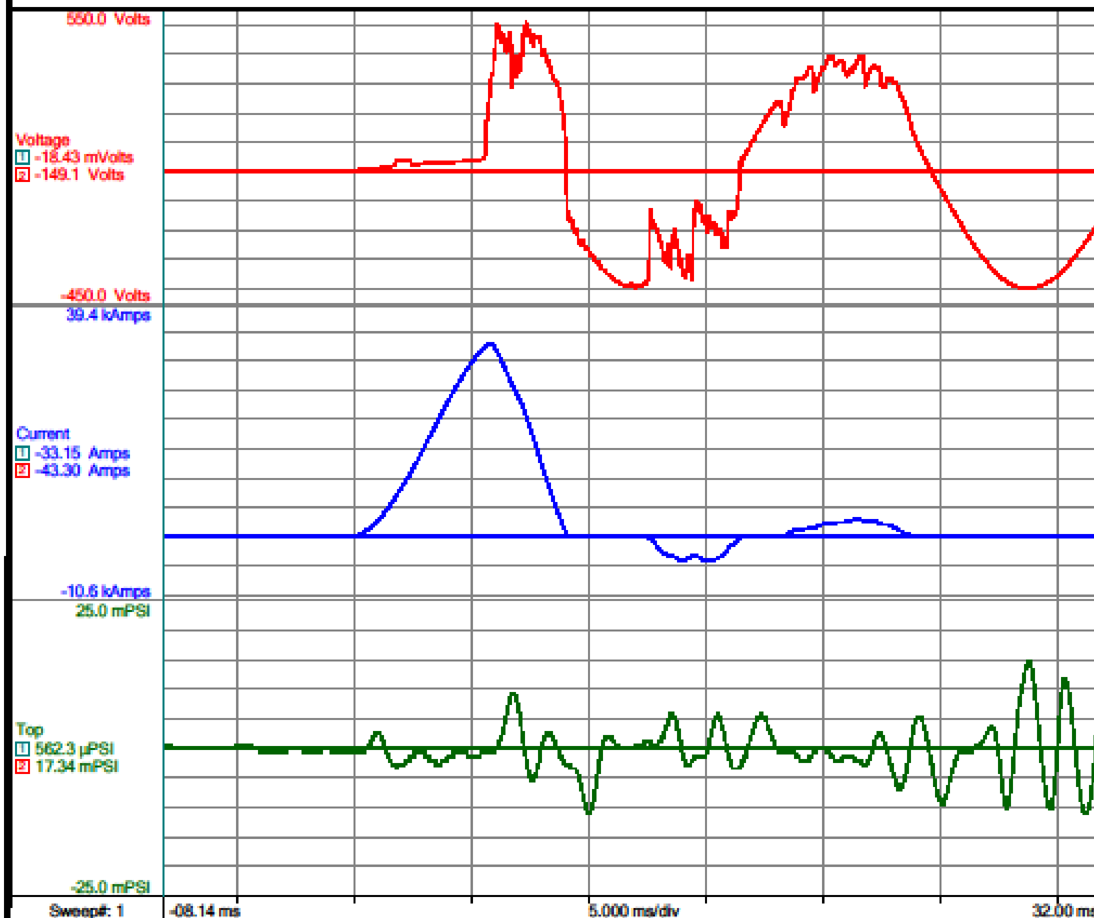
Oscillogram No.: HPL3-34317  OCV = 285 V
Date of Test: 9/28/2020  Time of Test: 10:32:50 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474  Calibration Date: 07/13/20
OCV = 278 V  Rms Sym Current = 18.29 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332  TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 3




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 4 Deg |
| Closing time (V0)+ | 194.3 µ Sec |
| Peak Current (Ip) | 32.91 k Amperes |
| Time to Ip | 5.898 m Sec. |
| I²t | 3.531 M Amp^2sec |
| I Duration | 24.14 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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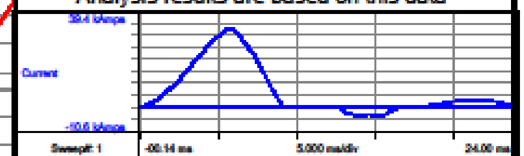
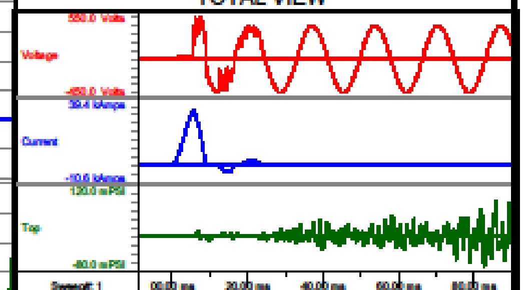
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 303-173
VOLTAGE 100X Scope Probe, C/N 131-808, 1%  PLOT FILE HPL3 CR_1_M
VOLTAGE 100X Scope Probe, C/N 131-804, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34317

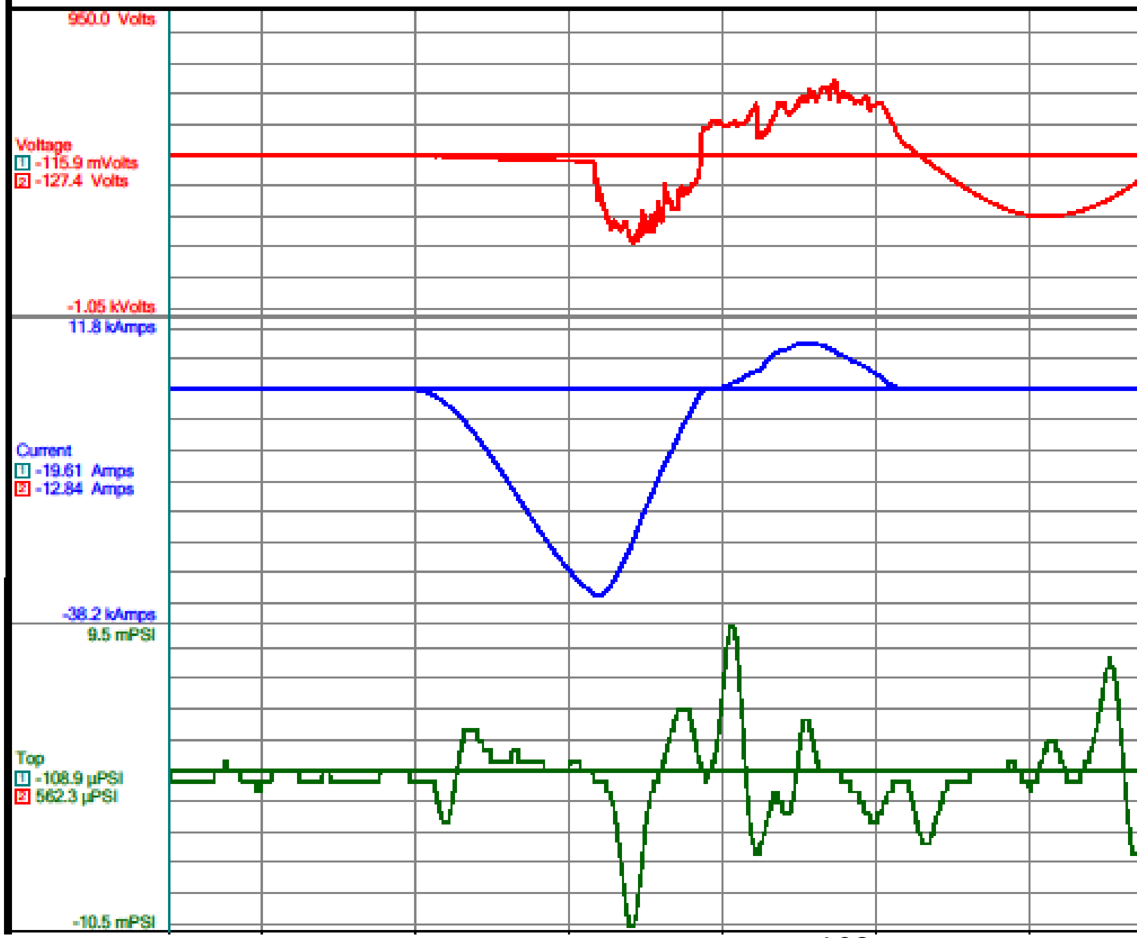
Oscillogram No.: HPL3-34318 OCV = 285 V
Date of Test: 9/28/2020 Time of Test: 10:47:25 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474 Calibration Date: 07/13/20
OCV = 278 V Rms Sym Current = 18.29 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 4




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 186 Deg |
| Closing time (V0)+ | 8.590 m Sec |
| Peak Current (Ip) | -33.94 k Amperes |
| Time to Ip | 6.001 m Sec. |
| I²t | 3.824 M Amp^2sec |
| I Duration | 15.88 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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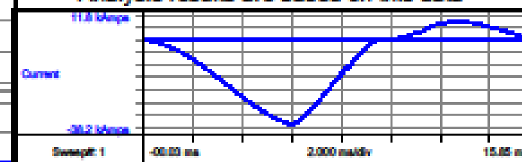
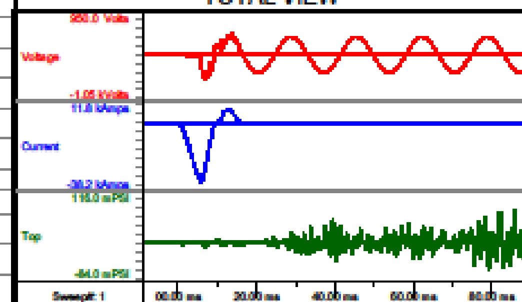
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System: HBM GEN7T C/N 083-173
VOLTAGE IDEX Scope Probe, C/N 131-088, 1% PLOT FILE HPL3 CR_1_H
VOLTAGE IDEX Scope Probe, C/N 131-604, 1%
CURRENT ROGOWSKI COIL, C/N 048-443
NOTE: Channel offset removed for analysis.
but not for display.

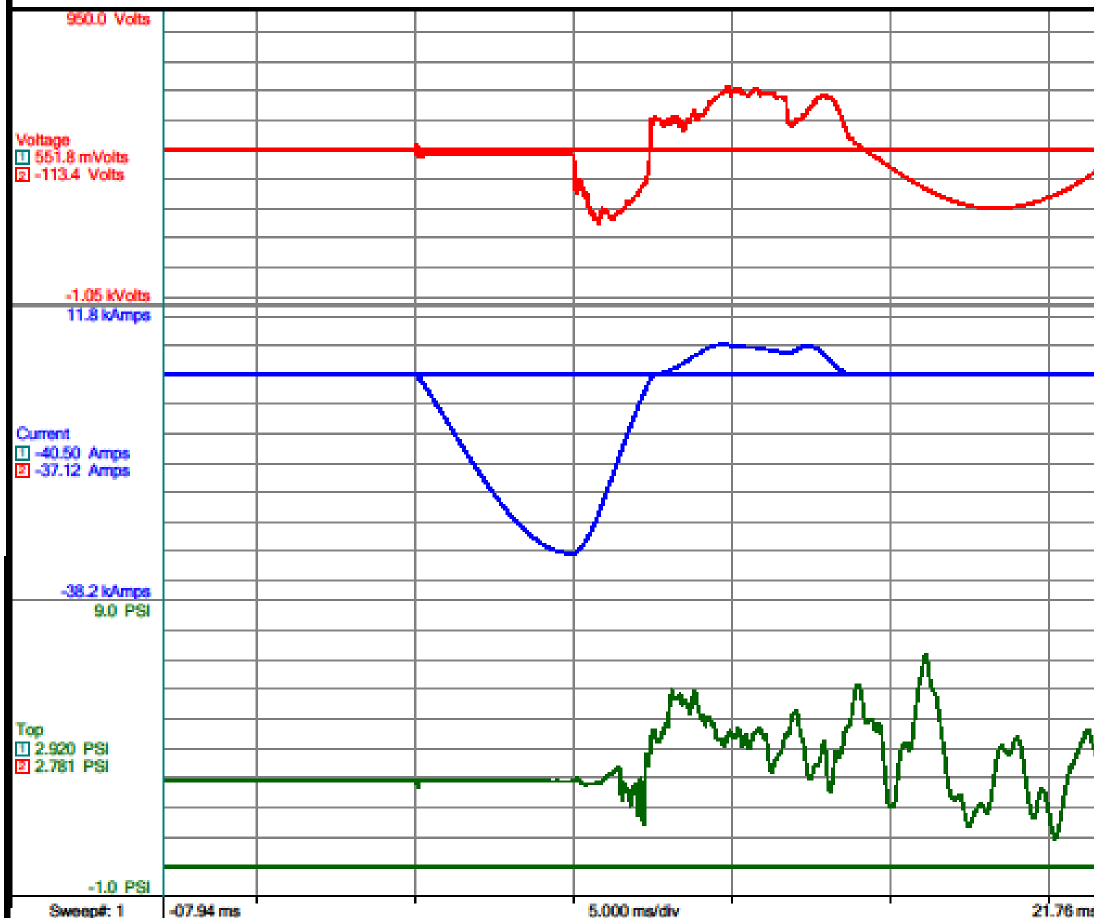
Oscillogram No.: HPL3-34330 OCV = 285 V
Date of Test: 9/28/2020 Time of Test: 12:40:44 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474 Calibration Date: 07/13/20
OCV = 278 V Rms Sym Current = 18.29 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 5




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 235 Deg |
| Closing time (V0)+ | 10.88 m Sec |
| Peak Current (Ip) | -30.34 k Amperes |
| Time to Ip | 4.848 m Sec. |
| I²t | 3.195 M Amp^2sec |
| I Duration | 13.71 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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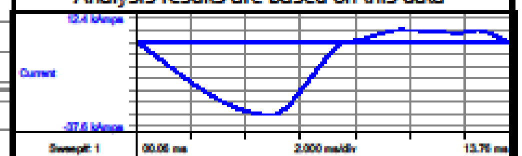
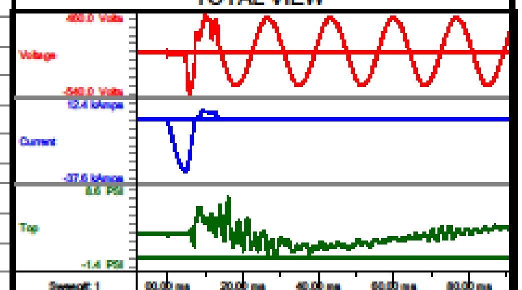
Analysis results are based on this data




TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

PLOT FILE HPL3 [illegible]

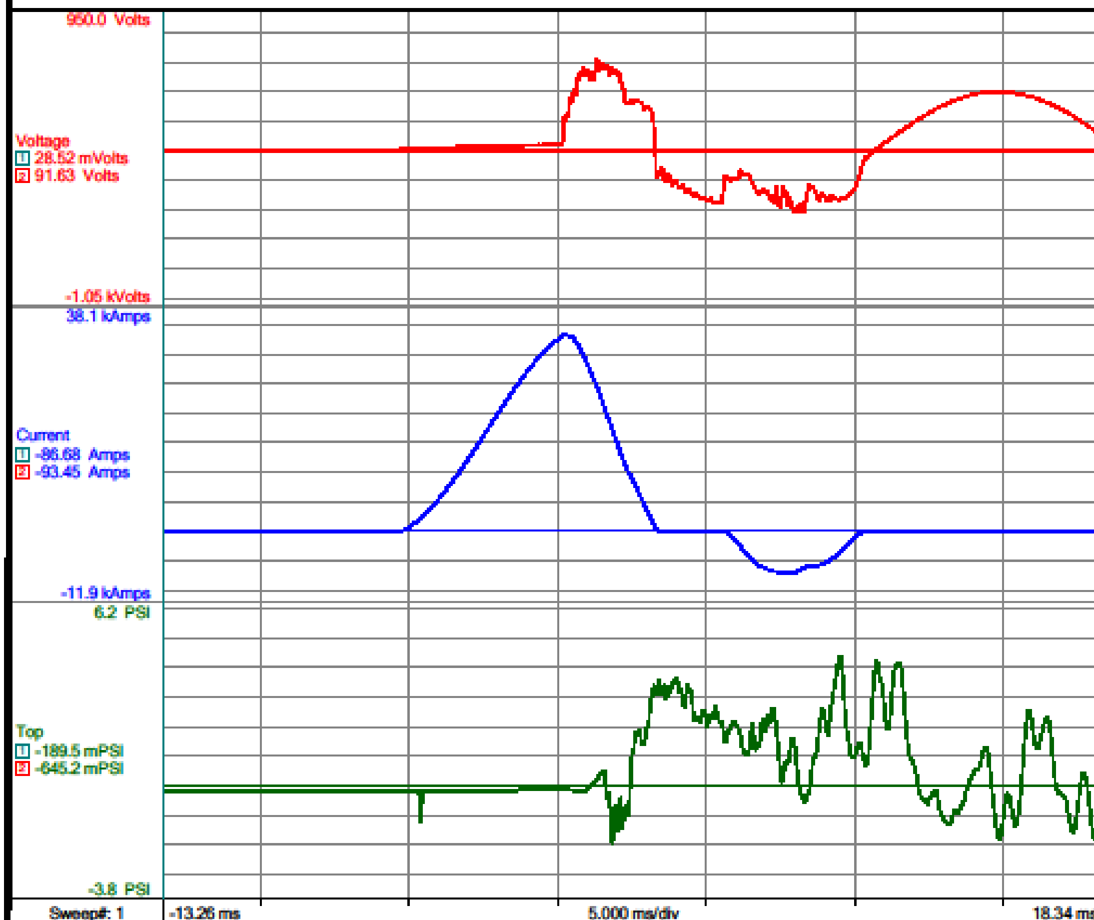
OSC. NO.: HPL3-34330

| |
|---|
| Oscillogram No.: HPL3-34333 OCV = 285 V<br>Date of Test: 9/28/2020 Time of Test: 12:57:41 PM |
| AVAILABLE CIRCUIT CHARACTERISTICS:<br>Osc. No: 30474 Calibration Date: 07/13/20<br>OCV = 278 V Rms Sym Current = 18.29 kA<br>Power Factor = 29% |

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 6




**ANALYSIS RESULTS TABLE**

| | |
|---|---|
| Closing Angle | 16 Deg |
| Closing time (V0)+ | 759.7 μ Sec |
| Peak Current (Ip) | 33.45 k Amperes |
| Time to Ip | 5.549 m Sec. |
| I²t | 3.580 M Amp^2sec |
| I Duration | 15.60 m Sec. |

**Performance Observations**

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

**Comment Section**

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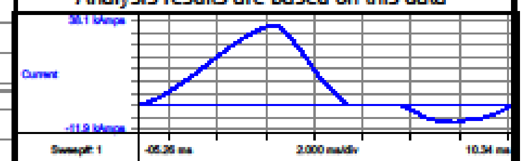
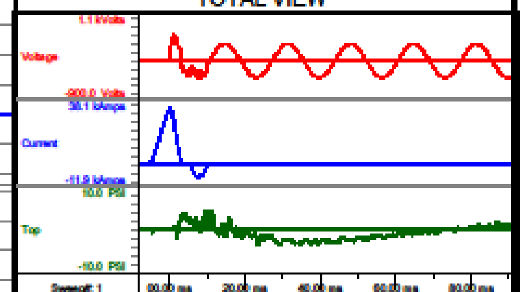
Analysis results are based on this data




**TOTAL VIEW**




**INSTRUMENTATION DATA**

Data Recording System [illegible]
VOLTAGE 100X Surge Probe, C/N [illegible], 1% PLOT FILE HPL3 [illegible]
VOLTAGE 100X Surge Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-34333**

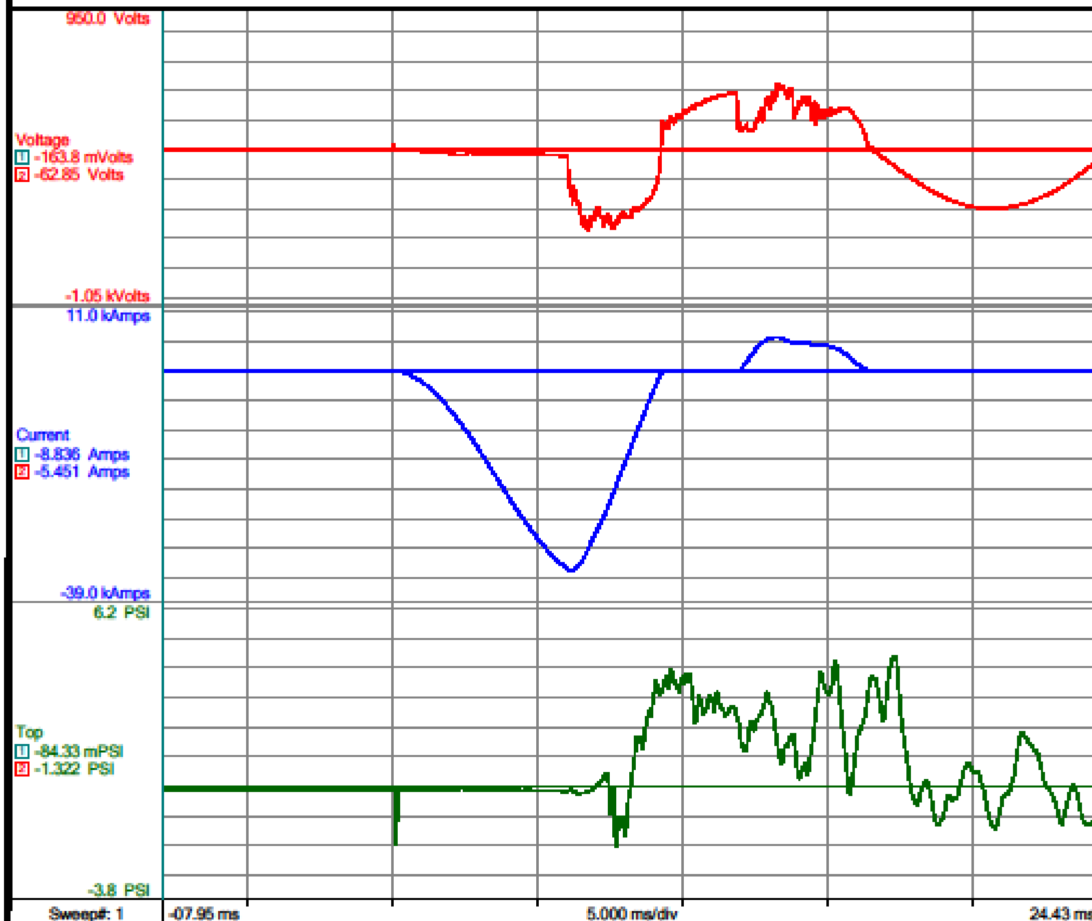
Oscillogram No.: HPL3-34334 OCV = 285 V
Date of Test: 9/28/2020 Time of Test: 1:08:46 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474 Calibration Date: 07/13/20
OCV = 278 V Rms Sym Current = 18.29 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 7




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 184 Deg |
| Closing time (V0)+ | 8.518 m Sec |
| Peak Current (Ip) | -33.88 k Amperes |
| Time to Ip | 6.089 m Sec. |
| I²t | 3.724 M Amp^2sec |
| I Duration | 18.38 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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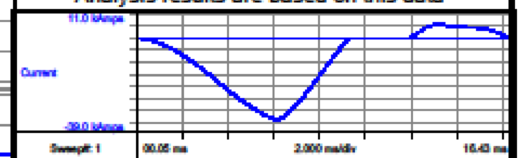
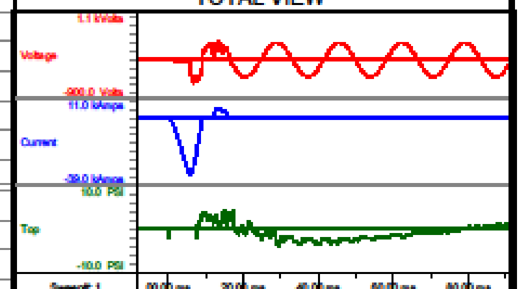
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 080-173
VOLTAGE 100X Scope Probe, C/N 131-805, 1%
VOLTAGE 100X Scope Probe, C/N 131-804, 1%
CURRENT ROGOWSKI COIL, C/N 040-445
NOTE: Channel offset removed for analysis
but not for display.
PLOT FILE HPL3 CR_1_3

OSC. NO.: HPL3-34334

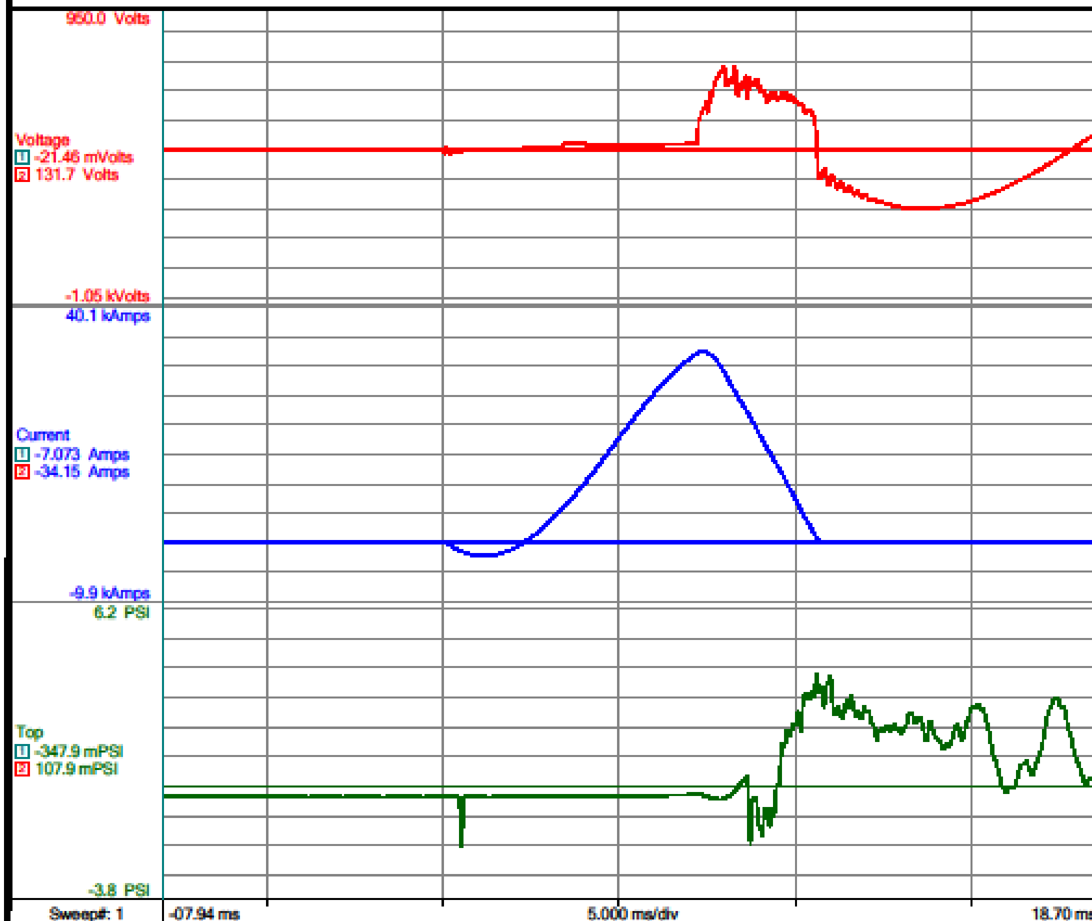
Oscillogram No.: HPL3-34335 OCV = 285 V
Date of Test: 9/28/2020 Time of Test: 1:20:18 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474 Calibration Date: 07/13/20
OCV = 278 V Rms Sym Current = 18.29 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 8




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 337 Deg |
| Closing time (V0)+ | 15.59 m Sec |
| Peak Current (Ip) | 32.48 k Amperes |
| Time to Ip | 7.299 m Sec. |
| I²t | 3.270 M Amp^2sec |
| I Duration | 10.84 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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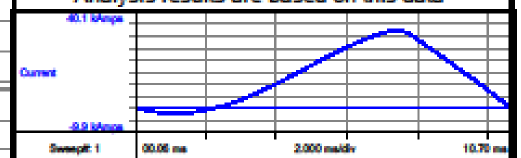
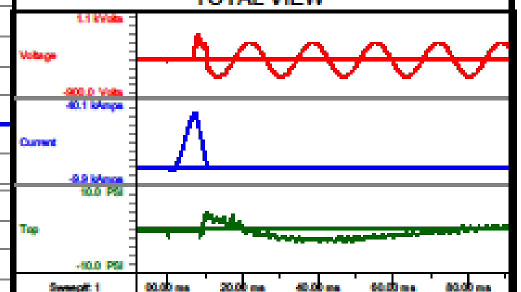
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE 1000X Scope Probe, C/N [illegible], 1% PLOT FILE HPL3 [illegible]
VOLTAGE 1000X Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34335

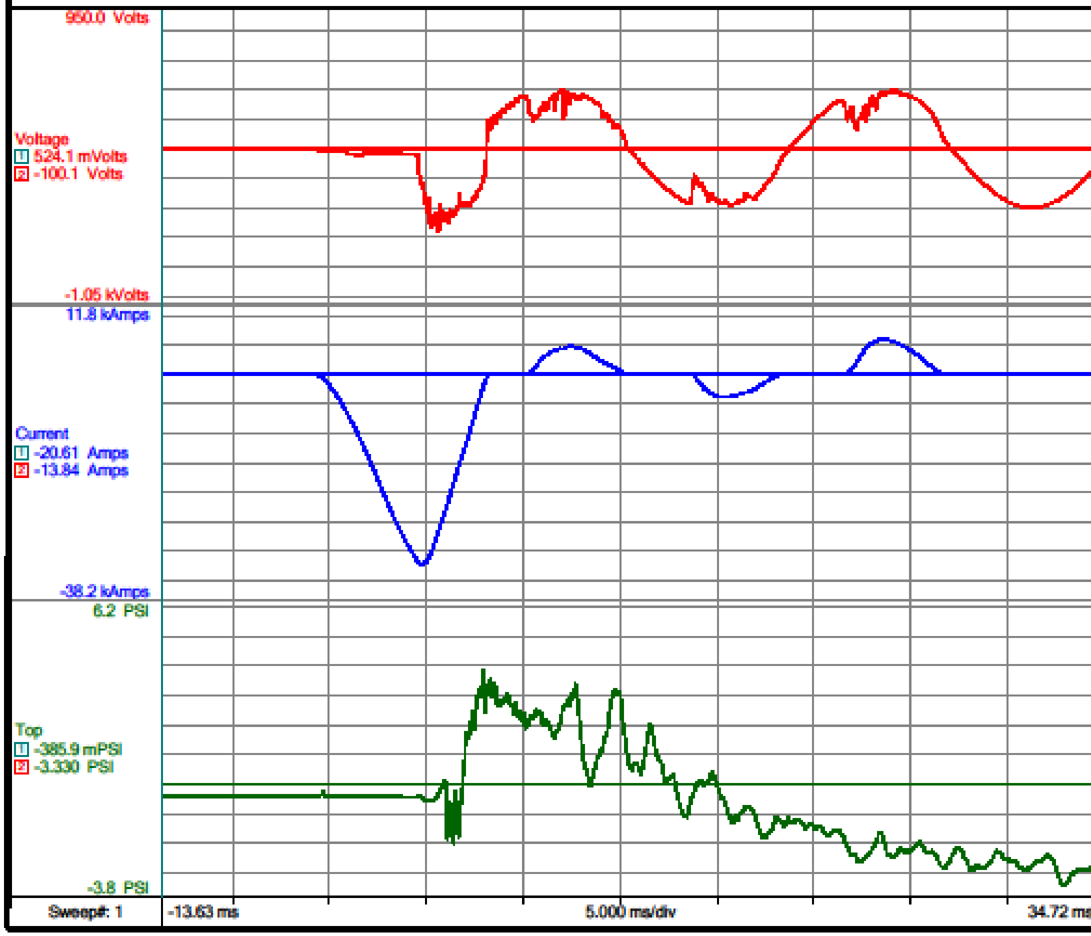
Oscillogram No.: HPL3-34336  OCV = 285 V
Date of Test: 9/28/2020  Time of Test: 1:31:14 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474  Calibration Date: 07/13/20
OCV = 278 V   Rms Sym Current = 18.29 kA
Power Factor = 29%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332  TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 9




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 193 Deg |
| Closing time (V0)+ | 8.931 m Sec |
| Peak Current (Ip) | -32.28 k Amperes |
| Time to Ip | 5.390 m Sec. |
| I²t | 3.400 M Amp^2sec |
| I Duration | 32.38 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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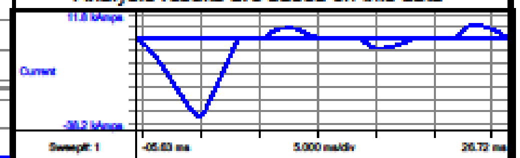
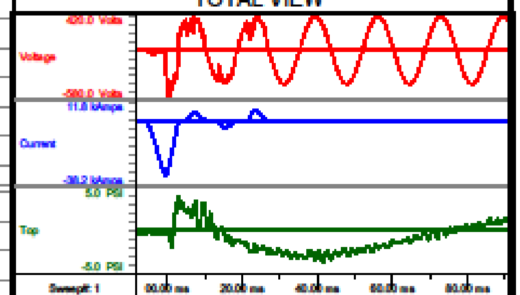
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 283-173
VOLTAGE 100X Scope Probe, C/N 131-008, 1%   PLOT FILE HPL3 CR_1_M
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 040-443
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-34336**

Oscillogram No.: HPL3-34337 OCV = 285 V
Date of Test: 9/28/2020 Time of Test: 1:46:03 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474 Calibration Date: 07/13/20
OCV = 278 V Rms Sym Current = 18.29 kA
Power Factor = 29%

Schneider Electric

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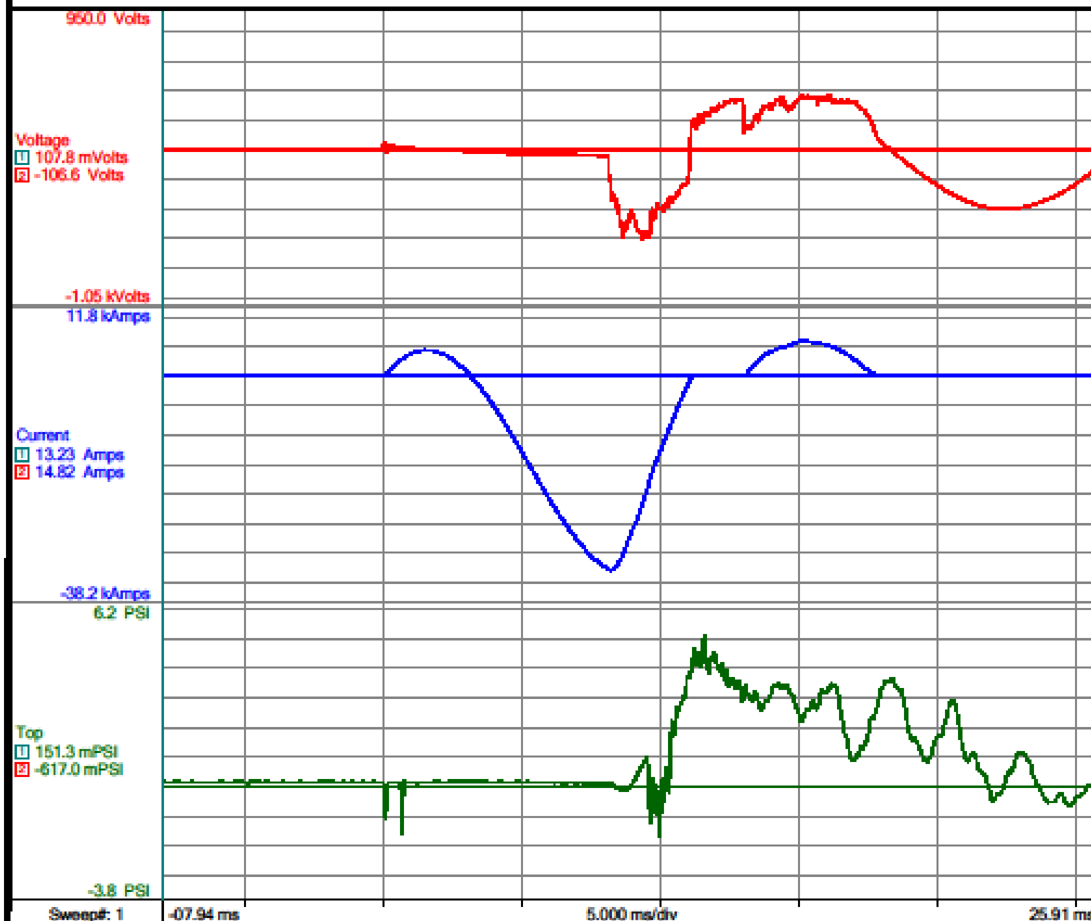
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 10




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 146 Deg |
| Closing time (V0)+ | 6.758 m Sec |
| Peak Current (Ip) | -32.93 k Amperes |
| Time to Ip | 6.183 m Sec. |
| I²t | 3.443 M Amp^2sec |
| I Duration | 17.85 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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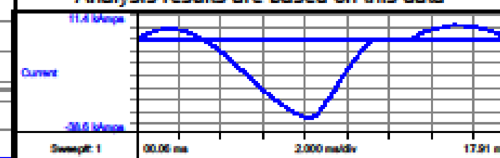
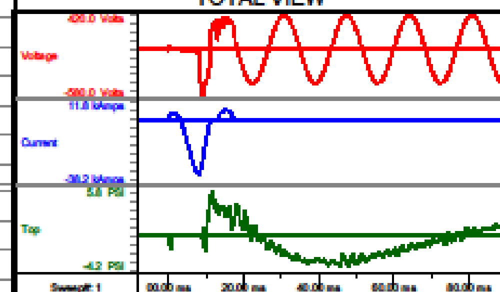
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34337

Oscillogram No.: HPL3-34338 OCV = 285 V
Date of Test: 9/28/2020 Time of Test: 1:54:45 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 30474 Calibration Date: 07/13/20
OCV = 278 V Rms Sym Current = 18.29 kA
Power Factor = 29%

Schneider Electric

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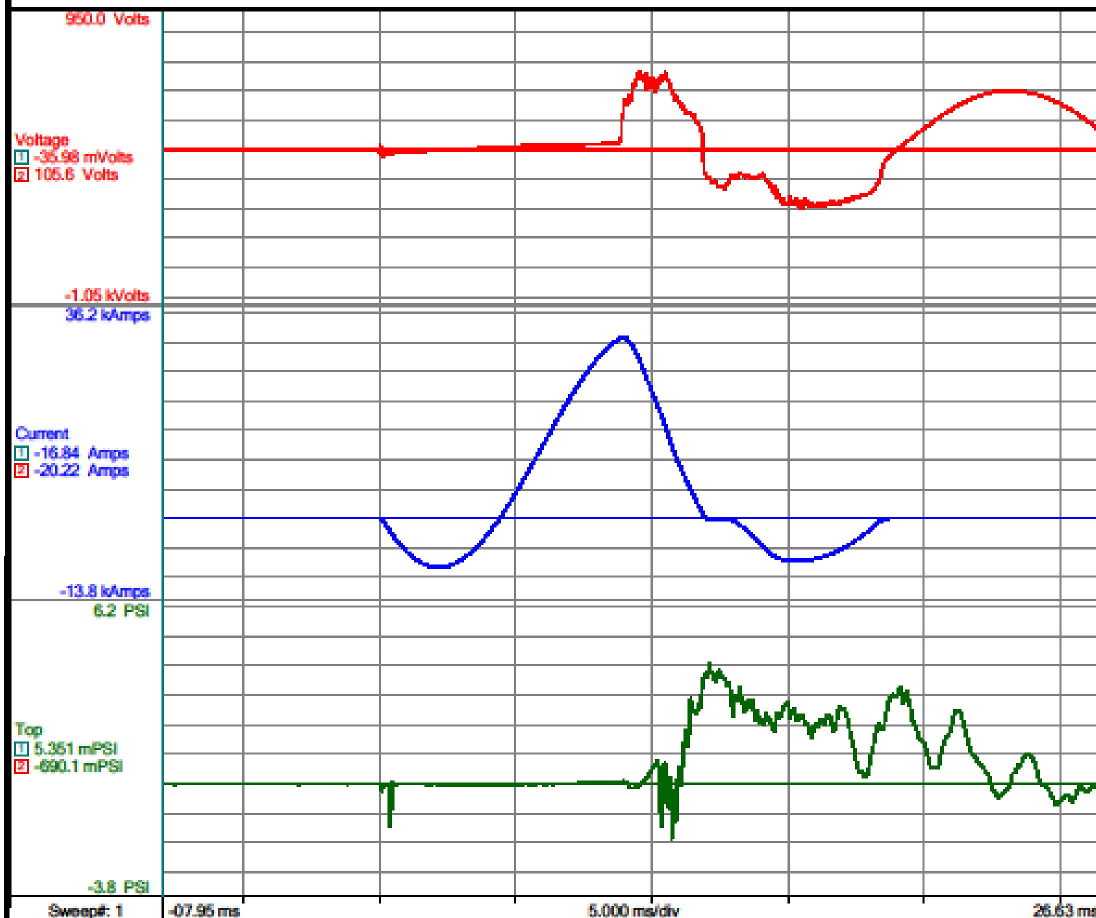
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 11




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 310 Deg |
| Closing time (V0)+ | 14.34 m Sec |
| Peak Current (Ip) | 30.88 k Amperes |
| Time to Ip | 8.905 m Sec. |
| I²t | 3.123 M Amp^2sec |
| I Duration | 18.58 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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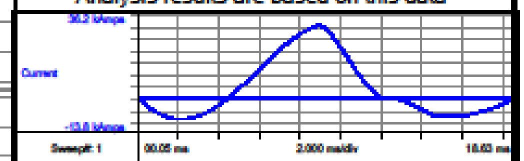
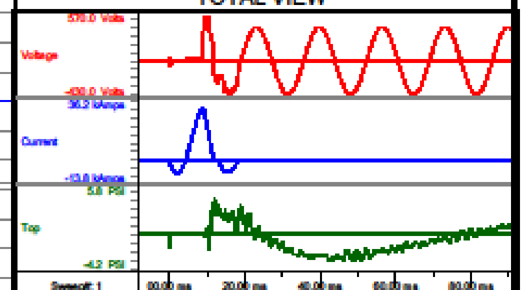
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173
VOLTAGE 1000X Scope Probe, C/N 131-005, 1% PLOT FILE HPL3 CR_1_III
VOLTAGE 1000X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34338

Oscillogram No.: HPL3-34342 OCV = 354 V
Date of Test: 9/28/2020 Time of Test: 3:02:00 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

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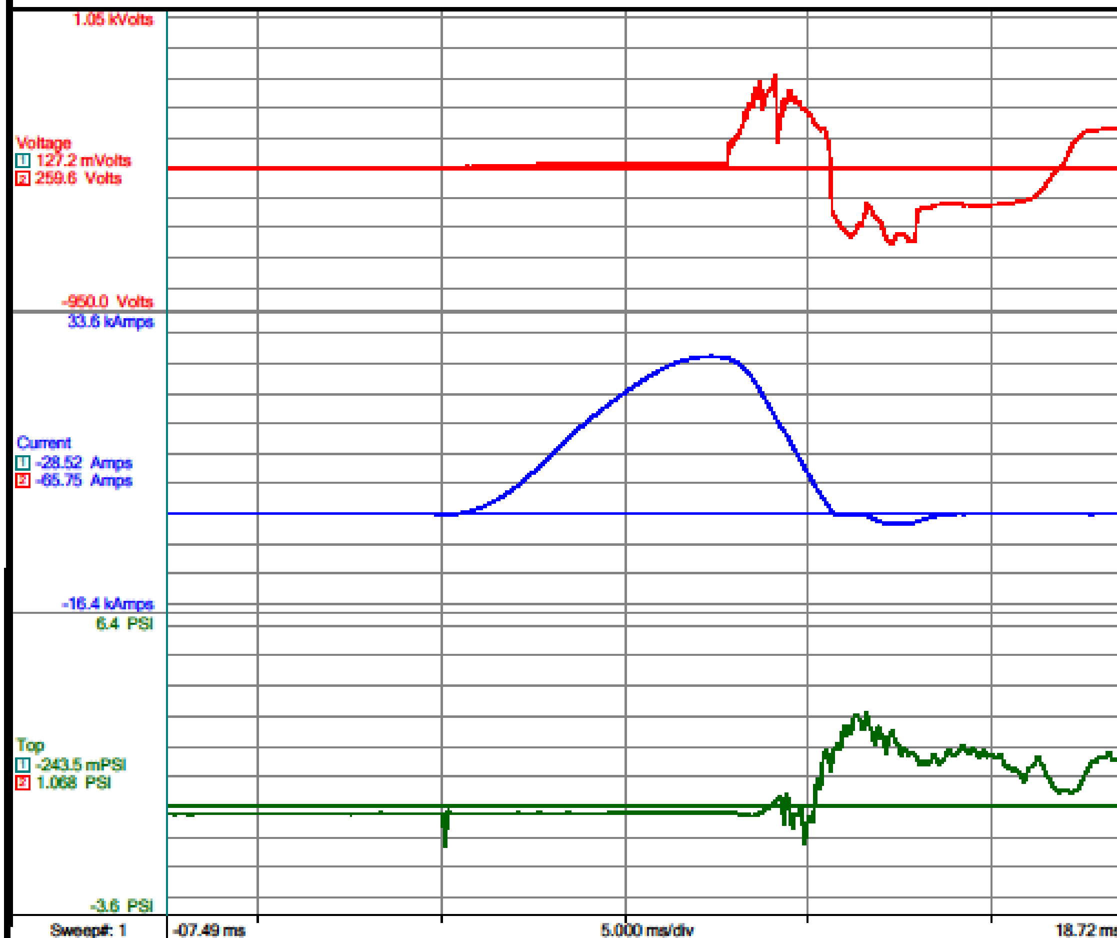
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 12




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 7 Deg |
| Closing time (V0)+ | 341.5 µ Sec |
| Peak Current (Ip) | 26.21 k Amperes |
| Time to Ip | 6.797 m Sec. |
| I²t | 3.006 M Amp^2sec |
| I Duration | 10.20 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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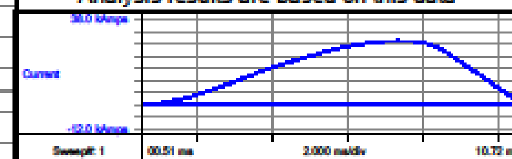
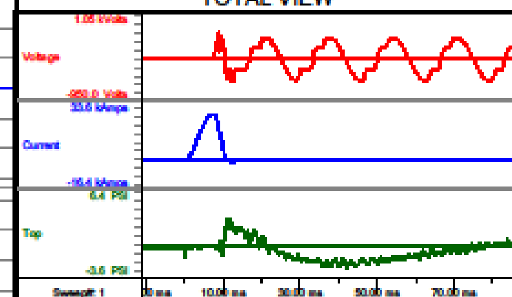
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System: HBM GEN3T C/N [illegible]
VOLTAGE: 100X Scope Probe, C/N 131-000, 1% PLOT FILE:HPL3 CR_1_8
VOLTAGE: 100X Scope Probe, C/N 131-004, 1%
CURRENT: ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34342

Oscillogram No.: HPL3-34343 OCV = 354 V
Date of Test: 9/28/2020 Time of Test: 3:08:27 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

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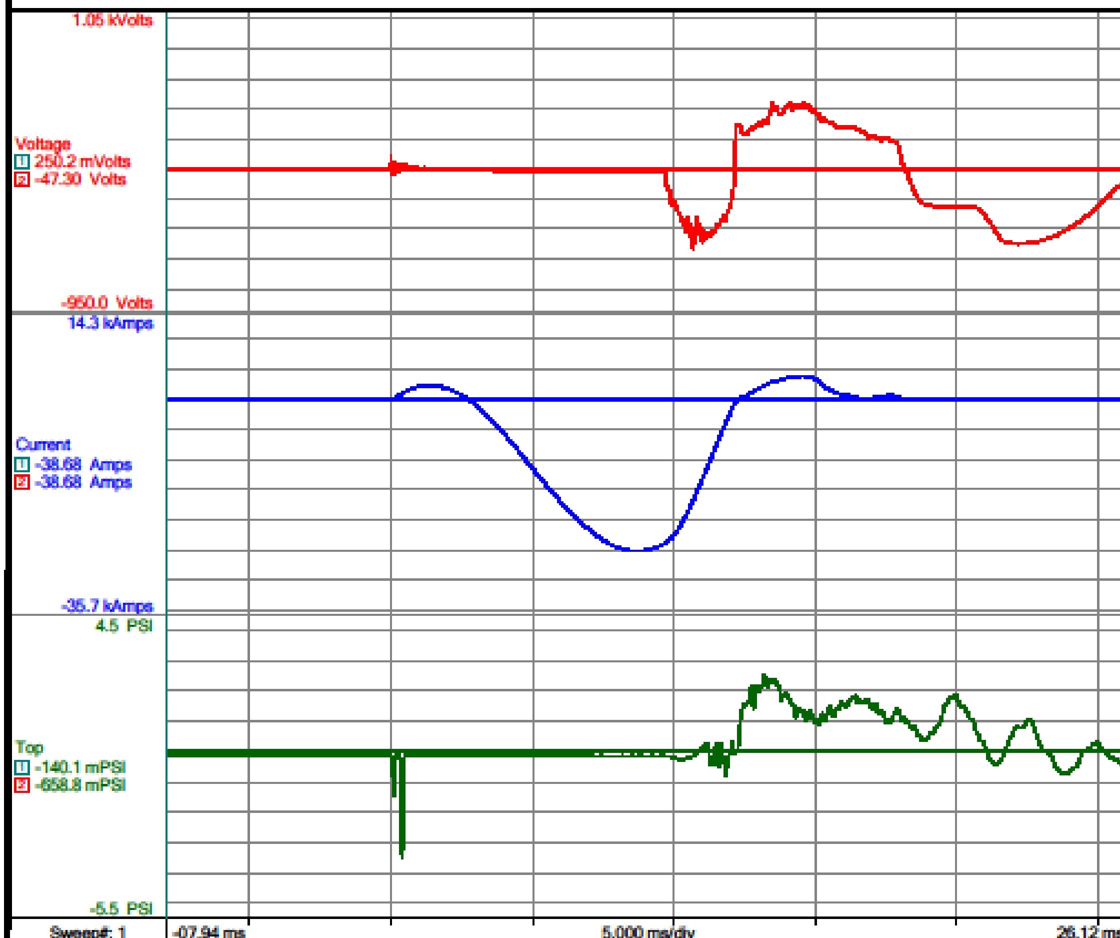
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 13




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 152 Deg |
| Closing time (V0)+ | 7.028 m Sec |
| Peak Current (Ip) | -25.23 k Amperes |
| Time to Ip | 8.828 m Sec. |
| I²t | 2.889 M Amp^2sec |
| I Duration | 18.05 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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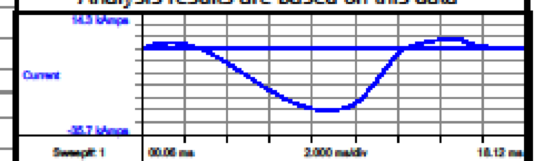
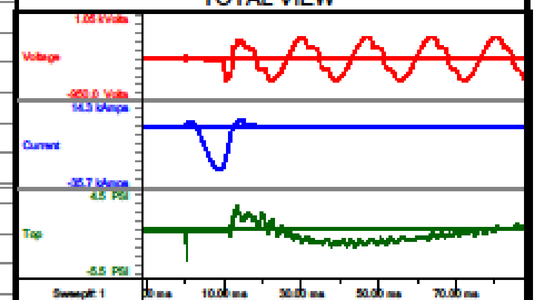
Analysis results are based on this data




TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 060-173
VOLTAGE 1000X Bogen Probe, C/N 131-000, 1% PLOT FILE HPL3 CR_1_M
VOLTAGE 1000X Bogen Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 040-448
NOTE: Channel offset removed for analysis.
but not for display.

OSC. NO.: HPL3-34343

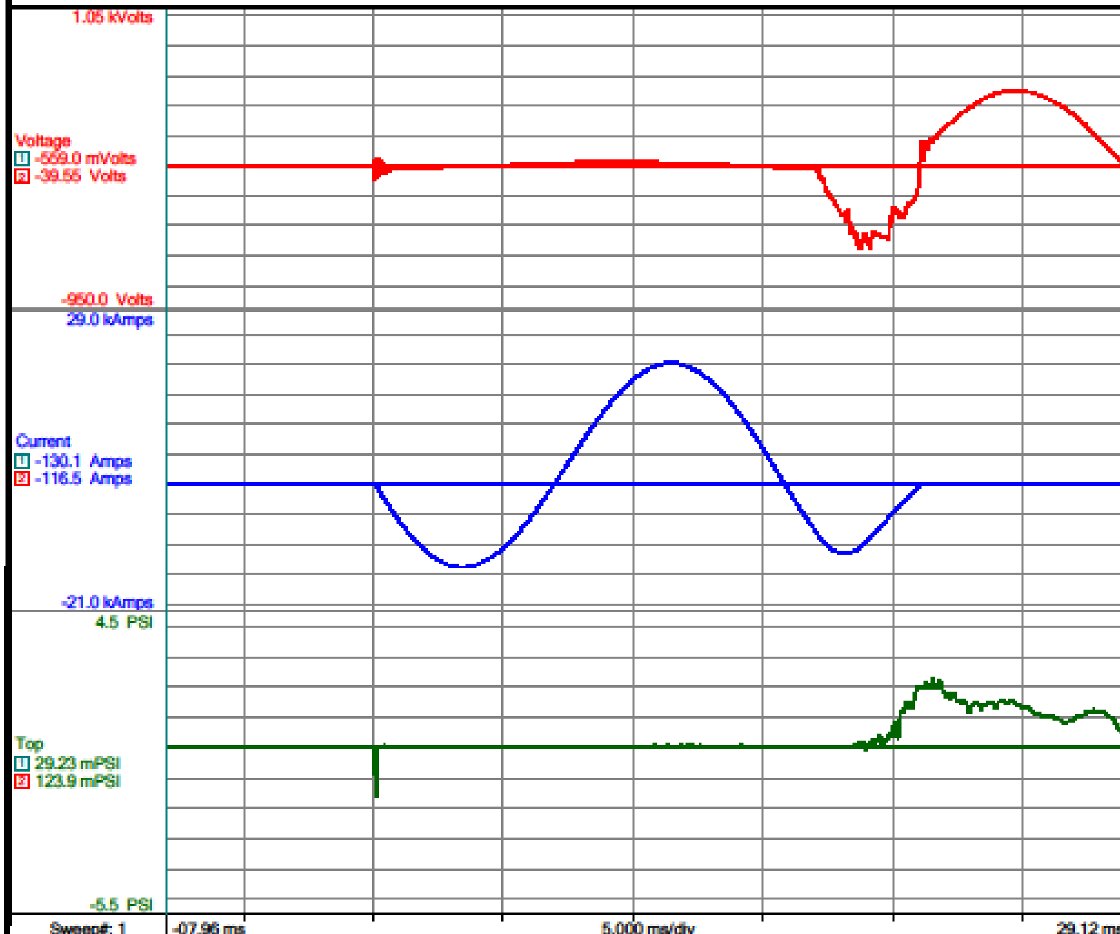
Oscillogram No.: HPL3-34344 OCV = 354 V
Date of Test: 9/28/2020 Time of Test: 3:17:03 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 14




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 278 Deg |
| Closing time (V0)+ | 12.79 m Sec |
| Peak Current (Ip) | 20.29 k Amperes |
| Time to Ip | 11.40 m Sec. |
| I²t | 2.760 M Amp^2sec |
| I Duration | 21.08 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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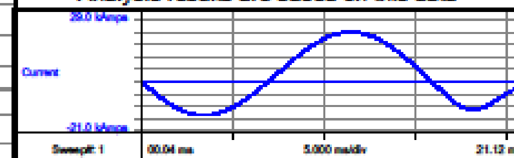
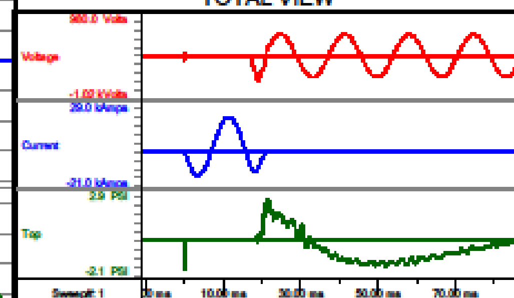
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 100X Bugs Probe, C/N 131-888, 1% PLOT FILE HPL3 CR_1_M
VOLTAGE 100X Bugs Probe, C/N 131-884, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34344

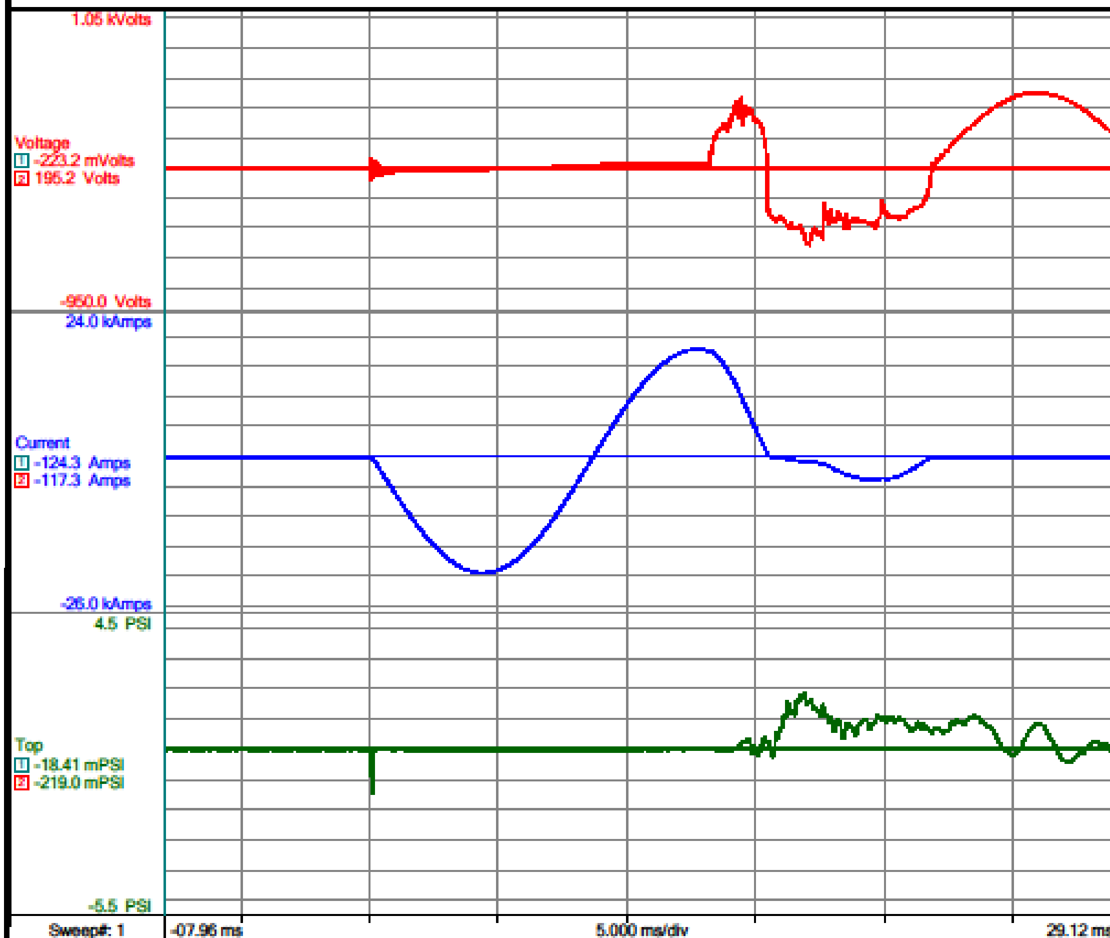
Oscillogram No.: HPL3-34345 OCV = 354 V
Date of Test: 9/28/2020 Time of Test: 3:22:34 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 15




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 250 Deg |
| Closing time (V0)+ | 11.56 m Sec |
| Peak Current (Ip) | -19.44 k Amperes |
| Time to Ip | 4.349 m Sec. |
| I²t | 2.748 M Amp^2sec |
| I Duration | 21.85 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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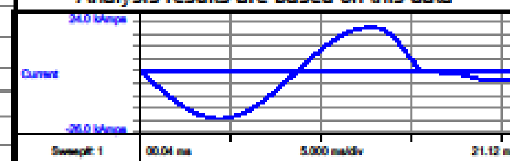
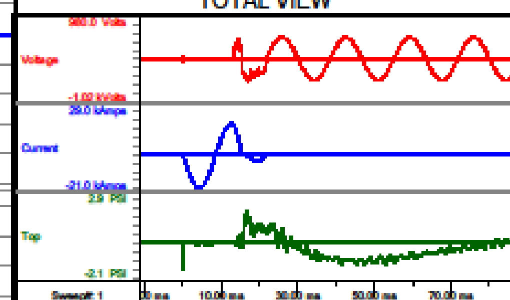
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

[illegible]
[illegible]
[illegible]
[illegible]
NOTE: Channel offset removed for analysis.
but not for display.

OSC. NO.: HPL3-34345

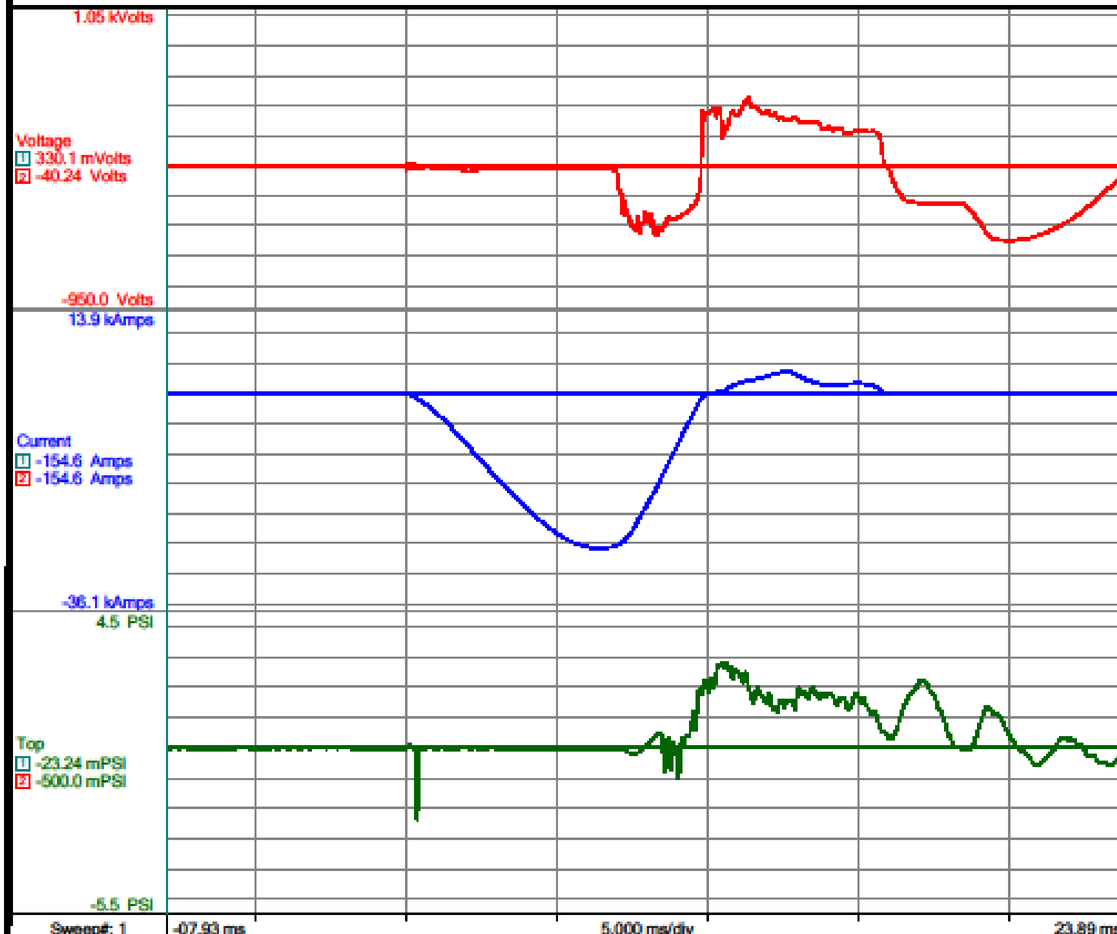
Oscillogram No.: HPL3-34346 OCV = 354 V
Date of Test: 9/28/2020 Time of Test: 3:27:30 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 16




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 201 Deg |
| Closing time (V0)+ | 9.300 m Sec |
| Peak Current (Ip) | -25.84 k Amperes |
| Time to Ip | 6.315 m Sec. |
| I²t | 2.880 M Amp^2sec |
| I Duration | 15.82 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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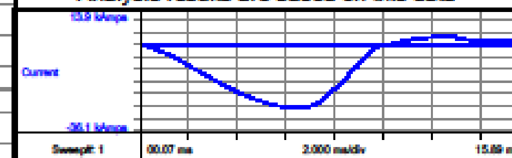
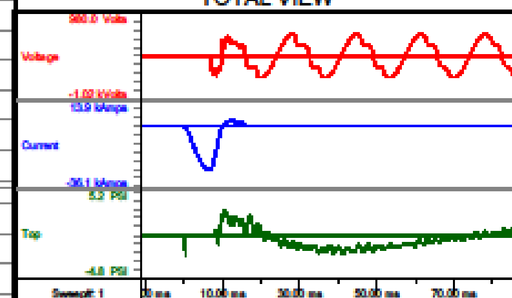
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN3T CAL 003-173
VOLTAGE 1000X Scope Probe, CAL 131-000, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 1000X Scope Probe, CAL 131-004, 1%
CURRENT ROGOWSKI COIL, CAL 045-445
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34346

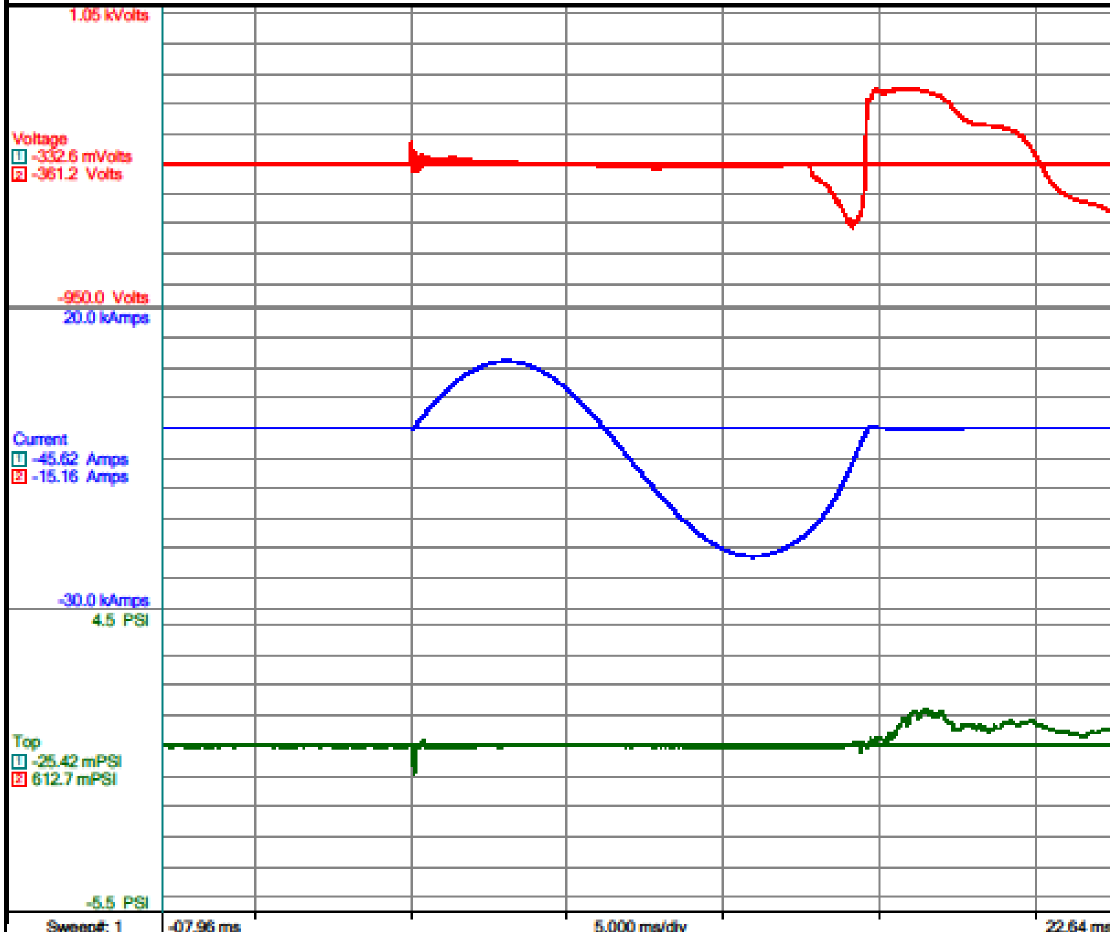
Oscillogram No.: HPL3-34349 OCV = 354 V
Date of Test: 9/29/2020 Time of Test: 7:19:50 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 17




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 107 Deg |
| Closing time (V0)+ | 4.948 m Sec |
| Peak Current (Ip) | -21.38 k Amperes |
| Time to Ip | 10.90 m Sec. |
| I²t | 2.390 M Amp^2sec |
| I Duration | 14.60 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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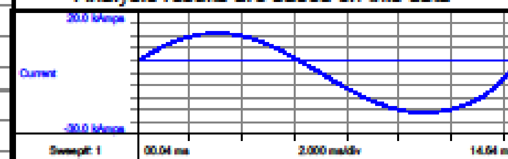
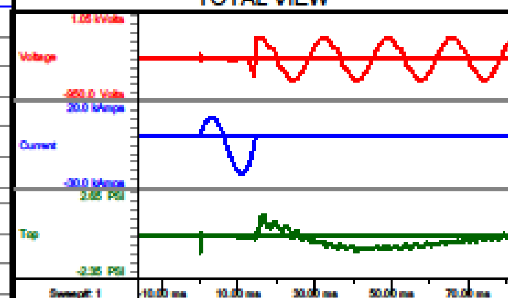
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System:HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-008, 1% PLOT FILE:HPL3 CR_1_W
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-448
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34349

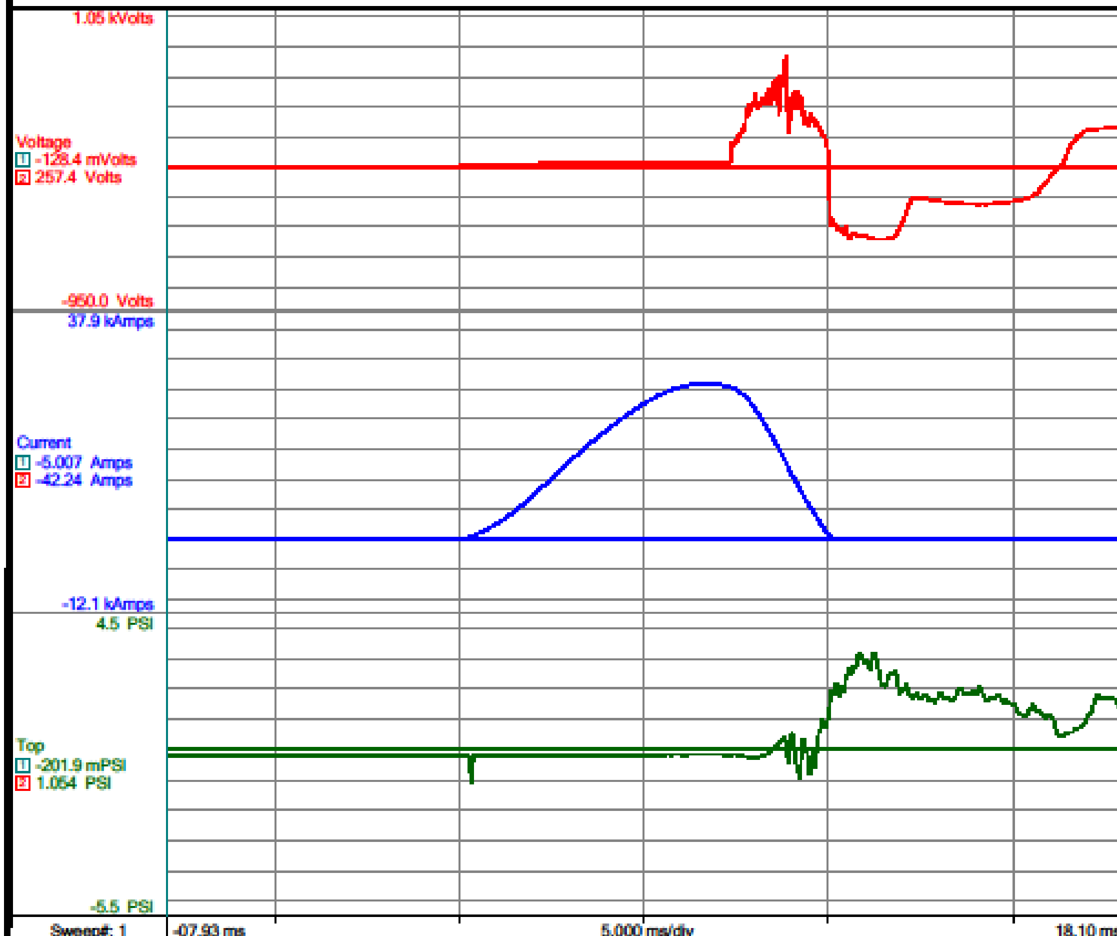
Oscillogram No.: HPL3-34350 OCV = 354 V
Date of Test: 9/29/2020 Time of Test: 7:26:22 AM

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 18




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 12 Deg |
| Closing time (V0)+ | 538.8 μ Sec |
| Peak Current (Ip) | 25.91 k Amperes |
| Time to Ip | 6.588 m Sec. |
| I²t | 2.969 M Amp^2sec |
| I Duration | 10.02 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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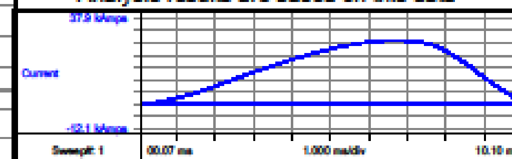
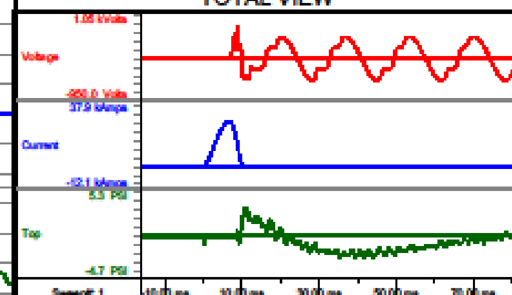
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34350

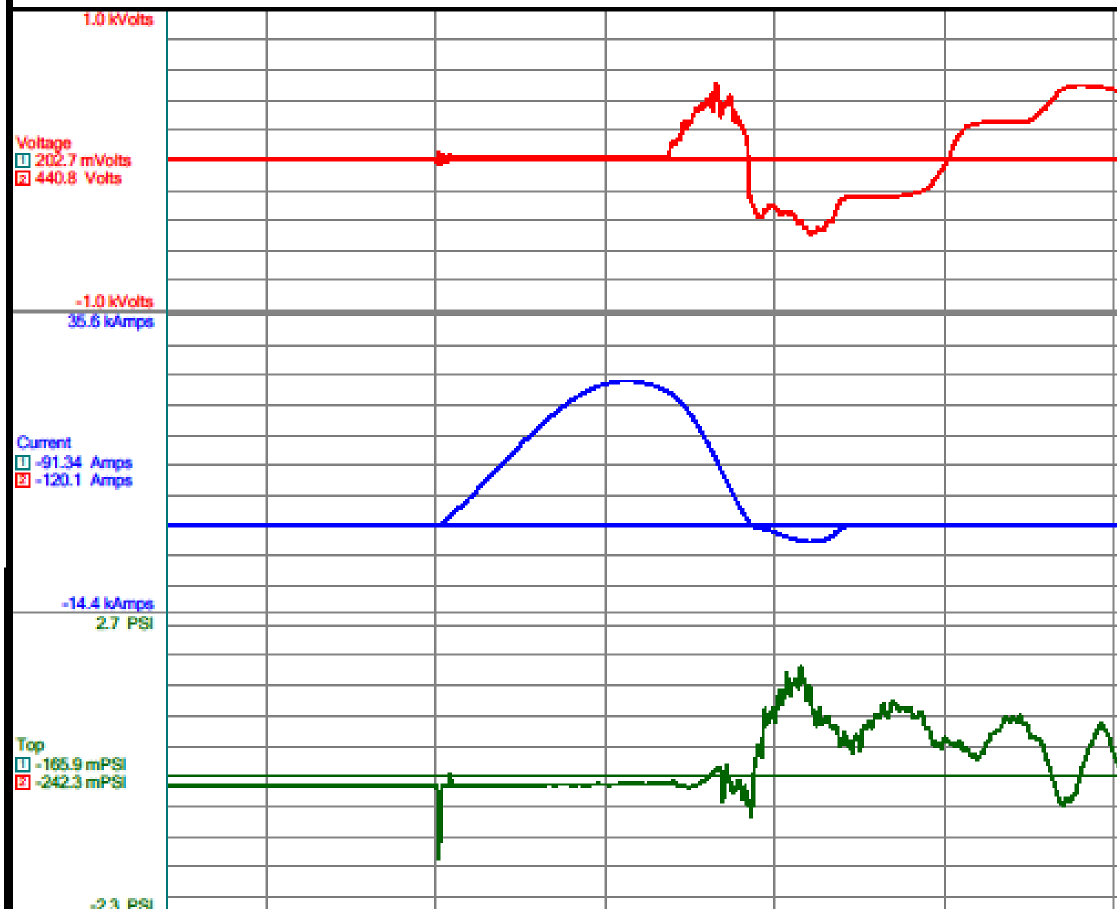
Oscillogram No.: HPL3-34351 OCV = 354 V
Date of Test: 9/29/2020 Time of Test: 7:30:13 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 19




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 37 Deg |
| Closing time (V0)+ | 1.702 m Sec |
| Peak Current (Ip) | 24.19 k Amperes |
| Time to Ip | 5.570 m Sec. |
| I²t | 2.652 M Amp^2sec |
| I Duration | 12.34 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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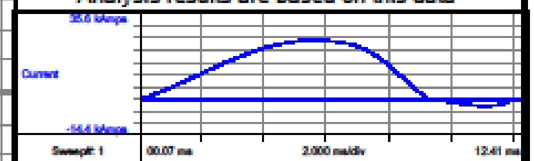
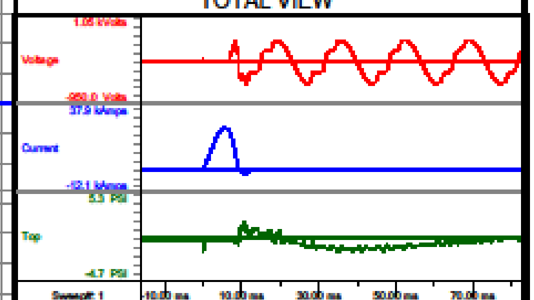
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

[illegible]

OSC. NO.: HPL3-34351

Oscillogram No.: HPL3-34352 OCV = 354 V
Date of Test: 9/29/2020 Time of Test: 7:35:00 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

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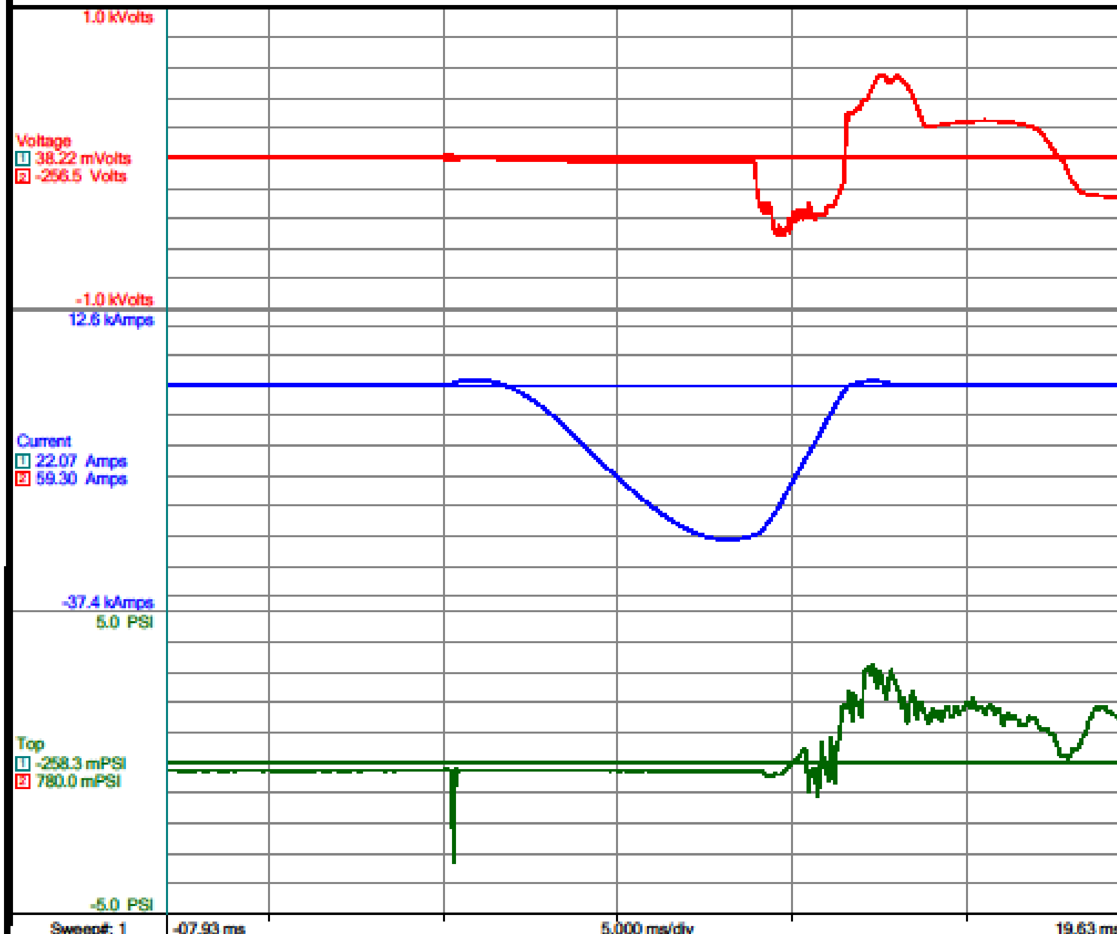
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 20




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 163 Deg |
| Closing time (V0)+ | 7.554 m Sec |
| Peak Current (Ip) | -25.67 k Amperes |
| Time to Ip | 8.088 m Sec. |
| I²t | 2.900 M Amp^2sec |
| I Duration | 11.56 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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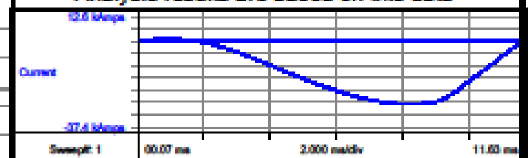
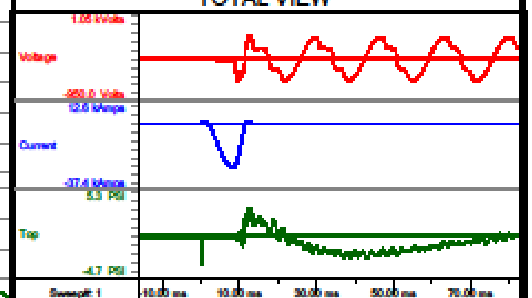
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1%
CURRENT [illegible] COIL, C/N [illegible]
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34352

Oscillogram No.: HPL3-34353 OCV = 354 V
Date of Test: 9/29/2020 Time of Test: 7:38:25 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

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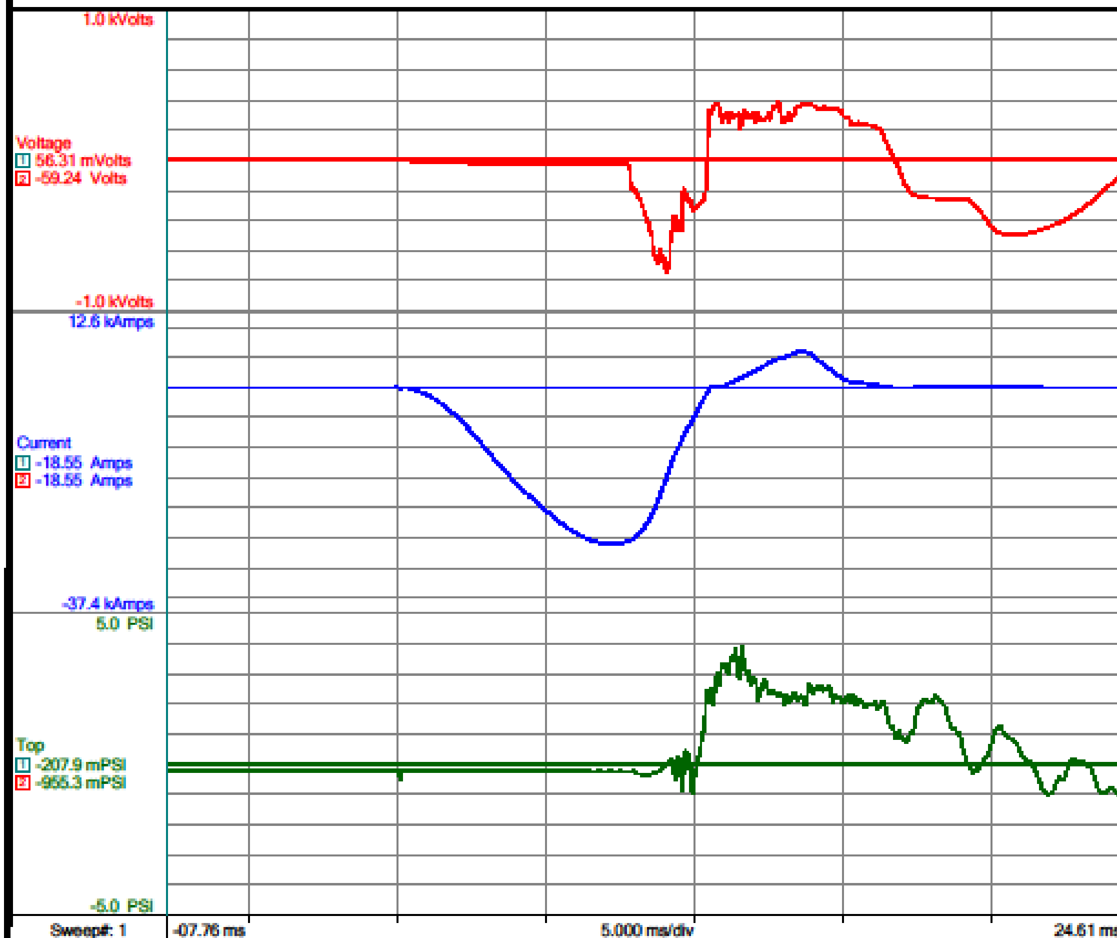
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 21




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 187 Deg |
| Closing time (V0)+ | 6.637 m Sec |
| Peak Current (Ip) | -26.06 k Amperes |
| Time to Ip | 6.952 m Sec. |
| I²t | 3.038 M Amp^2sec |
| I Duration | 16.37 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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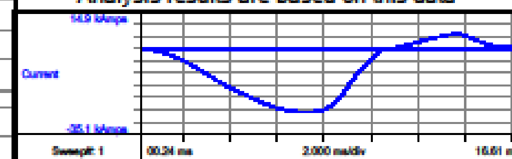
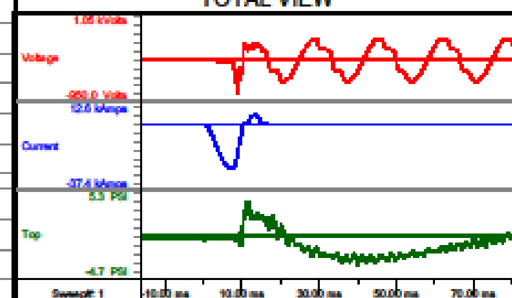
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN3T C/N [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
PLOT FILE:HPL3 [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34353

Oscillogram No.: HPL3-34354 OCV = 354 V
Date of Test: 9/29/2020 Time of Test: 7:42:33 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

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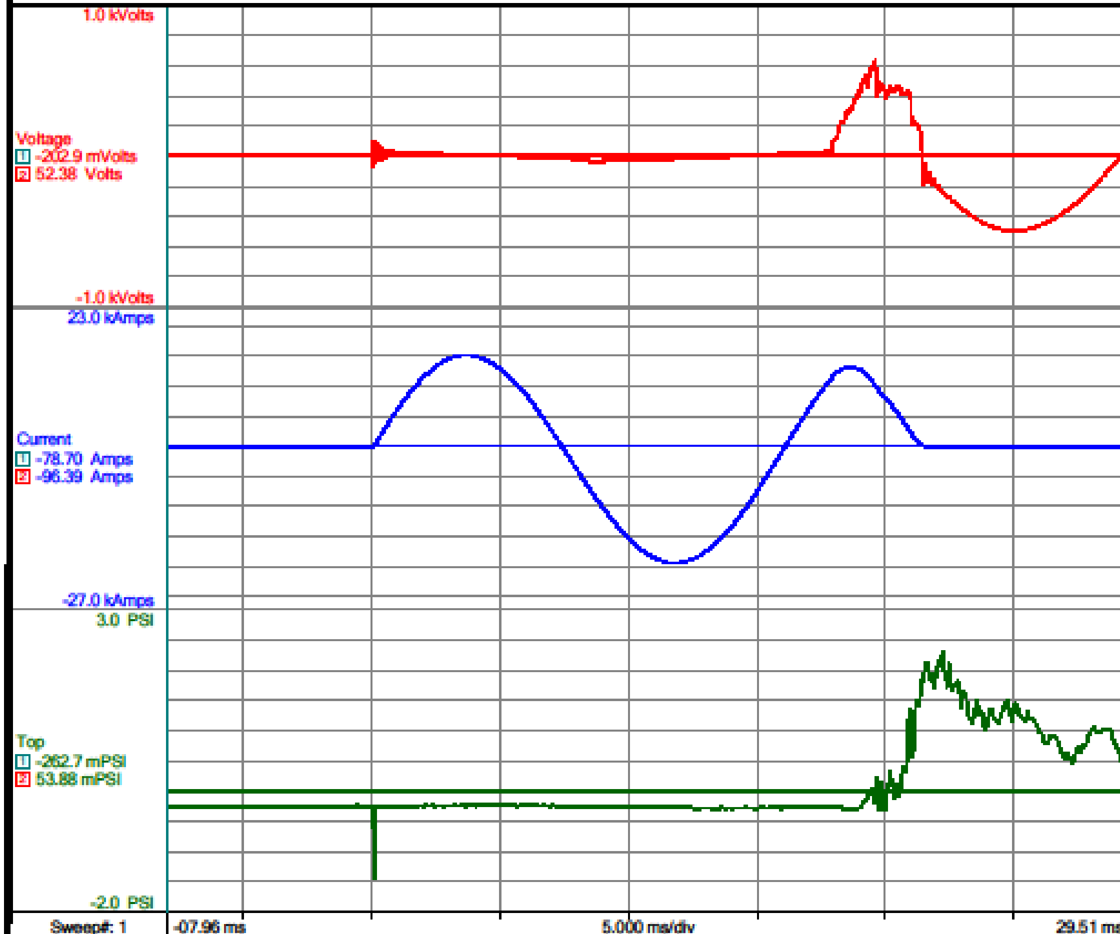
Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 22




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 90 Deg |
| Closing time (V0)+ | 4.147 m Sec |
| Peak Current (Ip) | -19.42 k Amperes |
| Time to Ip | 11.77 m Sec. |
| I²t | 2.890 M Amp^2sec |
| I Duration | 21.47 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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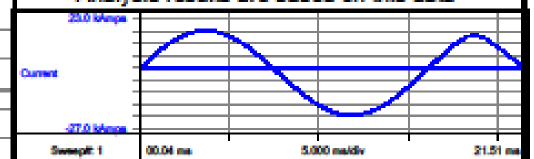
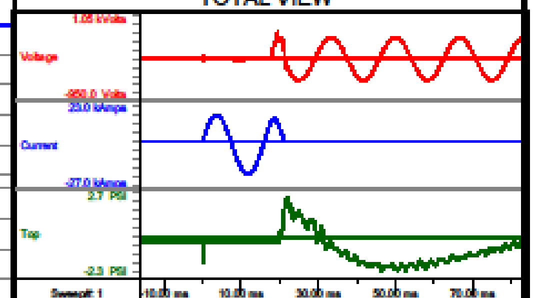
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE: [illegible] Probe, C/N [illegible] PLOT FILE [illegible]
VOLTAGE: [illegible] Probe, C/N [illegible]
CURRENT [illegible] COIL, C/N [illegible]
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34354

Oscillogram No.: HPL3-34357 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 8:25:31 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

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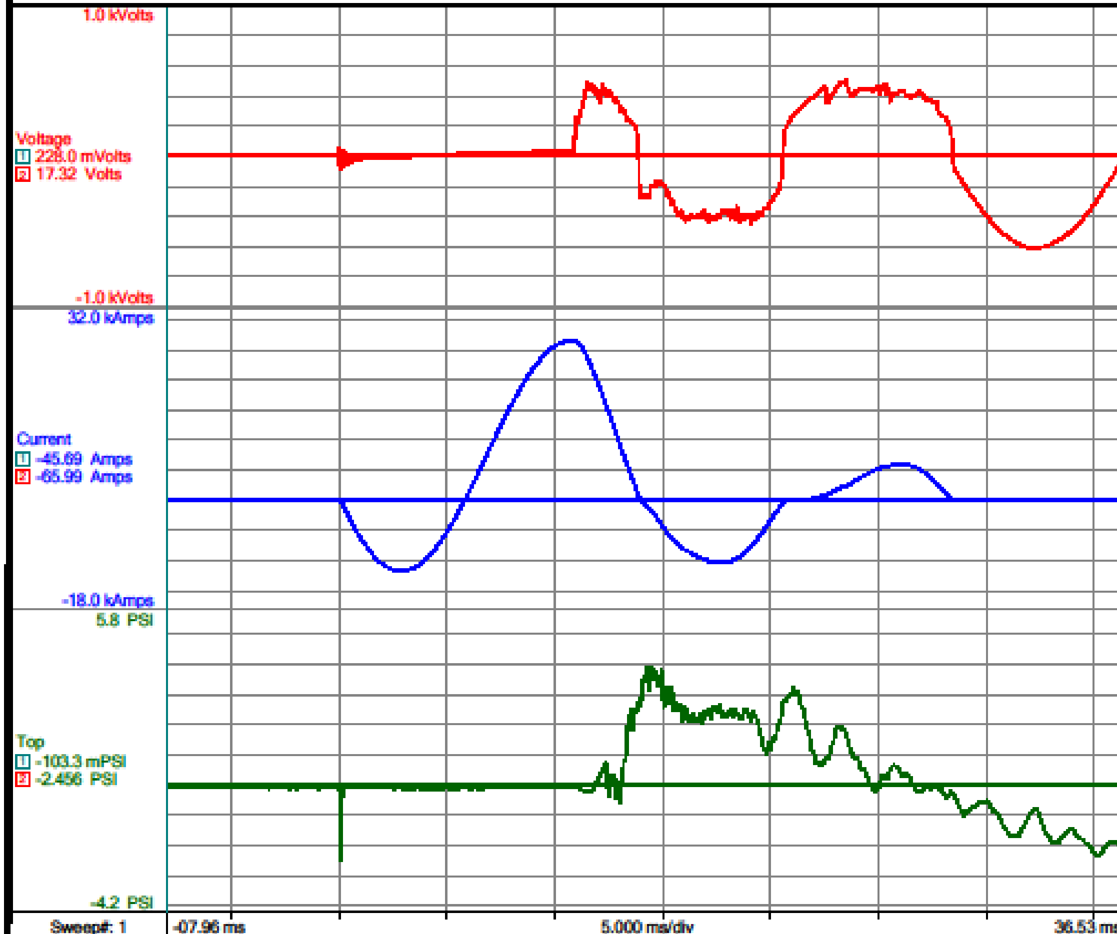
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 23




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 293 Deg |
| Closing time (V0)+ | 13.58 m Sec |
| Peak Current (Ip) | 26.58 k Amperes |
| Time to Ip | 10.72 m Sec. |
| I²t | 3.522 M Amp^2sec |
| I Duration | 28.50 m Sec. |

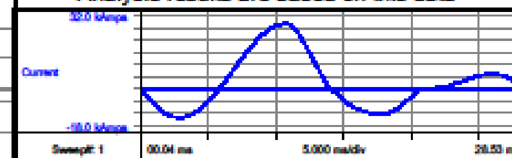
## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

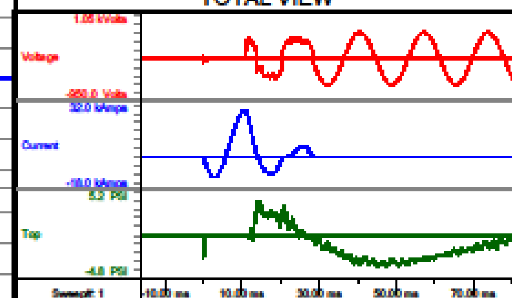
## Comment Section

12.88 kA
-
-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System: HBM GEN7T C/N 383-173
VOLTAGE: 100X Scope Probe, C/N 131-008, 1% PLOT FILE:HPL3 CR_1_M
VOLTAGE: 100X Scope Probe, C/N 131-004, 1%
CURRENT: ROGOWSKI COIL, C/N 045-443
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34357

Oscillogram No.: HPL3-34358 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 8:38:27 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

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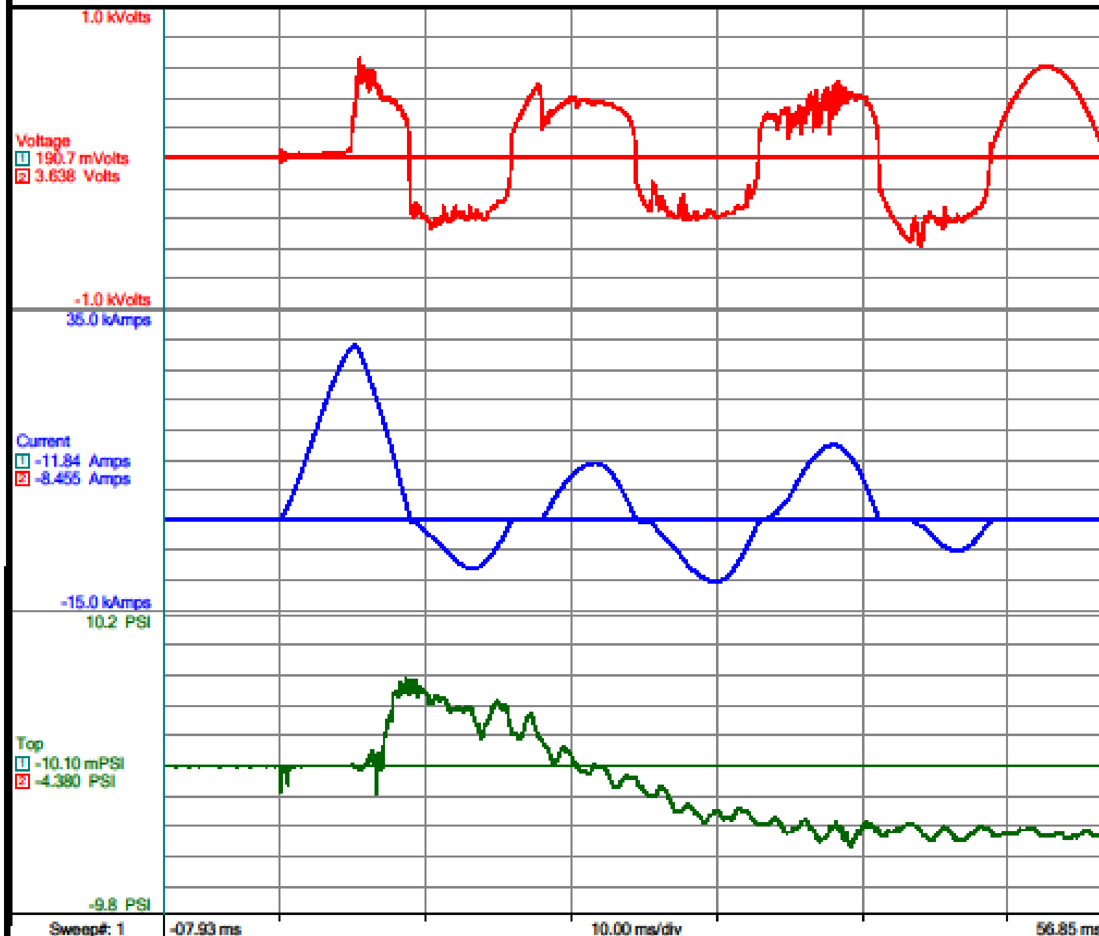
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 24




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 33 Deg |
| Closing time (V0)+ | 1.540 m Sec |
| Peak Current (Ip) | 29.06 k Amperes |
| Time to Ip | 5.037 m Sec. |
| I²t | 4.418 M Amp^2sec |
| I Duration | 48.78 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

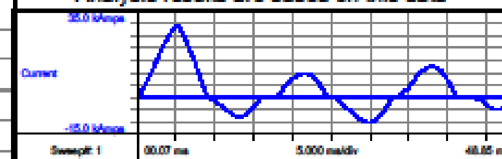
Comment Section

12.88 kA

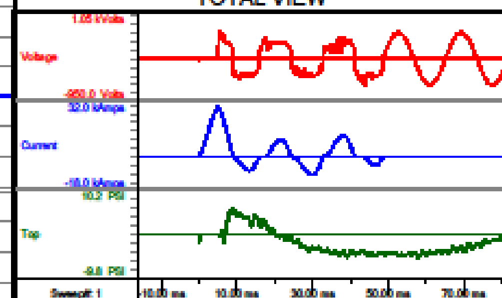
-

-

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System:HBM GEN7T CAI 383-173
VOLTAGE 100X Barge Probe, CAI 131-850, 1% PLOT FILE:HPL3 CR_1_M
VOLTAGE 100X Barge Probe, CAI 131-854, 1%
CURRENT ROGOWSKI COIL, CAI 048-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34358

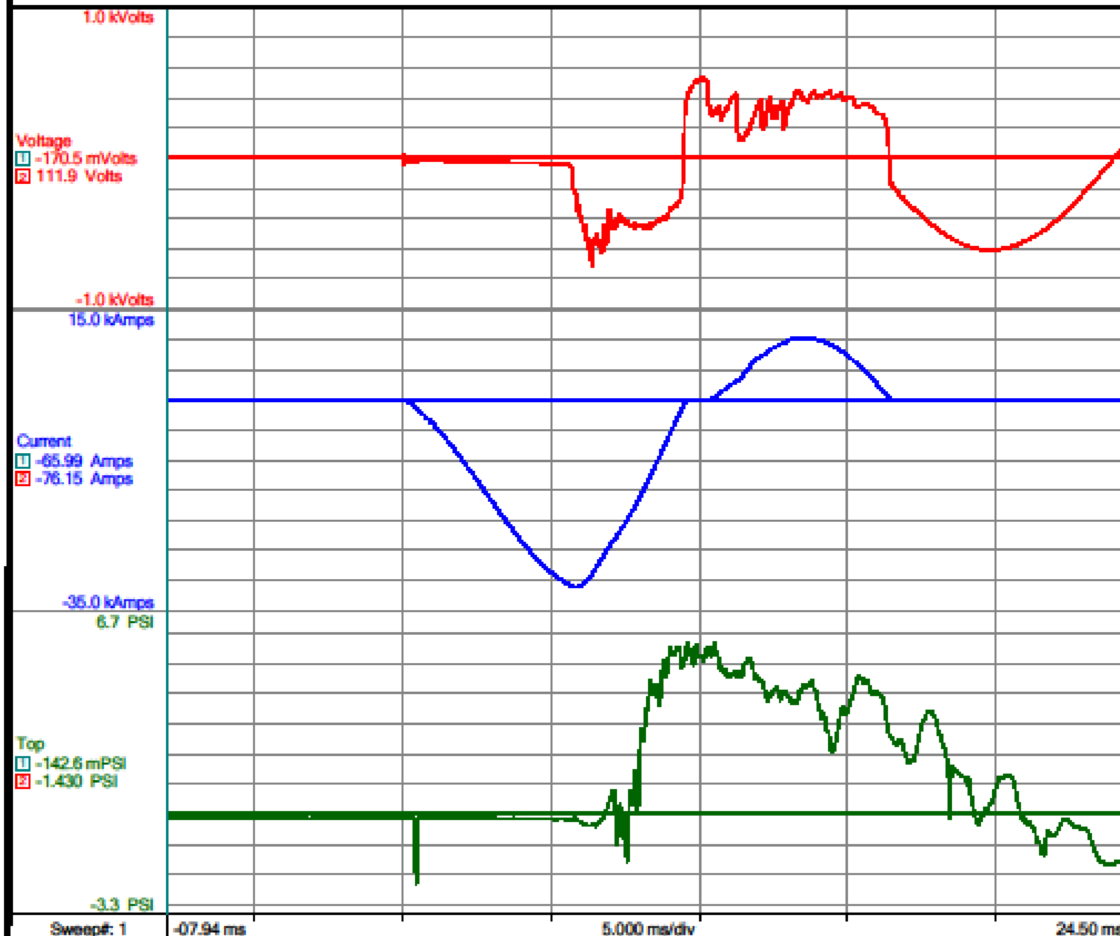
Oscillogram No.: HPL3-34359 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 8:45:01 AM

**AVAILABLE CIRCUIT CHARACTERISTICS:**
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 25




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 203 Deg |
| Closing time (V0)+ | 9.389 m Sec |
| Peak Current (Ip) | -31.12 k Amperes |
| Time to Ip | 5.777 m Sec. |
| I²t | 3.900 M Amp^2sec |
| I Duration | 16.45 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

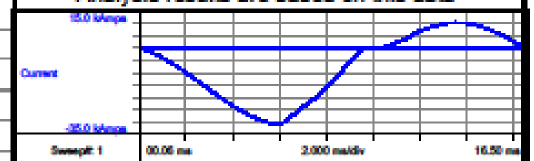
## Comment Section

12.88 kA

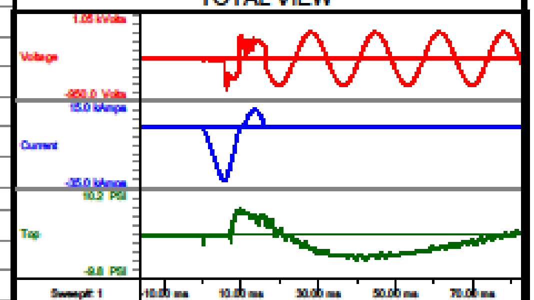
-

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE HPL3 [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-34359**

Oscillogram No.: HPL3-34360 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 8:50:25 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

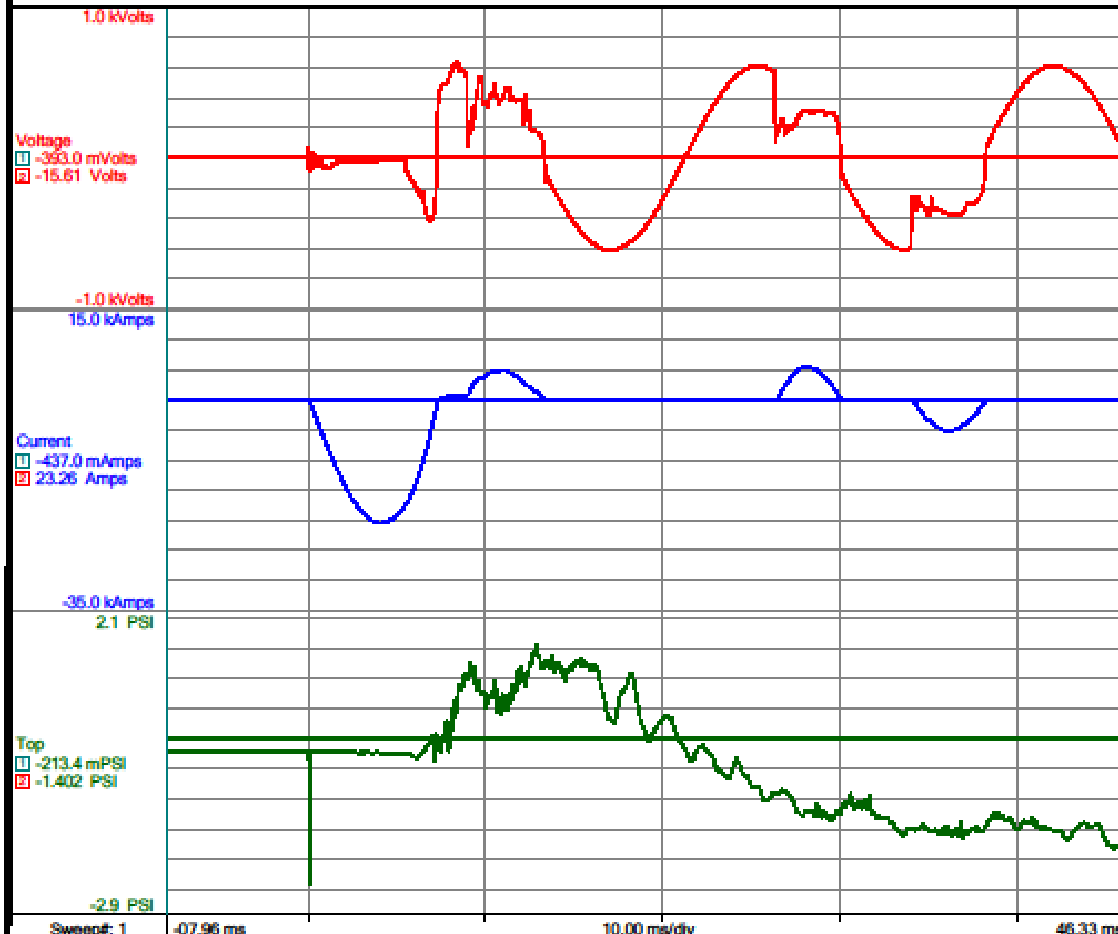
High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 26

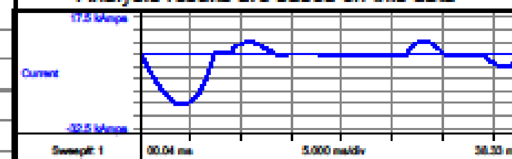
| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 262 Deg |
| Closing time (V0)+ | 12.13 m Sec |
| Peak Current (Ip) | -20.45 k Amperes |
| Time to Ip | 4.062 m Sec. |
| I²t | 1.771 M Amp^2sec |
| I Duration | 38.28 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

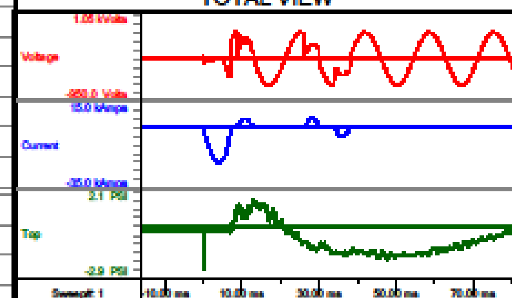
| Comment Section |
|---|
| 12.88 kA |
| - |
| - |




Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

[illegible]

OSC. NO.: HPL3-34360

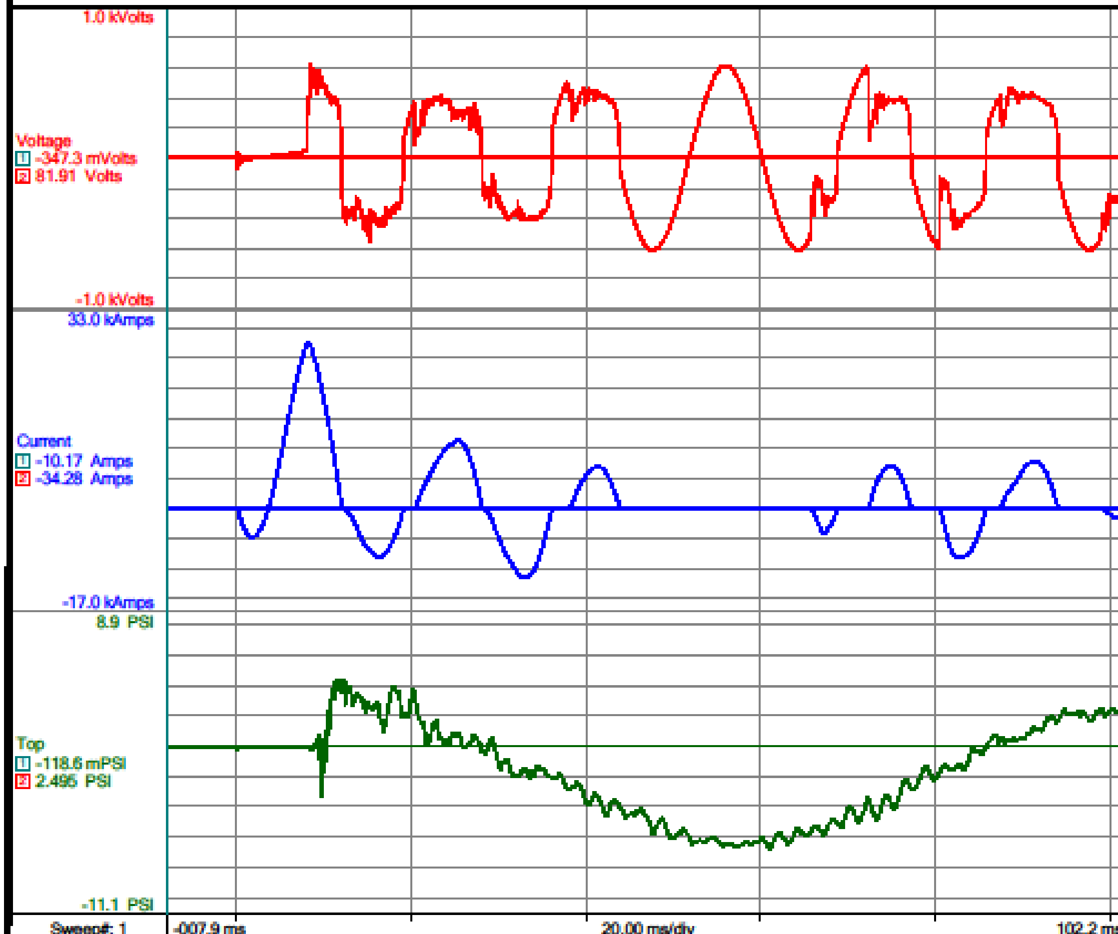
Oscillogram No.: HPL3-34361 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 8:55:56 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 27




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 322 Deg |
| Closing time (V0)+ | 14.91 m Sec |
| Peak Current (Ip) | 27.84 k Amperes |
| Time to Ip | 8.137 m Sec. |
| I²t | 4.472 M Amp^2sec |
| I Duration | 94.11 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

12.88 kA
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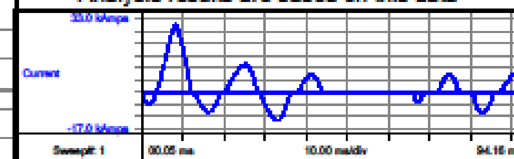
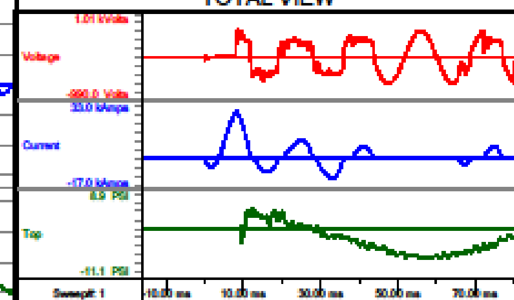
-

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T CAL 063-173
VOLTAGE 100X Scope Probe, CAL 131-088, 1% PLOT FILE HPL3 CR_1_II
VOLTAGE 100X Scope Probe, CAL 131-084, 1%
CURRENT ROGOWSKI COIL, CAL 048-448
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34361

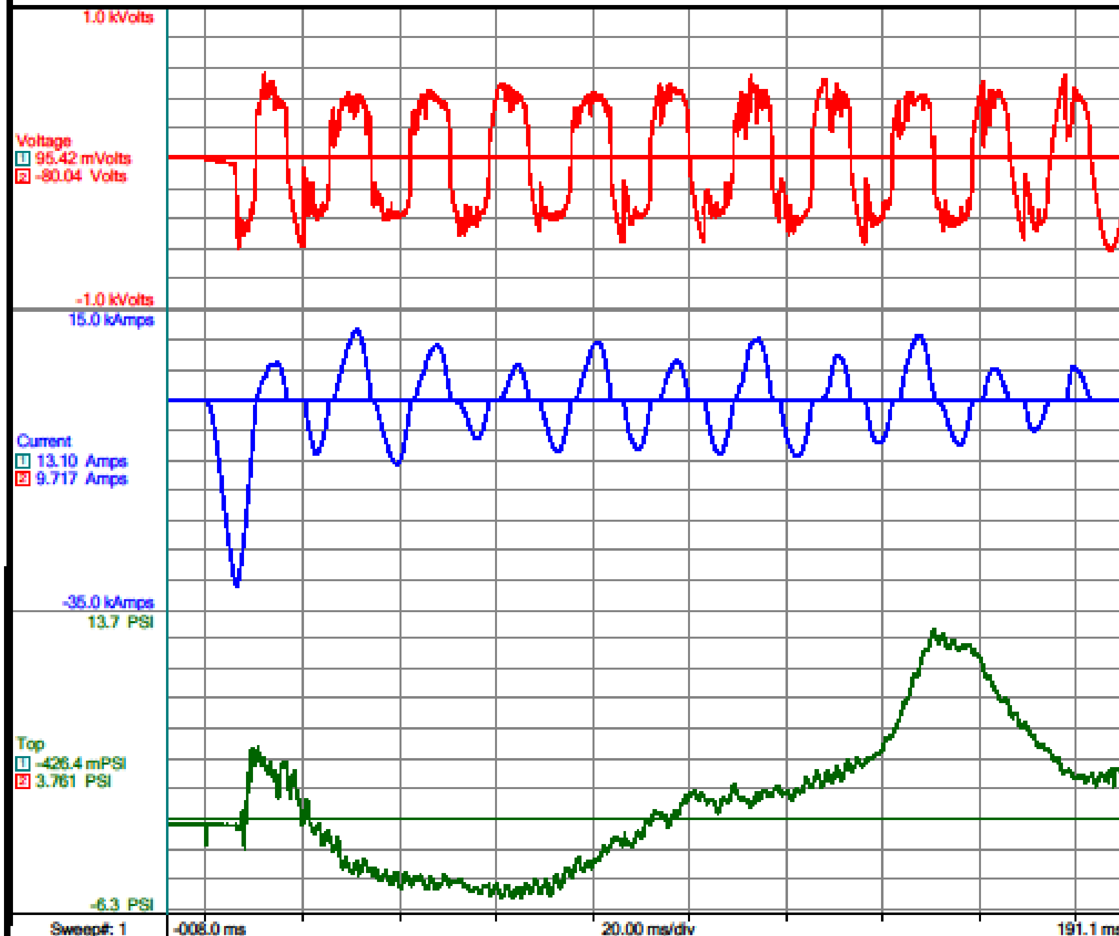
Oscillogram No.: HPL3-34362 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 9:00:08 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 28




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 90 Deg |
| Closing time (V0)+ | 35.44 μ Sec |
| Peak Current (Ip) | -31.14 k Amperes |
| Time to Ip | 6.352 m Sec. |
| I²t | 8.327 M Amp^2sec |
| I Duration | 183.0 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

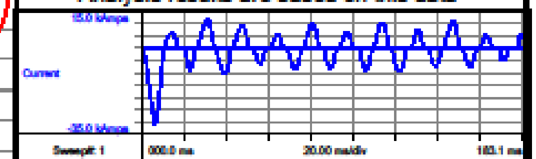
## Comment Section

12.88 kA

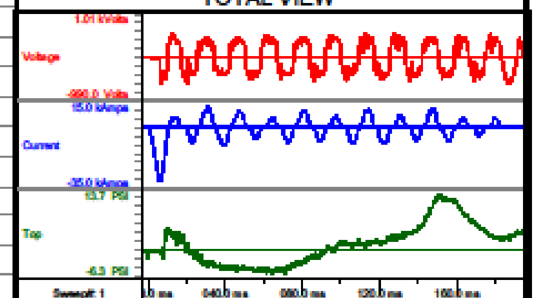
-

-

Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

[illegible]

OSC. NO.: HPL3-34362

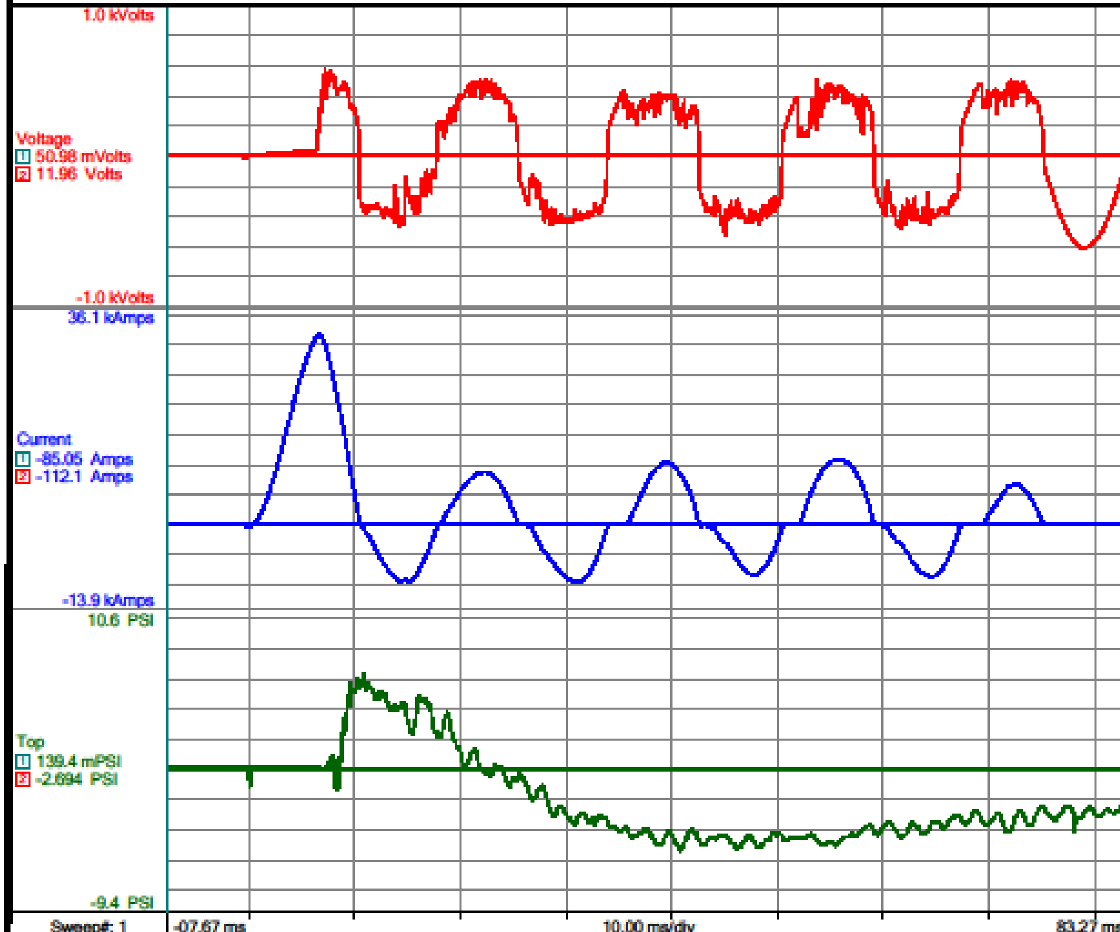
Oscillogram No.: HPL3-34363 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 9:10:58 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 29




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 10 Deg |
| Closing time (V0)+ | 440.1 μ Sec |
| Peak Current (Ip) | 31.84 k Amperes |
| Time to Ip | 6.350 m Sec. |
| I²t | 6.256 M Amp^2sec |
| I Duration | 74.94 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

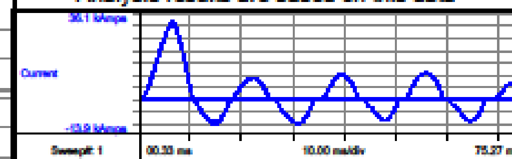
## Comment Section

12.88 kA

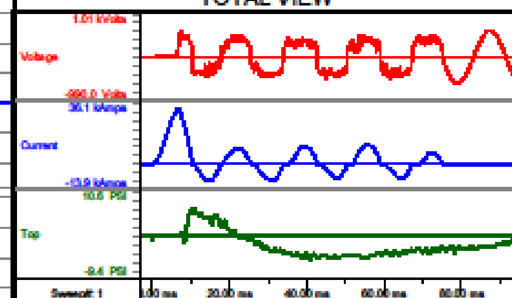
-

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

[illegible]

OSC. NO.: HPL3-34363

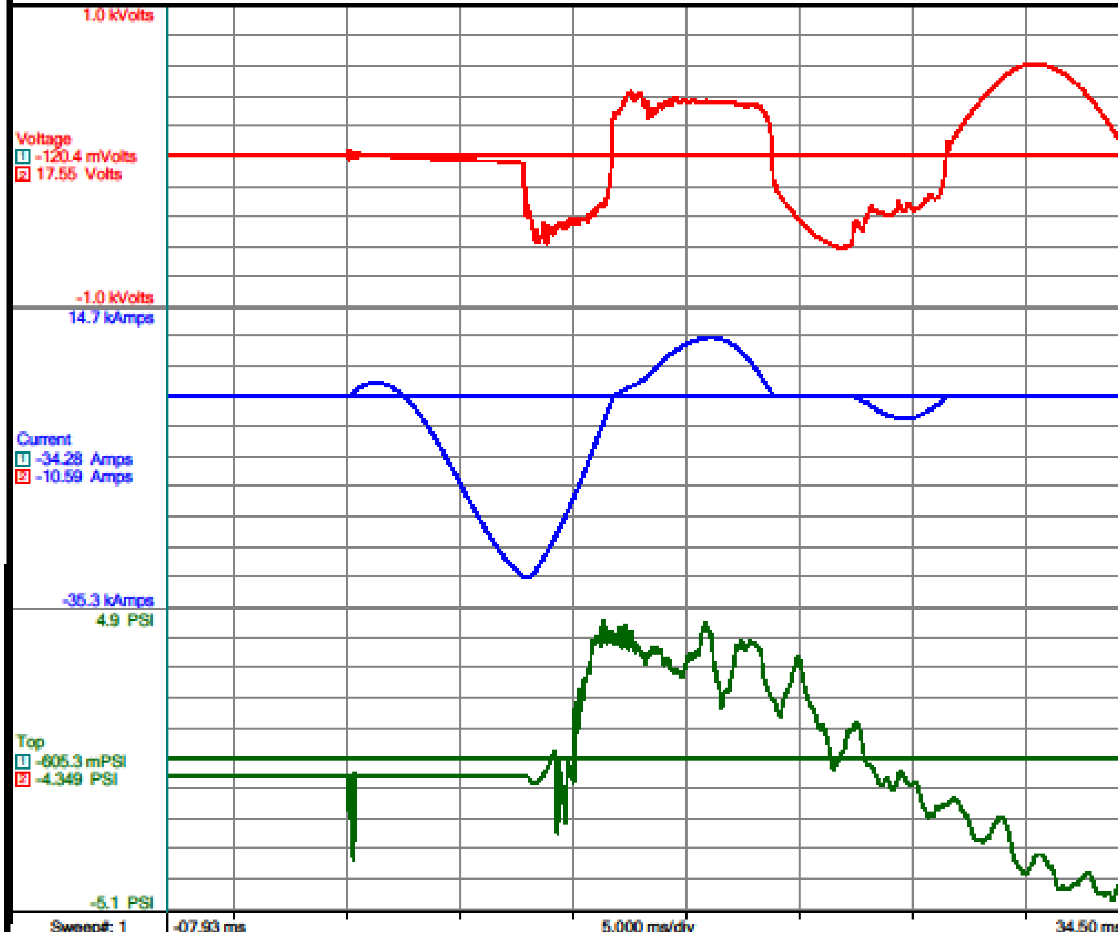
Oscillogram No.: HPL3-34364 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 9:15:40 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 30

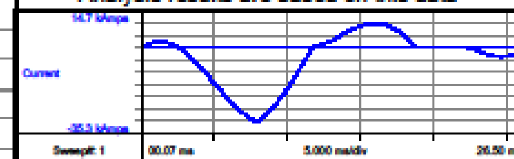



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 154 Deg |
| Closing time (V0)+ | 7.129 m Sec |
| Peak Current (Ip) | -30.30 k Amperes |
| Time to Ip | 7.858 m Sec. |
| I²t | 3.670 M Amp^2sec |
| I Duration | 26.44 m Sec. |

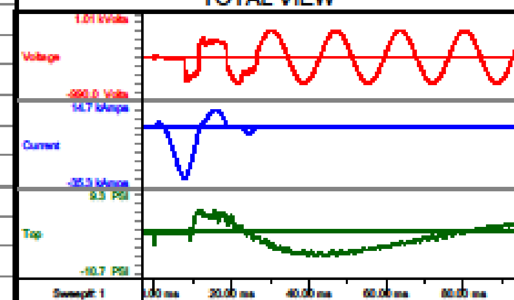
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 12.88 kA |
| - |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis

but not for display.

OSC. NO.: HPL3-34364

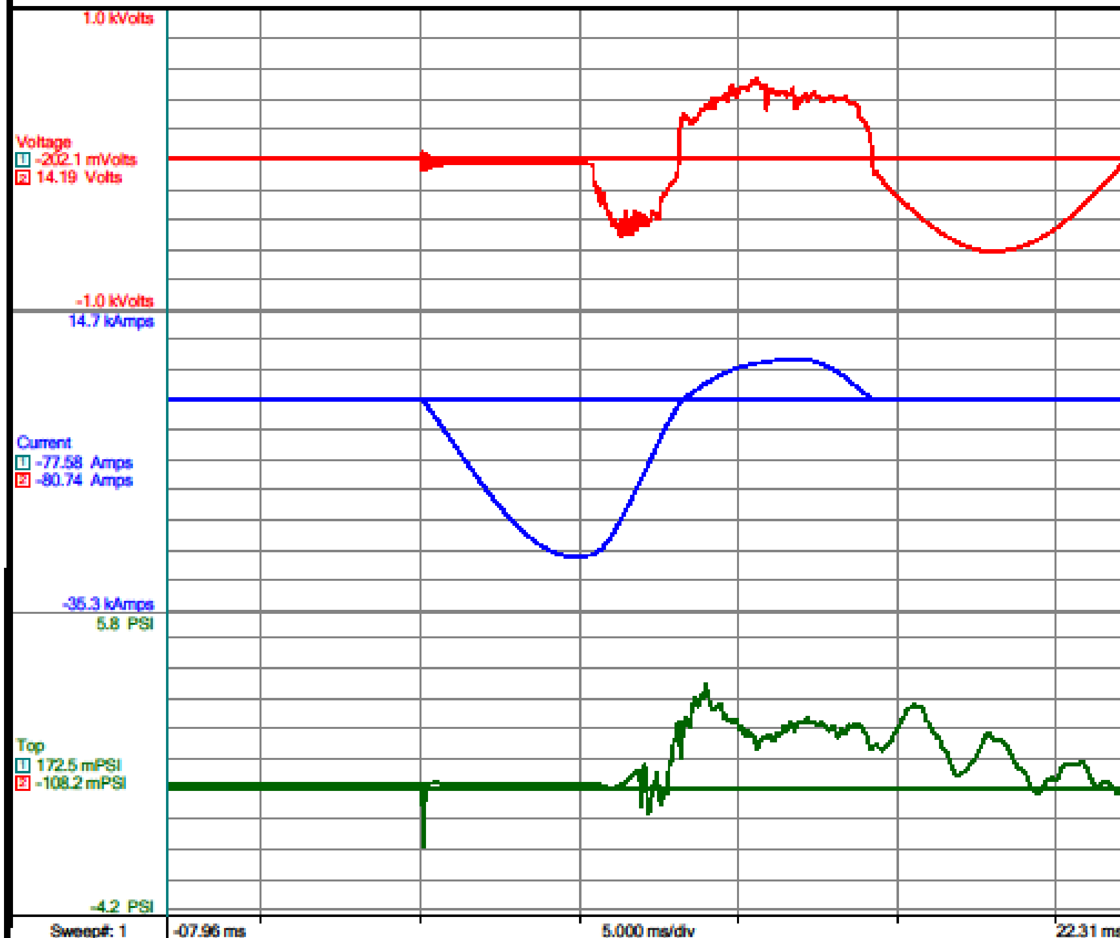
Oscillogram No.: HPL3-34365 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 9:19:51 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 31




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 240 Deg |
| Closing time (V0)+ | 11.13 m Sec |
| Peak Current (Ip) | -28.12 k Amperes |
| Time to Ip | 4.859 m Sec. |
| I²t | 2.813 M Amp^2sec |
| I Duration | 14.27 m Sec. |

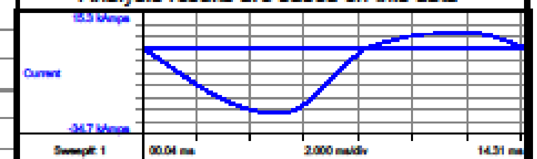
## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

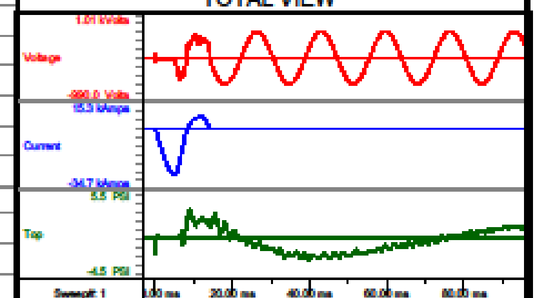
## Comment Section

12.88 kA
-
-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-558, 1% PLOT FILE HPL3 CR_1_B
VOLTAGE 100X Scope Probe, C/N 131-554, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34365

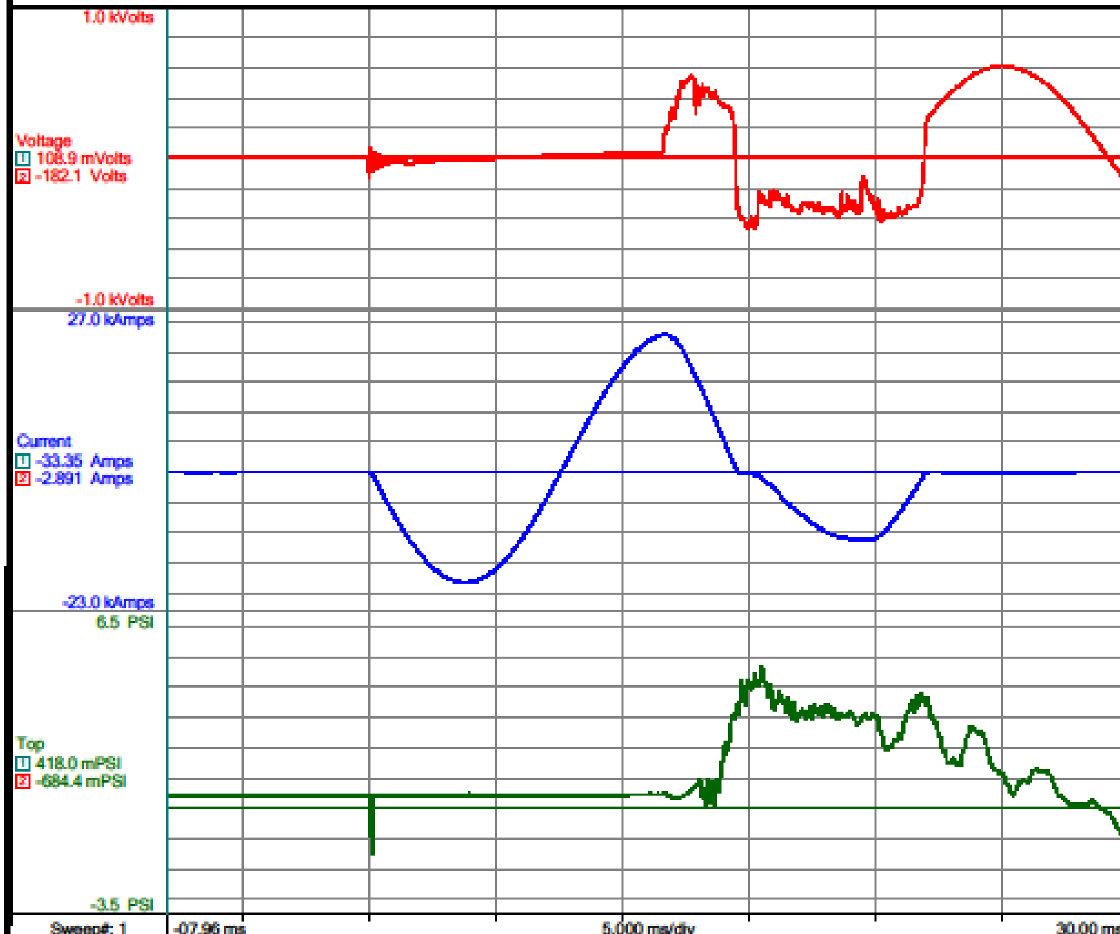
Oscillogram No.: HPL3-34366 OCV = 434 V
Date of Test: 9/29/2020 Time of Test: 9:25:25 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 32

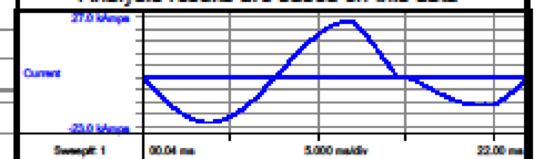



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 270 Deg |
| Closing time (V0)+ | 12.50 m Sec |
| Peak Current (Ip) | 23.01 k Amperes |
| Time to Ip | 11.88 m Sec. |
| I²t | 3.382 M Amp^2sec |
| I Duration | 21.98 m Sec. |

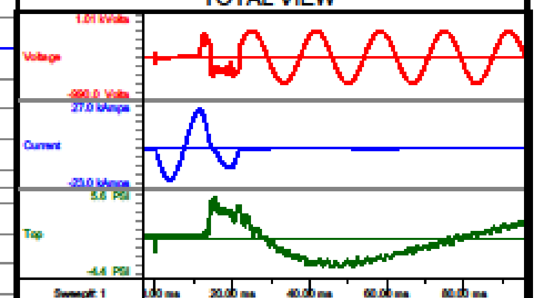
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 12.88 kA |
| - |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis.
but not for display.

OSC. NO.: HPL3-34366

Oscillogram No.: HPL3-34367 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 9:31:39 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 33

| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 231 Deg |
| Closing time (V0)+ | 29.29 µ Sec |
| Peak Current (Ip) | 23.97 k Amperes |
| Time to Ip | 10.99 m Sec. |
| I²t | 11.94 M Amp^2sec |
| I Duration | 186.7 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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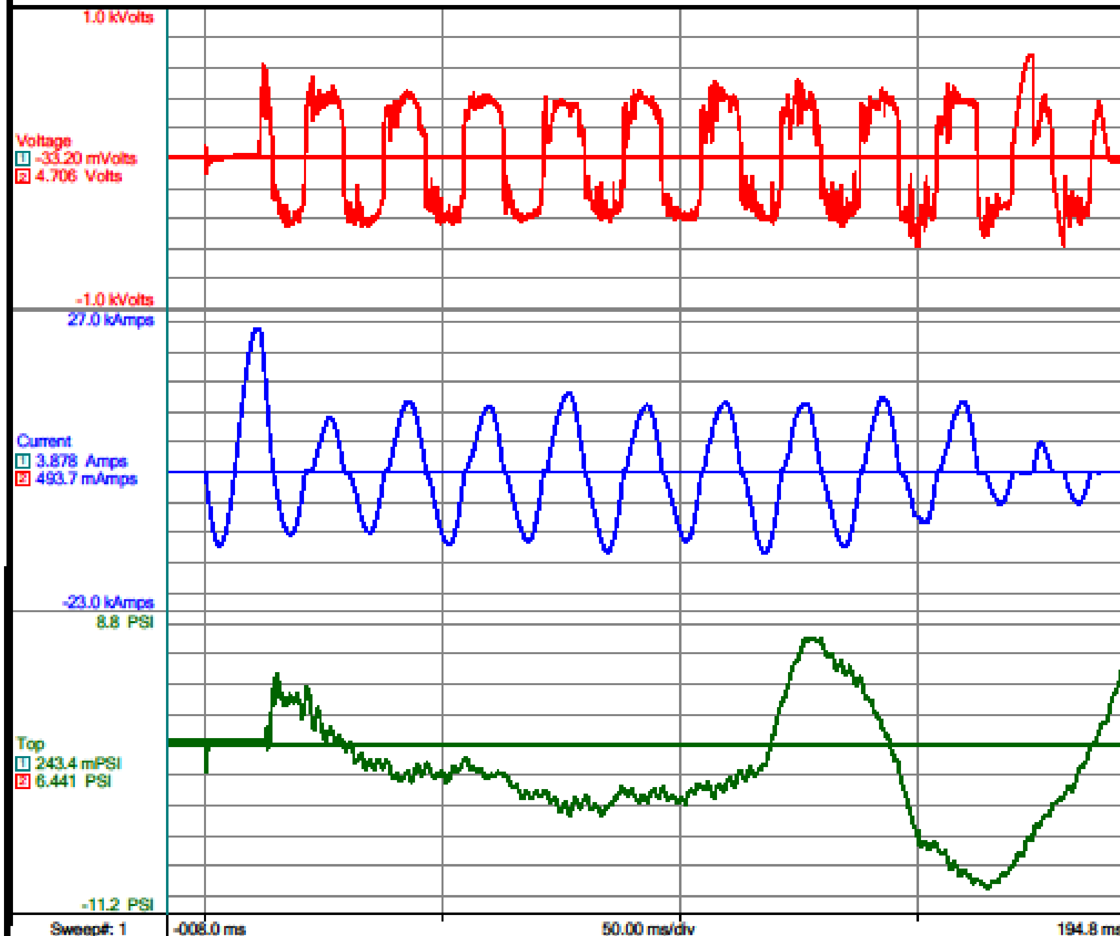
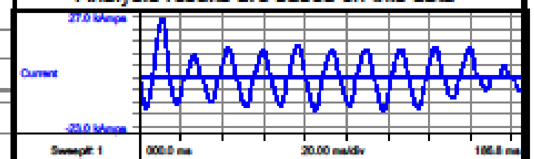
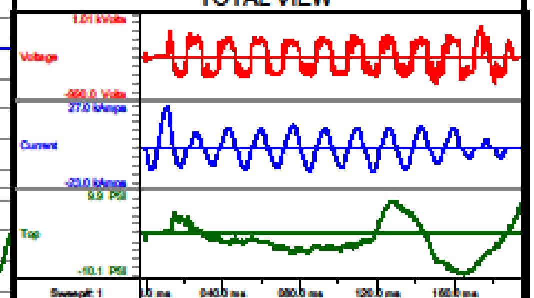



Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-008, 1%
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 040-448
NOTE: Channel offset removed for analysis but not for display.
PLOT FILE HPL3 CR_1_8

OSC. NO.: HPL3-34367

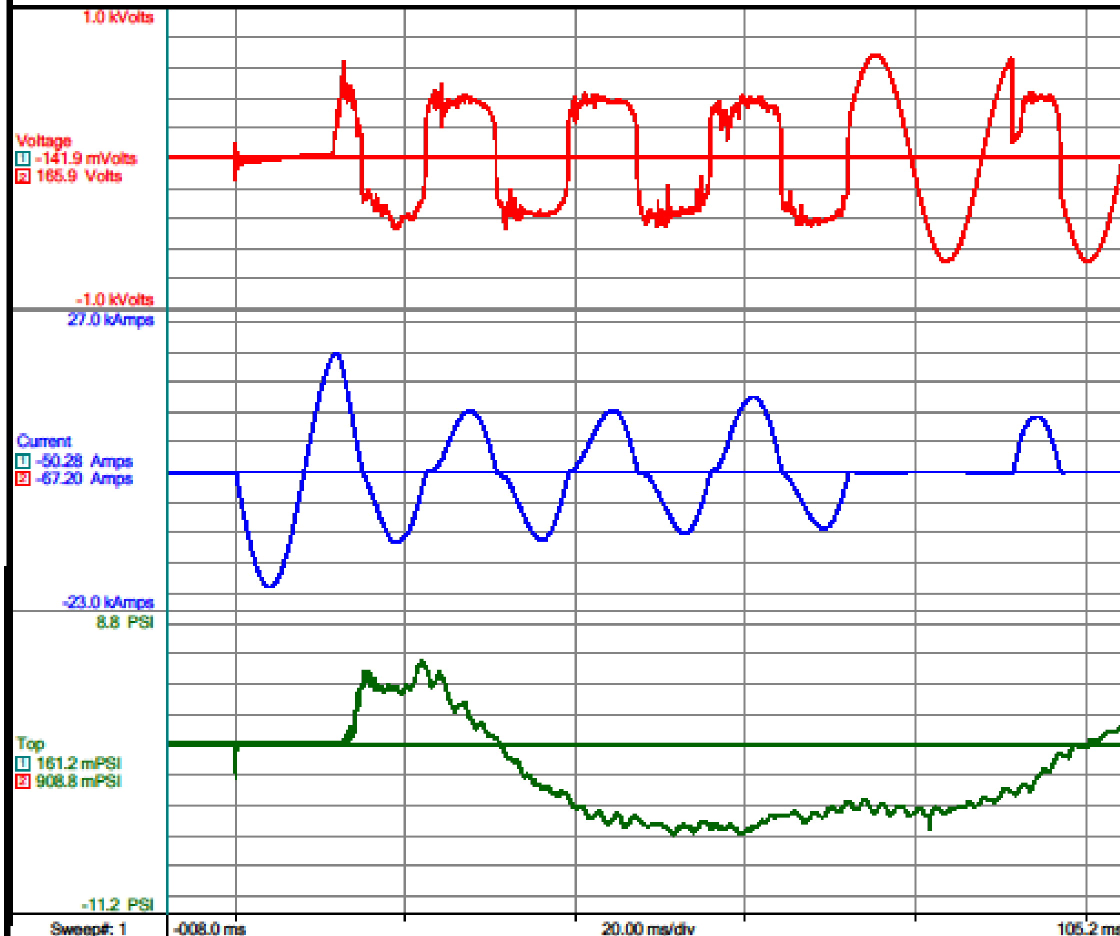
Oscillogram No.: HPL3-34368 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 9:38:57 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 34




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 283 Deg |
| Closing time (V0)+ | 12.18 m Sec |
| Peak Current (Ip) | 19.80 k Amperes |
| Time to Ip | 11.77 m Sec. |
| I²t | 5.872 M Amp^2sec |
| I Duration | 97.12 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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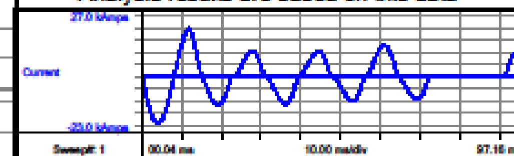
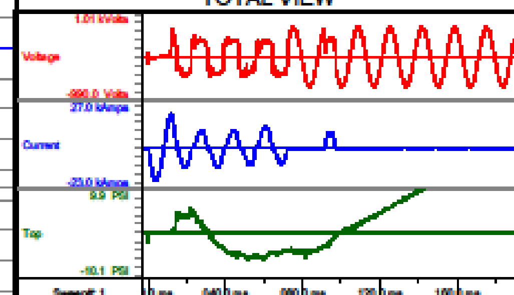
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis

but not for display.

OSC. NO.: HPL3-34368

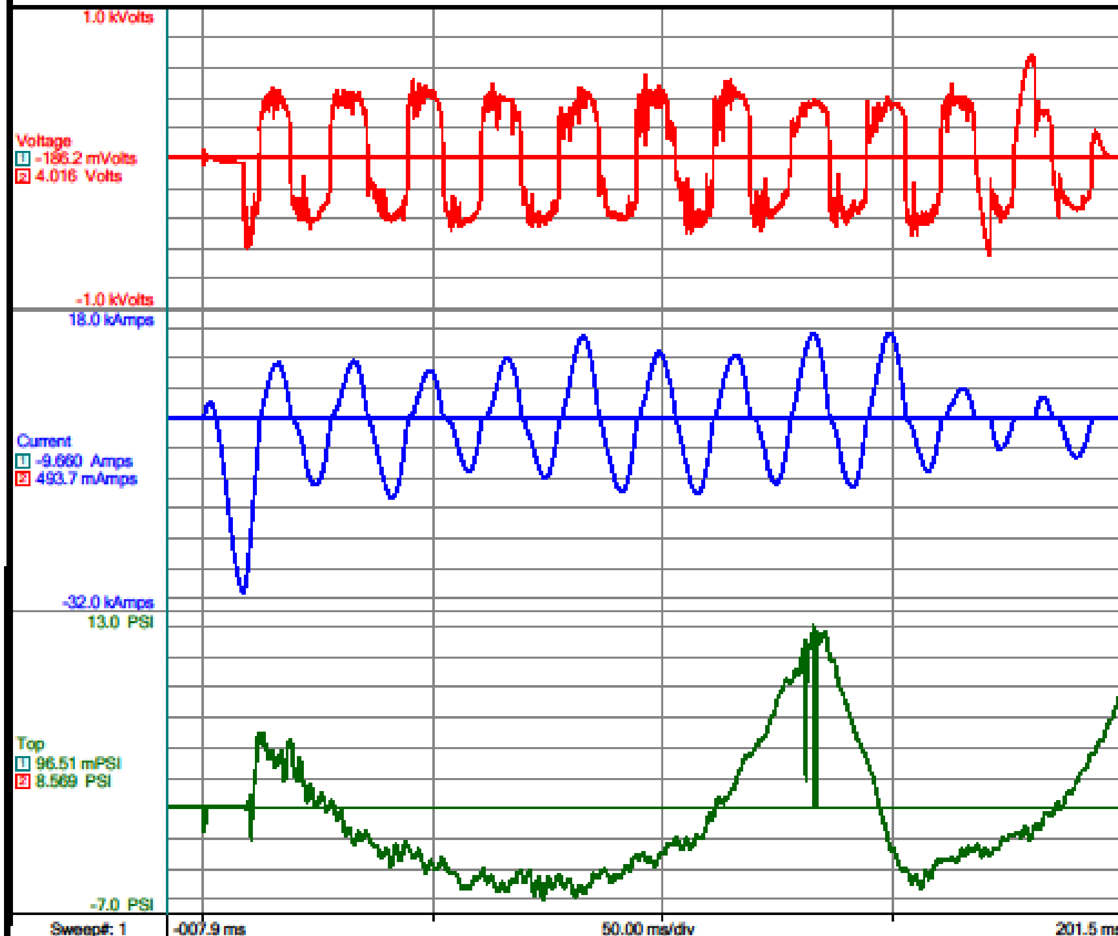
Oscillogram No.: HPL3-34369 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 9:46:55 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 35




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 331 Deg |
| Closing time (V0)+ | 41.38 µ Sec |
| Peak Current (Ip) | -29.02 k Amperes |
| Time to Ip | 8.887 m Sec. |
| I²t | 12.17 M Amp^2sec |
| I Duration | 193.4 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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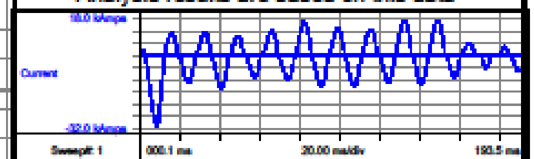
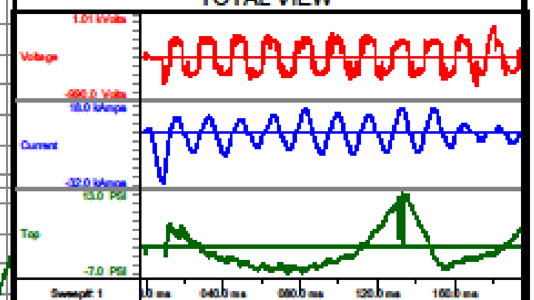
Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-34369**

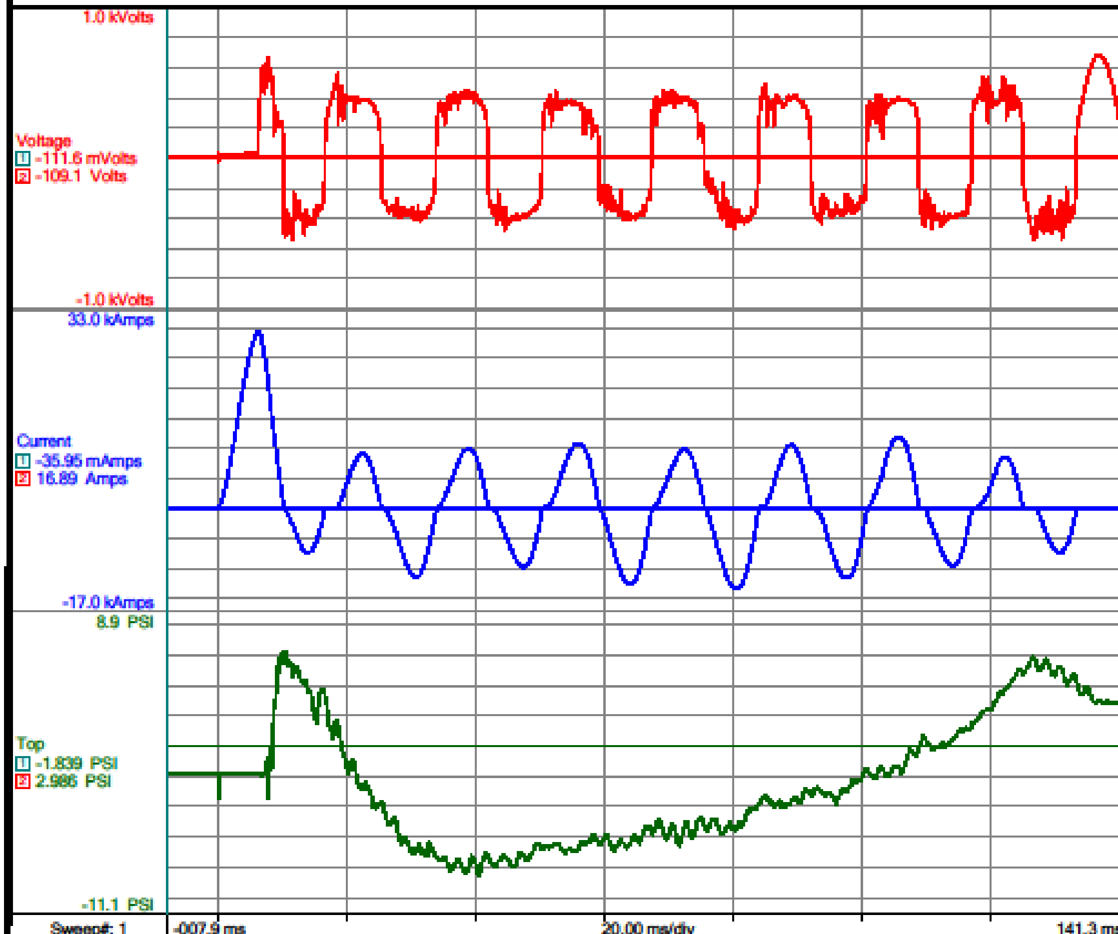
Oscillogram No.: HPL3-34370 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 9:50:56 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 36




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 19 Deg |
| Closing time (V0)+ | 902.3 μ Sec |
| Peak Current (Ip) | 29.54 k Amperes |
| Time to Ip | 6.193 m Sec. |
| I²t | 9.219 M Amp^2sec |
| I Duration | 133.2 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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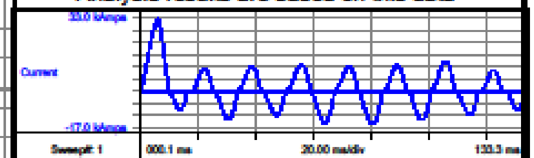
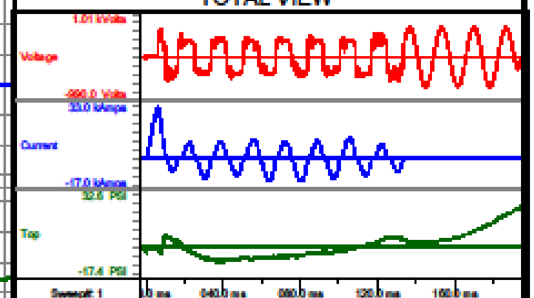
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1% PLOT FILE HPL3 [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34370

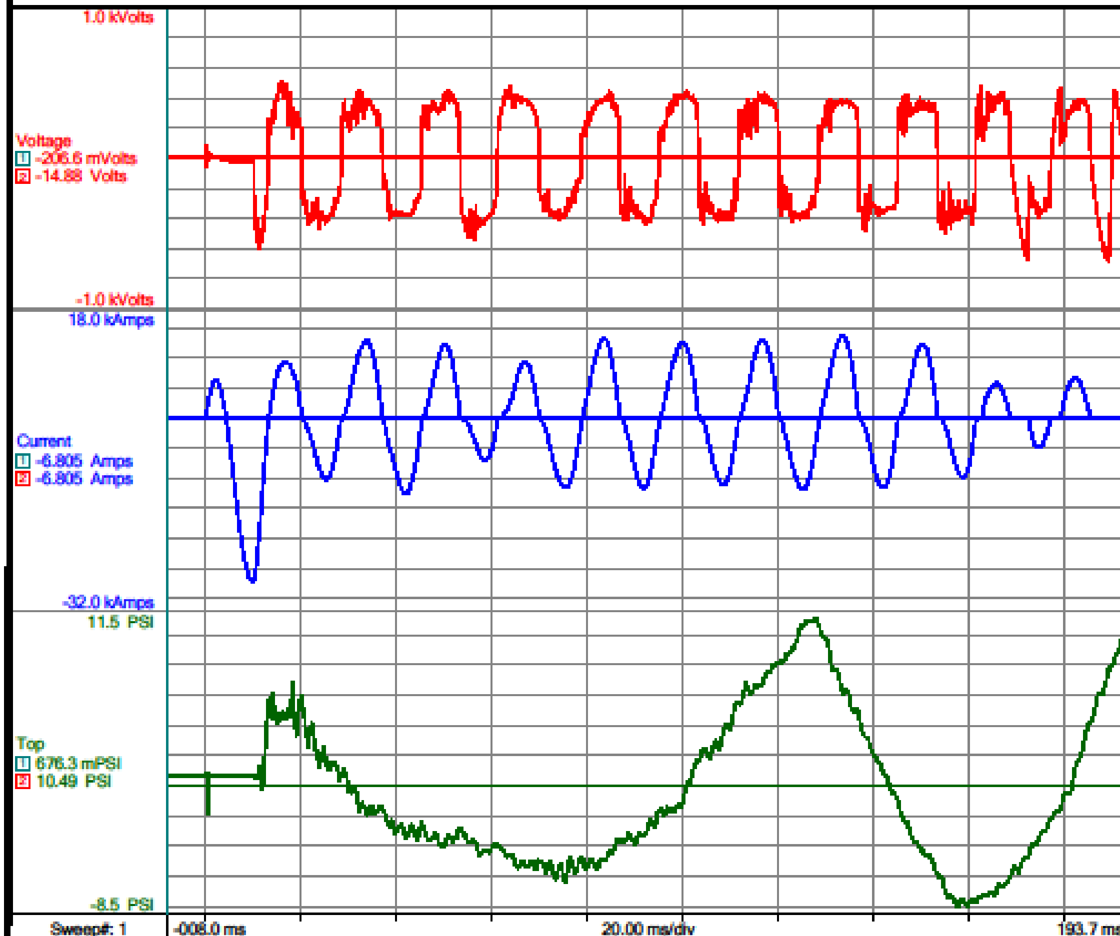
Oscillogram No.: HPL3-34371 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 9:57:47 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 37




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 175 Deg |
| Closing time (V0)+ | 23.07 µ Sec |
| Peak Current (Ip) | -27.10 k Amperes |
| Time to Ip | 9.800 m Sec. |
| I²t | 12.38 M Amp^2sec |
| I Duration | 185.7 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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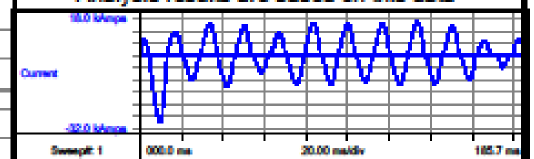
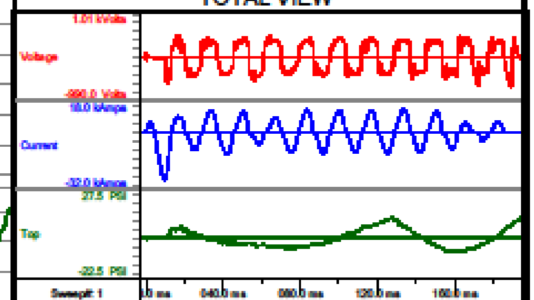
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 100X Bugge Probe, C/N 131-000, 1%
VOLTAGE 100X Bugge Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis,
but not for display.

PLOT FILE HPL3 CR_1_8

OSC. NO.: HPL3-34371

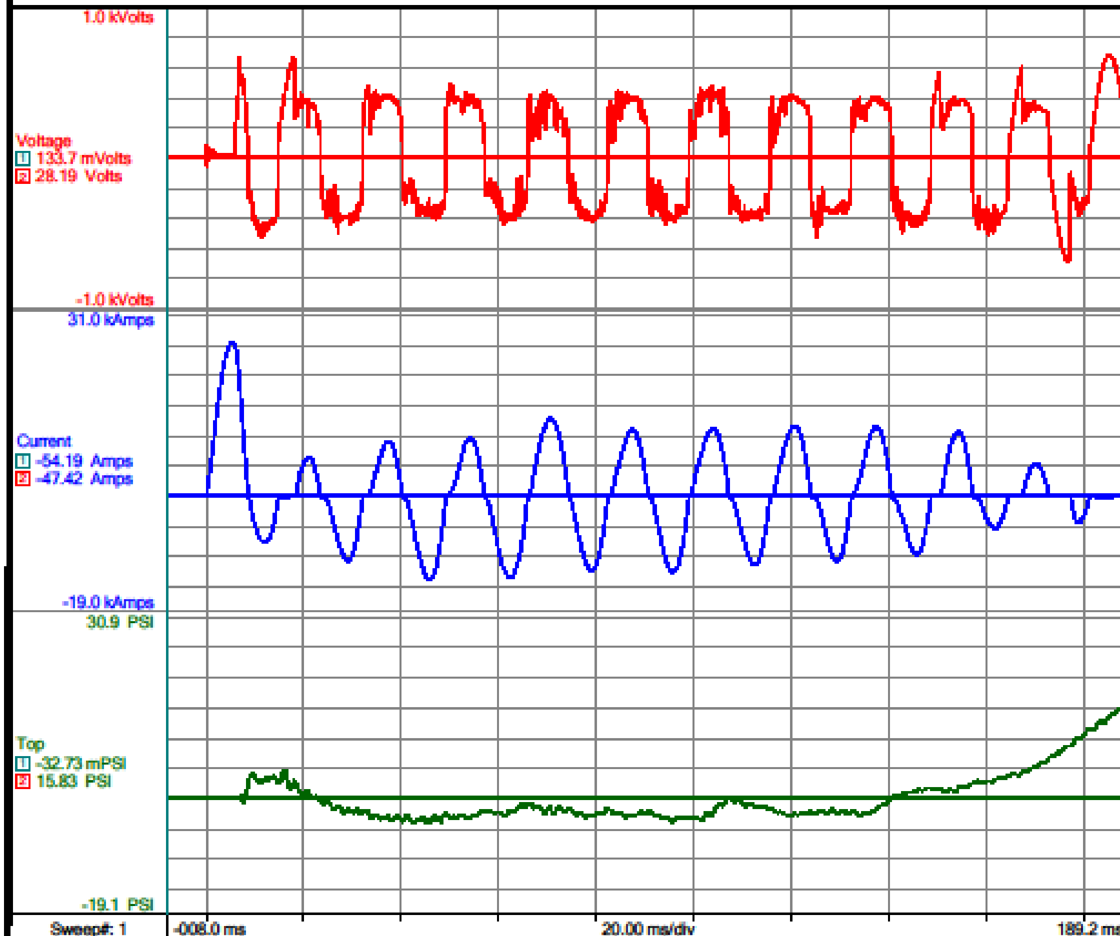
Oscillogram No.: HPL3-34372 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:01:21 AM

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 38




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 283 Deg |
| Closing time (V0)+ | 2.641 m Sec |
| Peak Current (Ip) | 25.63 k Amperes |
| Time to Ip | 5.235 m Sec. |
| I²t | 11.21 M Amp^2sec |
| I Duration | 181.2 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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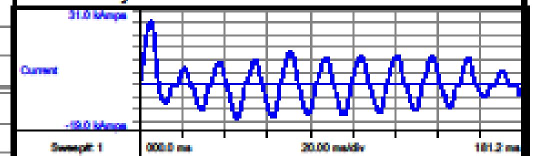
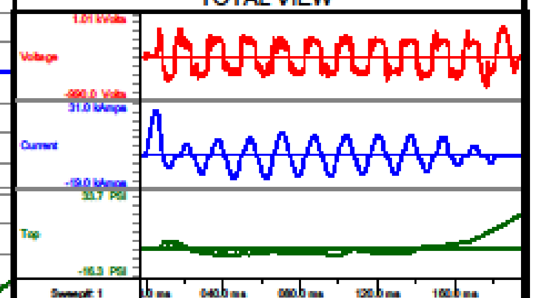
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN3T C/N 083-173
VOLTAGE 100X Scope Probe, C/N 131-008, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 048-443
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34372

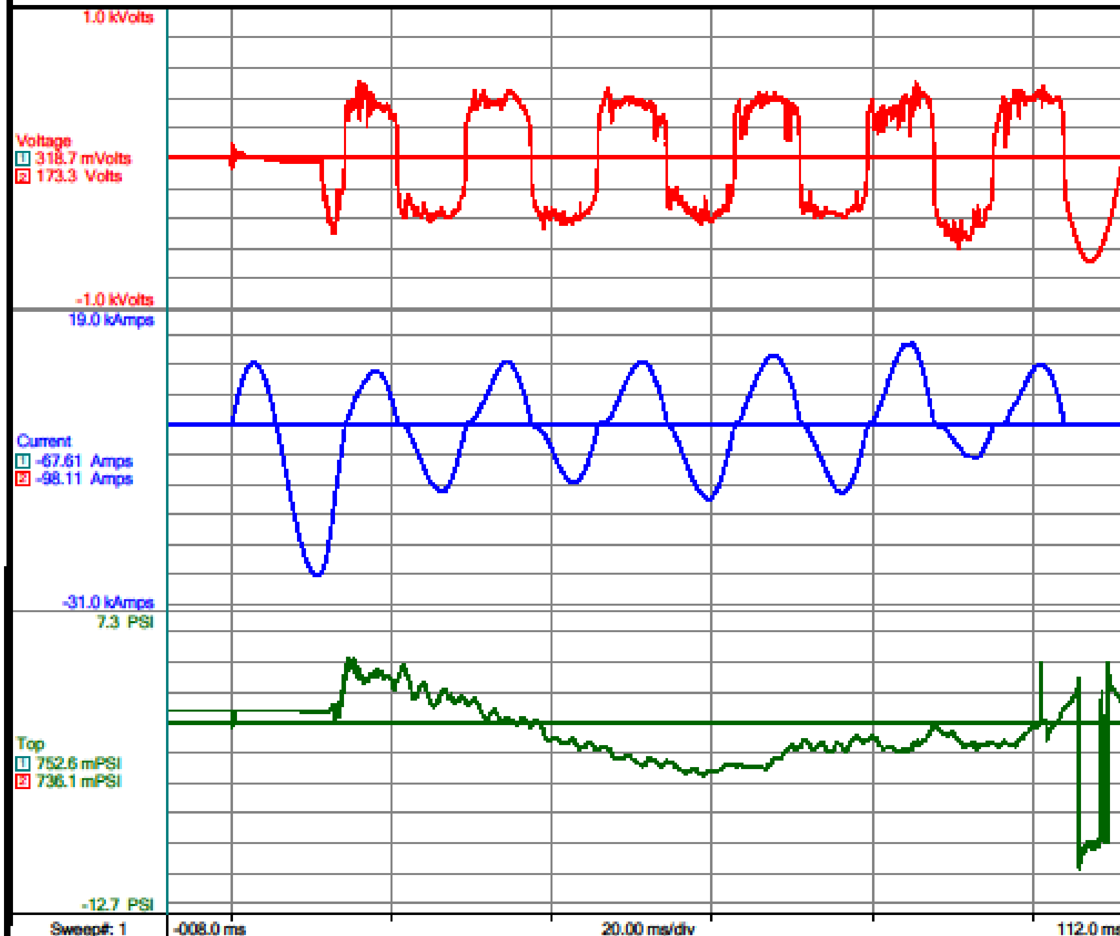
Oscillogram No.: HPL3-34373 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:07:00 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 39




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 115 Deg |
| Closing time (V0)+ | 5.302 m Sec |
| Peak Current (Ip) | -25.09 k Amperes |
| Time to Ip | 10.63 m Sec. |
| I²t | 7.355 M Amp^2sec |
| I Duration | 104.0 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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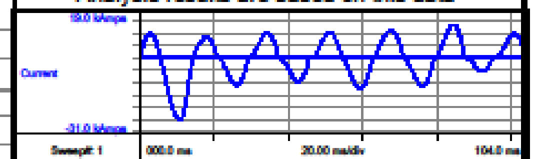
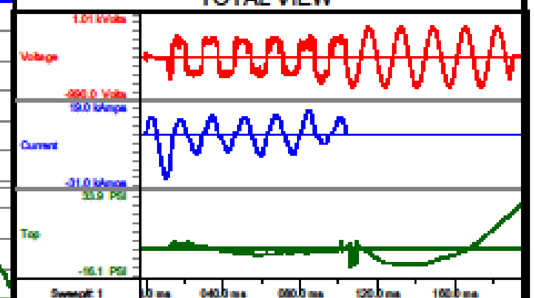
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173
VOLTAGE 100X Scope Probe, C/N 131-806, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 100X Scope Probe, C/N 131-804, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34373

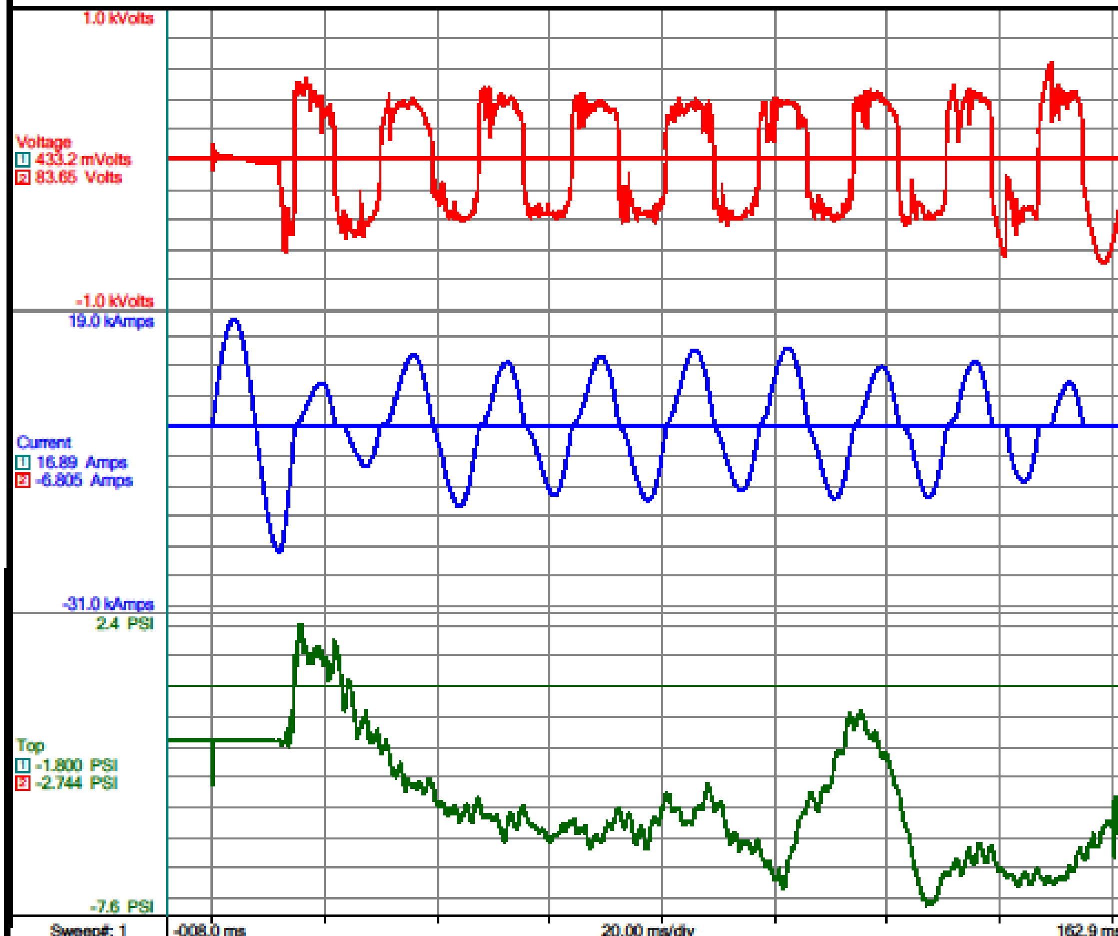
Oscillogram No.: HPL3-34374 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:10:34 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 40




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 203 Deg |
| Closing time (V0)+ | 1.815 m Sec |
| Peak Current (Ip) | -21.13 k Amperes |
| Time to Ip | 11.97 m Sec. |
| I²t | 9.992 M Amp^2sec |
| I Duration | 154.9 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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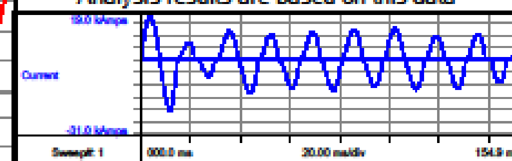
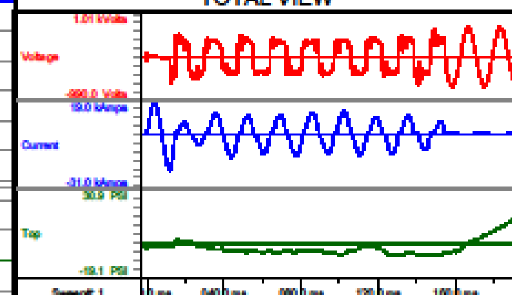
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE: HPL3 [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34374

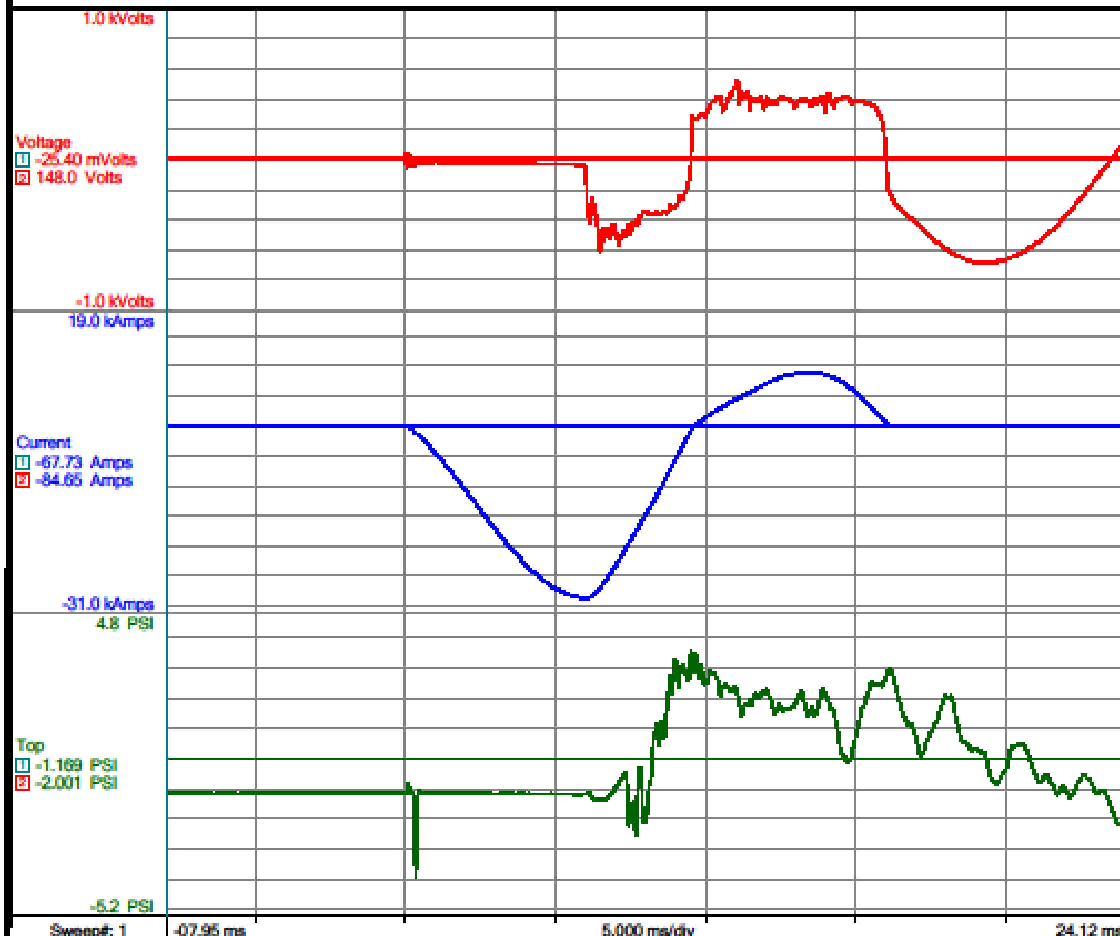
Oscillogram No.: HPL3-34375 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:14:19 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 41




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 213 Deg |
| Closing time (V0)+ | 9.839 m Sec |
| Peak Current (Ip) | -28.68 k Amperes |
| Time to Ip | 5.983 m Sec. |
| I²t | 3.559 M Amp^2sec |
| I Duration | 16.07 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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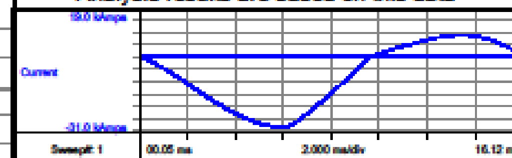
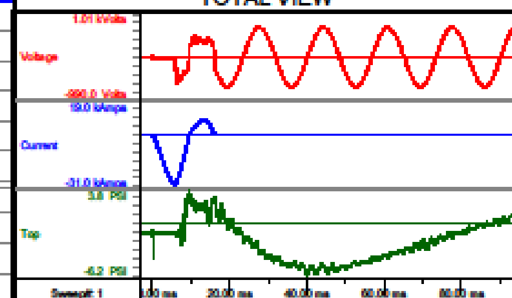
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 303-173
VOLTAGE 1000X Bulge Probe, C/N 131-608, 1%
VOLTAGE 1000X Bulge Probe, C/N 131-604, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis,
but not for display.

PLOT FILE HPL3 CR_1_M

OSC. NO.: HPL3-34375

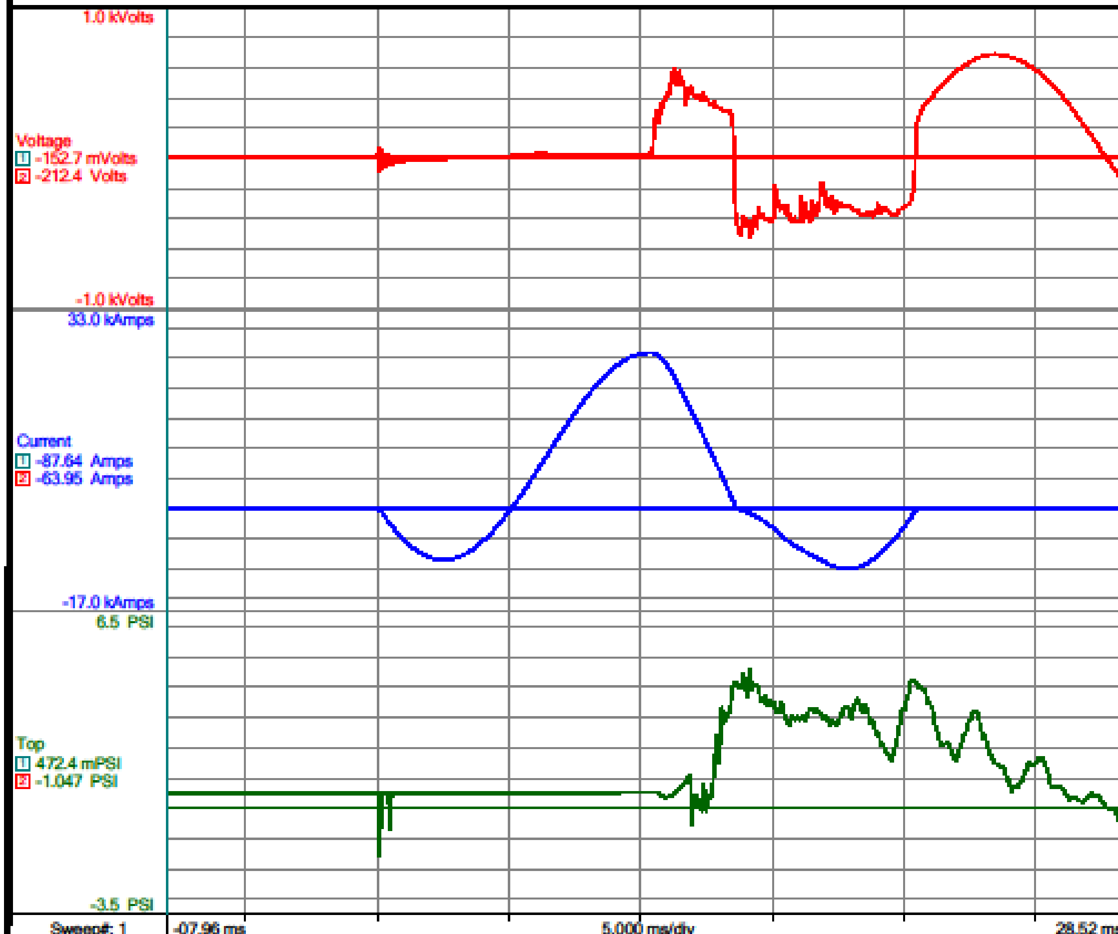
Oscillogram No.: HPL3-34376 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:19:47 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 42




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 303 Deg |
| Closing time (V0)+ | 14.05 m Sec |
| Peak Current (Ip) | 25.92 k Amperes |
| Time to Ip | 10.28 m Sec. |
| I²t | 3.113 M Amp^2sec |
| I Duration | 20.49 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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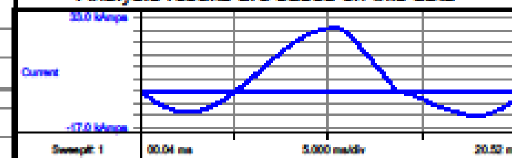
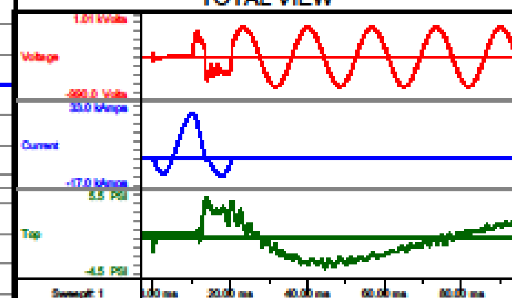
## Analysis results are based on this data




## TOTAL VIEW



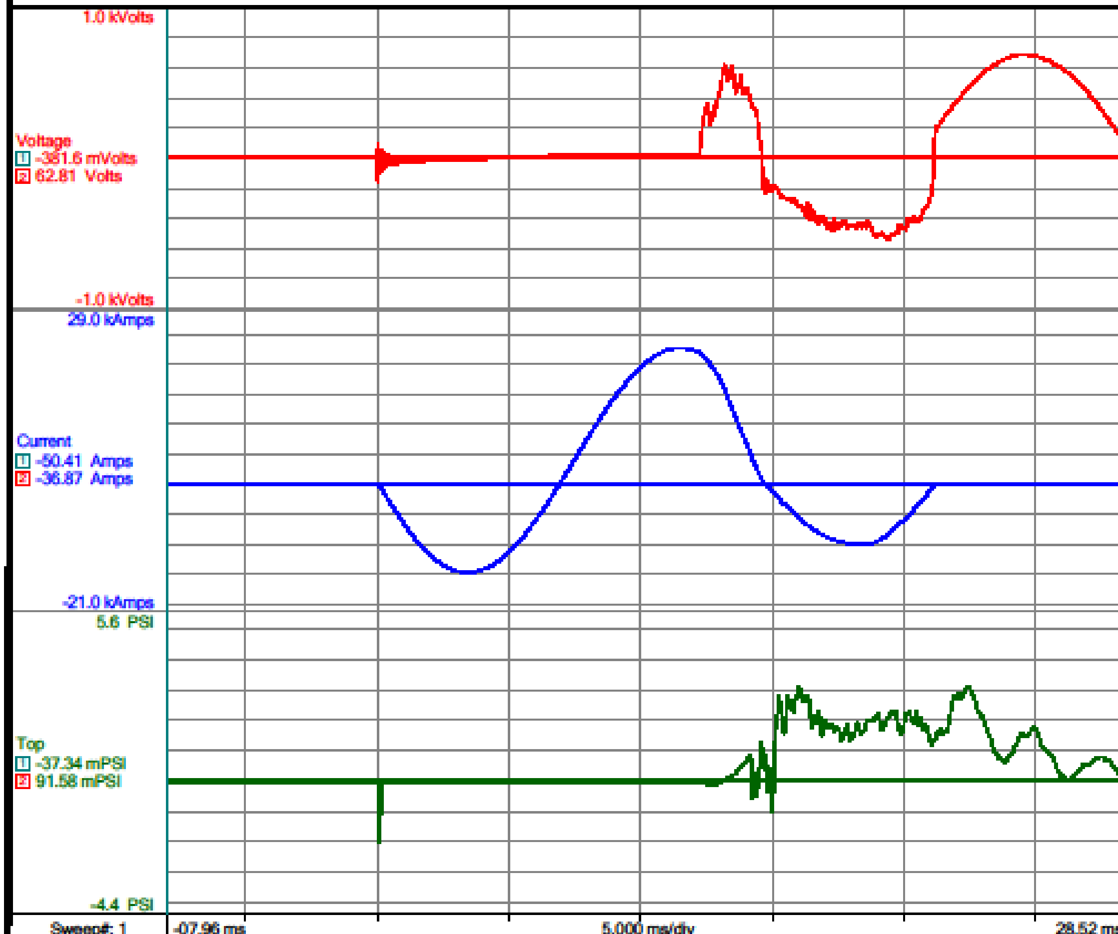

## INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34376

| Oscillogram No.: HPL3-34377 OCV = 488 V<br>Date of Test: 9/29/2020 Time of Test: 10:28:28 AM | Schneider Electric |
|---|---|
| AVAILABLE CIRCUIT CHARACTERISTICS:<br>Osc. No: 28484 Calibration Date: 05/13/20<br>OCV = 481 V Rms Sym Current = 14.25 kA<br>Power Factor = 26% | High Power Laboratory, HPL3 Facility<br>Cedar Rapids, Iowa, USA |

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 43




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 279 Deg |
| Closing time (V0)+ | 12.92 m Sec |
| Peak Current (Ip) | 22.70 k Amperes |
| Time to Ip | 11.48 m Sec. |
| I²t | 3.087 M Amp^2sec |
| I Duration | 21.19 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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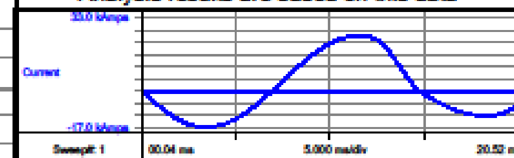
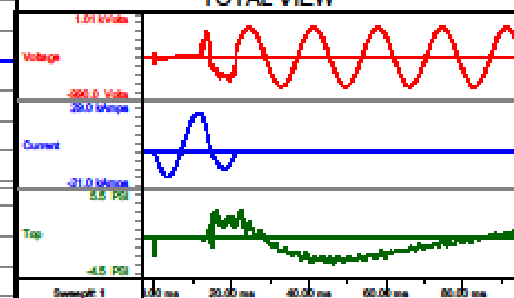
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

OSC. NO.: HPL3-34377

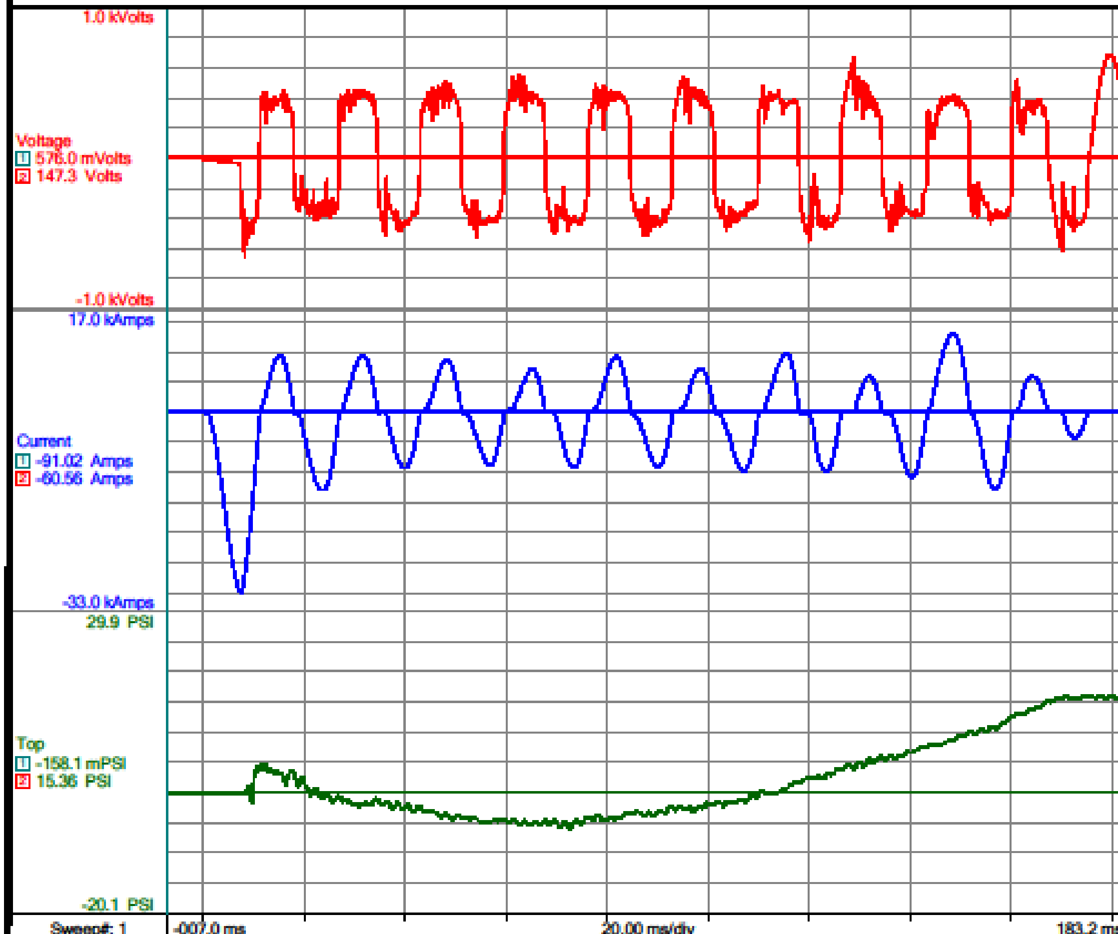
Oscillogram No.: HPL3-34378 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:34:12 AM

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 44




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 330 Deg |
| Closing time (V0)+ | 4.934 m Sec |
| Peak Current (Ip) | -30.08 k Amperes |
| Time to Ip | 6.569 m Sec. |
| I²t | 9.821 M Amp^2sec |
| I Duration | 174.2 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.

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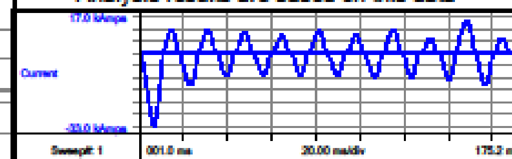
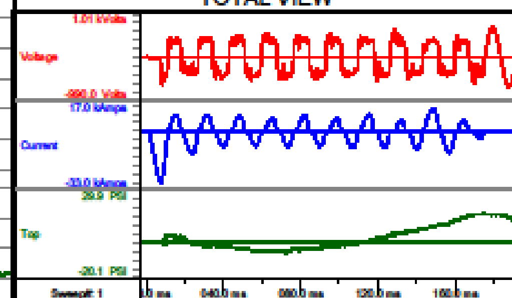
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-005, 1% PLOT FILE HPL3 CR_1_M
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 040-448
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34378

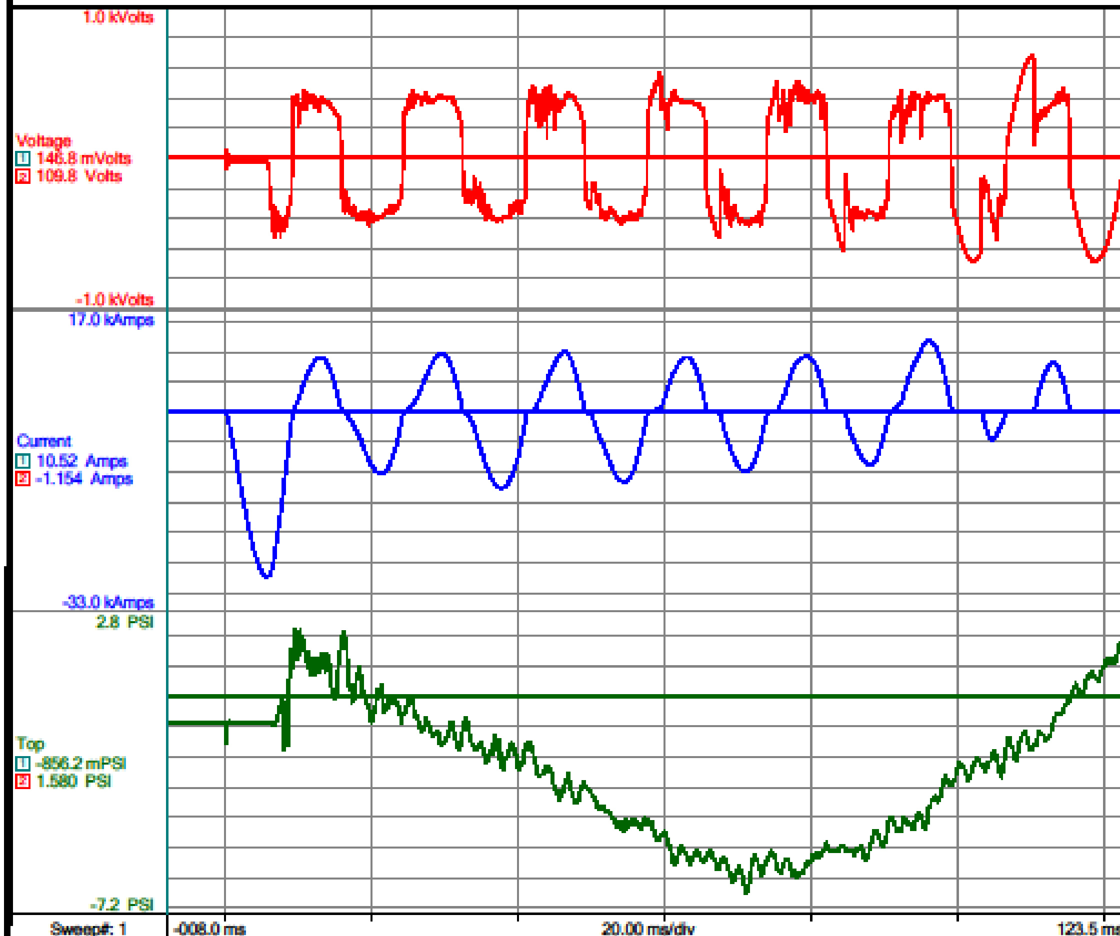
Oscillogram No.: HPL3-34379 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:39:40 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 45




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 222 Deg |
| Closing time (V0)+ | 10.29 m Sec |
| Peak Current (Ip) | -27.40 k Amperes |
| Time to Ip | 5.813 m Sec. |
| I²t | 7.417 M Amp^2sec |
| I Duration | 115.4 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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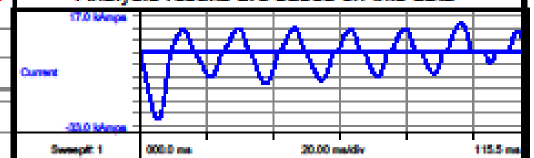
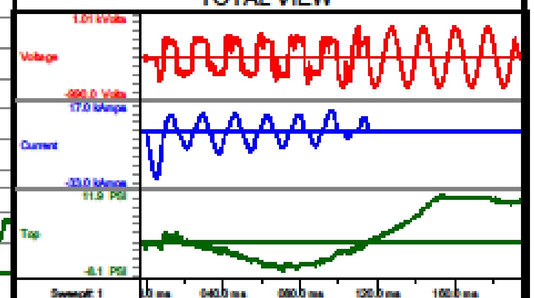
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34379

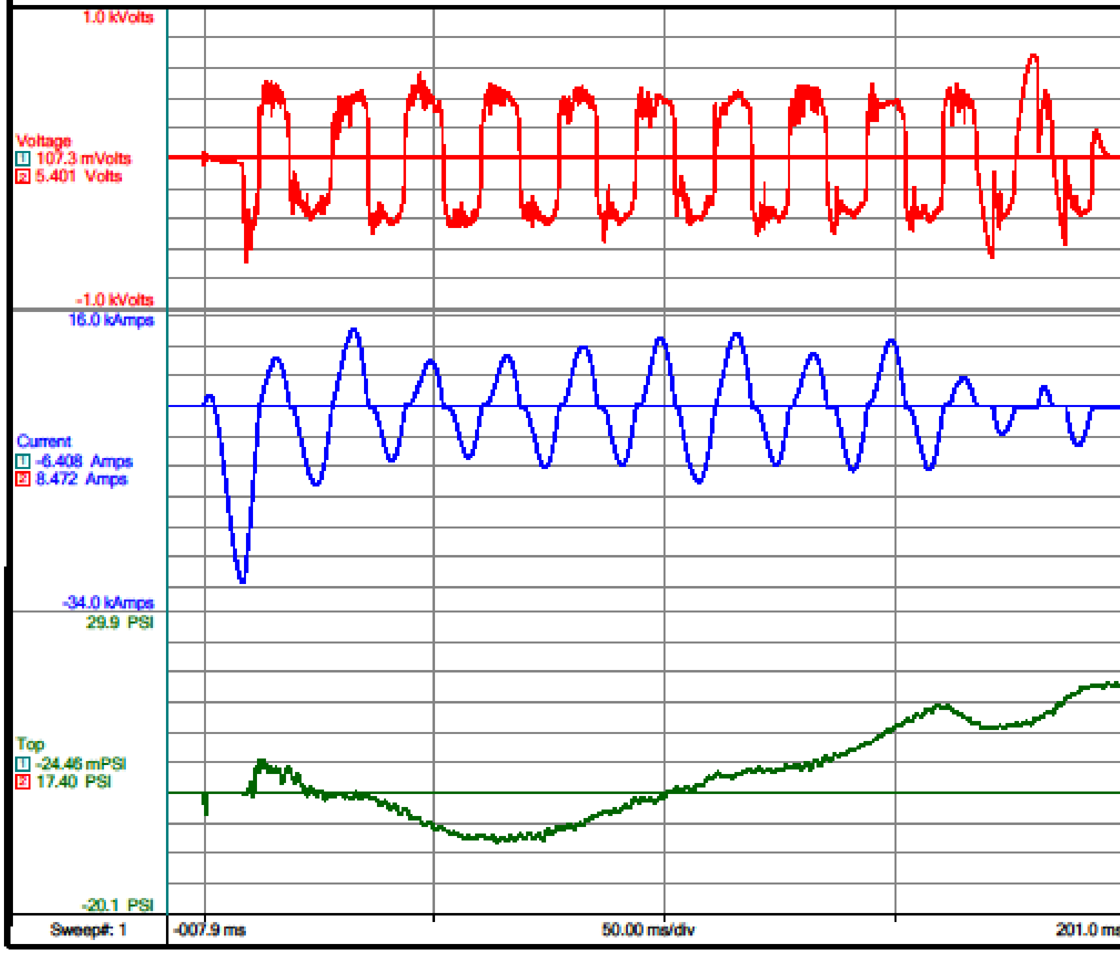
Oscillogram No.: HPL3-34380 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:46:33 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 46




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 162 Deg |
| Closing time (V0)+ | 17.97 µ Sec |
| Peak Current (Ip) | -29.42 k Amperes |
| Time to Ip | 8.509 m Sec. |
| I²t | 10.52 M Amp^2sec |
| I Duration | 192.9 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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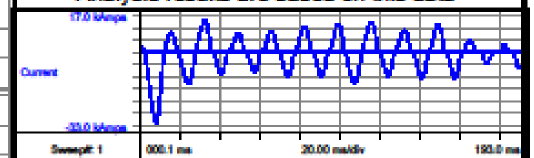
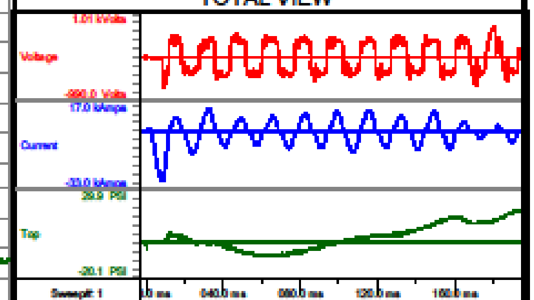
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

OSC. NO.: HPL3-34380

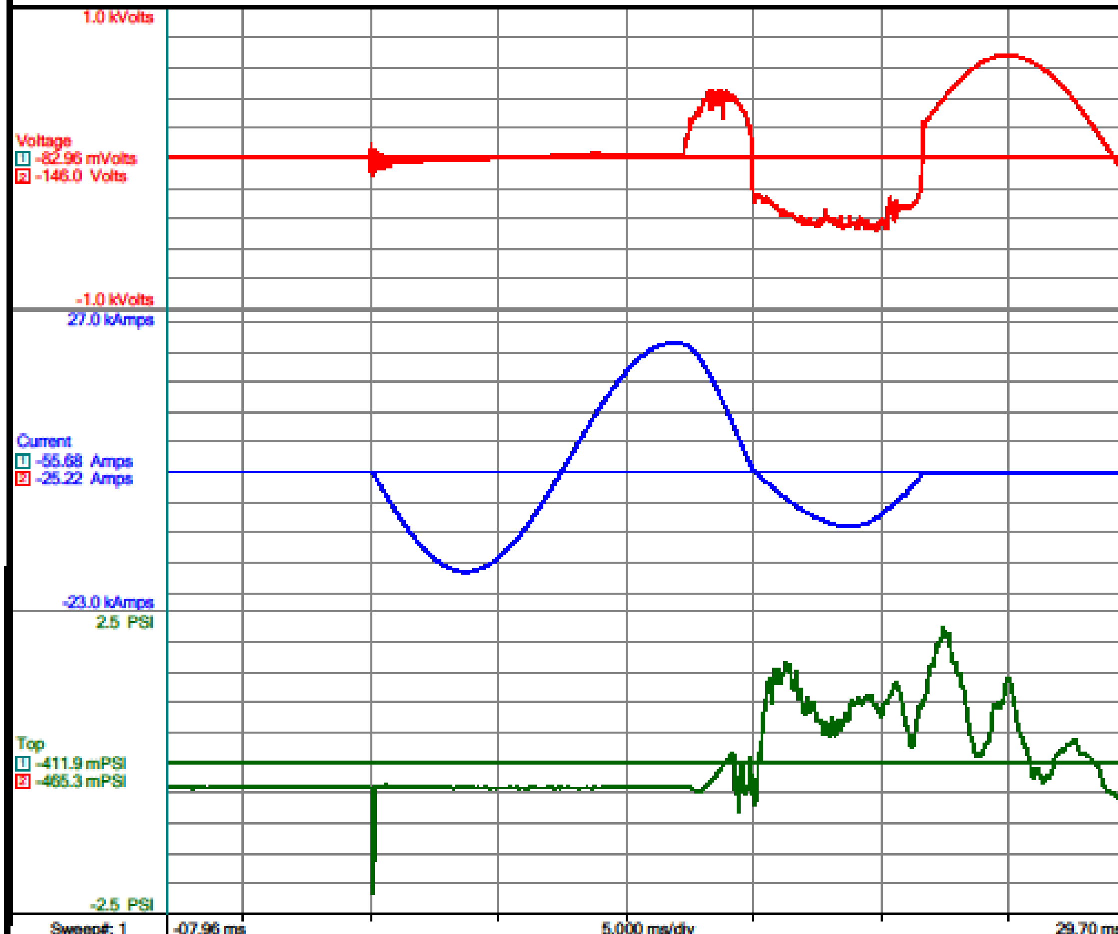
Oscillogram No.: HPL3-34381 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:53:17 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 47




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 272 Deg |
| Closing time (V0)+ | 12.60 m Sec |
| Peak Current (Ip) | 21.60 k Amperes |
| Time to Ip | 11.85 m Sec. |
| I²t | 3.024 M Amp^2sec |
| I Duration | 21.68 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.

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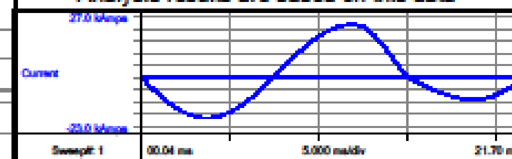
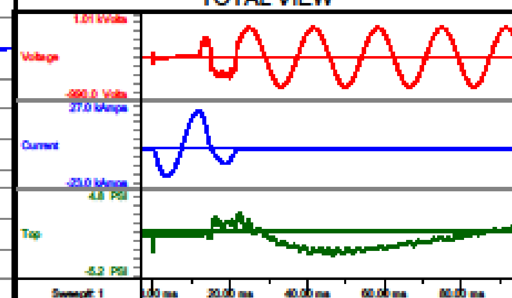
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis but not for display.

OSC. NO.: HPL3-34381

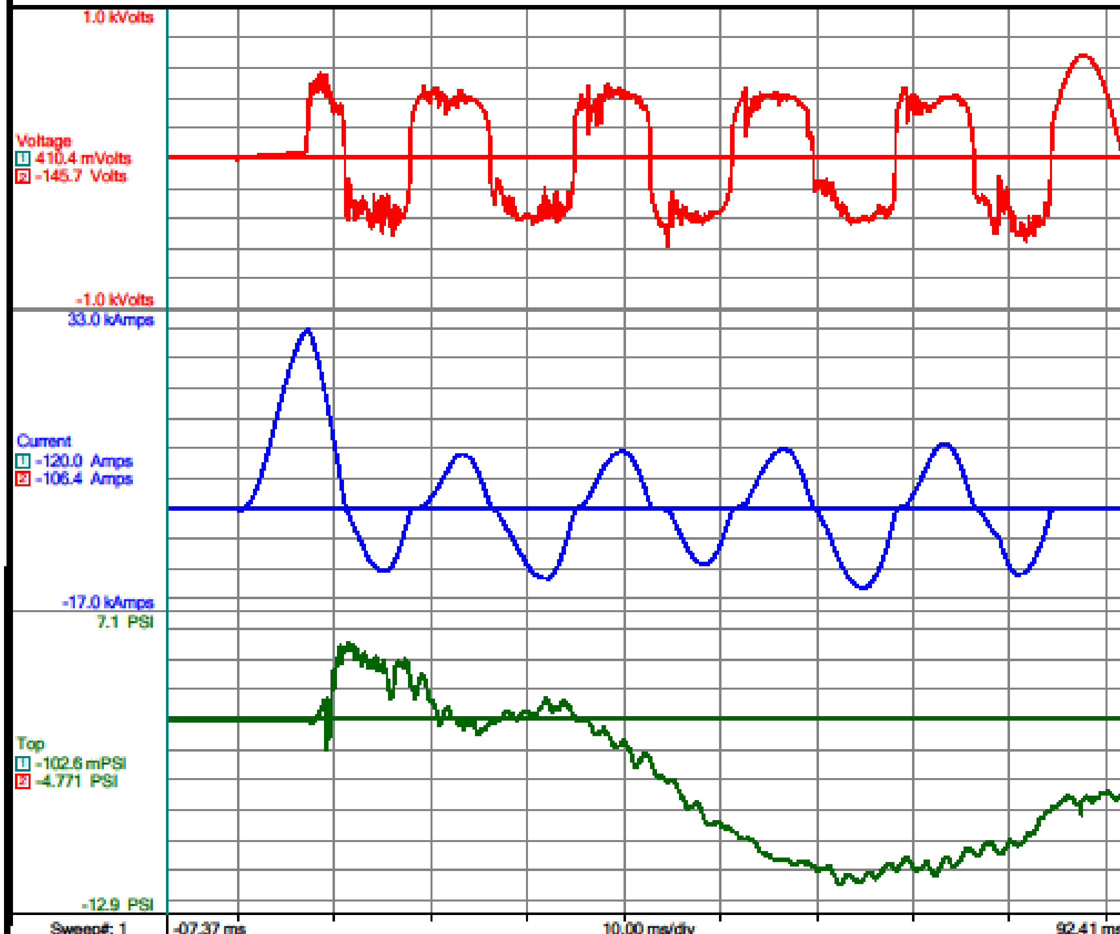
Oscillogram No.: HPL3-34382 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 10:57:50 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 48




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 10 Deg |
| Closing time (V0)+ | 451.9 µ Sec |
| Peak Current (Ip) | 29.80 k Amperes |
| Time to Ip | 6.578 m Sec. |
| I²t | 7.169 M Amp^2sec |
| I Duration | 83.78 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

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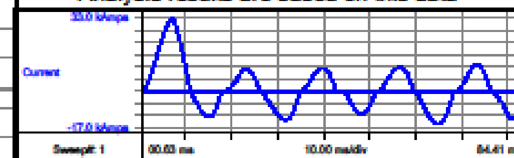
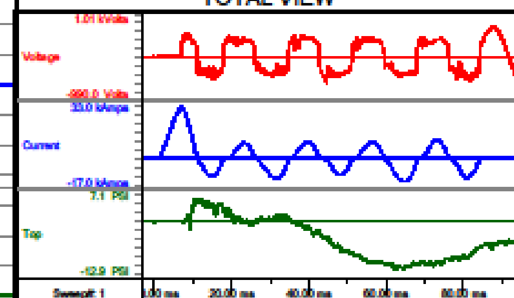
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 1000X Scope Probe, C/N 131-008, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 1000X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 040-448
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34382

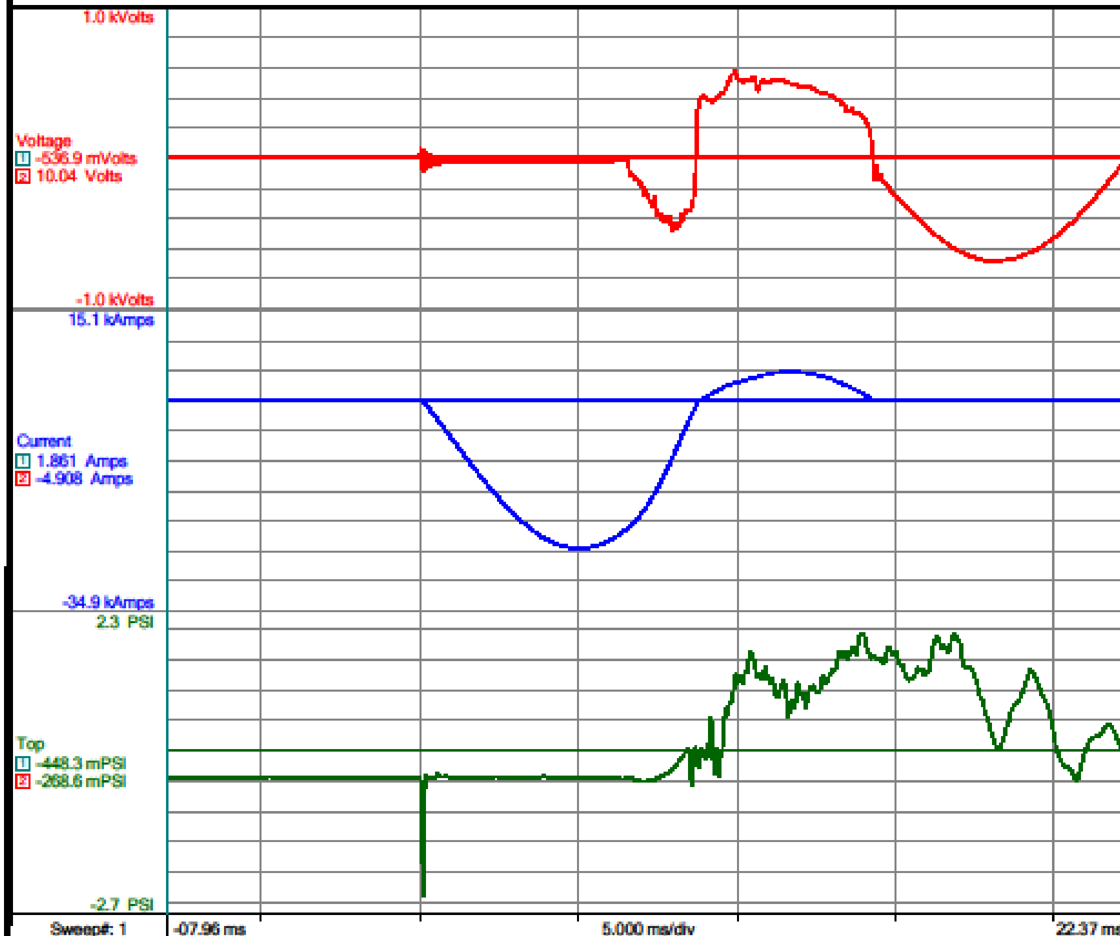
Oscillogram No.: HPL3-34383 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 11:02:58 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 49




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 239 Deg |
| Closing time (V0)+ | 11.06 m Sec |
| Peak Current (Ip) | -24.61 k Amperes |
| Time to Ip | 4.987 m Sec. |
| I²t | 2.754 M Amp^2sec |
| I Duration | 14.32 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

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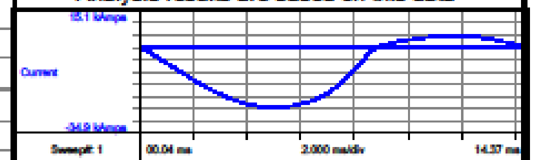
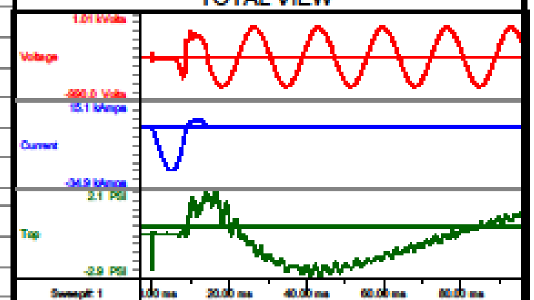
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]

VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE [illegible]

VOLTAGE [illegible] Probe, C/N [illegible], 1%

CURRENT ROGOWSKI COIL, C/N [illegible]

NOTE: Channel offset removed for analysis

but not for display.

OSC. NO.: HPL3-34383

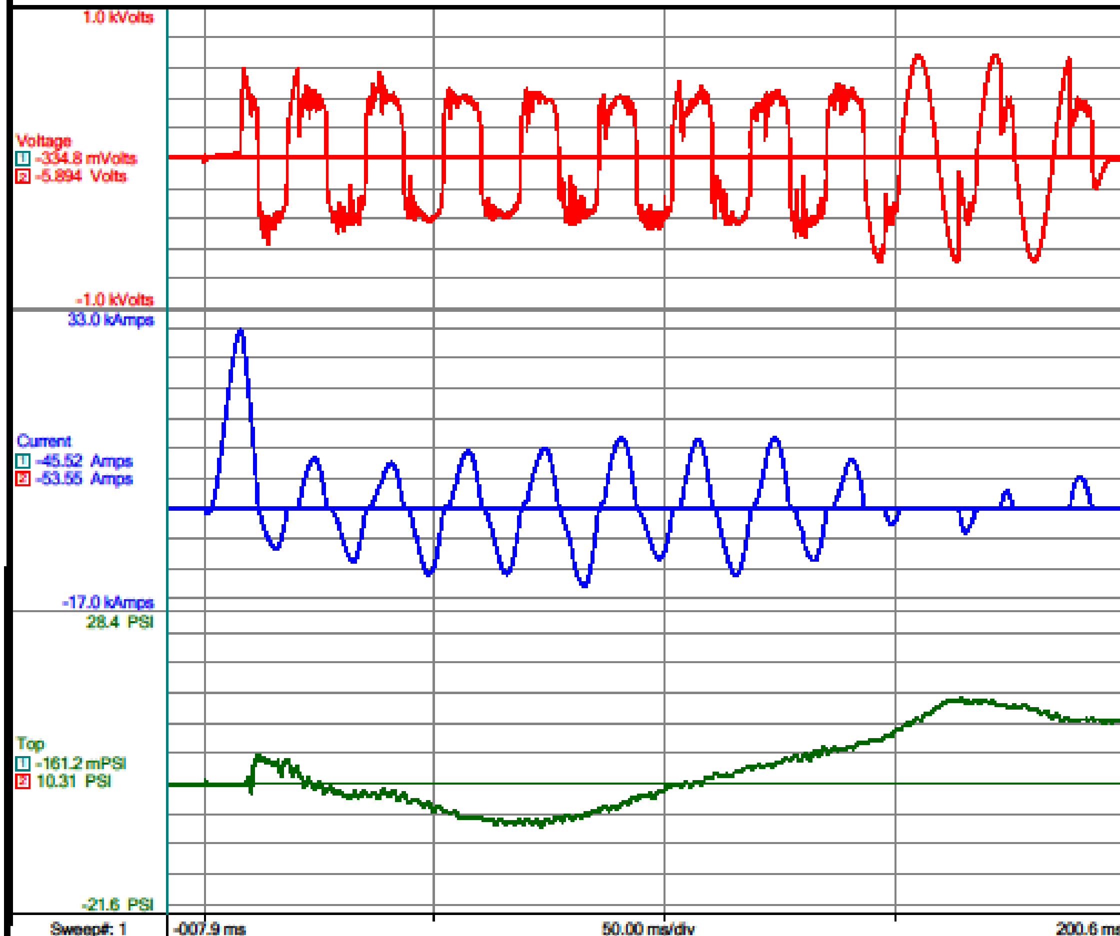
Oscillogram No.: HPL3-34384  OCV = 488 V
Date of Test: 9/29/2020  Time of Test: 11:07:00 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484  Calibration Date: 05/13/20
OCV = 481 V  Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332  TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 50




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 189 Deg |
| Closing time (V0)+ | 18.38 µ Sec |
| Peak Current (Ip) | 29.74 k Amperes |
| Time to Ip | 7.922 m Sec. |
| I²t | 9.282 M Amp^2sec |
| I Duration | 192.5 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.

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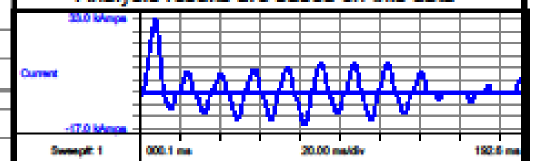
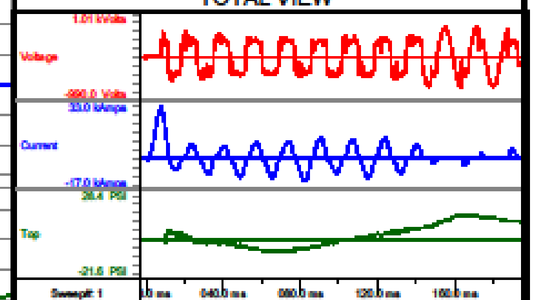
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]

VOLTAGE: [illegible] Probe, C/N [illegible], 1%  PLOT FILE:HPL3 [illegible]

VOLTAGE: [illegible] Probe, C/N [illegible], 1%

CURRENT: ROGOWSKI COIL, C/N [illegible]

NOTE: Channel offset removed for analysis, but not for display.

**OSC. NO.: HPL3-34384**

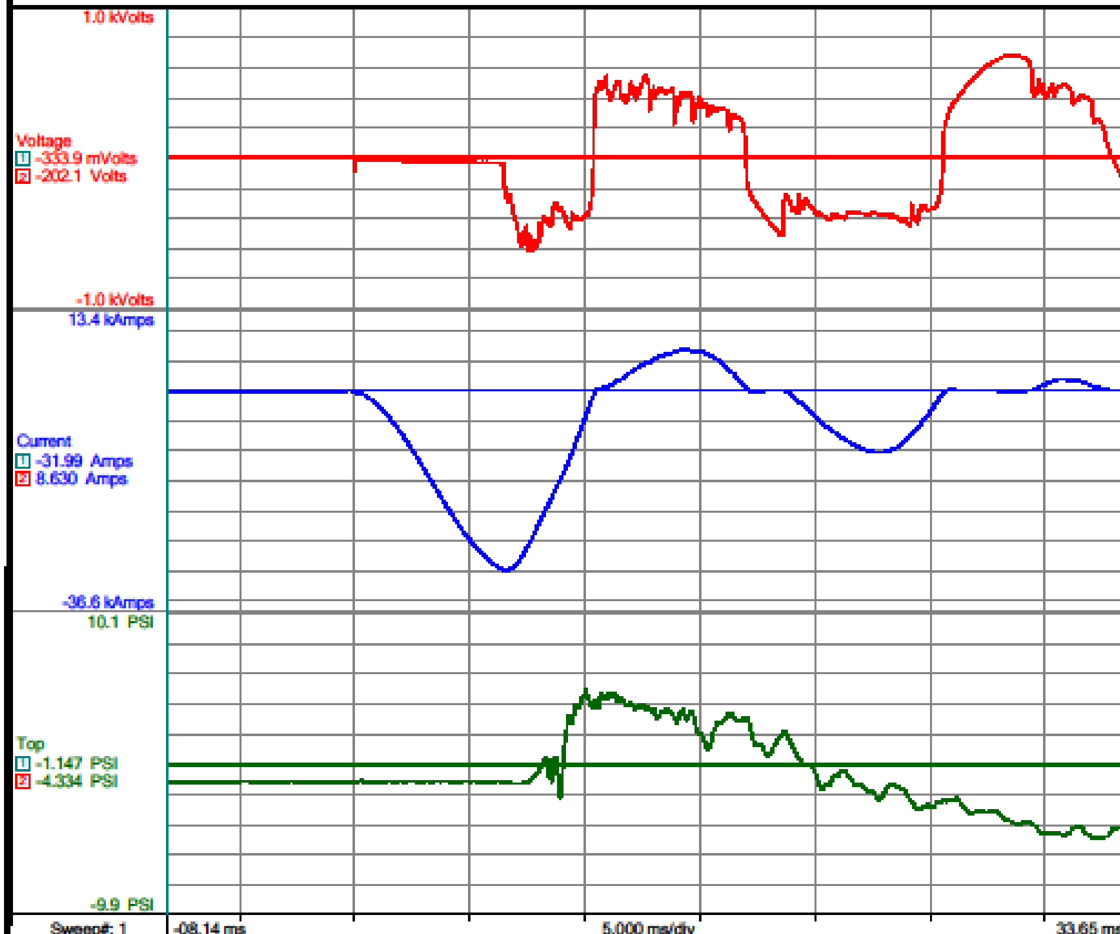
Oscillogram No.: HPL3-34385 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 11:11:37 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 51




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 187 Deg |
| Closing time (V0)+ | 8.843 m Sec |
| Peak Current (Ip) | -29.98 k Amperes |
| Time to Ip | 6.731 m Sec. |
| I²t | 4.102 M Amp^2sec |
| I Duration | 25.79 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.
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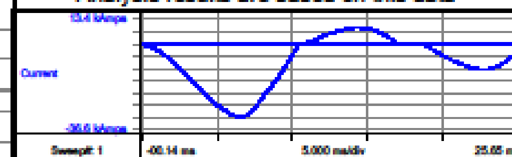
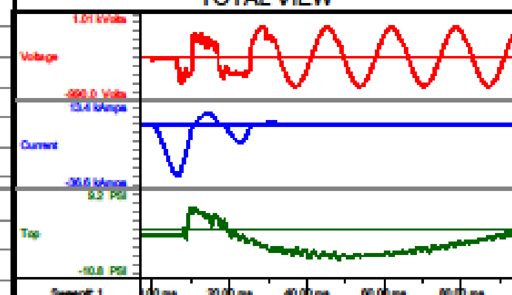
Analysis results are based on this data




TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173
VOLTAGE 1000X Bugge Probe, C/N 131-888, 1%    PLOT FILE HPL3 CR_1_M
VOLTAGE 1000X Bugge Probe, C/N 131-884, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34385

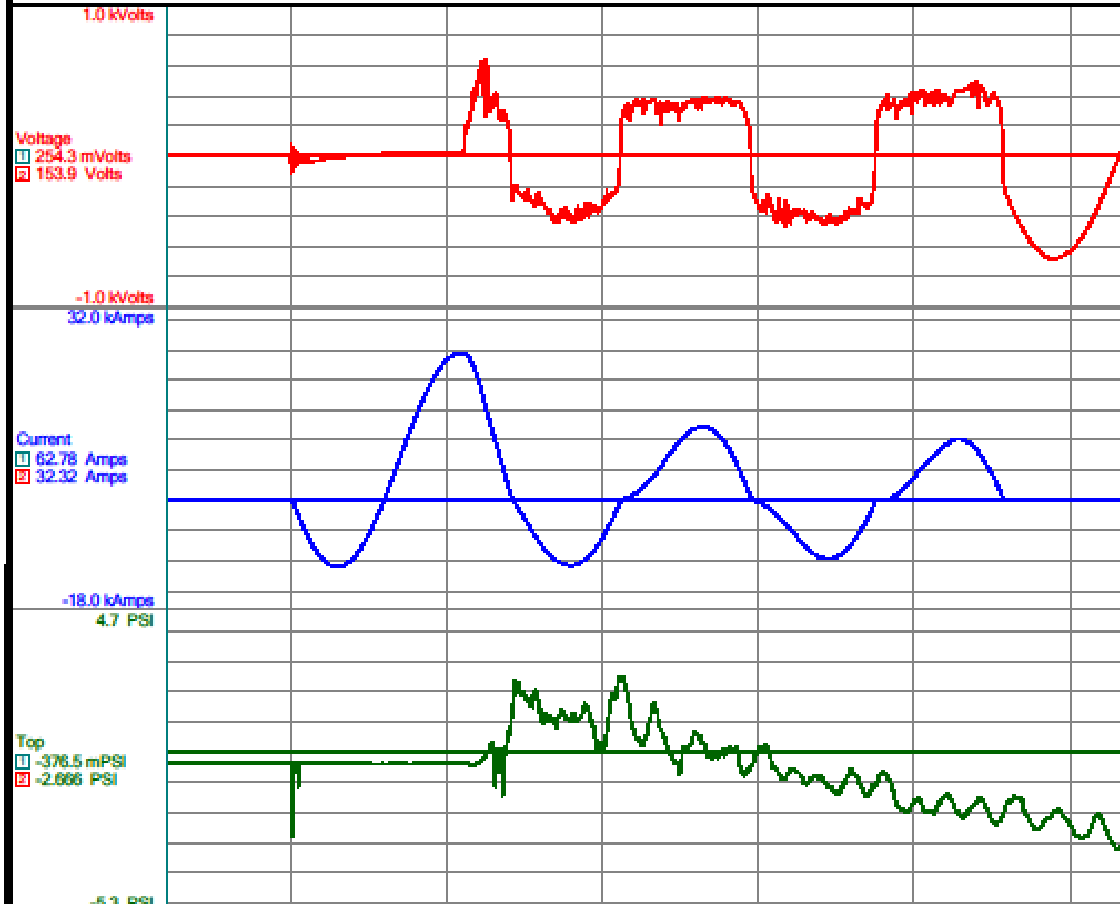
Oscillogram No.: HPL3-34386 OCV = 488 V
Date of Test: 9/29/2020 Time of Test: 11:15:17 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28484 Calibration Date: 05/13/20
OCV = 481 V Rms Sym Current = 14.25 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 52

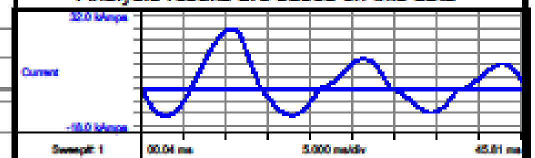



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 292 Deg |
| Closing time (V0)+ | 13.50 m Sec |
| Peak Current (Ip) | 24.37 k Amperes |
| Time to Ip | 10.84 m Sec. |
| I²t | 4.272 M Amp^2sec |
| I Duration | 45.77 m Sec. |

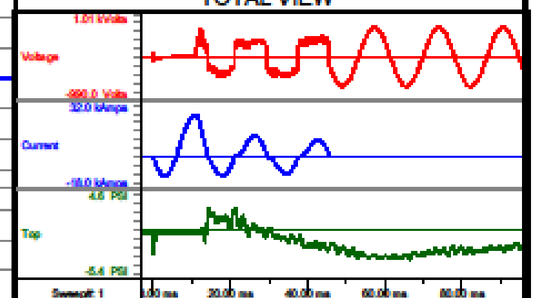
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 18 in. |
| - |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1%
VOLTAGE [illegible] Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis [illegible] for display.
PLOT FILE [illegible]

OSC. NO.: HPL3-34386

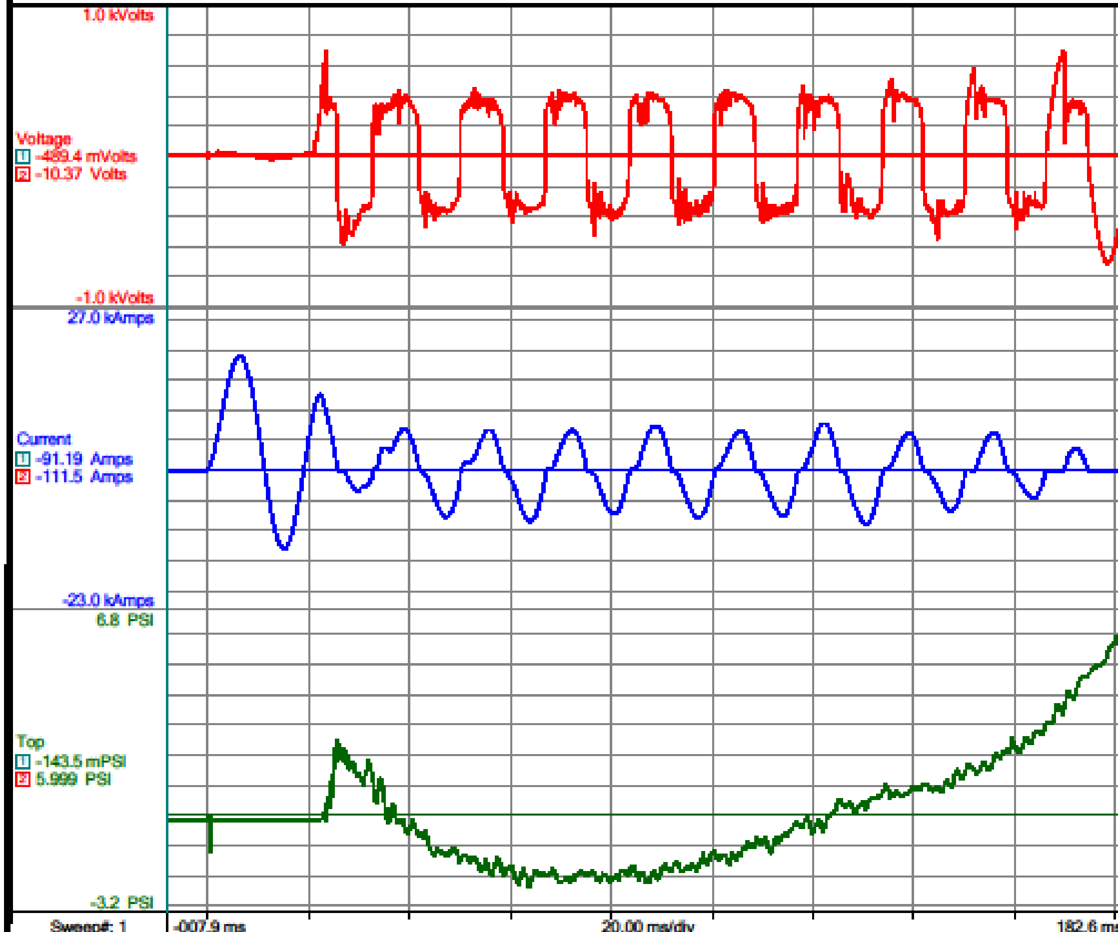
Oscillogram No.: HPL3-34389 OCV = 503 V
Date of Test: 9/29/2020 Time of Test: 12:29:06 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 27476 Calibration Date: 03/25/20
OCV = 500 V Rms Sym Current = 10.53 kA
Power Factor = 41%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 53




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 101 Deg |
| Closing time (V0)+ | 303.6 μ Sec |
| Peak Current (Ip) | 19.09 k Amperes |
| Time to Ip | 6.370 m Sec. |
| I²t | 5.985 M Amp^2sec |
| I Duration | 174.5 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 18 in. |
| - |
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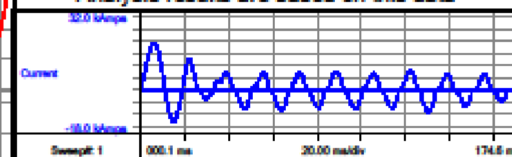
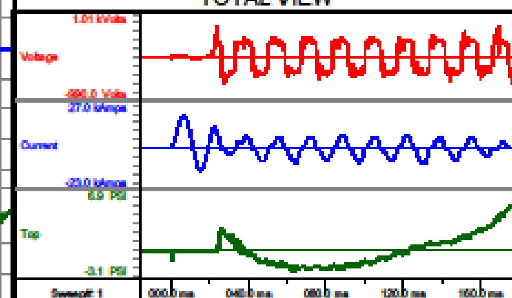
Analysis results are based on this data




TOTAL VIEW



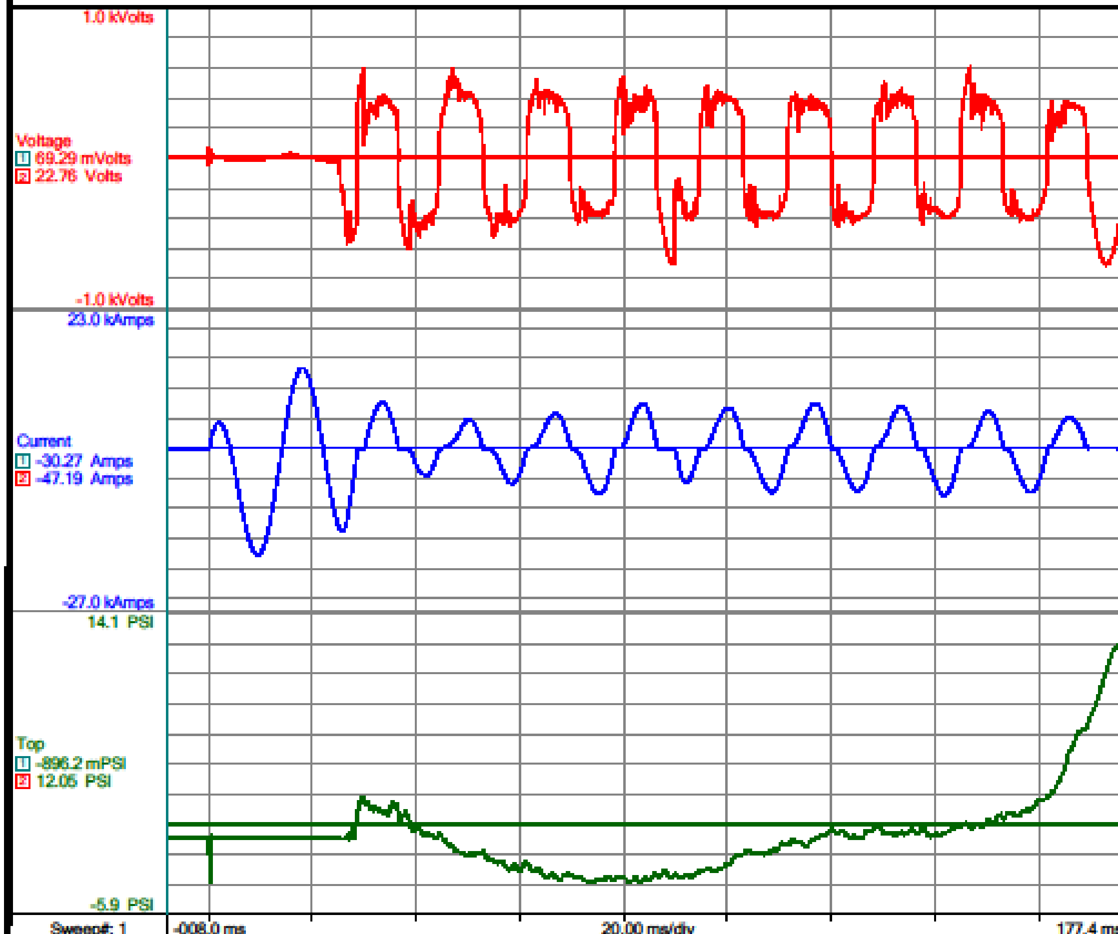

INSTRUMENTATION DATA

Data Recording System HBM GEN3T C/N 083-173
VOLTAGE 1000X Surge Probe, C/N 131-030, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 1000X Surge Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 040-448
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34389

| Oscillogram No.: HPL3-34390 OCV = 503 V<br>Date of Test: 9/29/2020 Time of Test: 12:33:31 PM | Schneider Electric |
|---|---|
| AVAILABLE CIRCUIT CHARACTERISTICS:<br>Osc. No: 27476 Calibration Date: 03/25/20<br>OCV = 500 V Rms Sym Current = 10.53 kA<br>Power Factor = 41% | High Power Laboratory, HPL3 Facility<br>Cedar Rapids, Iowa, USA |

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 54




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 302 Deg |
| Closing time (V0)+ | 1.498 m Sec |
| Peak Current (Ip) | -17.80 k Amperes |
| Time to Ip | 9.417 m Sec. |
| I²t | 5.351 M Amp^2sec |
| I Duration | 169.3 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.

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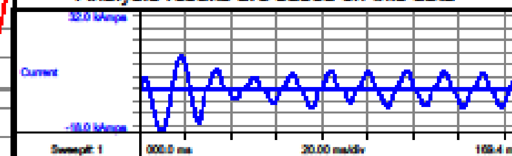
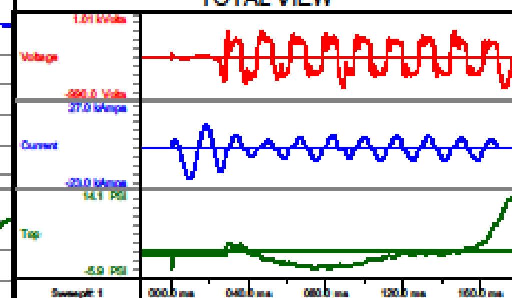
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE [illegible]
VOLTAGE [illegible] Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis, but not for display.

OSC. NO.: HPL3-34390

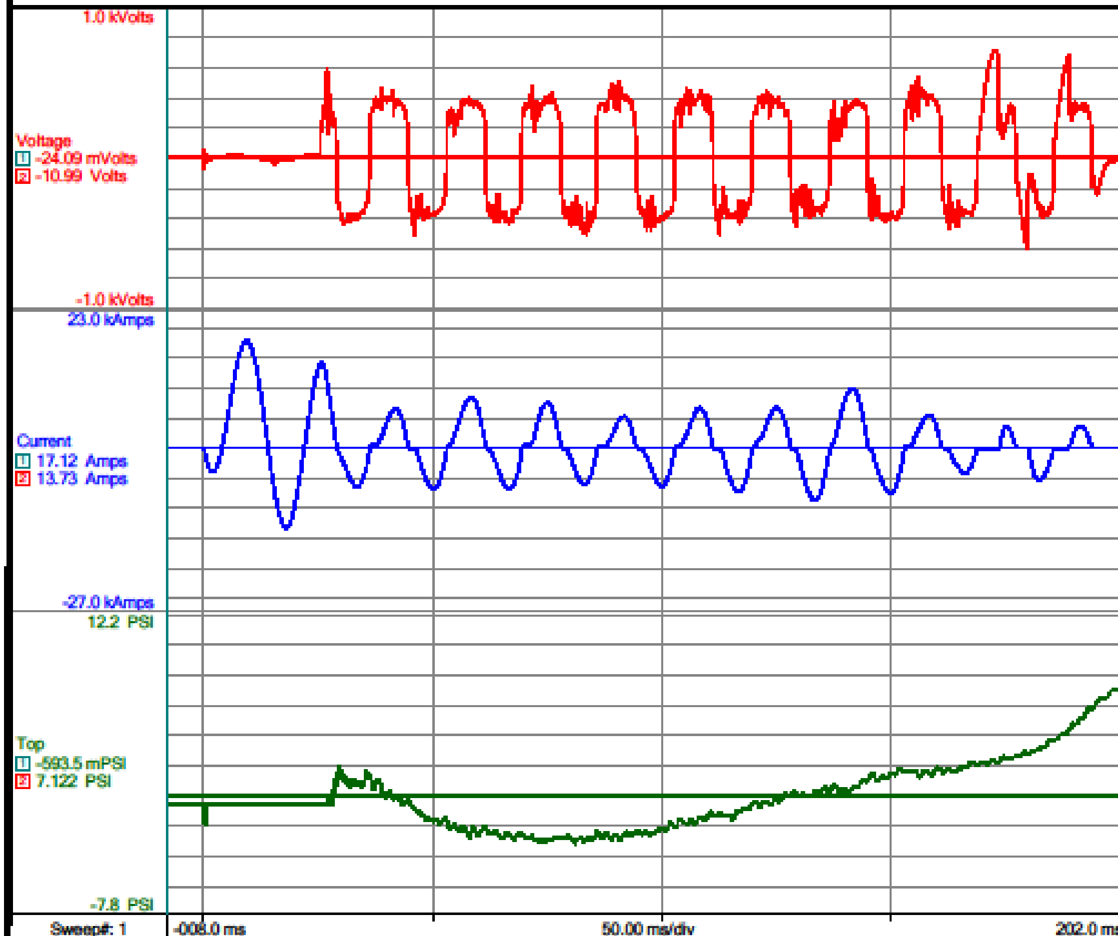
Oscillogram No.: HPL3-34391 OCV = 503 V
Date of Test: 9/29/2020 Time of Test: 12:39:09 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 27476 Calibration Date: 03/25/20
OCV = 500 V Rms Sym Current = 10.53 kA
Power Factor = 41%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 55




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 165 Deg |
| Closing time (V0)+ | 421.1 µ Sec |
| Peak Current (Ip) | 17.86 k Amperes |
| Time to Ip | 9.325 m Sec. |
| I²t | 5.956 M Amp^2sec |
| I Duration | 194.0 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 18 in. |
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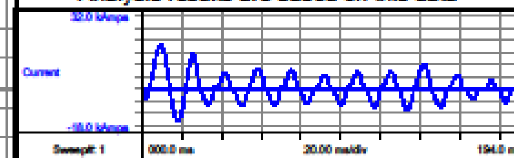
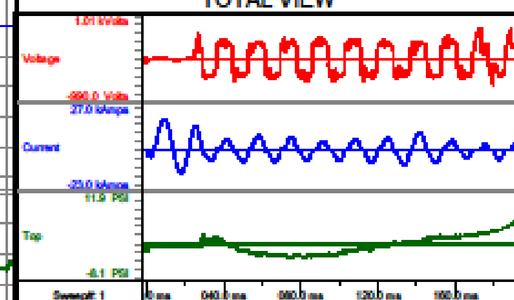
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Scope Probe, C/N [illegible], 1% PLOT FILE [illegible]
VOLTAGE [illegible] Scope Probe, C/N [illegible], 1%
CURRENT [illegible] COIL, C/N [illegible]
NOTE: Channel offset removed for analysis [illegible]

OSC. NO.: HPL3-34391

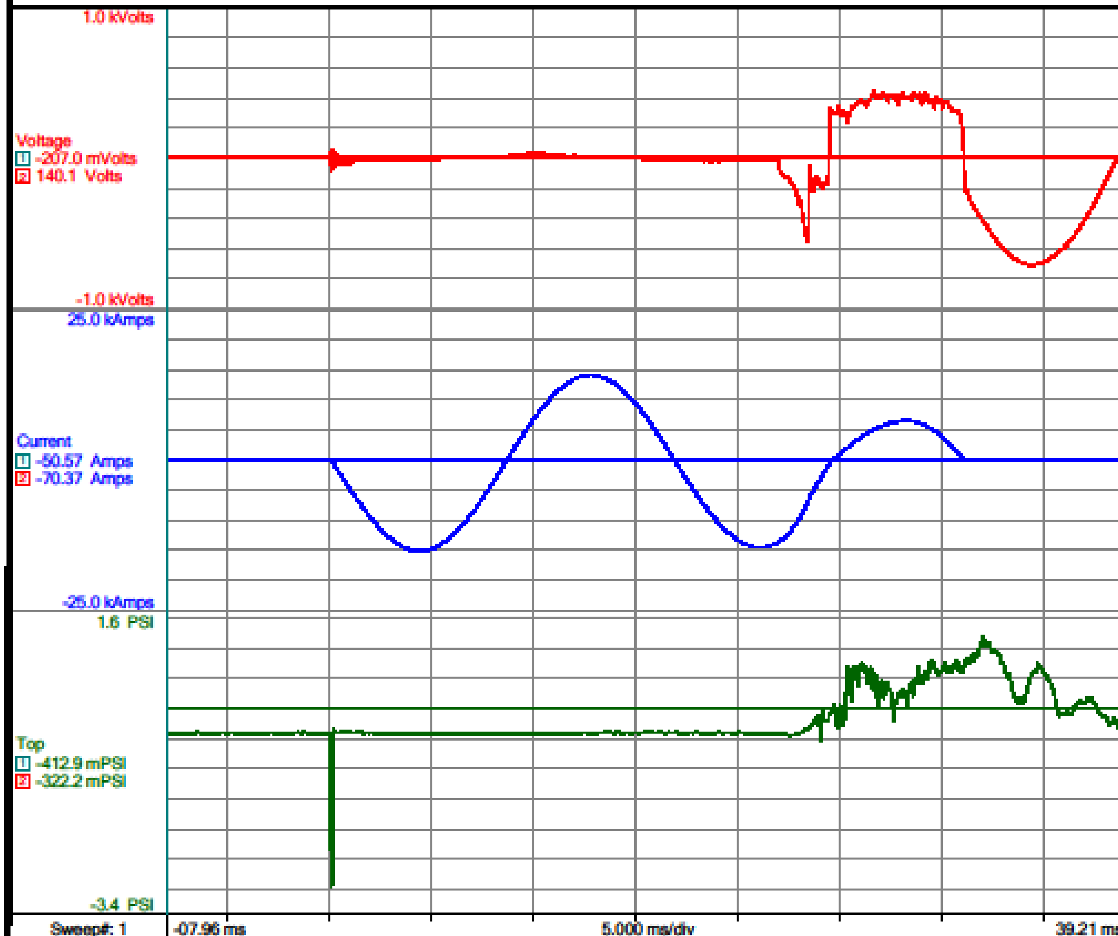
Oscillogram No.: HPL3-34392 OCV = 503 V
Date of Test: 9/29/2020 Time of Test: 12:44:36 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 27476 Calibration Date: 03/25/20
OCV = 500 V Rms Sym Current = 10.53 kA
Power Factor = 41%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 56




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 248 Deg |
| Closing time (V0)+ | 11.38 m Sec |
| Peak Current (Ip) | -15.12 k Amperes |
| Time to Ip | 4.398 m Sec. |
| Pt | 2.757 M Amp^2sec |
| I Duration | 31.17 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.

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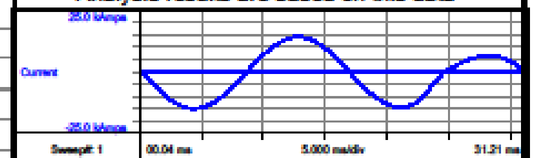
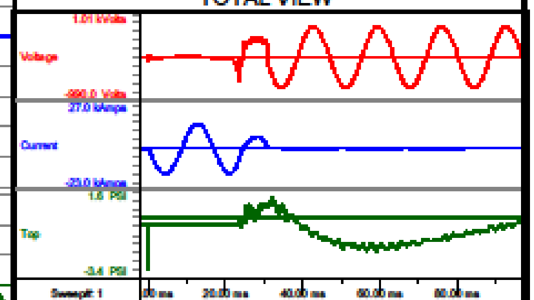
Analysis results are based on this data




TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]

VOLTAGE [illegible] PLOT FILE [illegible]

VOLTAGE [illegible]

CURRENT [illegible]

NOTE: Channel offset removed for analysis [illegible]

OSC. NO.: HPL3-34392

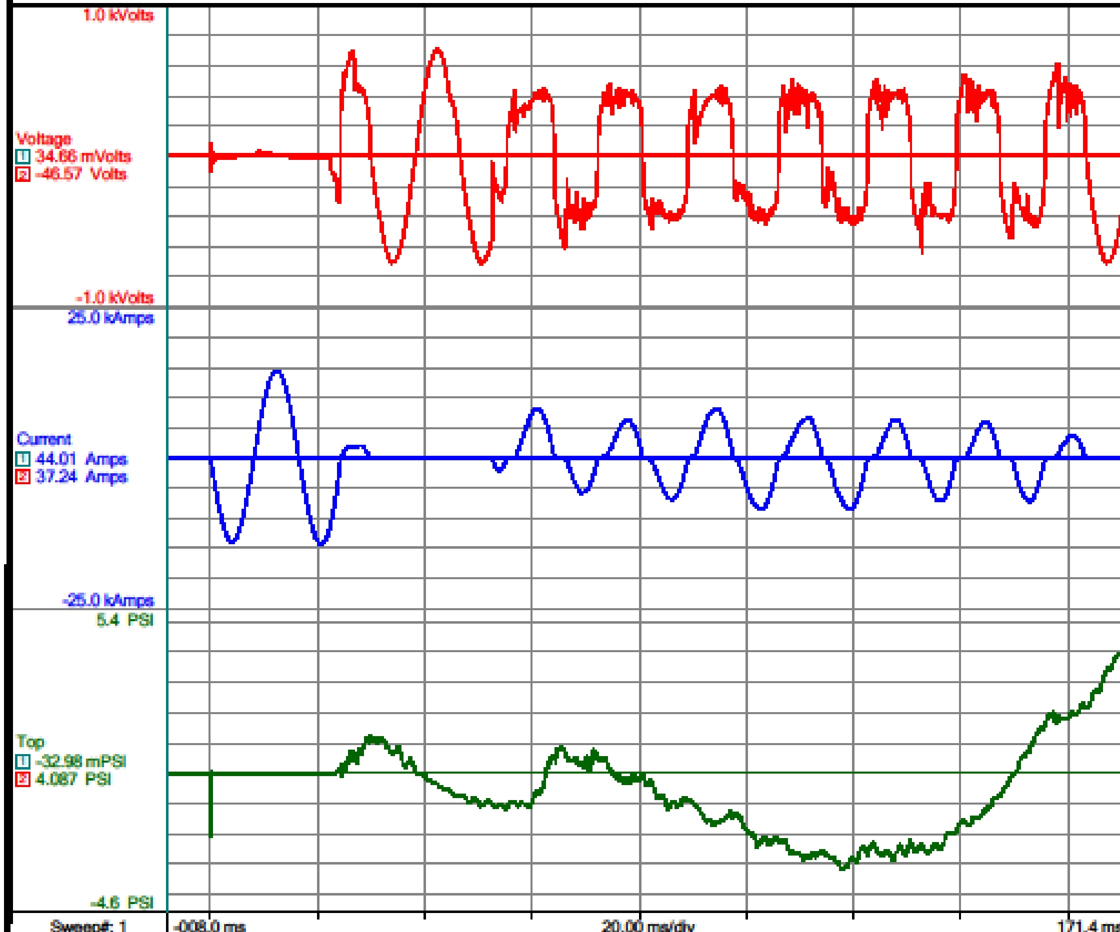
Oscillogram No.: HPL3-34393 OCV = 503 V
Date of Test: 9/29/2020 Time of Test: 12:49:12 PM

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 27476 Calibration Date: 03/25/20
OCV = 500 V Rms Sym Current = 10.53 kA
Power Factor = 41%

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 57




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 233 Deg |
| Closing time (V0)+ | 10.21 m Sec |
| Peak Current (Ip) | 14.52 k Amperes |
| Time to Ip | 12.38 m Sec. |
| Pt | 4.700 M Amp^2sec |
| I Duration | 163.4 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.
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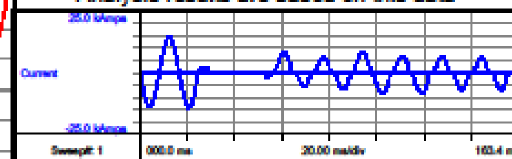
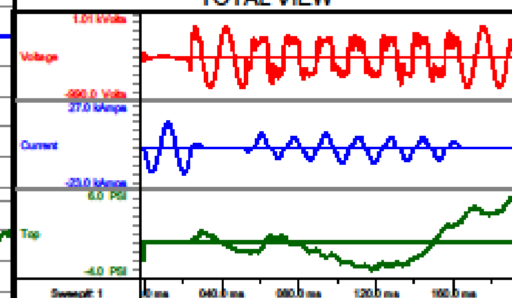
## Analysis results are based on this data




## TOTAL VIEW



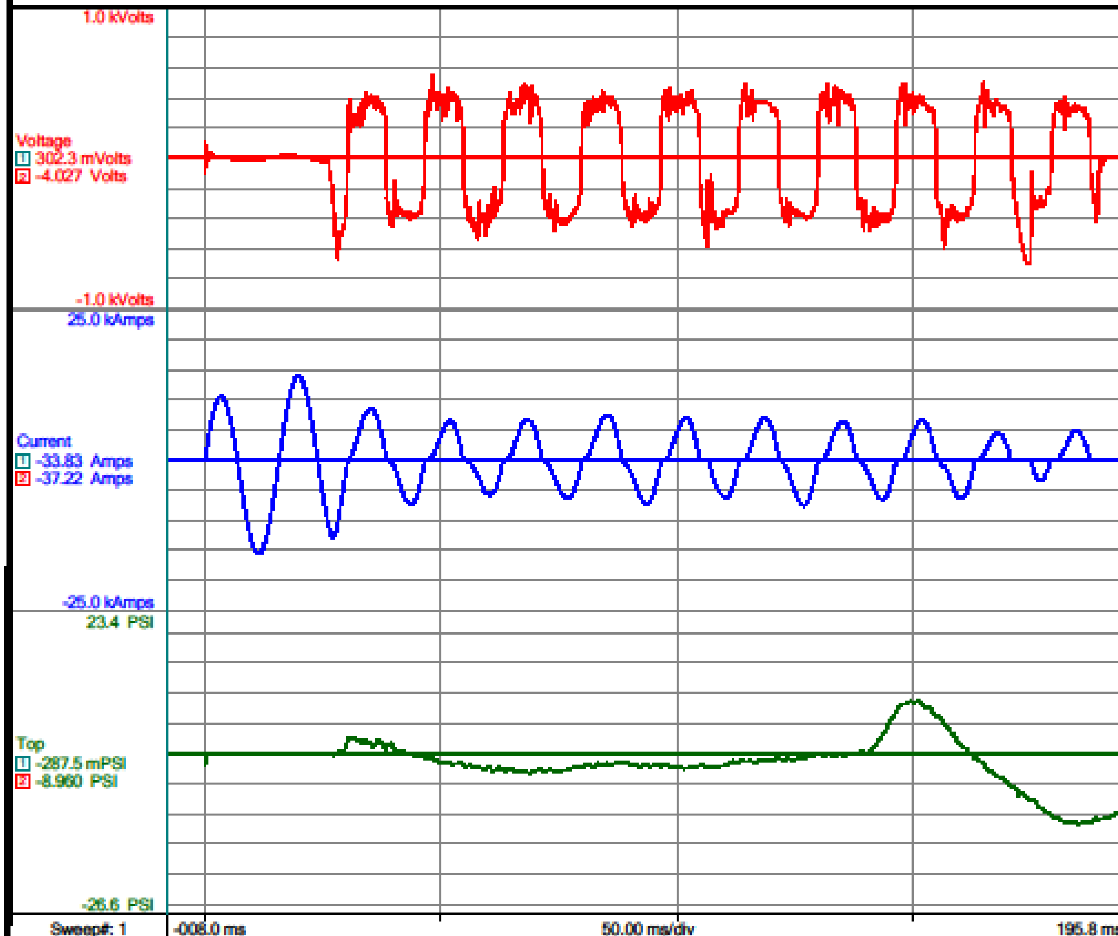

## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173
VOLTAGE 100X Scope Probe, C/N 131-658, 1% PLOT FILE HPL3 CR_1_M
VOLTAGE 100X Scope Probe, C/N 131-654, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis.
but not for display.

OSC. NO.: HPL3-34393

| | |
|---|---|
| Oscillogram No.: HPL3-34394 OCV = 503 V<br>Date of Test: 9/29/2020 Time of Test: 12:56:35 PM | **Schneider Electric**<br>High Power Laboratory, HPL3 Facility<br>Cedar Rapids, Iowa, USA |
| AVAILABLE CIRCUIT CHARACTERISTICS:<br>Osc. No: 27476 Calibration Date: 03/25/20<br>OCV = 500 V Rms Sym Current = 10.53 kA<br>Power Factor = 41% | |

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 58




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 47 Deg |
| Closing time (V0)+ | 25.74 µ Sec |
| Peak Current (Ip) | -15.63 k Amperes |
| Time to Ip | 11.38 m Sec. |
| I²t | 5.538 M Amp^2sec |
| I Duration | 187.8 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.
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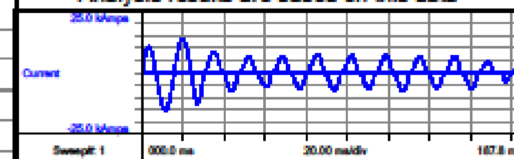
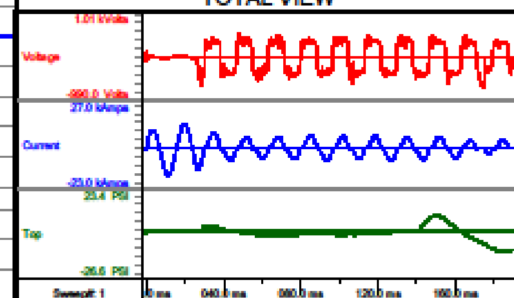
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN3T C/N 063-173
VOLTAGE 100X Scope Probe, C/N 131-000, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 040-440
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34394

Oscillogram No.: HPL3-34395 OCV = 503 V
Date of Test: 9/29/2020 Time of Test: 1:04:10 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 27476 Calibration Date: 03/25/20
OCV = 500 V Rms Sym Current = 10.53 kA
Power Factor = 41%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 59

| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 188 Deg |
| Closing time (V0)+ | 8.881 m Sec |
| Peak Current (Ip) | -19.27 k Amperes |
| Time to Ip | 6.758 m Sec. |
| I²t | 3.560 M Amp^2sec |
| I Duration | 58.88 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

18 in.

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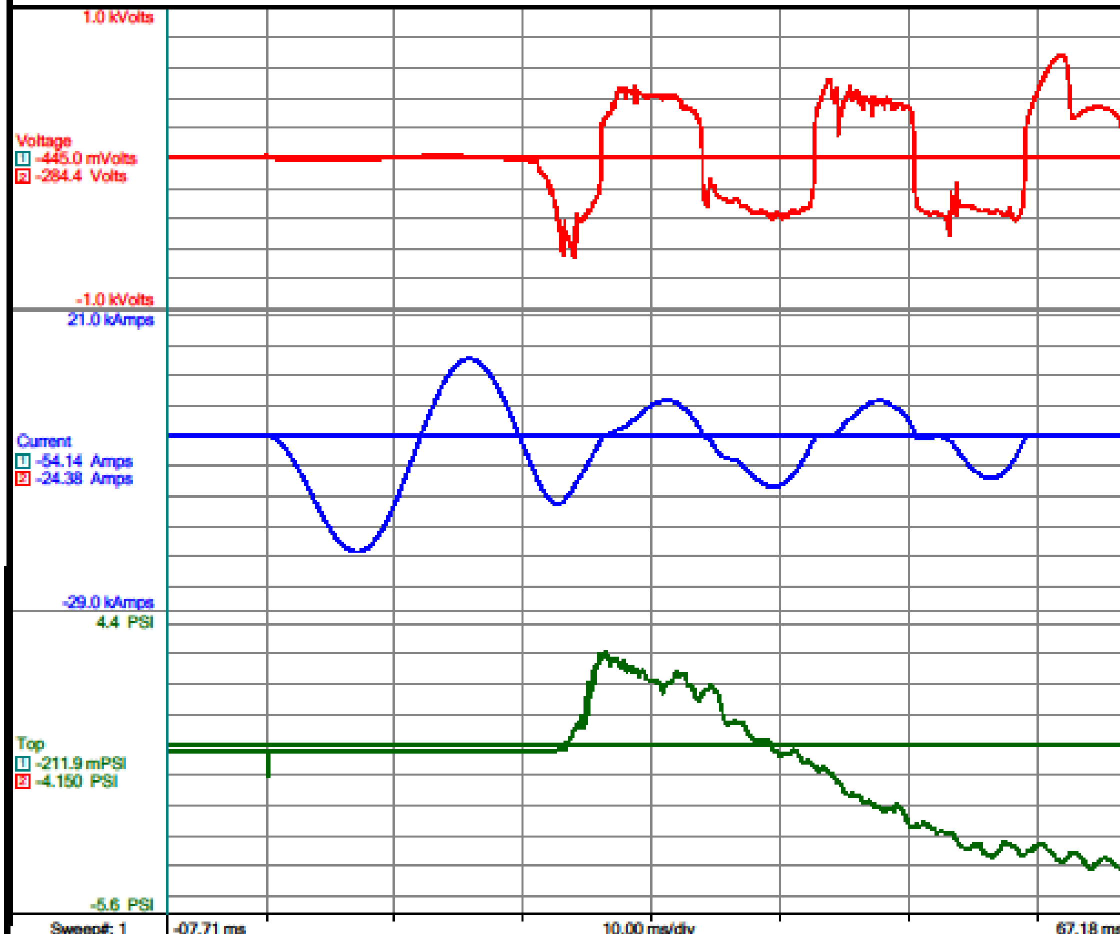
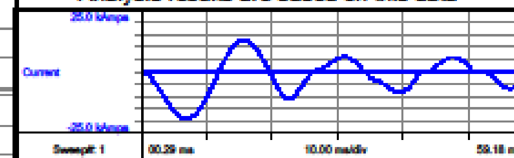
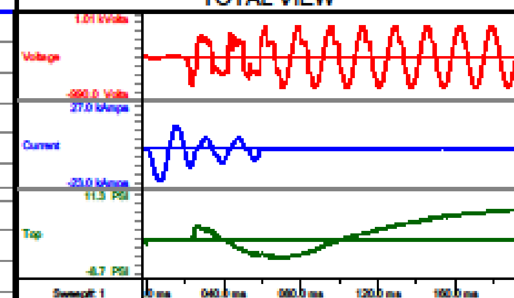



Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

[illegible]

NOTE: Channel offset removed for analysis but not for display.

OSC. NO.: HPL3-34395

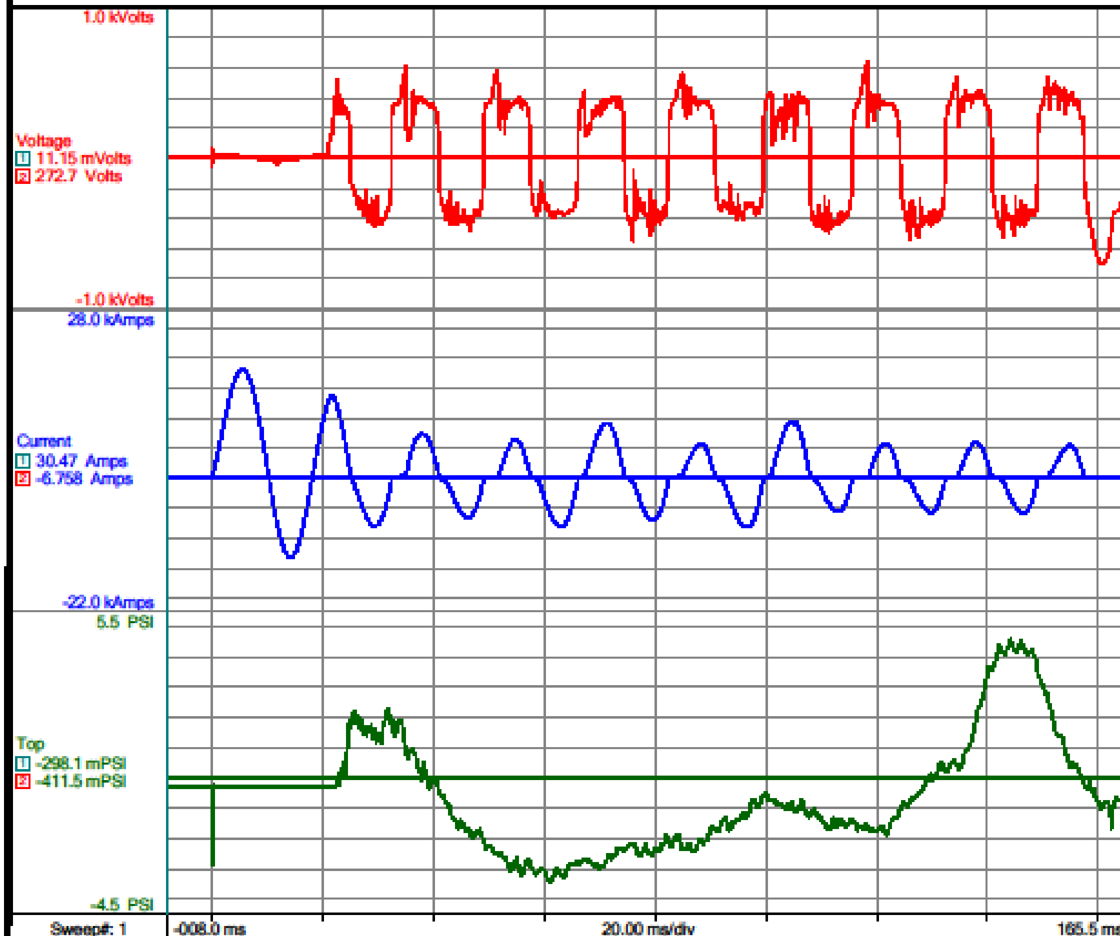
Oscillogram No.: HPL3-34396 OCV = 503 V
Date of Test: 9/29/2020 Time of Test: 1:08:25 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 27476 Calibration Date: 03/25/20
OCV = 500 V Rms Sym Current = 10.53 kA
Power Factor = 41%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 60




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 249 Deg |
| Closing time (V0)+ | 2.298 m Sec |
| Peak Current (Ip) | 18.14 k Amperes |
| Time to Ip | 5.575 m Sec. |
| I²t | 5.581 M Amp^2sec |
| I Duration | 157.5 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.

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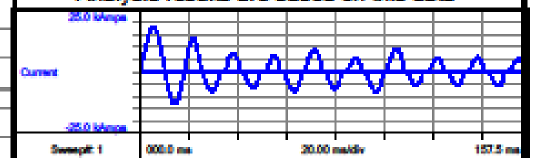
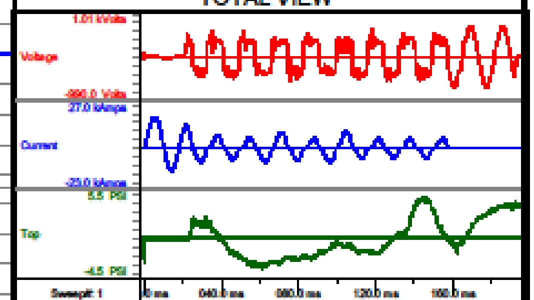
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

[illegible]

OSC. NO.: HPL3-34396

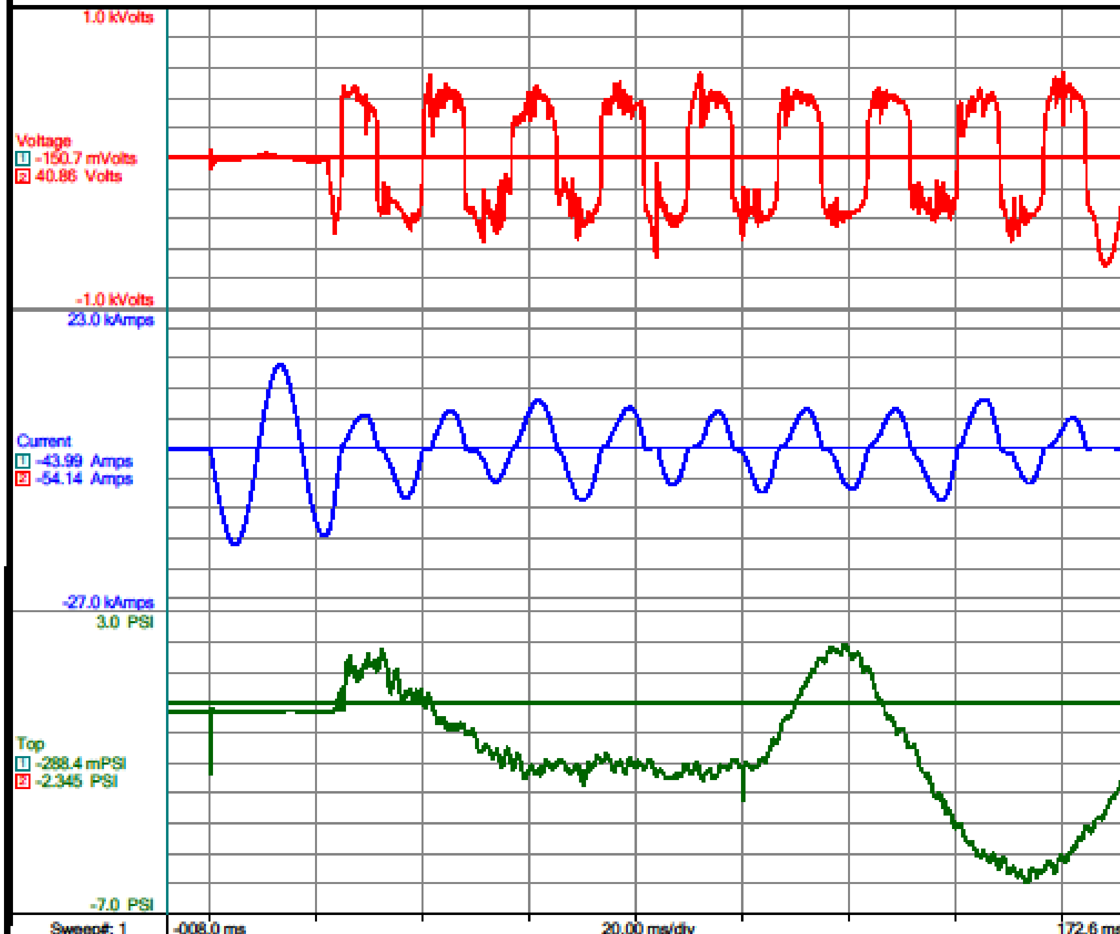
Oscillogram No.: HPL3-34397 OCV = 503 V
Date of Test: 9/29/2020 Time of Test: 1:14:01 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 27476 Calibration Date: 03/25/20
OCV = 500 V Rms Sym Current = 10.53 kA
Power Factor = 41%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 61




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 237 Deg |
| Closing time (V0)+ | 10.98 m Sec |
| Peak Current (Ip) | -18.14 k Amperes |
| Time to Ip | 4.677 m Sec. |
| I²t | 5.579 M Amp^2sec |
| I Duration | 164.5 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 18 in. |
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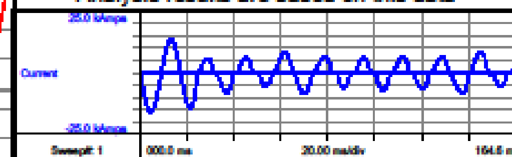
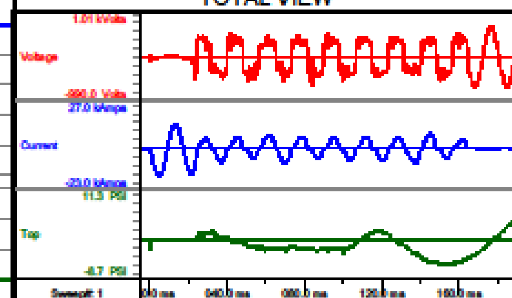
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 100X Scope Probe, C/N 131-850, 1%
VOLTAGE 100X Scope Probe, C/N 131-854, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis,
but not for display.

PLOT FILE HPL3 OR_1_8

OSC. NO.: HPL3-34397

Oscillogram No.: HPL3-34398 OCV = 503 V
Date of Test: 9/29/2020 Time of Test: 1:17:39 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 27476 Calibration Date: 03/25/20
OCV = 500 V Rms Sym Current = 10.53 kA
Power Factor = 41%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 62

| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 27 Deg |
| Closing time (V0)+ | 1.234 m Sec |
| Peak Current (Ip) | 18.68 k Amperes |
| Time to Ip | 5.918 m Sec. |
| I²t | 4.559 M Amp^2sec |
| I Duration | 133.0 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

18 in.

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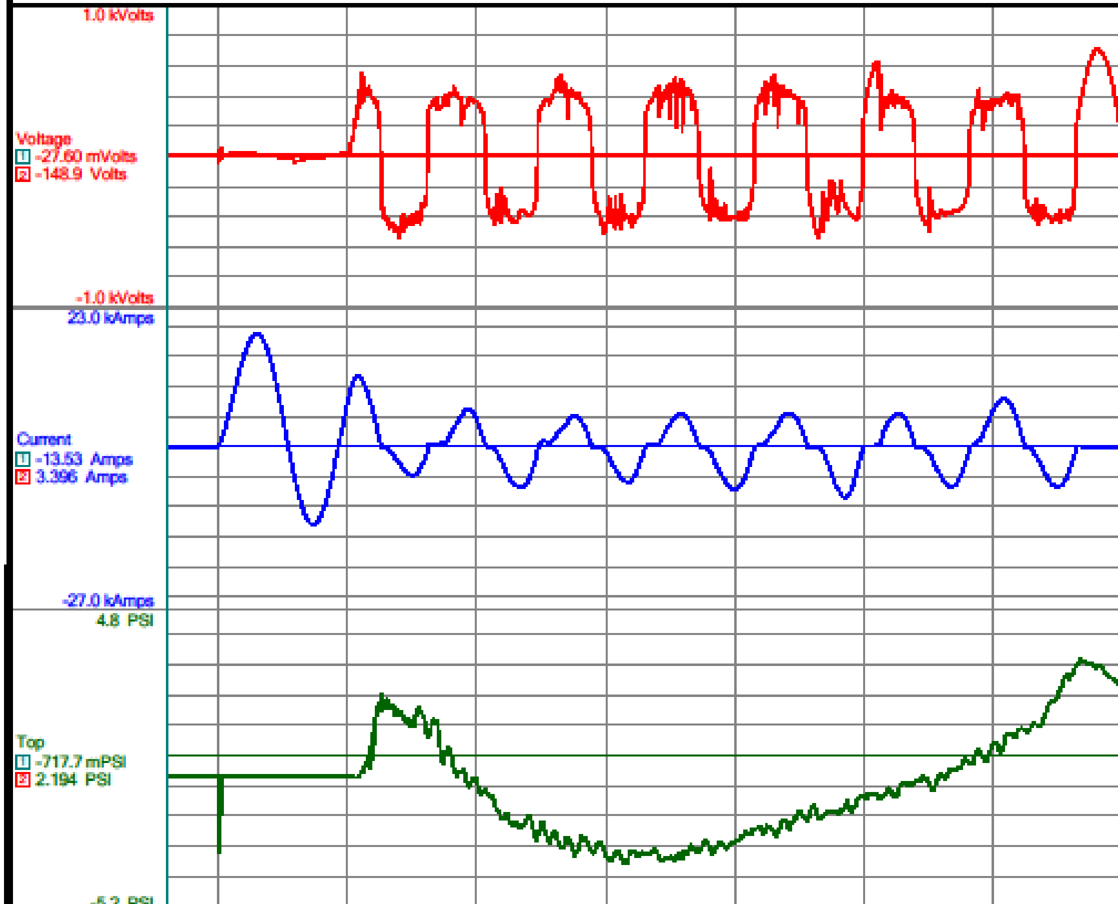
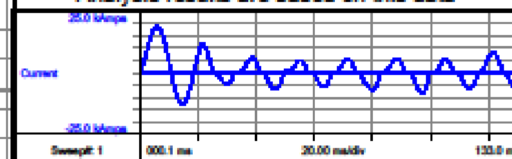
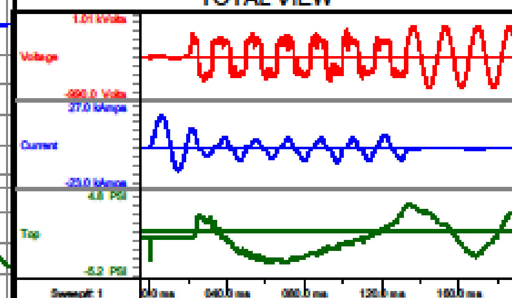



Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N [illegible]

VOLTAGE 100X Scope Probe, C/N [illegible], 1% PLOT FILE HPL3 CR_1_B

VOLTAGE 100X Scope Probe, C/N [illegible], 1%

CURRENT ROGOWSKI COIL, C/N [illegible]

NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34398

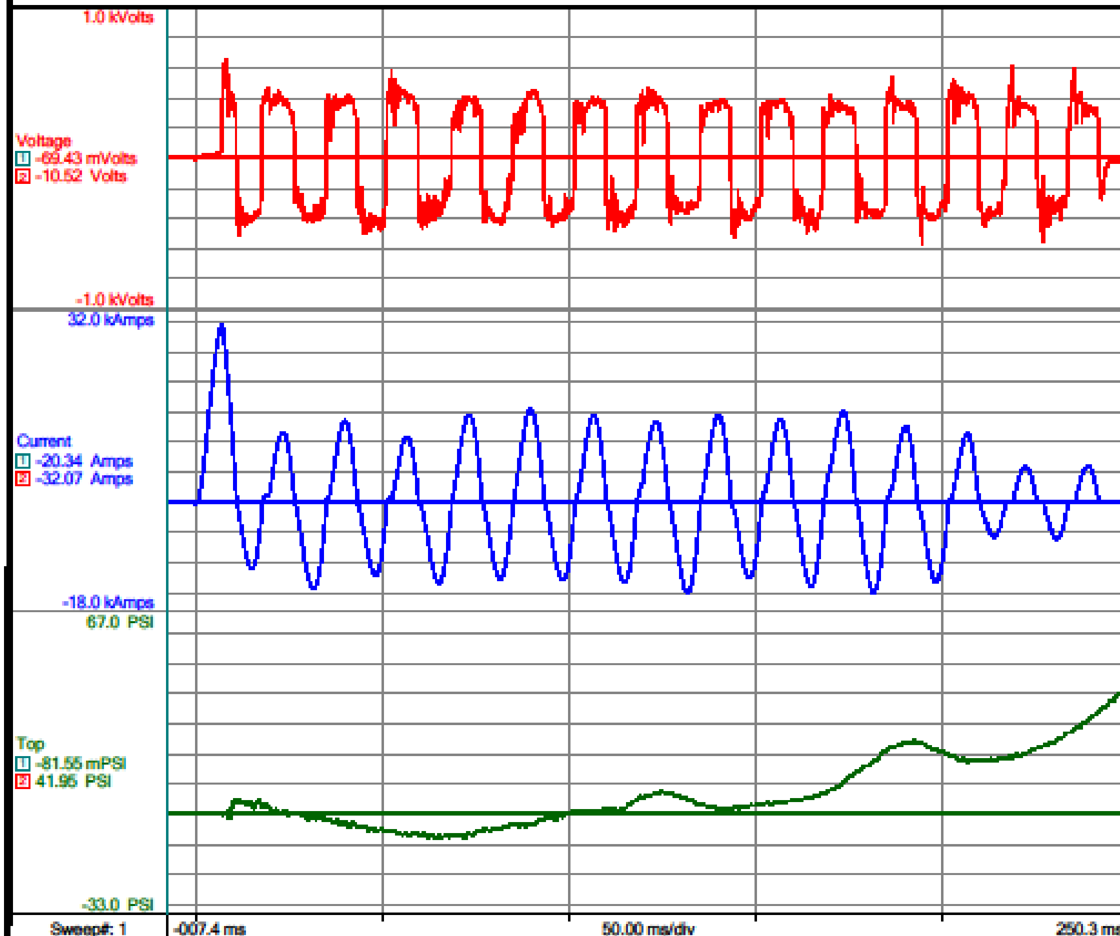
Oscillogram No.: HPL3-34400 OCV = 604 V
Date of Test: 9/29/2020 Time of Test: 1:52:04 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 25632 Calibration Date: 01/15/20
OCV = 606 V Rms Sym Current = 14.55 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 63




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 94 Deg |
| Closing time (V0)+ | 58.18 µ Sec |
| Peak Current (Ip) | 29.47 k Amperes |
| Time to Ip | 6.601 m Sec. |
| I²t | 20.63 M Amp^2sec |
| I Duration | 241.8 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.

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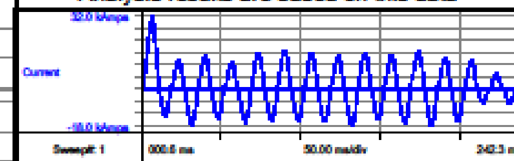
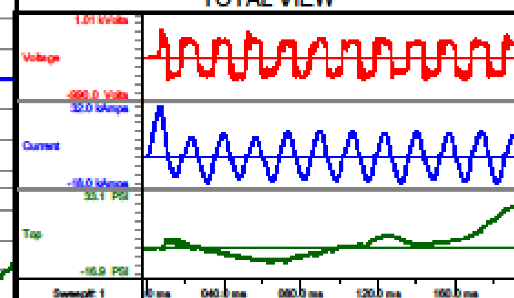
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-000, 1%    PLOT FILE HPL3 CR_1_M
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34400

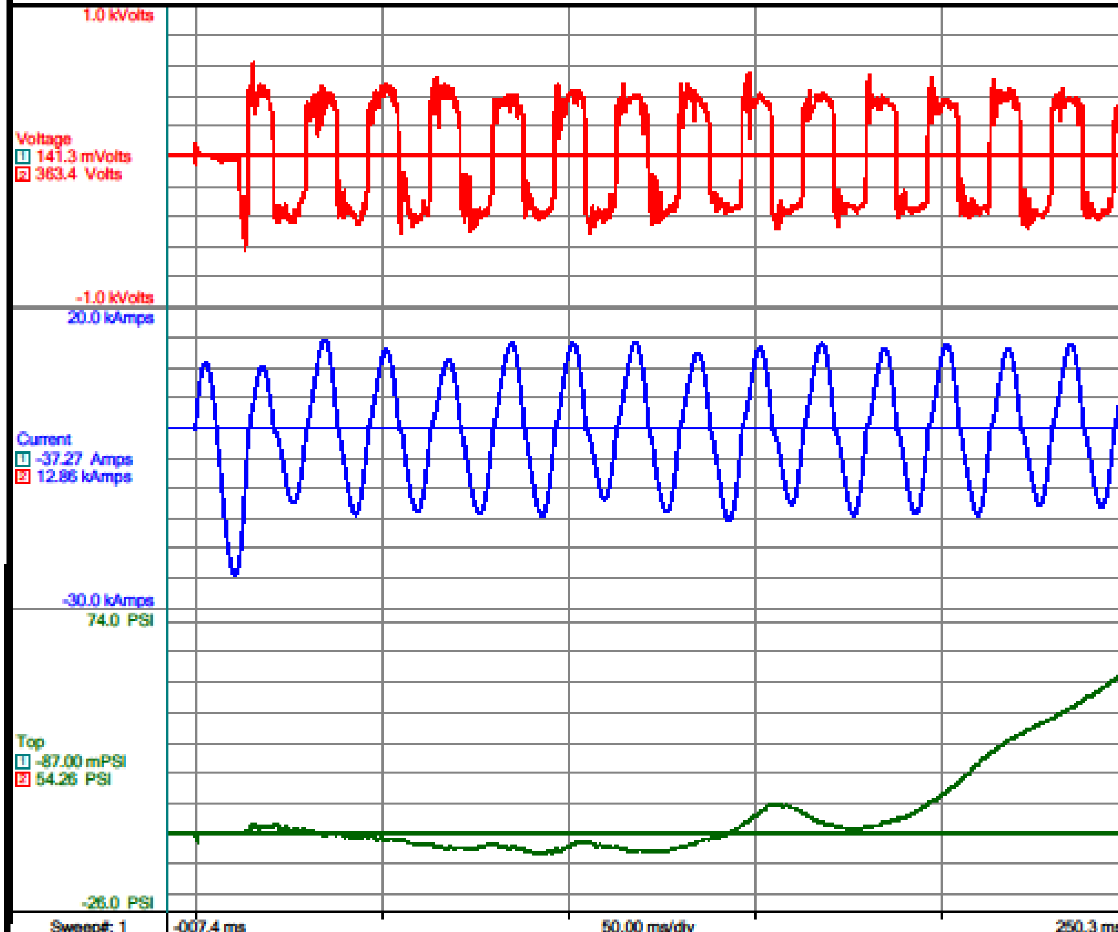
Oscillogram No.: HPL3-34401 OCV = 604 V
Date of Test: 9/29/2020 Time of Test: 2:09:57 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 25632 Calibration Date: 01/15/20
OCV = 606 V Rms Sym Current = 14.55 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 64




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 275 Deg |
| Closing time (V0)+ | 165.9 μ Sec |
| Peak Current (Ip) | -24.58 k Amperes |
| Time to Ip | 10.69 m Sec. |
| I²t | 28.83 M Amp^2sec |
| I Duration | 328.4 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

18 in.

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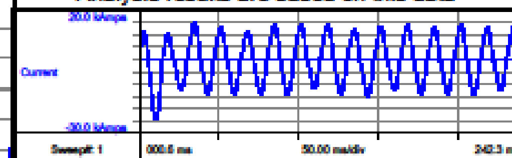
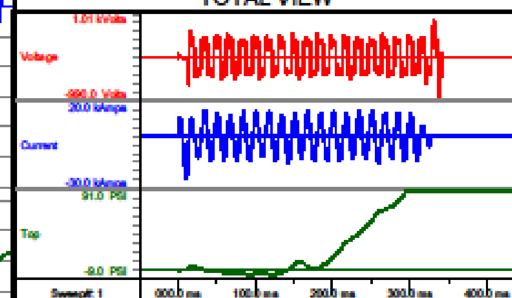
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

[illegible]

[illegible]

[illegible]

[illegible]

NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34401

Oscillogram No.: HPL3-34402 OCV = 604 V
Date of Test: 9/29/2020 Time of Test: 2:20:12 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 25632 Calibration Date: 01/15/20
OCV = 606 V Rms Sym Current = 14.55 kA
Power Factor = 26%

Schneider Electric

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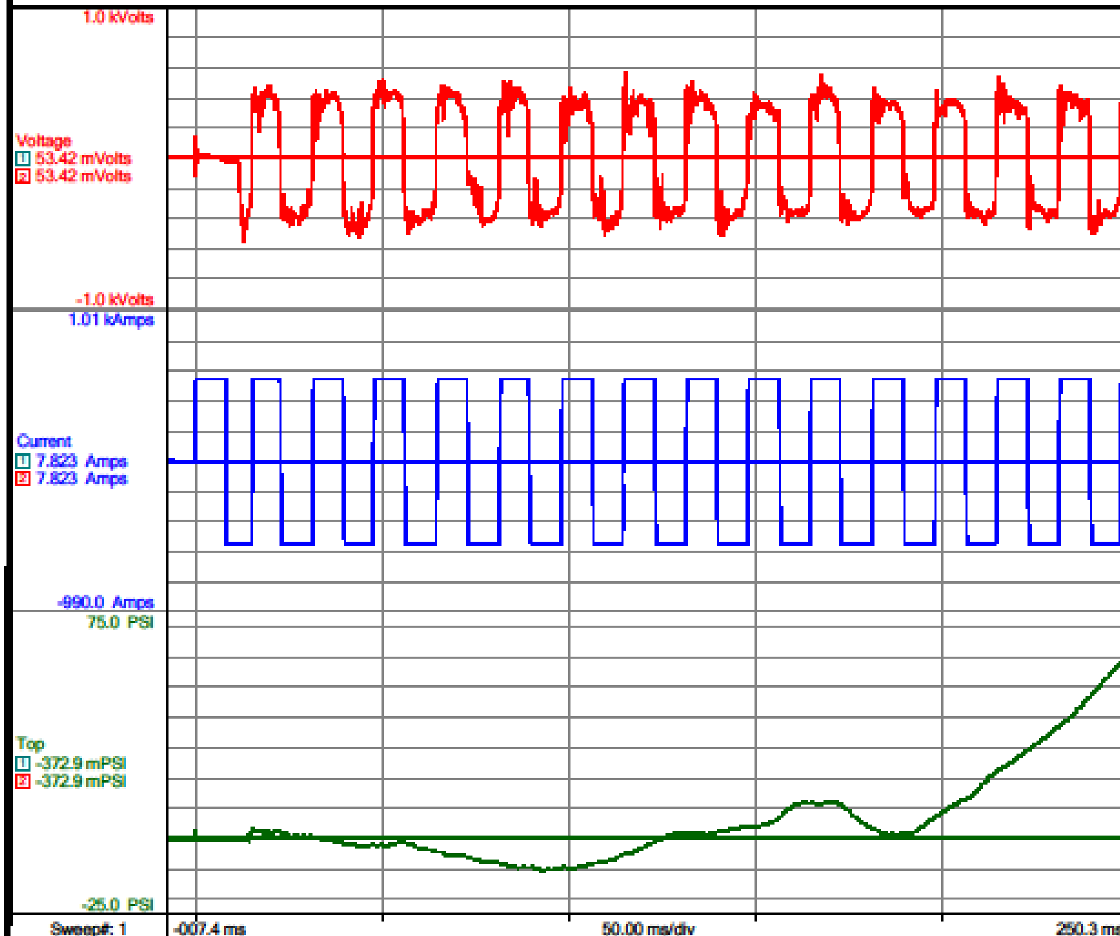
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 65

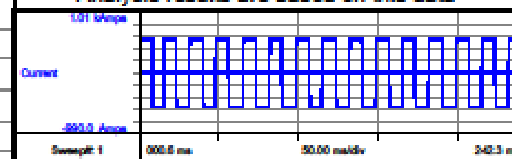



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | *** Deg |
| Closing time (V0)+ | - - - Sec |
| Peak Current (Ip) | - - - Amperes |
| Time to Ip | - - - Sec. |
| I²t | - - - Amp^2sec |
| I Duration | - - - Sec. |

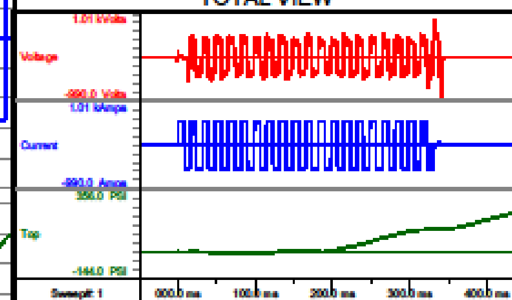
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 18 in. |
| - |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE: [illegible] Scope Probe, C/N [illegible], 1% PLOT FILE [illegible]
VOLTAGE: [illegible] Scope Probe, C/N [illegible], 1%
CURRENT: [illegible] COIL, C/N [illegible]
NOTE: Channel offset removed for analysis [illegible] for display.

OSC. NO.: HPL3-34402

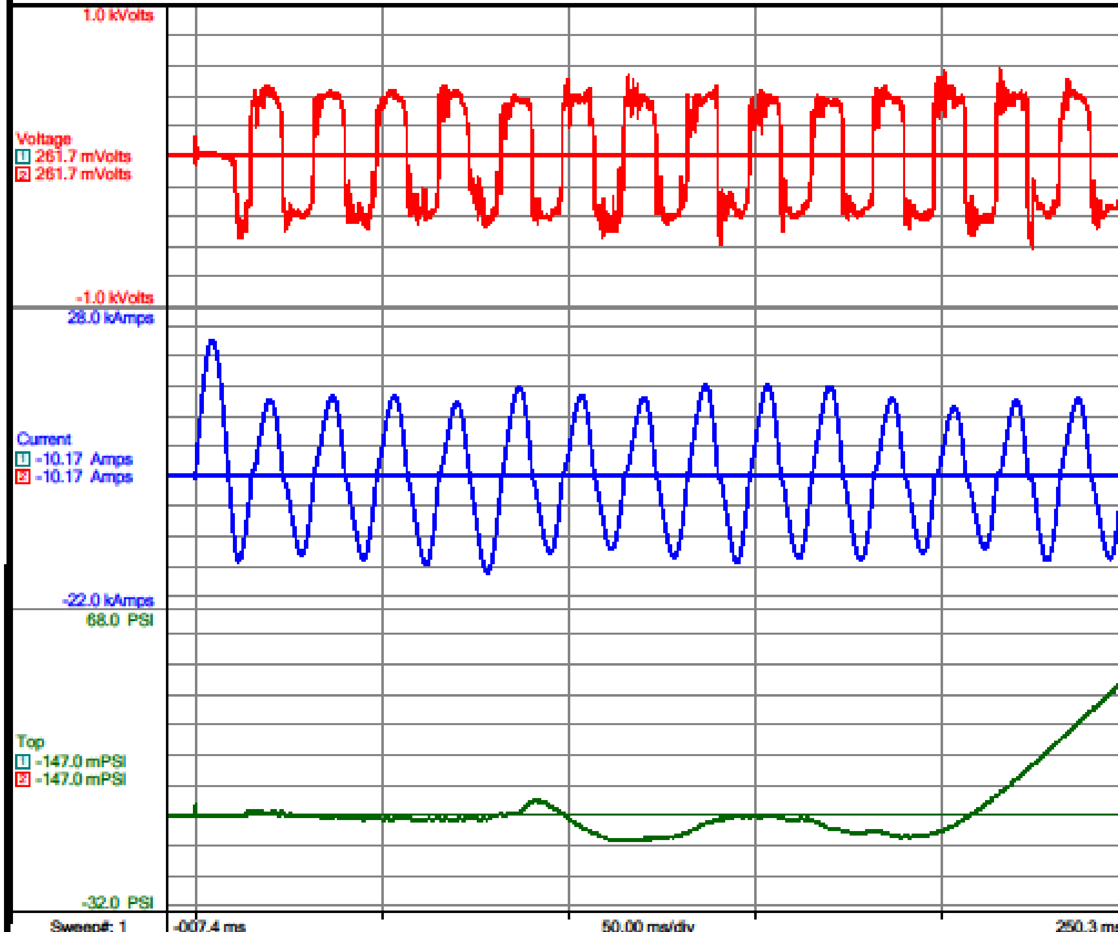
Oscillogram No.: HPL3-34403 OCV = 604 V
Date of Test: 9/29/2020 Time of Test: 2:29:31 PM

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 25632 Calibration Date: 01/15/20
OCV = 606 V Rms Sym Current = 14.55 kA
Power Factor = 26%

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 66

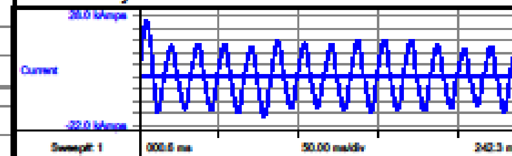



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 167 Deg |
| Closing time (V0)+ | 10.20 m Sec |
| Peak Current (Ip) | 22.68 k Amperes |
| Time to Ip | 4.577 m Sec. |
| I²t | 26.66 M Amp^2sec |
| I Duration | 306.8 m Sec. |

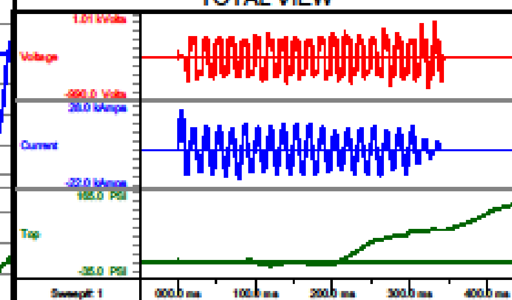
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 18 in. |
| - |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System:HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-003, 1% PLOT FILE:HPL3 CR_1_8
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34403

Oscillogram No.: HPL3-34404 OCV = 604 V
Date of Test: 9/29/2020 Time of Test: 2:35:47 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 25632 Calibration Date: 01/15/20
OCV = 606 V Rms Sym Current = 14.55 kA
Power Factor = 26%

**Schneider Electric**

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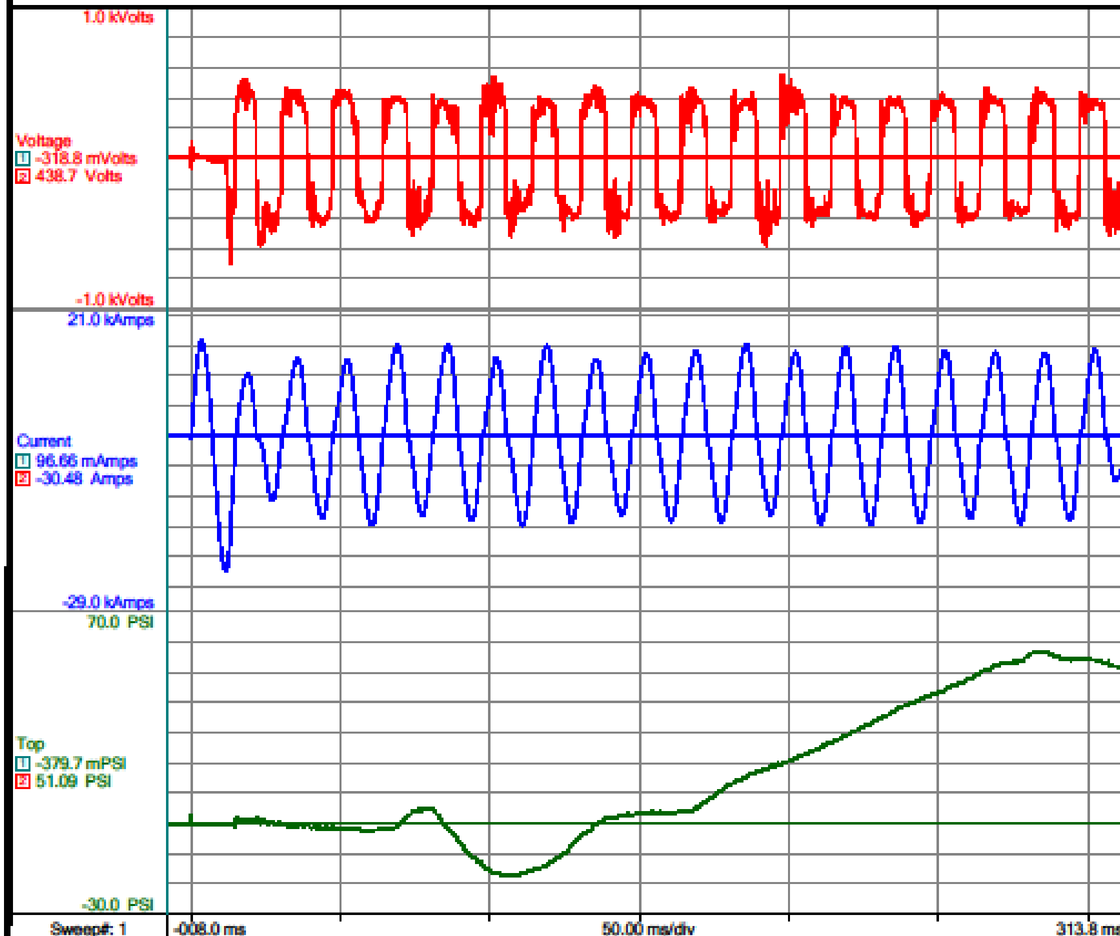
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 67




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 231 Deg |
| Closing time (V0)+ | 482.7 μ Sec |
| Peak Current (Ip) | -22.47 k Amperes |
| Time to Ip | 11.58 m Sec. |
| I²t | 29.14 M Amp^2sec |
| I Duration | 305.7 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

18 in.

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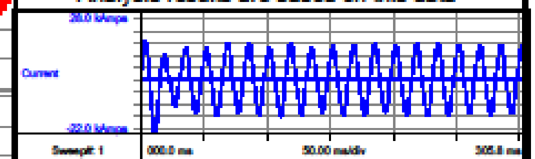
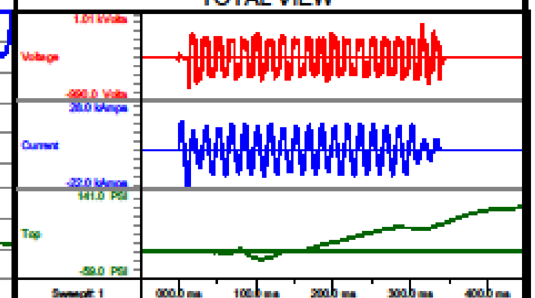
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 393-173
VOLTAGE 1000X Burge Probe, C/N 131-888, 1% PLOT FILE HPL3 CR_1_M
VOLTAGE 1000X Burge Probe, C/N 131-894, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34404

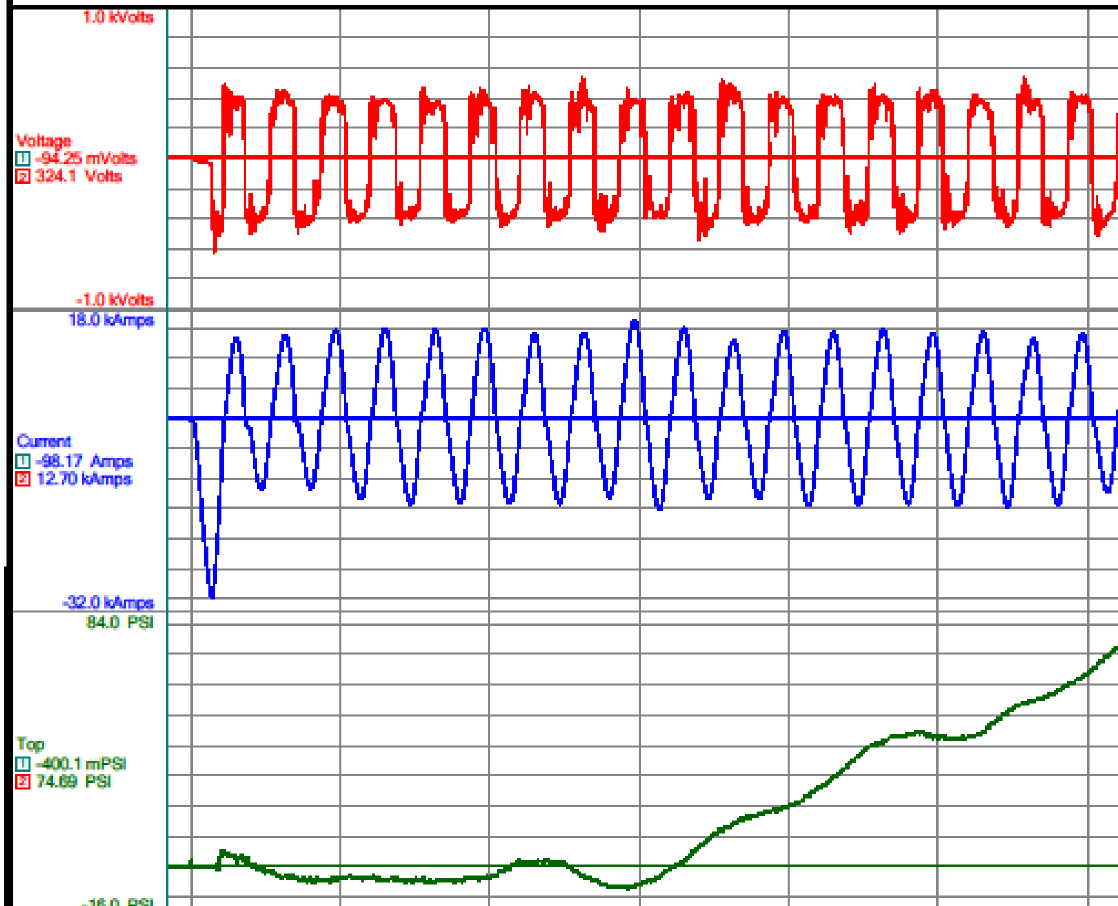
Oscillogram No.: HPL3-34405 OCV = 604 V
Date of Test: 9/29/2020 Time of Test: 2:42:29 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 25632 Calibration Date: 01/15/20
OCV = 606 V Rms Sym Current = 14.55 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 68




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 60 Deg |
| Closing time (V0)+ | 5.050 m Sec |
| Peak Current (Ip) | -29.77 k Amperes |
| Time to Ip | 6.595 m Sec. |
| I²t | 38.12 M Amp^2sec |
| I Duration | 359.6 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

18 in.
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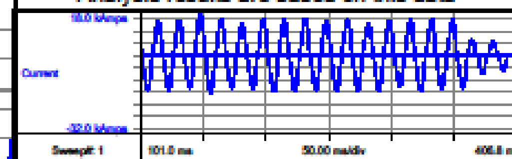
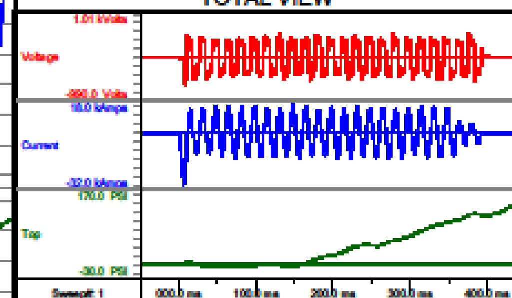
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 1000X Scope Probe, C/N 131-808, 1%    PLOT FILE HPL3 CR_1_M
VOLTAGE 1000X Scope Probe, C/N 131-804, 1%
CURRENT ROGOWSKI COIL, C/N 045-448
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34405

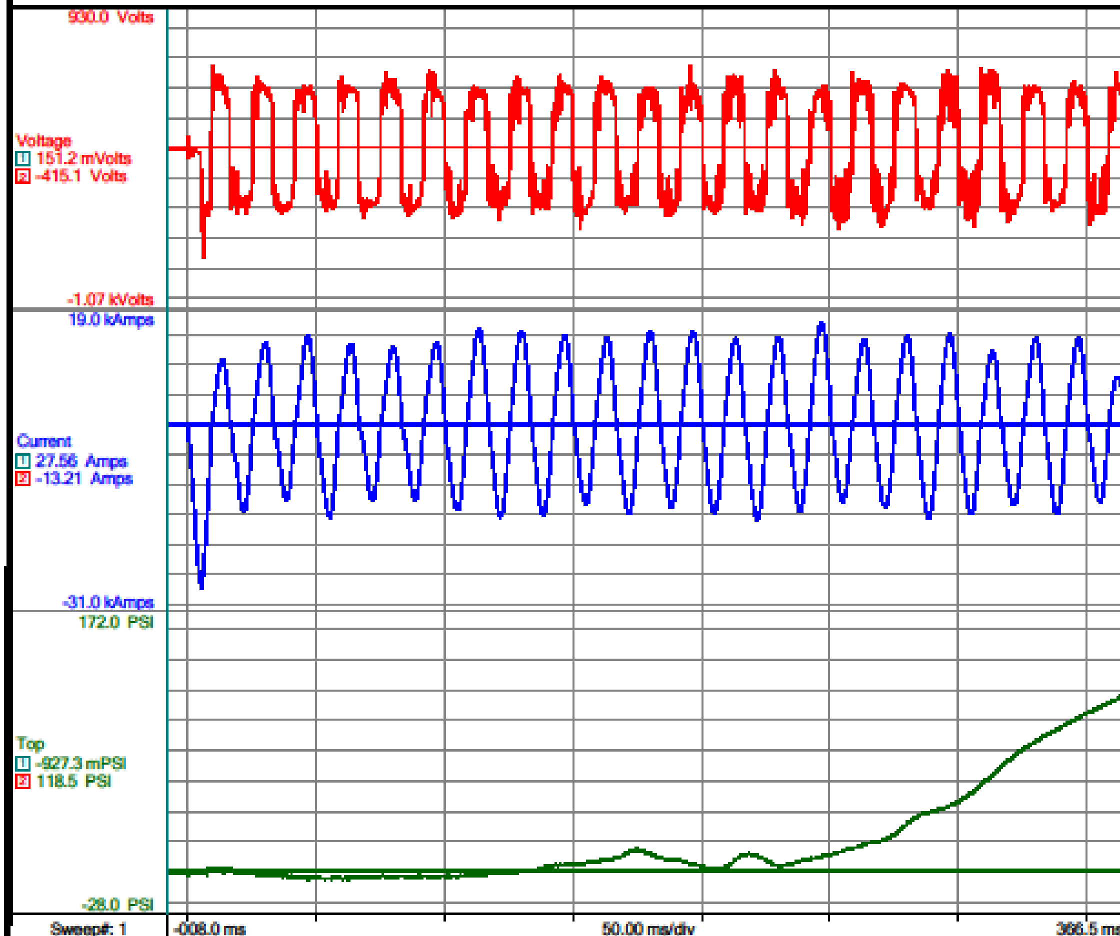
Oscillogram No.: HPL3-34406 OCV = 604 V
Date of Test: 9/29/2020 Time of Test: 2:48:18 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 25632 Calibration Date: 01/15/20
OCV = 606 V Rms Sym Current = 14.55 kA
Power Factor = 26%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 69




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 138 Deg |
| Closing time (V0)+ | 1.198 m Sec |
| Peak Current (Ip) | -27.34 k Amperes |
| Time to Ip | 5.308 m Sec. |
| I²t | 38.74 M Amp^2sec |
| I Duration | 358.5 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

18 in.

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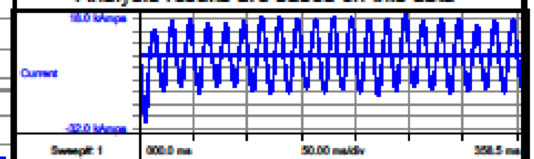
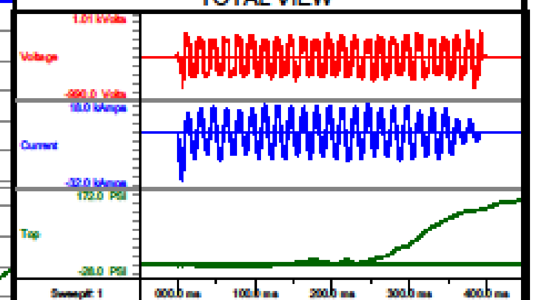
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]

VOLTAGE [illegible] Scope Probe, C/N [illegible], 1% PLOT FILE [illegible]

VOLTAGE [illegible] Scope Probe, C/N [illegible], 1%

CURRENT ROGOWSKI COIL, C/N [illegible]

NOTE: Channel offset removed for analysis but not for display.

OSC. NO.: HPL3-34406

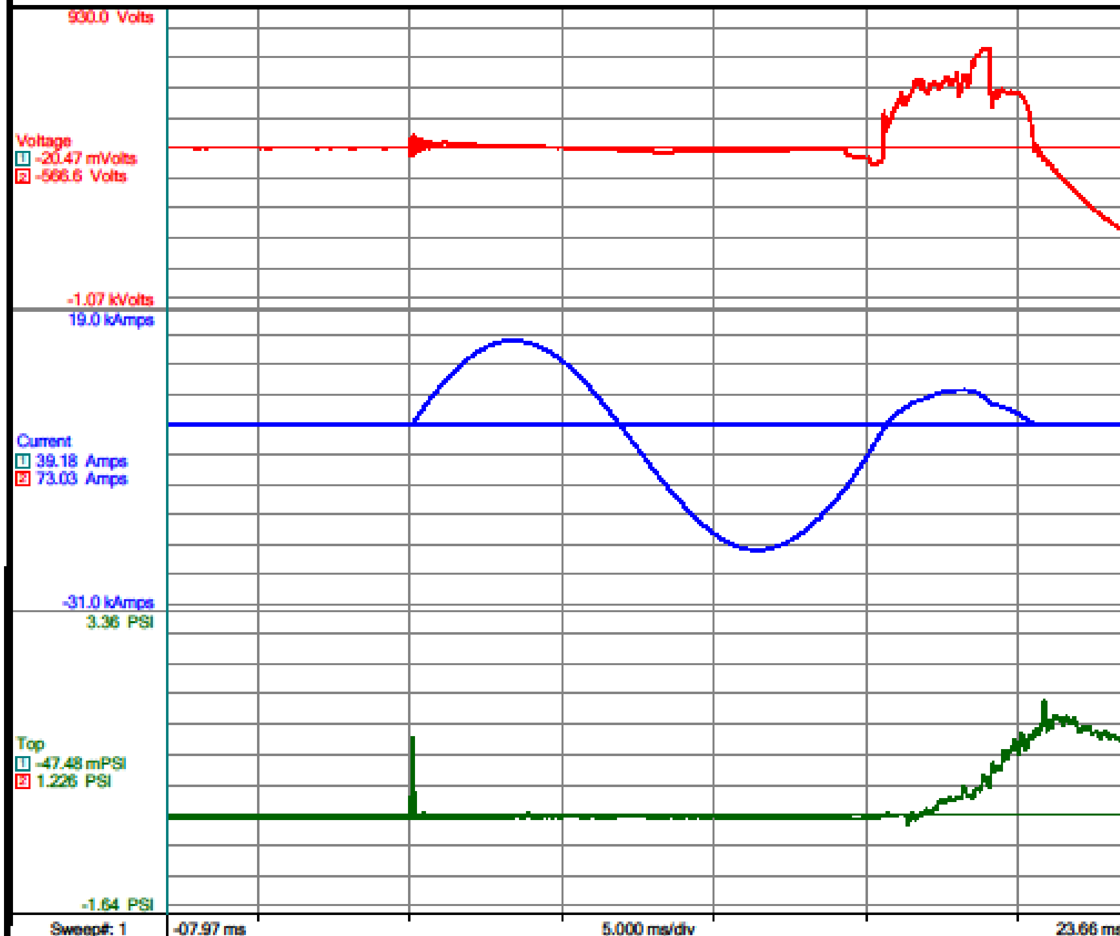
Oscillogram No.: HPL3-34408 OCV = 434 V
Date of Test: 9/30/2020 Time of Test: 8:08:00 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 05/12/20
OCV = 487 V Rms Sym Current = 14.22 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 70




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 97 Deg |
| Closing time (V0)+ | 4.512 m Sec |
| Peak Current (Ip) | -21.04 k Amperes |
| Time to Ip | 11.40 m Sec. |
| I²t | 2.613 M Amp^2sec |
| I Duration | 15.62 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

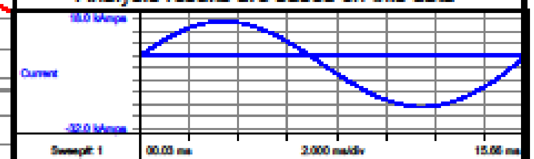
## Comment Section

18 in.

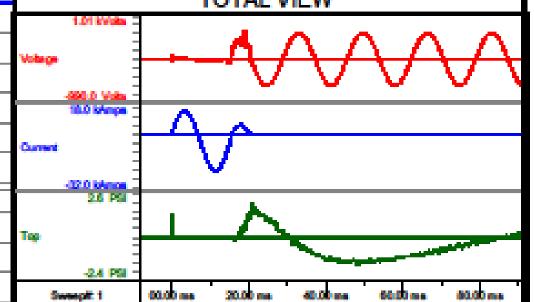
10.89 kA

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis, but not for display.

OSC. NO.: HPL3-34408

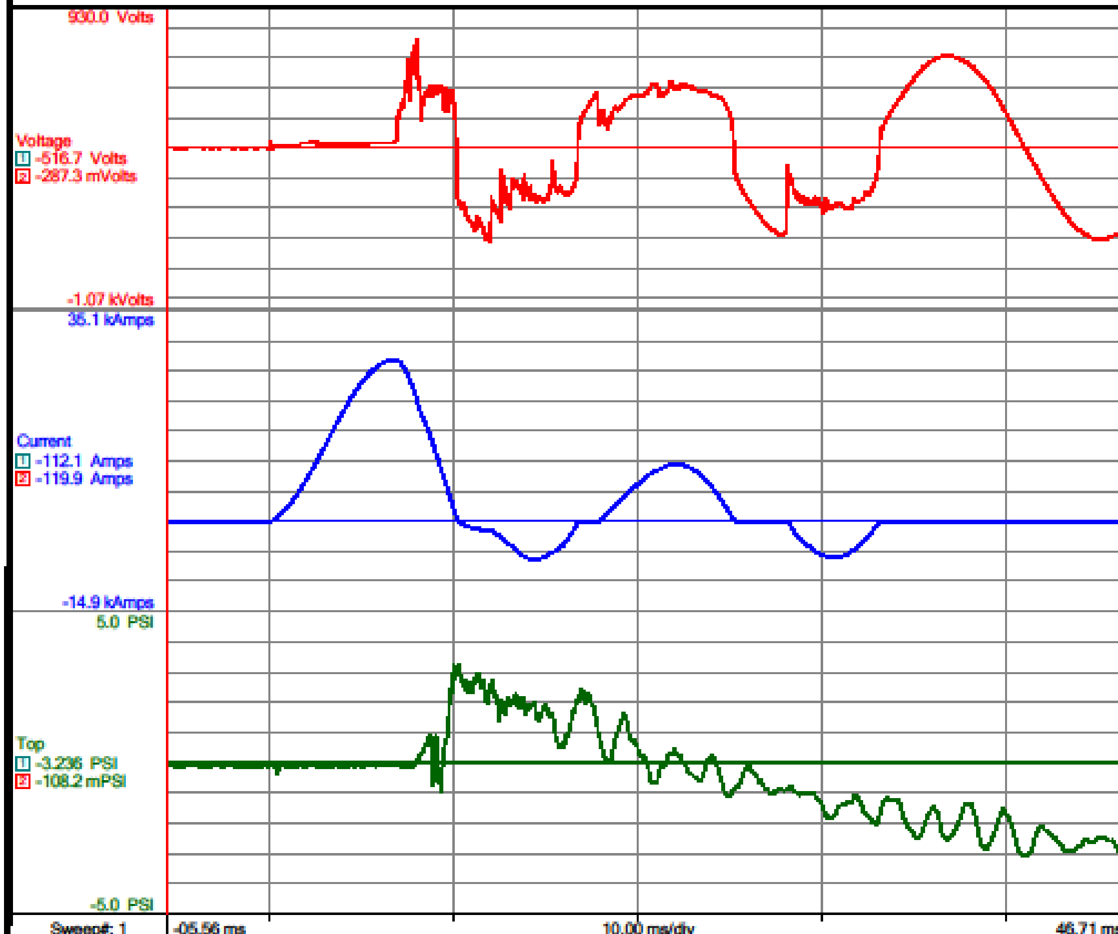
Oscillogram No.: HPL3-34409 OCV = 434 V
Date of Test: 9/30/2020 Time of Test: 8:14:37 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 05/12/20
OCV = 487 V Rms Sym Current = 14.22 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 71




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 15 Deg |
| Closing time (V0)+ | 666.6 μ Sec |
| Peak Current (Ip) | 26.89 k Amperes |
| Time to Ip | 6.660 m Sec. |
| I²t | 3.034 M Amp^2sec |
| I Duration | 10.11 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

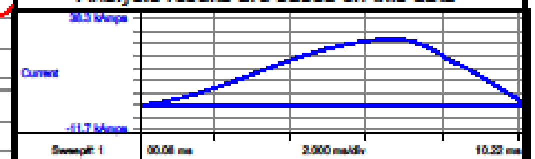
## Comment Section

18 in.

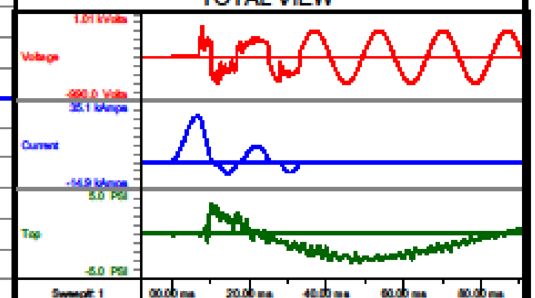
10.89 kA

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173

VOLTAGE 100X Scope Probe, C/N 131-088, 1% PLOT FILE HPL3 C8_1_8

VOLTAGE 100X Scope Probe, C/N 131-084, 1%

CURRENT ROGOWSKI COIL, C/N 048-448

NOTE: Channel offset removed for analysis but not for display.

OSC. NO.: HPL3-34409

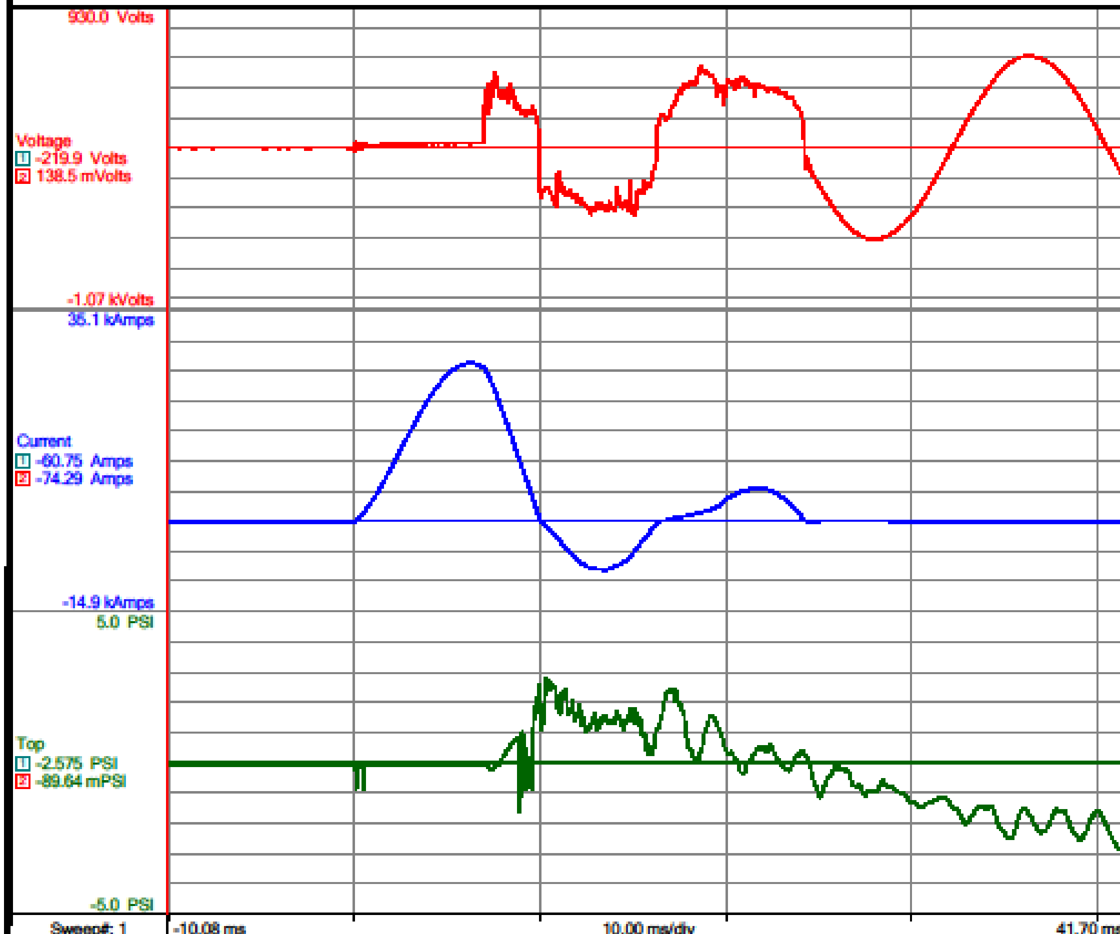
Oscillogram No.: HPL3-34410  OCV = 434 V
Date of Test: 9/30/2020  Time of Test: 8:25:11 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470  Calibration Date: 05/12/20
OCV = 487 V   Rms Sym Current = 14.22 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332  TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 72




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 27 Deg |
| Closing time (V0)+ | 1.243 m Sec |
| Peak Current (Ip) | 28.28 k Amperes |
| Time to Ip | 6.146 m Sec. |
| I²t | 3.055 M Amp^2sec |
| I Duration | 9.891 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

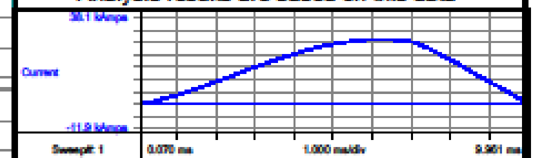
## Comment Section

18 in.

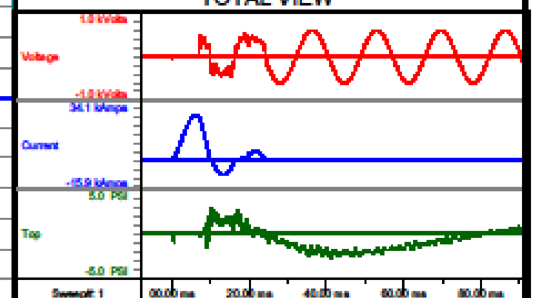
10.89 kA

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173

VOLTAGE 100X Scope Probe, C/N 131-008, 1%

VOLTAGE 100X Scope Probe, C/N 131-004, 1%

CURRENT ROGOWSKI COIL, C/N 040-448

NOTE: Channel offset removed for analysis

but not for display.

PLOT FILE HPL3 CR_1_8

**OSC. NO.: HPL3-34410**

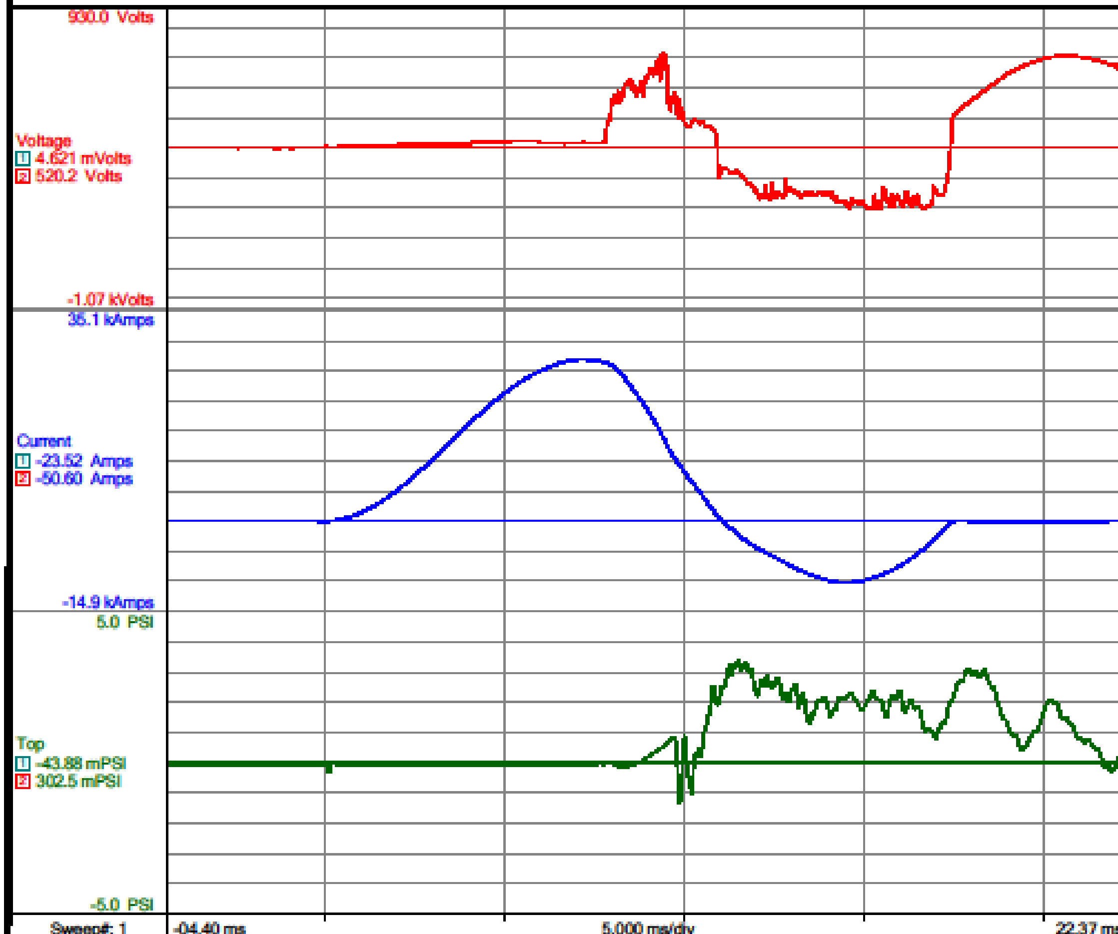
Oscillogram No.: HPL3-34411 OCV = 434 V
Date of Test: 9/30/2020 Time of Test: 8:30:08 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 05/12/20
OCV = 487 V Rms Sym Current = 14.22 kA
Power Factor = 25%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 73




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 7 Deg |
| Closing time (V0)+ | 341.8 μ Sec |
| Peak Current (Ip) | 26.88 k Amperes |
| Time to Ip | 7.004 m Sec. |
| I²t | 3.243 M Amp^2sec |
| I Duration | 10.77 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

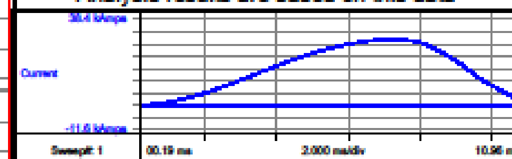
## Comment Section

18 in.

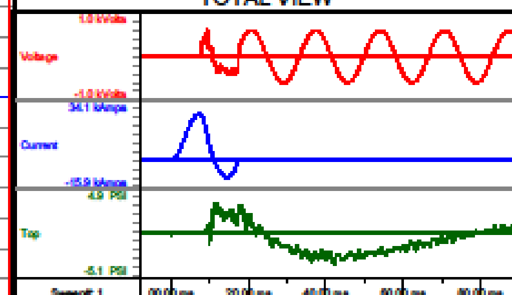
10.89 kA

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-005, 1% PLOT FILE:HPL3 CR_1_#
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis,
but not for display.

**OSC. NO.: HPL3-34411**

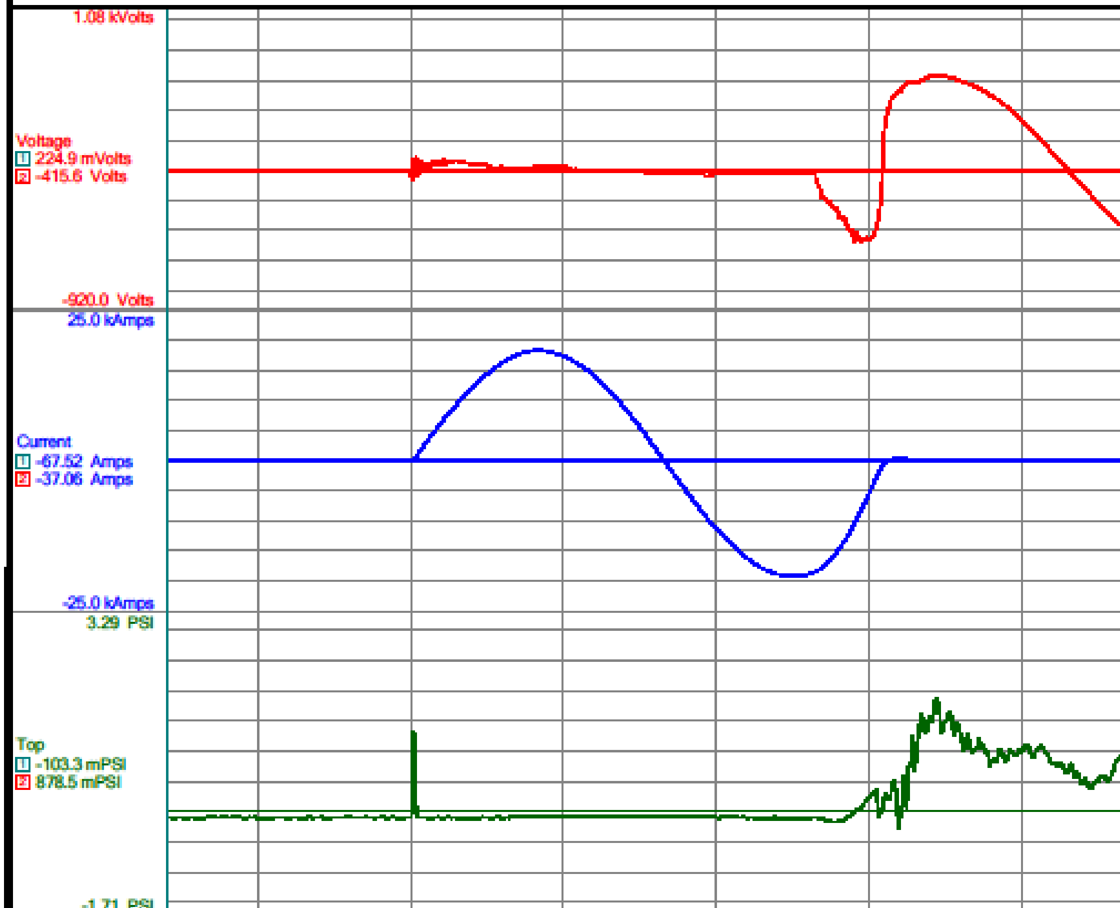
Oscillogram No.: HPL3-34412  OCV = 434 V
Date of Test: 9/30/2020  Time of Test: 8:34:22 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470  Calibration Date: 05/12/20
OCV = 487 V   Rms Sym Current = 14.22 kA
Power Factor = 25%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332  TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 74




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 76 Deg |
| Closing time (V0)+ | 3.514 m Sec |
| Peak Current (Ip) | -19.19 k Amperes |
| Time to Ip | 12.47 m Sec. |
| I²t | 2.752 M Amp^2sec |
| I Duration | 15.49 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

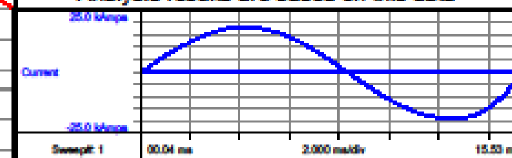
## Comment Section

18 in.

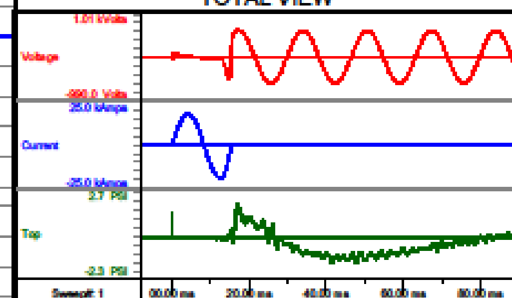
10.89 kA

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE: 100X Scope Probe, C/N [illegible], 1%   PLOT FILE [illegible]
VOLTAGE: 100X Scope Probe, C/N [illegible], 1%
CURRENT: ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34412

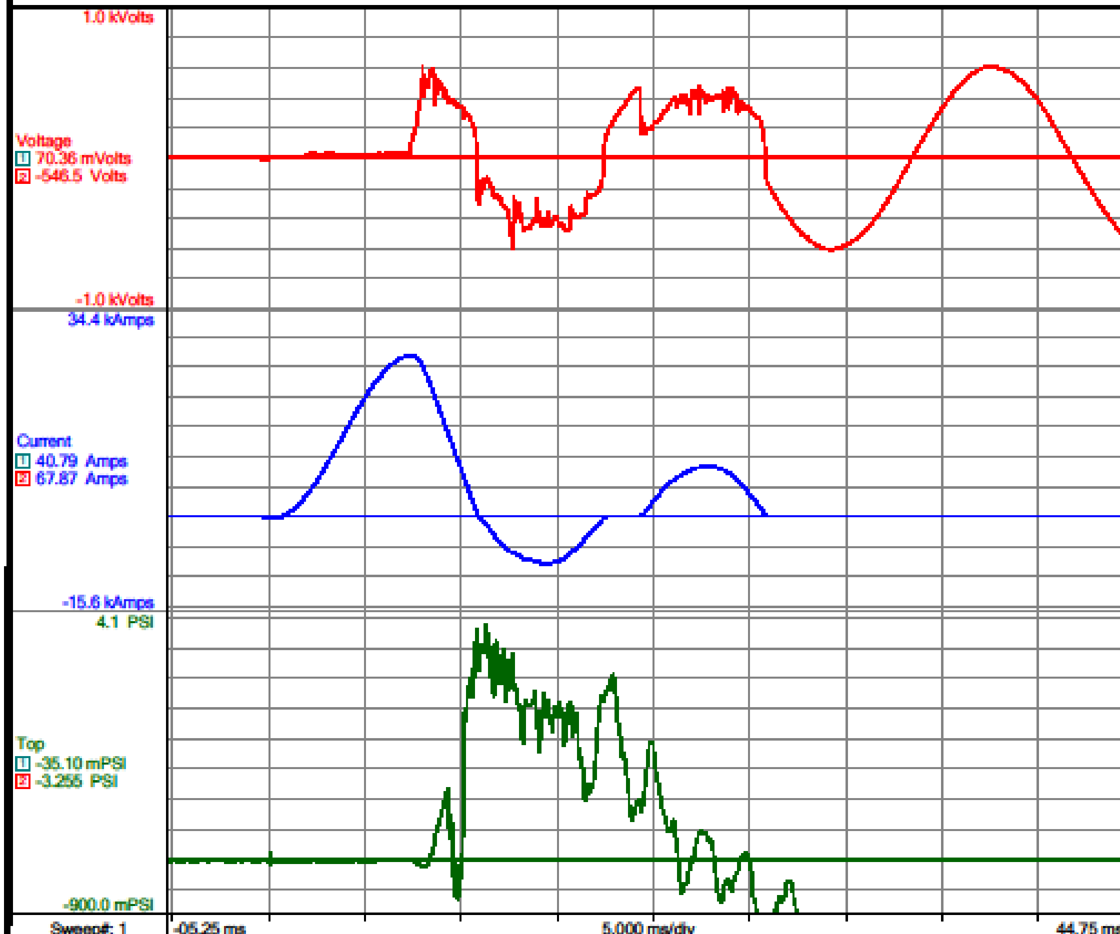
Oscillogram No.: HPL3-34413 OCV = 434 V
Date of Test: 9/30/2020 Time of Test: 8:41:03 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 05/12/20
OCV = 487 V Rms Sym Current = 14.22 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 75




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 351 Deg |
| Closing time (V0)+ | 18.23 m Sec |
| Peak Current (Ip) | 28.78 k Amperes |
| Time to Ip | 7.729 m Sec. |
| I²t | 2.919 M Amp^2sec |
| I Duration | 11.19 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

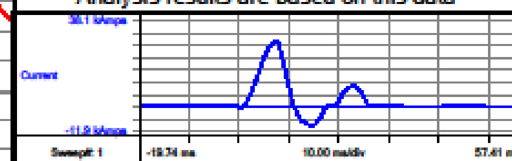
Comment Section

18 in.

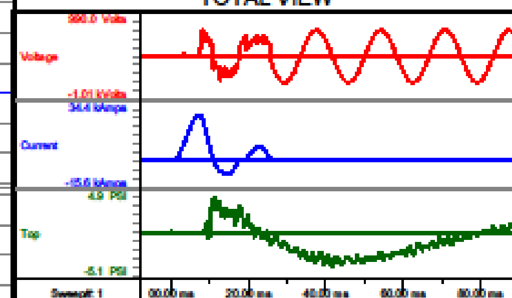
10.89 kA

-

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN3T C/N [illegible]

VOLTAGE 100X Scope Probe, C/N [illegible], 1% PLOT FILE HPL3 CR_1_M

VOLTAGE 100X Scope Probe, C/N [illegible], 1%

CURRENT ROGOWSKI COIL, C/N [illegible]

NOTE: Channel offset removed for analysis

but not for display.

OSC. NO.: HPL3-34413

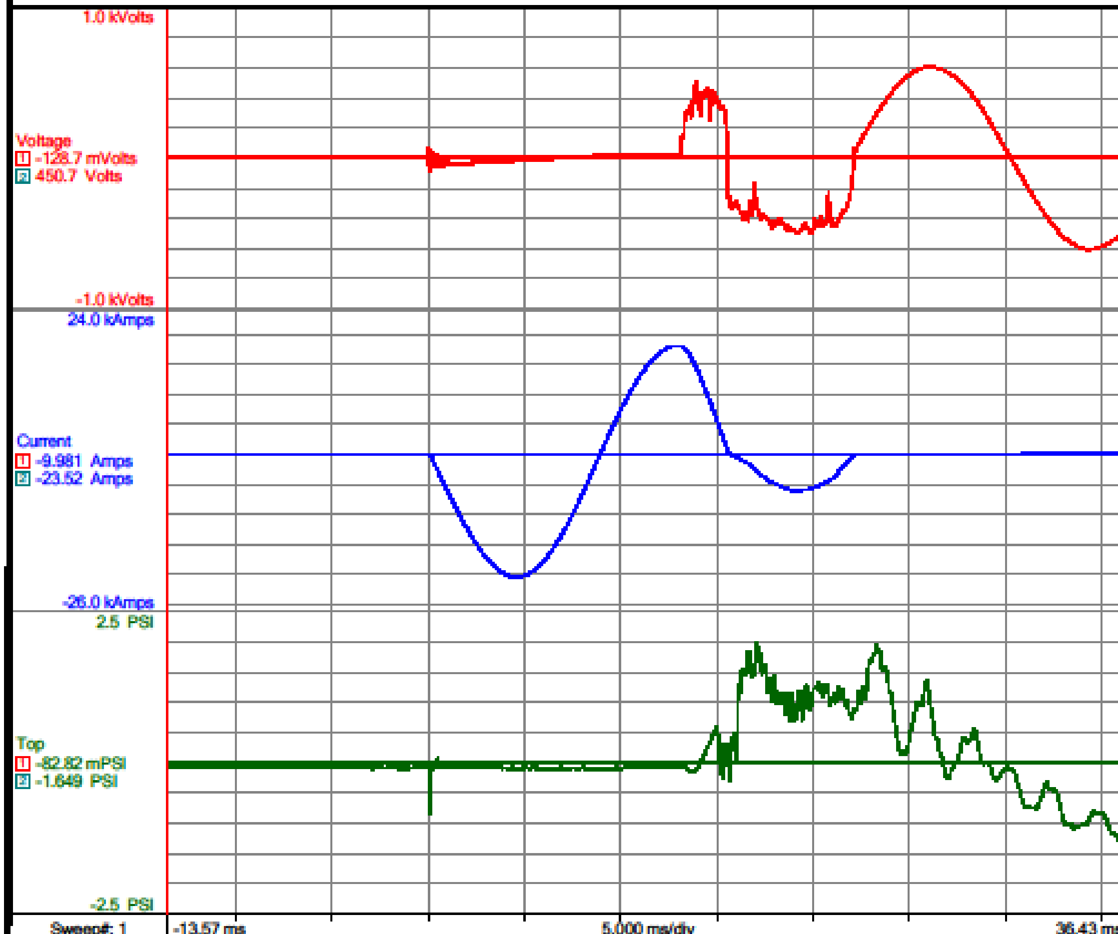
Oscillogram No.: HPL3-34414 OCV = 434 V
Date of Test: 9/30/2020 Time of Test: 8:44:13 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 05/12/20
OCV = 487 V Rms Sym Current = 14.22 kA
Power Factor = 25%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 76




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 247 Deg |
| Closing time (V0)+ | 11.41 m Sec |
| Peak Current (Ip) | -20.50 k Amperes |
| Time to Ip | 4.528 m Sec. |
| I²t | 2.890 M Amp^2sec |
| I Duration | 15.60 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

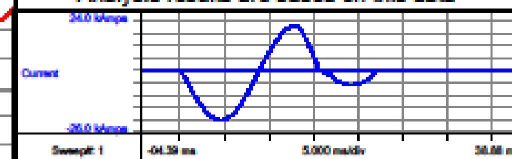
## Comment Section

18 in.

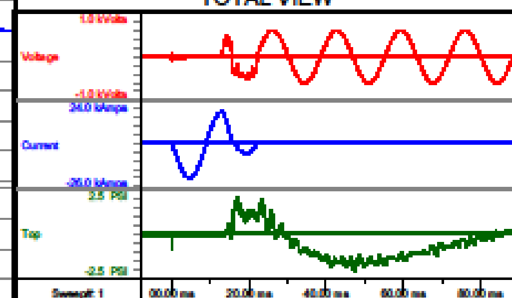
10.89 kA

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]

VOLTAGE: [illegible] Probe, C/N [illegible], 1% PLOT FILE [illegible]

VOLTAGE: [illegible] Probe, C/N [illegible], 1%

CURRENT: ROGOWSKI COIL, C/N [illegible]

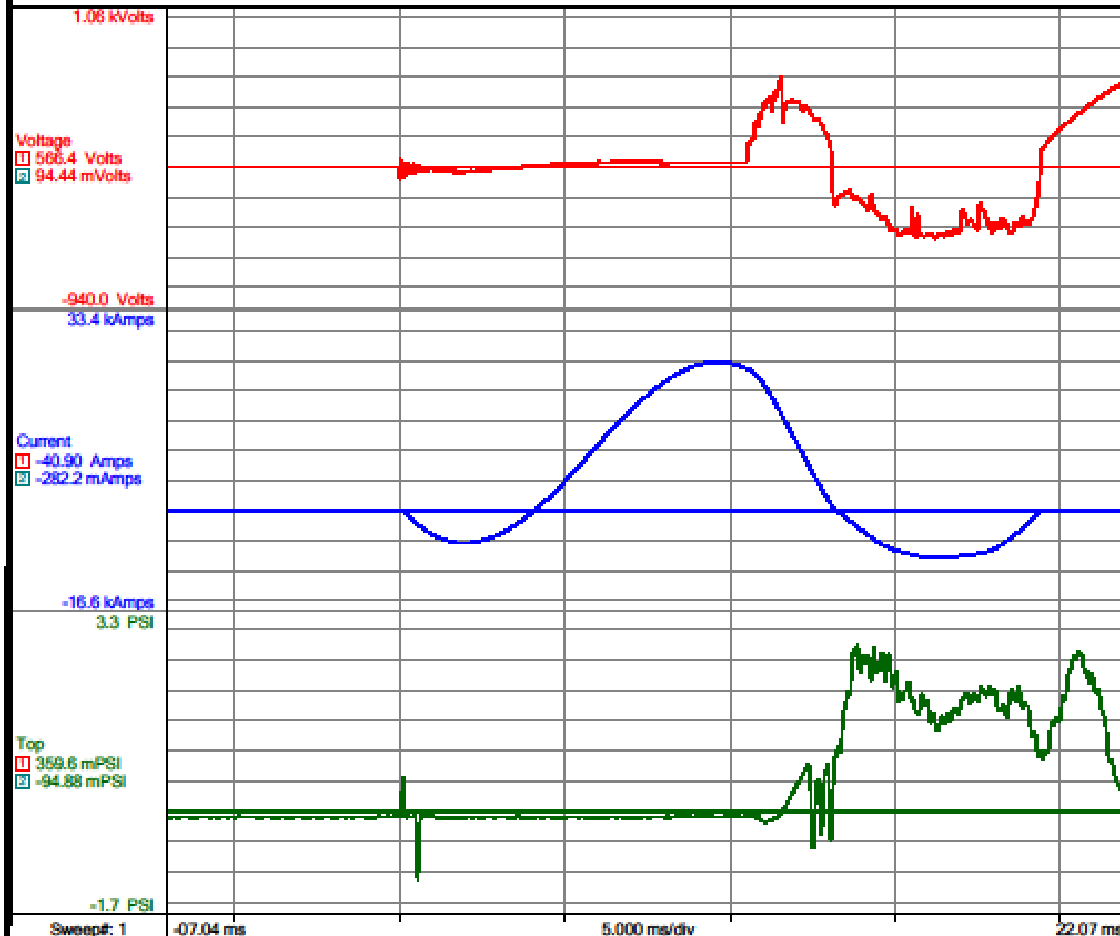
NOTE: Channel offset removed for analysis [illegible]

[illegible] for display.

**OSC. NO.: HPL3-34414**

| | |
|---|---|
| Oscillogram No.: HPL3-34415 OCV = 434 V<br>Date of Test: 9/30/2020 Time of Test: 8:50:24 AM | Schneider Electric |
| AVAILABLE CIRCUIT CHARACTERISTICS:<br>Osc. No: 28470 Calibration Date: 05/12/20<br>OCV = 487 V Rms Sym Current = 14.22 kA<br>Power Factor = 25% | High Power Laboratory, HPL3 Facility<br>Cedar Rapids, Iowa, USA |

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 77




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 314 Deg |
| Closing time (V0)+ | 14.52 m Sec |
| Peak Current (Ip) | 24.71 k Amperes |
| Time to Ip | 9.568 m Sec. |
| I²t | 2.703 M Amp^2sec |
| I Duration | 13.11 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

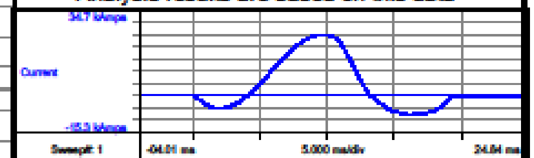
**Comment Section**

18 in.

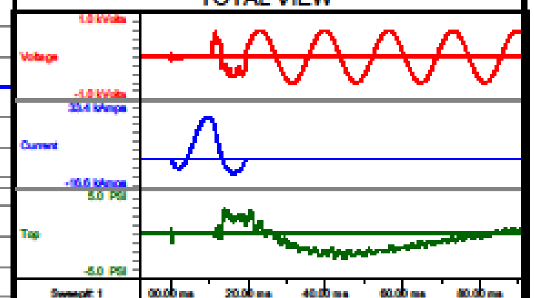
10.89 kA

-

**Analysis results are based on this data**




**TOTAL VIEW**




**INSTRUMENTATION DATA**

Data Recording System [illegible]

VOLTAGE [illegible] Scope Probe, C/N [illegible] PLOT FILE [illegible]

VOLTAGE [illegible] Scope Probe, C/N [illegible]

CURRENT [illegible] COIL, C/N [illegible]

NOTE: Channel offset removed for analysis

but not for display.

**OSC. NO.: HPL3-34415**

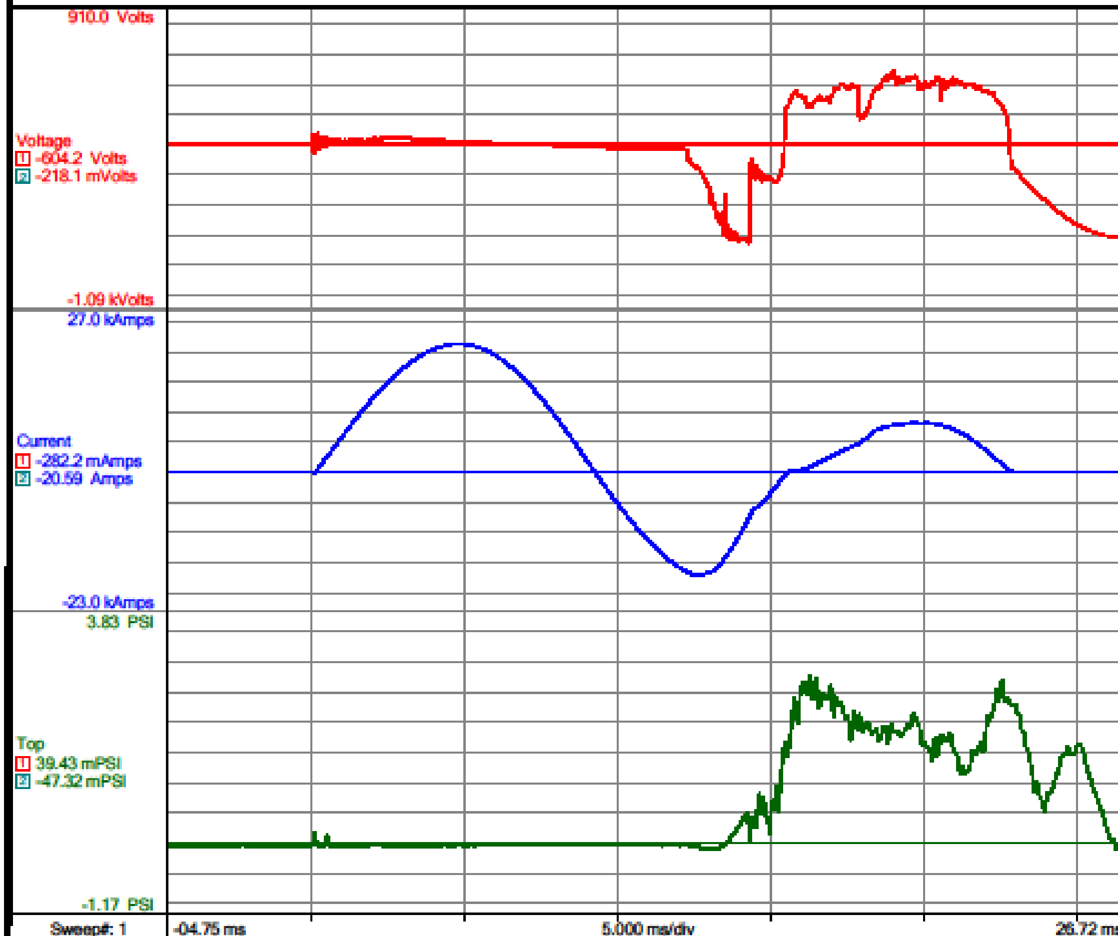
Oscillogram No.: HPL3-34416 OCV = 434 V
Date of Test: 9/30/2020 Time of Test: 8:54:55 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 05/12/20
OCV = 487 V Rms Sym Current = 14.22 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 78

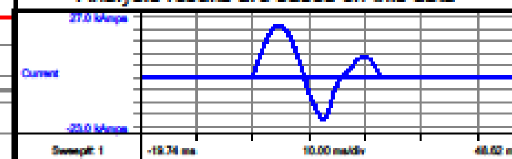



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 61 Deg |
| Closing time (V0)+ | 2.831 m Sec |
| Peak Current (Ip) | 21.38 k Amperes |
| Time to Ip | 4.760 m Sec. |
| I²t | 2.870 M Amp^2sec |
| I Duration | 15.46 m Sec. |

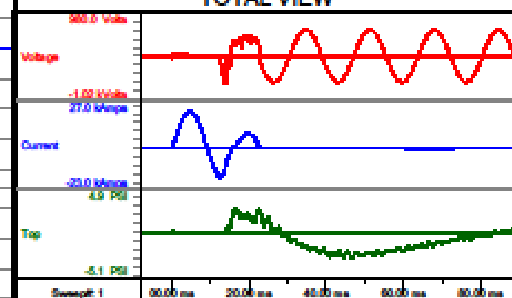
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 18 in. |
| 10.89 kA |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 1000X Scope Probe, C/N 131-589, 1% PLOT FILE:HPL3 CR_1_W
VOLTAGE 1000X Scope Probe, C/N 131-604, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34416

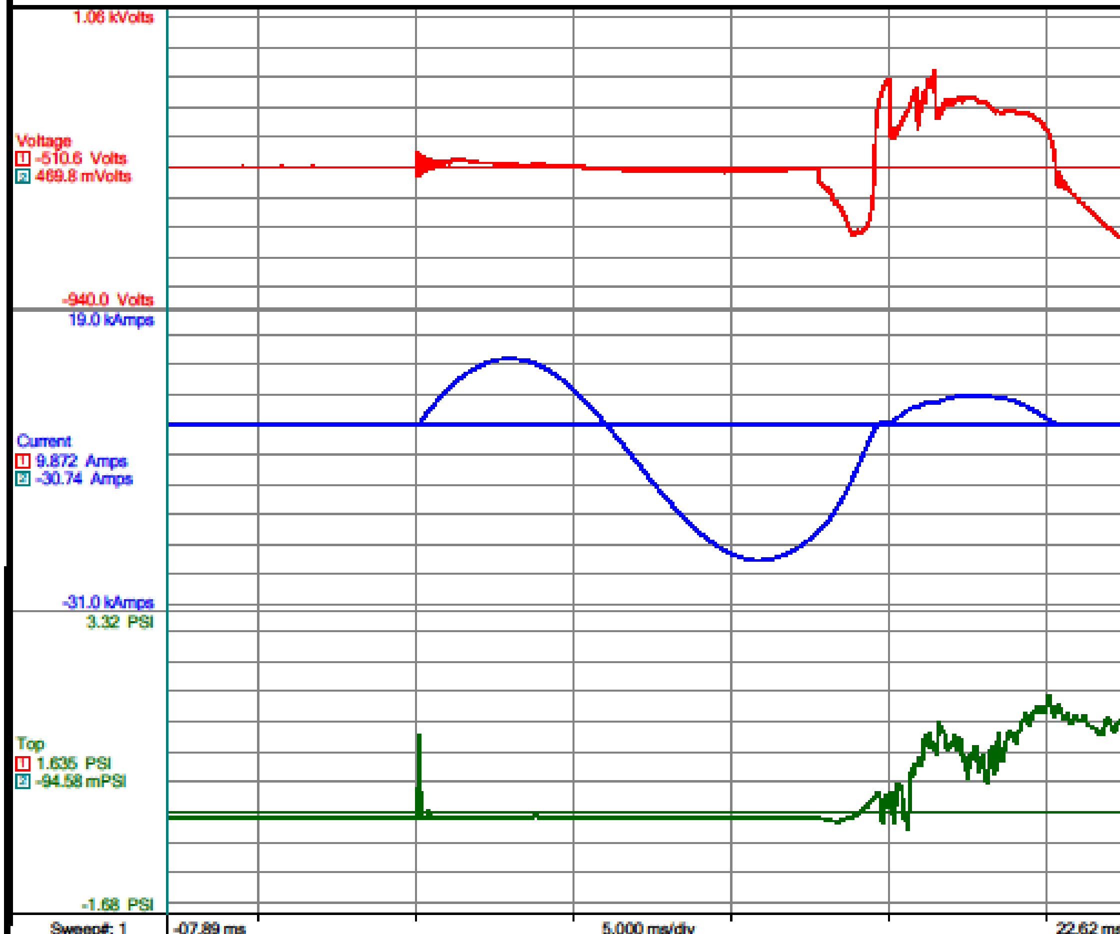
Oscillogram No.: HPL3-34417 OCV = 434 V
Date of Test: 9/30/2020 Time of Test: 8:58:31 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 28470 Calibration Date: 05/12/20
OCV = 487 V Rms Sym Current = 14.22 kA
Power Factor = 25%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 79

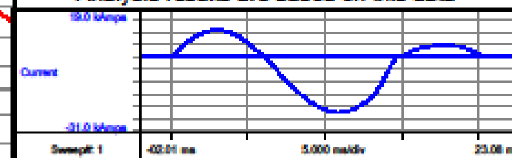



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 109 Deg |
| Closing time (V0)+ | 5.081 m Sec |
| Peak Current (Ip) | -22.68 k Amperes |
| Time to Ip | 10.75 m Sec. |
| I²t | 2.640 M Amp^2sec |
| I Duration | 14.50 m Sec. |

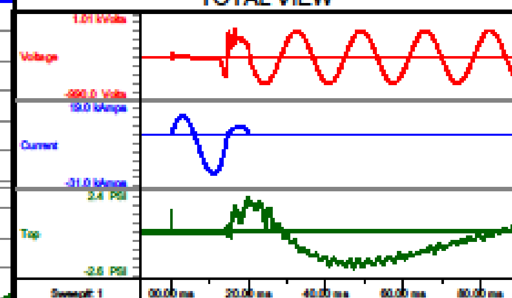
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 18 in. |
| 10.89 kA |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE [illegible] Scope Probe, C/N [illegible], 1%
VOLTAGE [illegible] Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

PLOT FILE [illegible]

OSC. NO.: HPL3-34417

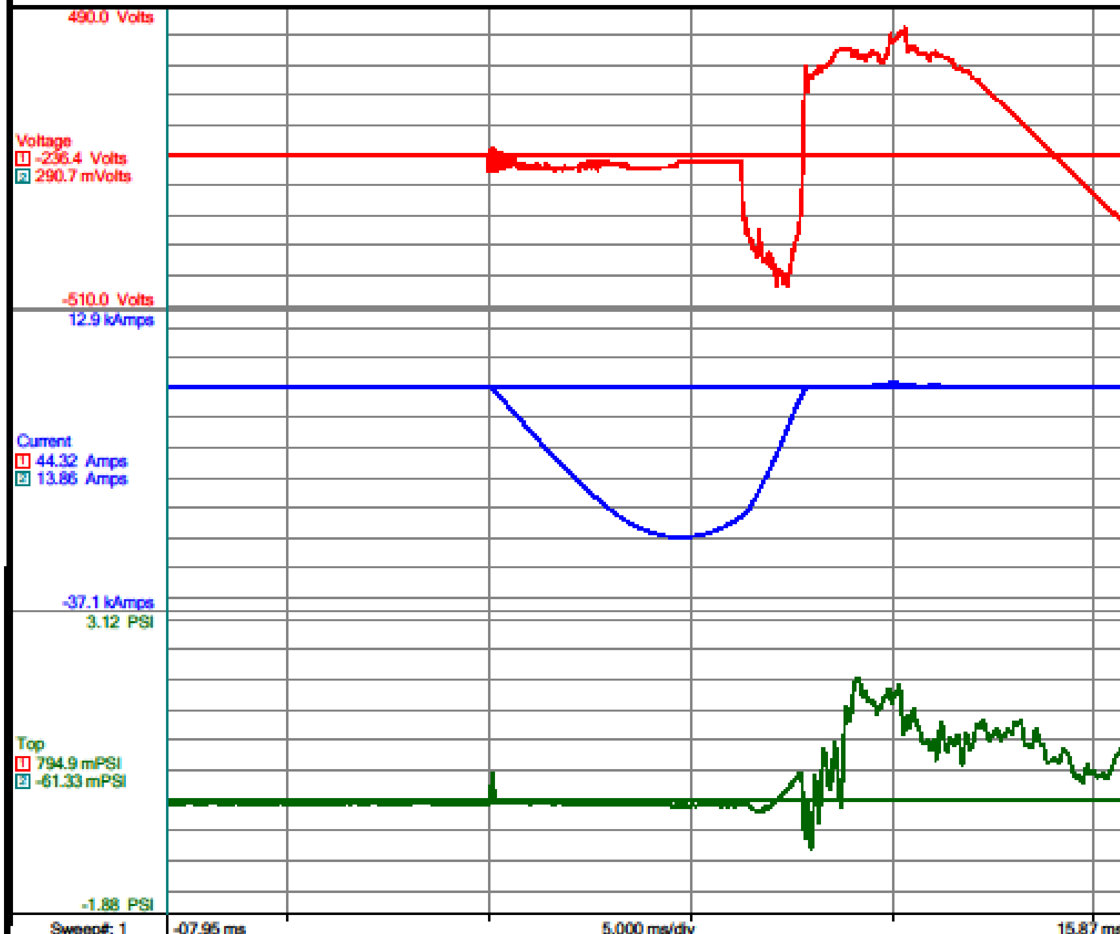
Oscillogram No.: HPL3-34419 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 9:45:38 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 80




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 240 Deg |
| Closing time (V0)+ | 11.10 m Sec |
| Peak Current (Ip) | -24.93 k Amperes |
| Time to Ip | 4.718 m Sec. |
| I²t | 2.553 M Amp^2sec |
| I Duration | 7.816 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

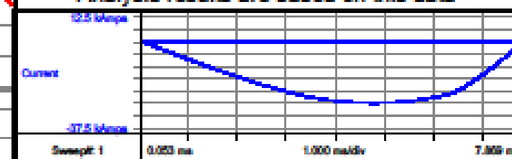
## Comment Section

9.79 kA

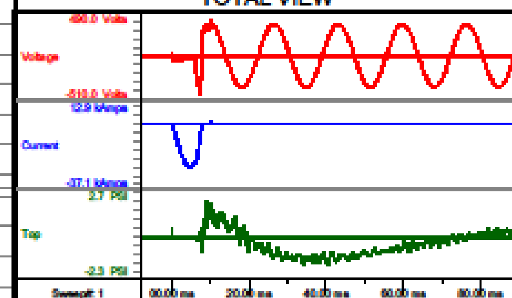
-

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-170
VOLTAGE: 100X Scope Probe, C/N 131-008, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE: 100X Scope Probe, C/N 131-004, 1%
CURRENT: ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34419

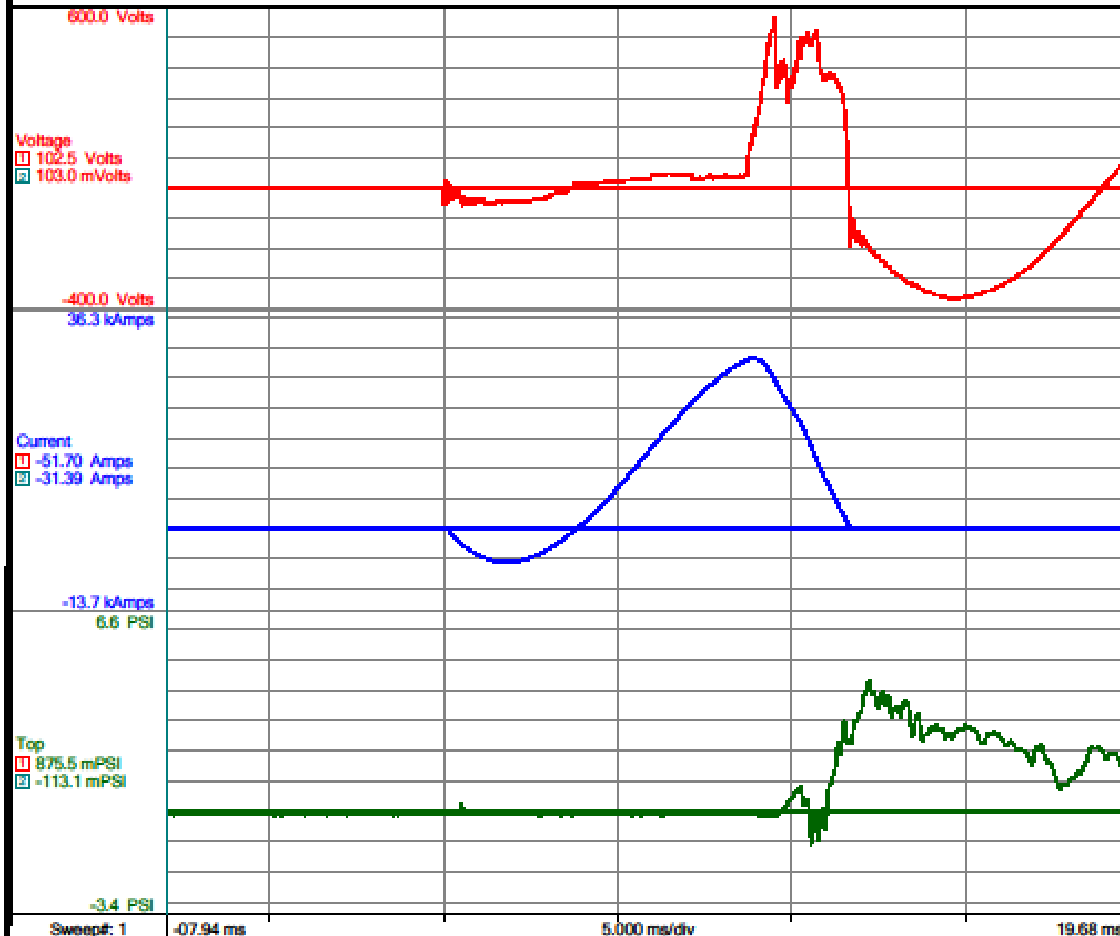
Oscillogram No.: HPL3-34420 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 9:49:13 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 81




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 312 Deg |
| Closing time (V0)+ | 14.43 m Sec |
| Peak Current (Ip) | 28.28 k Amperes |
| Time to Ip | 8.832 m Sec. |
| I²t | 2.573 M Amp^2sec |
| I Duration | 11.62 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

9.79 kA

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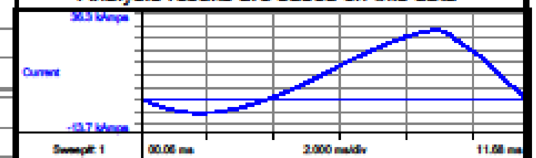
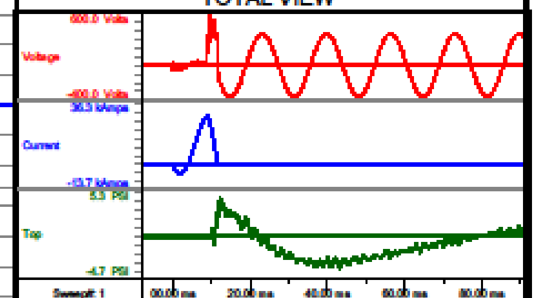
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]

VOLTAGE: 100X Scope Probe, C/N [illegible], 1%

VOLTAGE: 100X Scope Probe, C/N [illegible], 1%

CURRENT: ROGOWSKI COIL, C/N [illegible]

NOTE: Channel offset removed for analysis

but not for display.

PLOT FILE [illegible]

**OSC. NO.: HPL3-34420**

Oscillogram No.: HPL3-34421 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 9:52:28 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 82


## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 218 Deg |
| Closing time (V0)+ | 10.09 m Sec |
| Peak Current (Ip) | -27.88 k Amperes |
| Time to Ip | 5.634 m Sec. |
| I²t | 2.738 M Amp^2sec |
| I Duration | 8.169 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

9.79 kA

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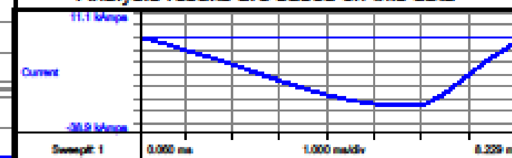
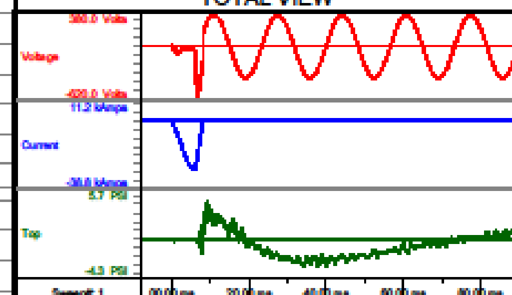
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N [illegible]

VOLTAGE 1000X Scope Probe, C/N [illegible], 1% PLOT FILE HPL3 CR_1_8

VOLTAGE 1000X Scope Probe, C/N [illegible], 1%

CURRENT ROGOWSKI COIL, C/N [illegible]

NOTE: Channel offset removed for analysis

but not for display.

OSC. NO.: HPL3-34421

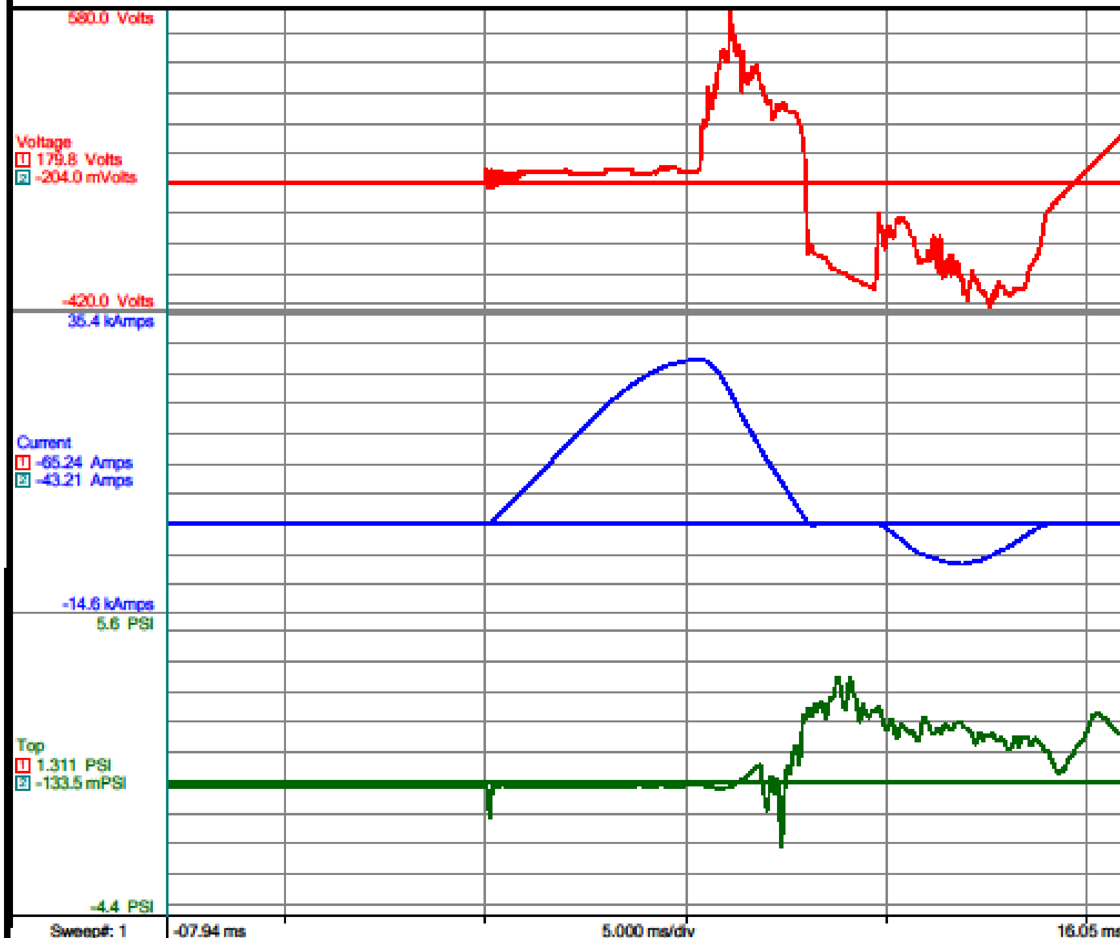
Oscillogram No.: HPL3-34422 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 9:56:18 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 83

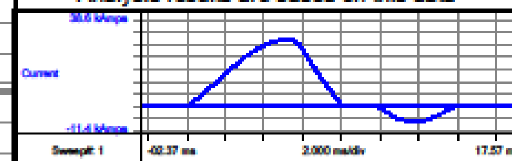



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 47 Deg |
| Closing time (V0)+ | 2.158 m Sec |
| Peak Current (Ip) | 27.37 k Amperes |
| Time to Ip | 5.270 m Sec. |
| I²t | 2.603 M Amp^2sec |
| I Duration | 7.993 m Sec. |

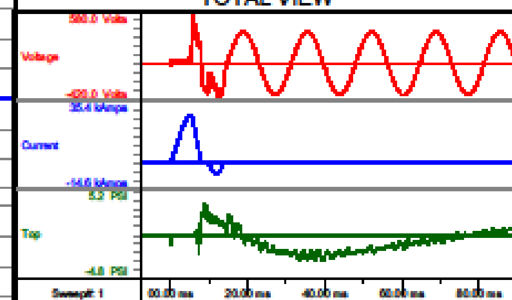
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 9.79 kA |
| - |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N [illegible]

VOLTAGE [illegible] Scope Probe, C/N [illegible], 1% PLOT FILE:HPL3 [illegible]

VOLTAGE [illegible] Scope Probe, C/N [illegible], 1%

CURRENT ROGOWSKI COIL, C/N [illegible]

NOTE: Channel offset removed for analysis

but not for display.

OSC. NO.: HPL3-34422

Oscillogram No.: HPL3-34423 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 9:59:51 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

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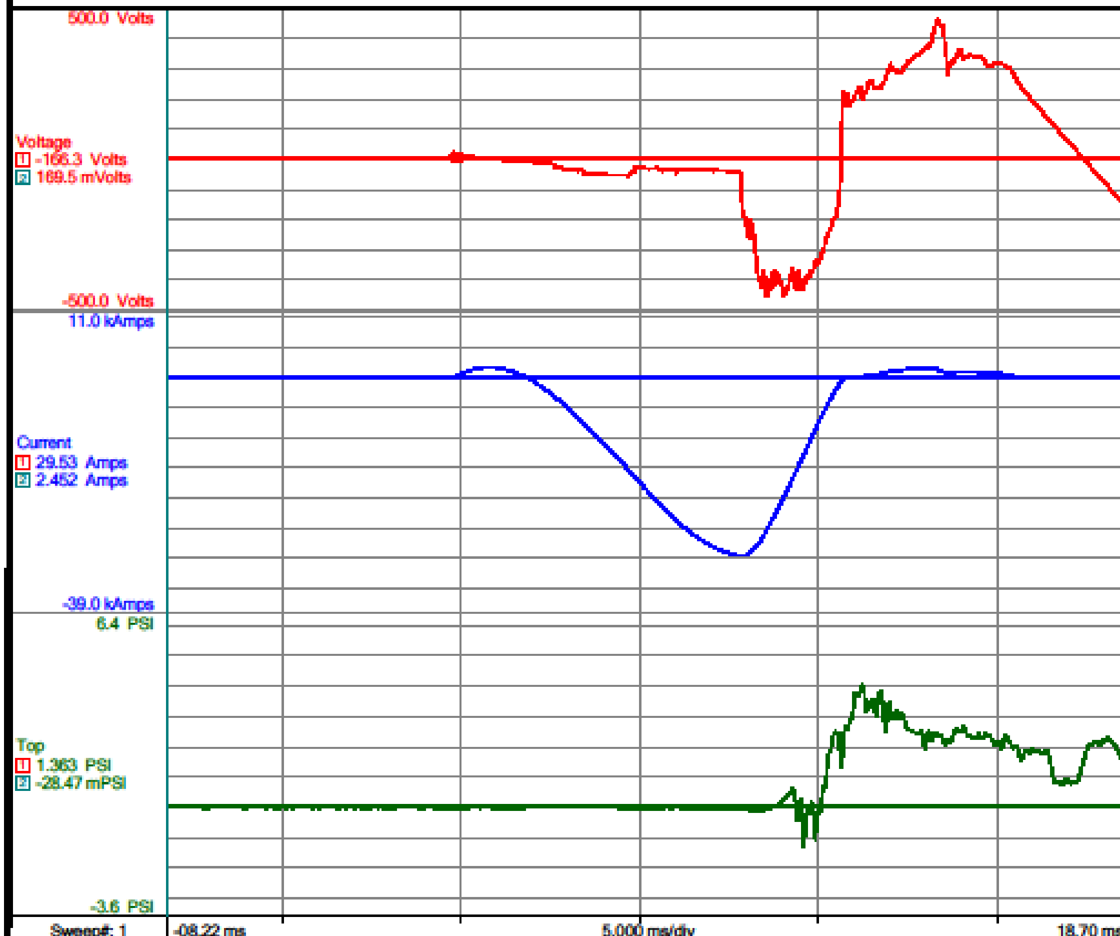
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 84




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 159 Deg |
| Closing time (V0)+ | 7.370 m Sec |
| Peak Current (Ip) | -29.67 k Amperes |
| Time to Ip | 8.128 m Sec. |
| I²t | 3.132 M Amp^2sec |
| I Duration | 10.92 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

9.79 kA

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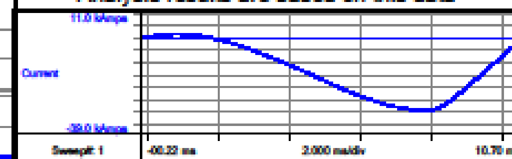
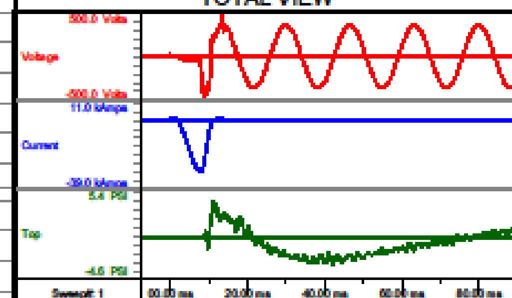
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

[illegible]

OSC. NO.: HPL3-34423

Oscillogram No.: HPL3-34424 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 10:04:07 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

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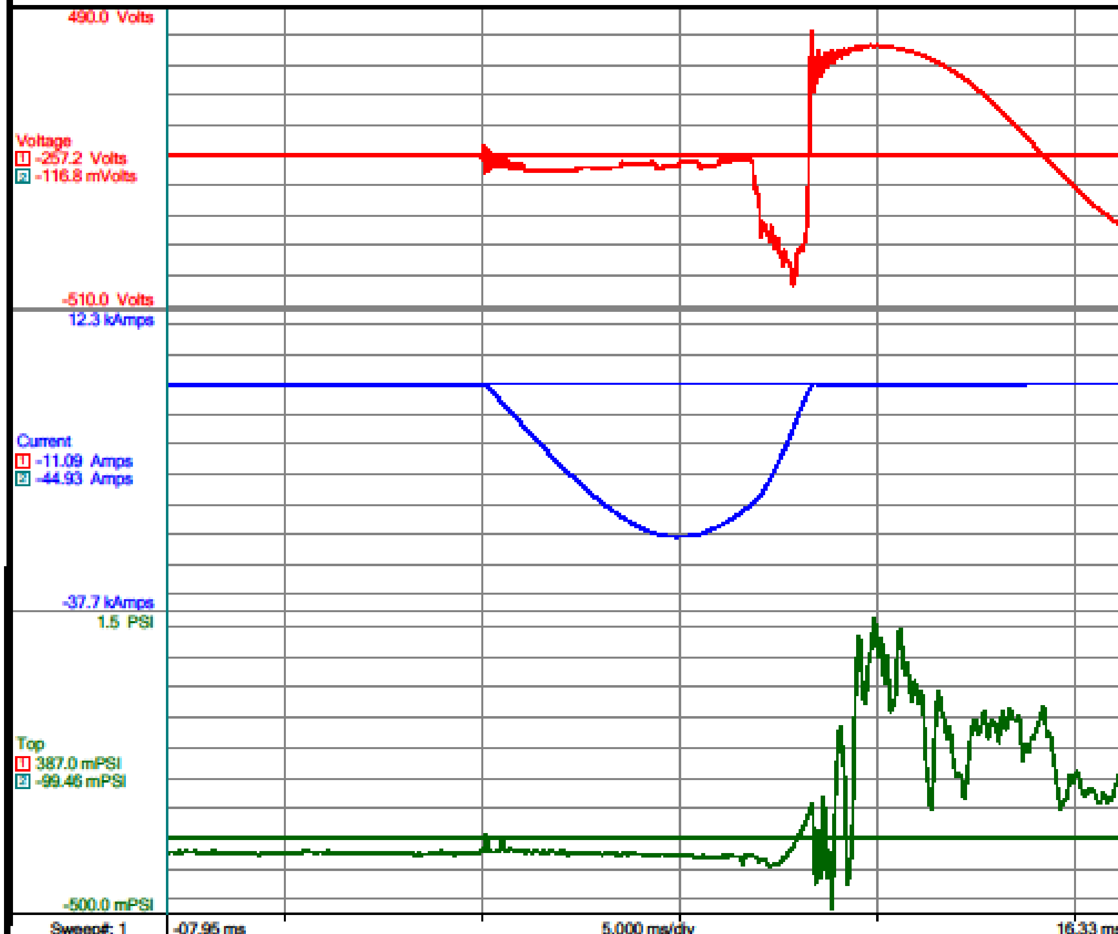
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 85




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 234 Deg |
| Closing time (V0)+ | 10.83 m Sec |
| Peak Current (Ip) | -25.38 k Amperes |
| Time to Ip | 4.877 m Sec. |
| I²t | 2.766 M Amp^2sec |
| I Duration | 8.282 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

**Comment Section**

9.79 kA

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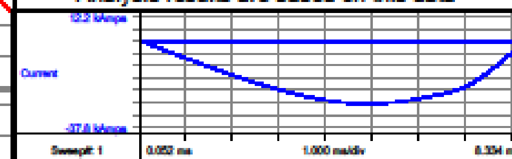
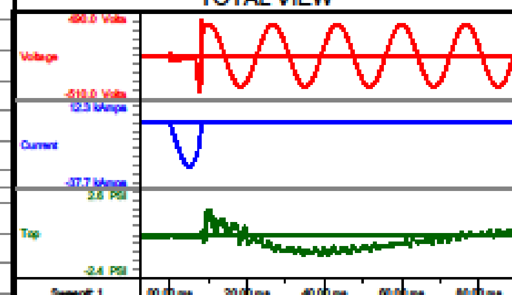
**Analysis results are based on this data**




**TOTAL VIEW**




**INSTRUMENTATION DATA**

Data Recording System [illegible]

VOLTAGE: [illegible] Probe, C/N [illegible], 1% PLOT FILE [illegible]

VOLTAGE: [illegible] Probe, C/N [illegible], 1%

CURRENT ROGOWSKI COIL, C/N [illegible]

NOTE: Channel offset removed for analysis,

but not for display.

**OSC. NO.: HPL3-34424**

Oscillogram No.: HPL3-34425 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 10:07:41 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

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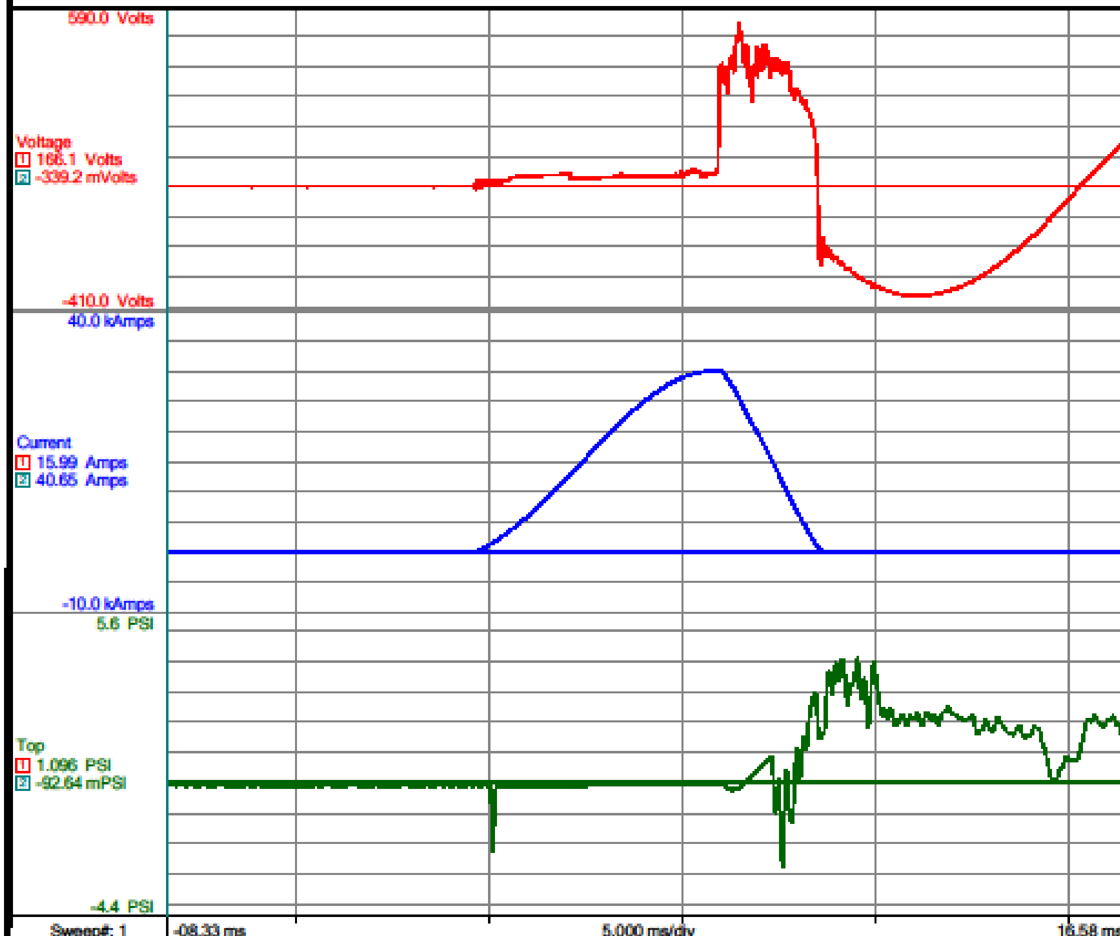
Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 86

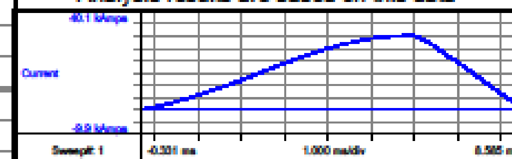



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 21 Deg |
| Closing time (V0)+ | 984.1 µ Sec |
| Peak Current (Ip) | 30.10 k Amperes |
| Time to Ip | 6.214 m Sec. |
| I²t | 3.271 M Amp^2sec |
| I Duration | 8.916 m Sec. |

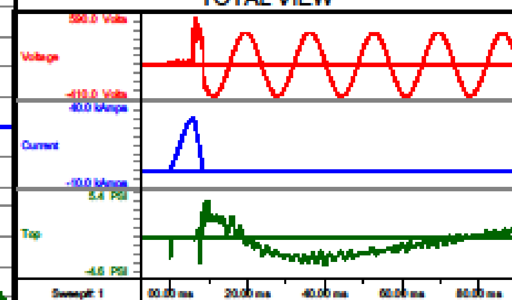
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 9.79 kA |
| - |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34425

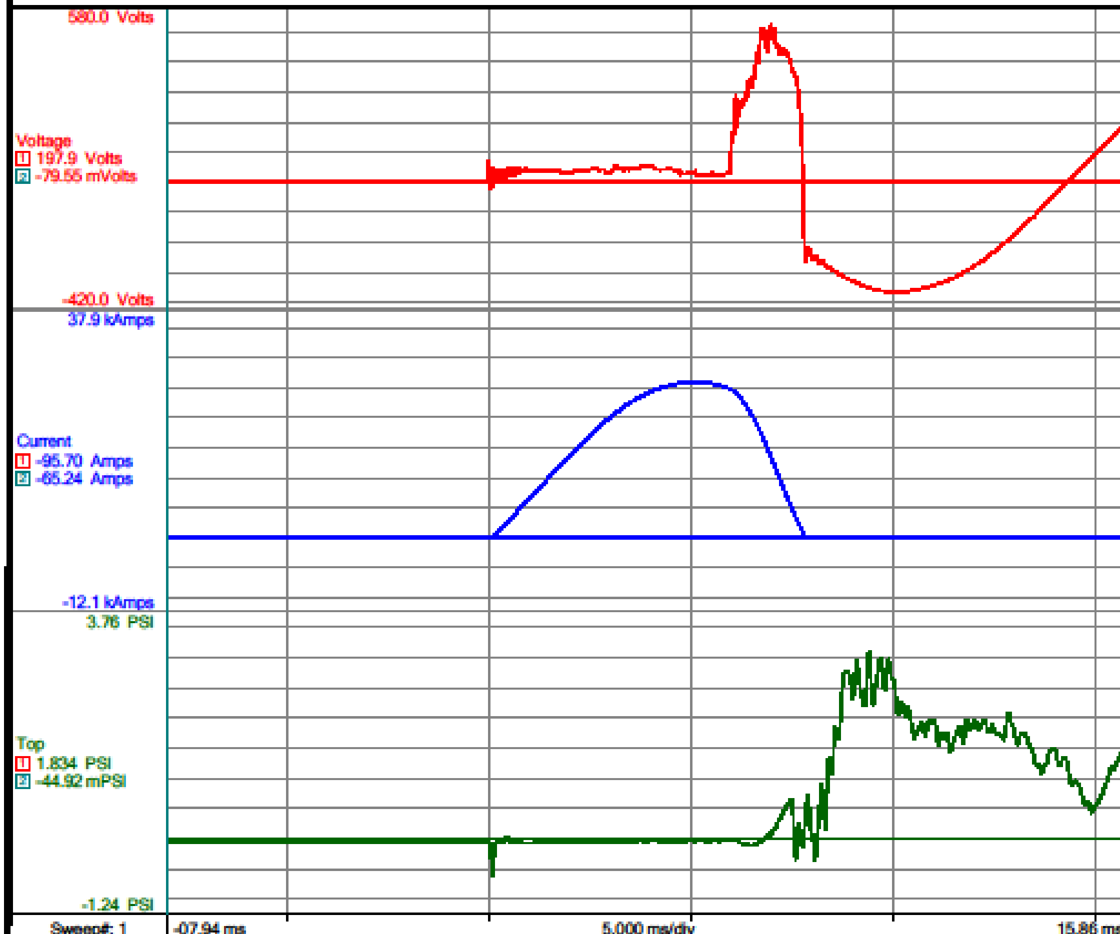
Oscillogram No.: HPL3-34426 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 10:11:16 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 87




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 51 Deg |
| Closing time (V0)+ | 2.371 m Sec |
| Peak Current (Ip) | 28.00 k Amperes |
| Time to Ip | 5.047 m Sec. |
| I²t | 2.875 M Amp^2sec |
| I Duration | 7.800 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

9.79 kA
-
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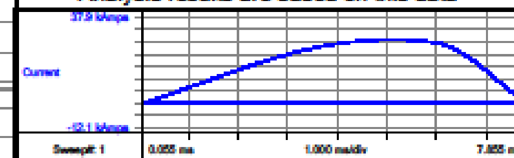
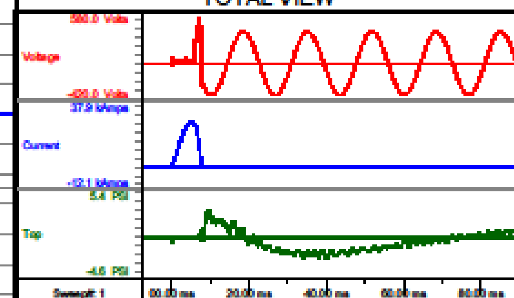
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1% PLOT FILE HPL3 [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

## OSC. NO.: HPL3-34426

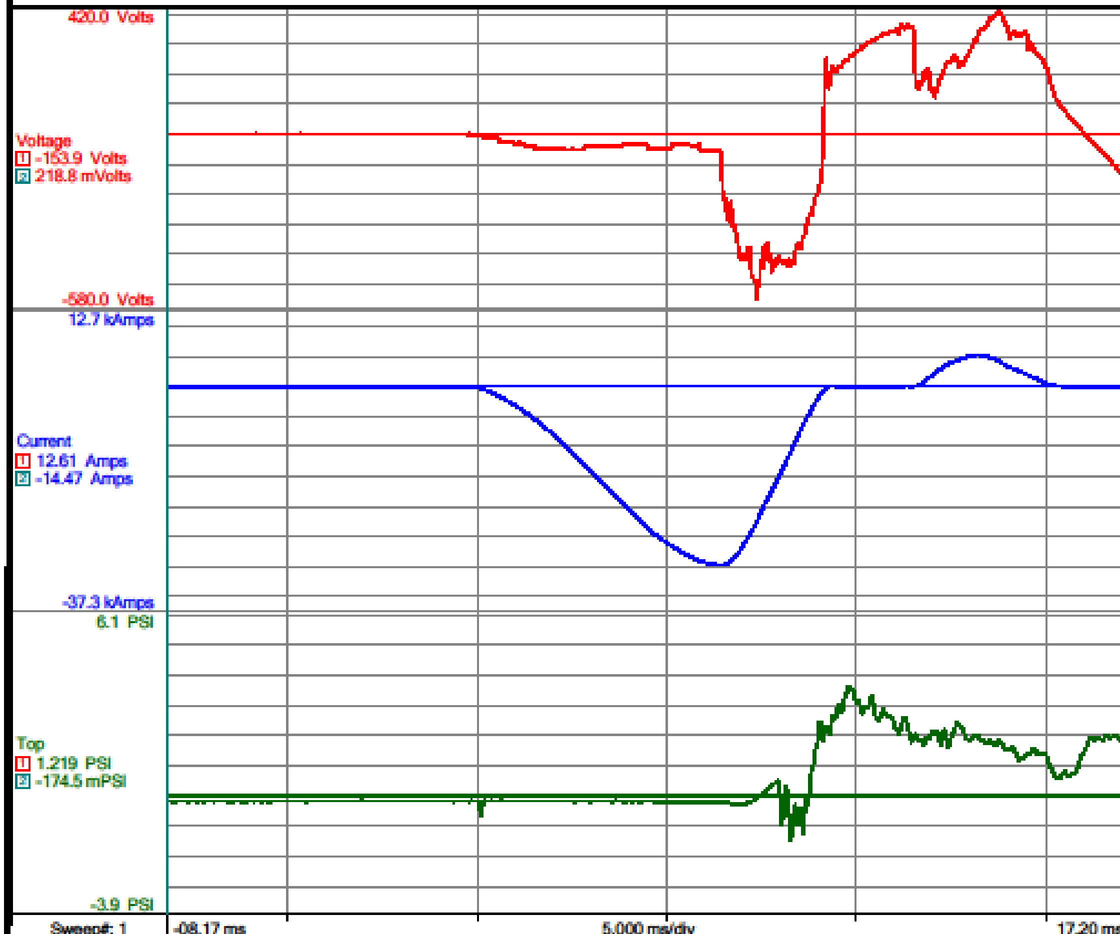
Oscillogram No.: HPL3-34427 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 10:15:02 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 88




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 190 Deg |
| Closing time (V0)+ | 8.780 m Sec |
| Peak Current (Ip) | -29.75 k Amperes |
| Time to Ip | 8.849 m Sec. |
| I²t | 3.178 M Amp^2sec |
| I Duration | 9.374 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

9.79 kA

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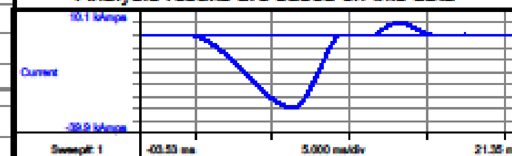
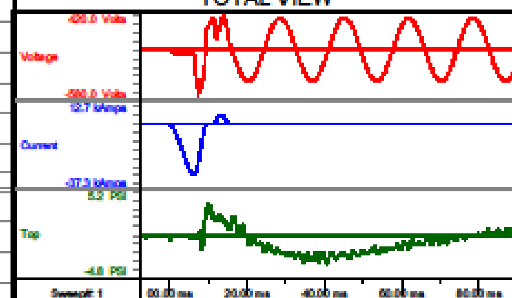
## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

[illegible]

VOLTAGE [illegible]

VOLTAGE [illegible]

CURRENT [illegible]

NOTE: Channel offset removed for analysis

but not for display.

OSC. NO.: HPL3-34427

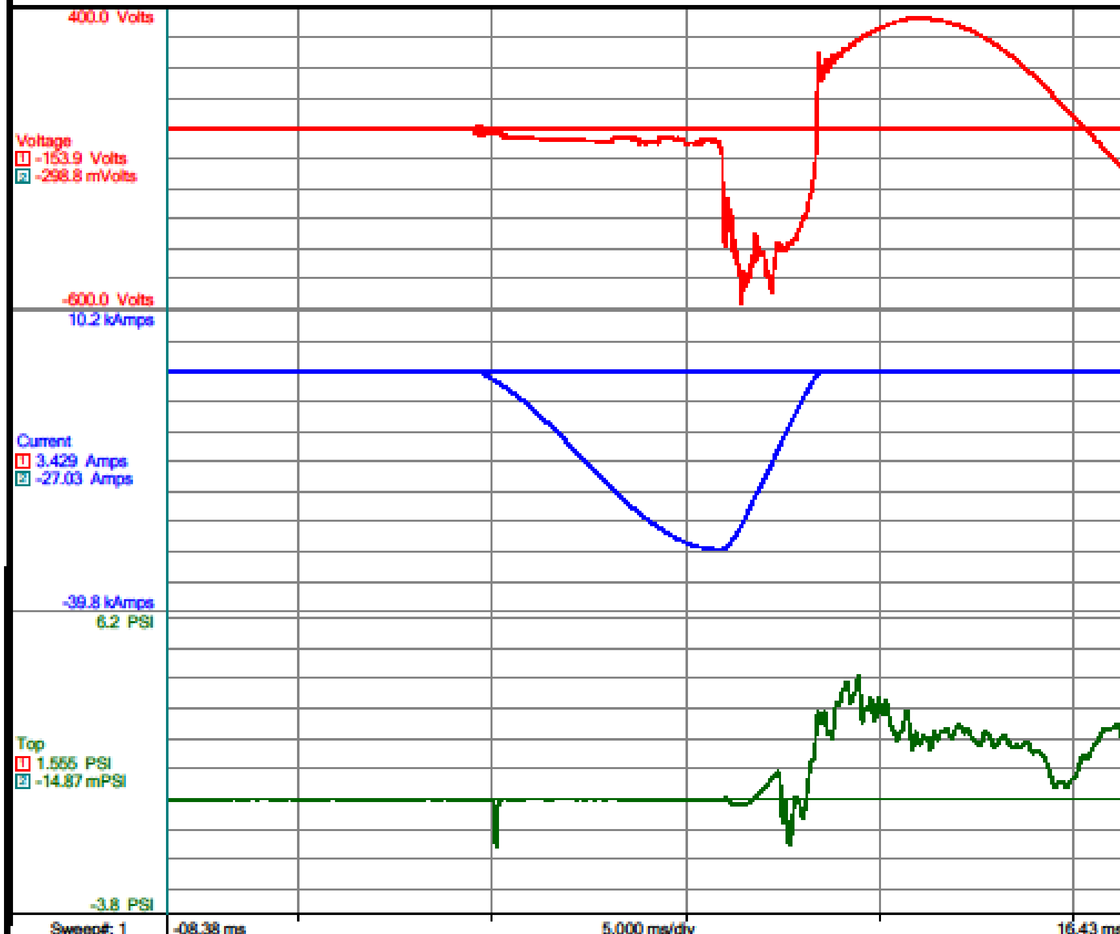
Oscillogram No.: HPL3-34428 OCV = 260 V
Date of Test: 9/30/2020 Time of Test: 10:18:56 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 34341 Calibration Date: 09/28/20
OCV = 354 V Rms Sym Current = 13.34 kA
Power Factor = 29%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 89




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 202 Deg |
| Closing time (V0)+ | 9.353 m Sec |
| Peak Current (Ip) | -29.84 k Amperes |
| Time to Ip | 6.205 m Sec. |
| I²t | 3.169 M Amp^2sec |
| I Duration | 8.812 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

## Comment Section

9.79 kA

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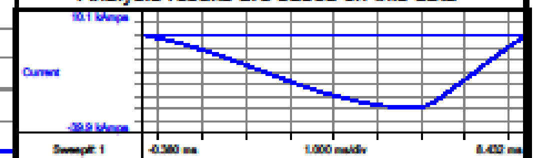
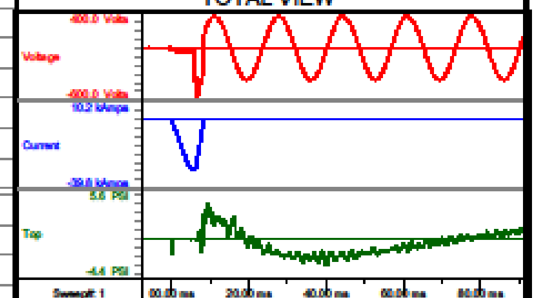
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System:HBM GEN7T C/N 003-173
VOLTAGE: 100X Scope Probe, C/N 131-005, 1%
PLOT FILE:HPL3 CR_1_8
VOLTAGE: 100X Scope Probe, C/N 131-004, 1%
CURRENT: ROGOWSKI COIL, C/N 045-445
NOTE: Channel offset removed for analysis,
but not for display.

OSC. NO.: HPL3-34428

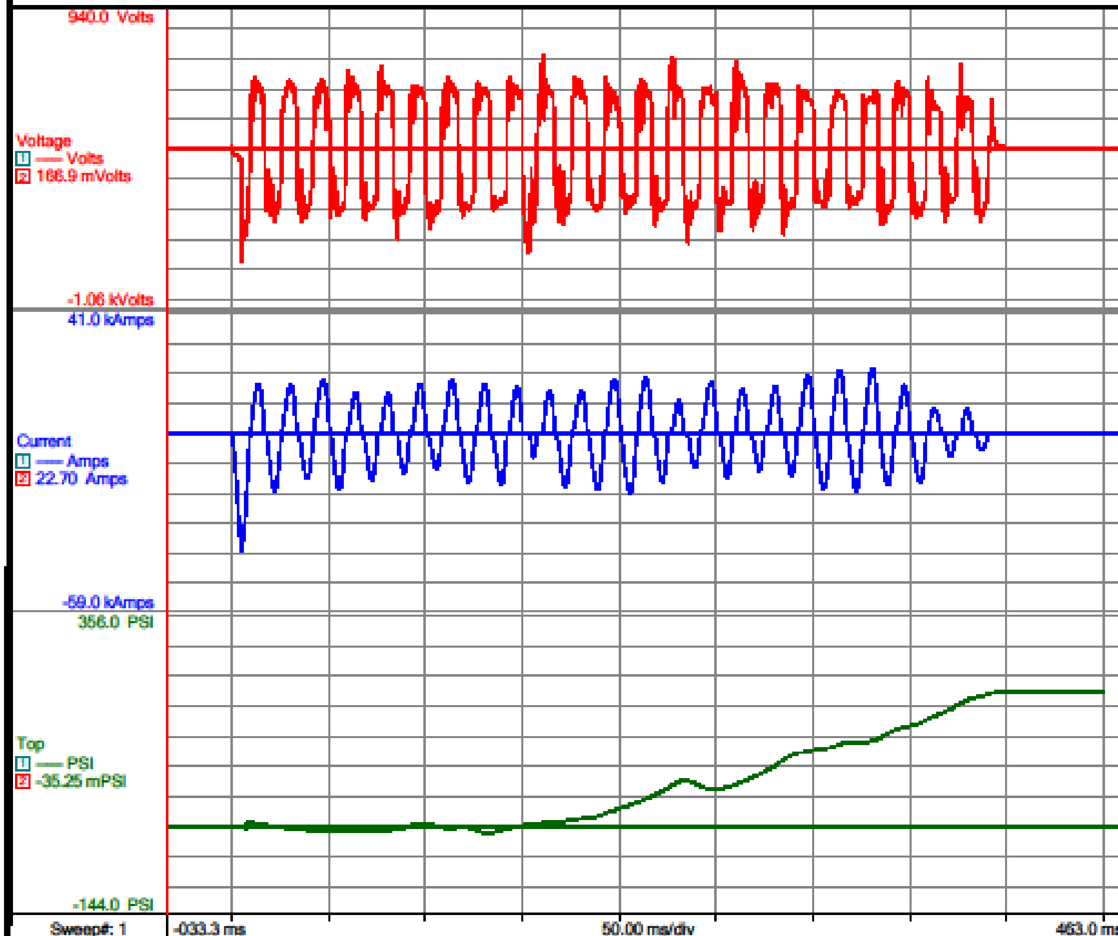
Oscillogram No.: HPL3-34430 OCV = 485 V
Date of Test: 9/30/2020 Time of Test: 10:59:39 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 90




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 174 Deg |
| Closing time (V0)+ | 252.7 μ Sec |
| Peak Current (Ip) | -39.08 k Amperes |
| Time to Ip | 5.075 m Sec. |
| I²t | 45.89 M Amp^2sec |
| I Duration | 358.6 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

Comment Section

21.87 kA

18 in.

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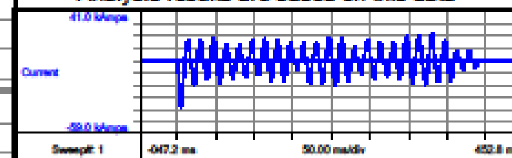
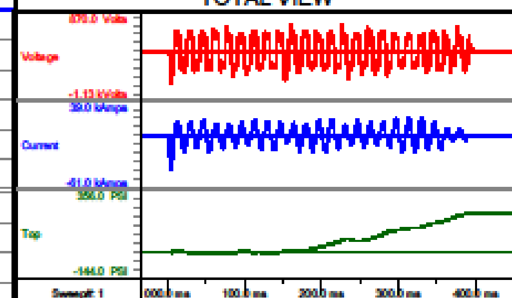
Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

OSC. NO.: HPL3-34430

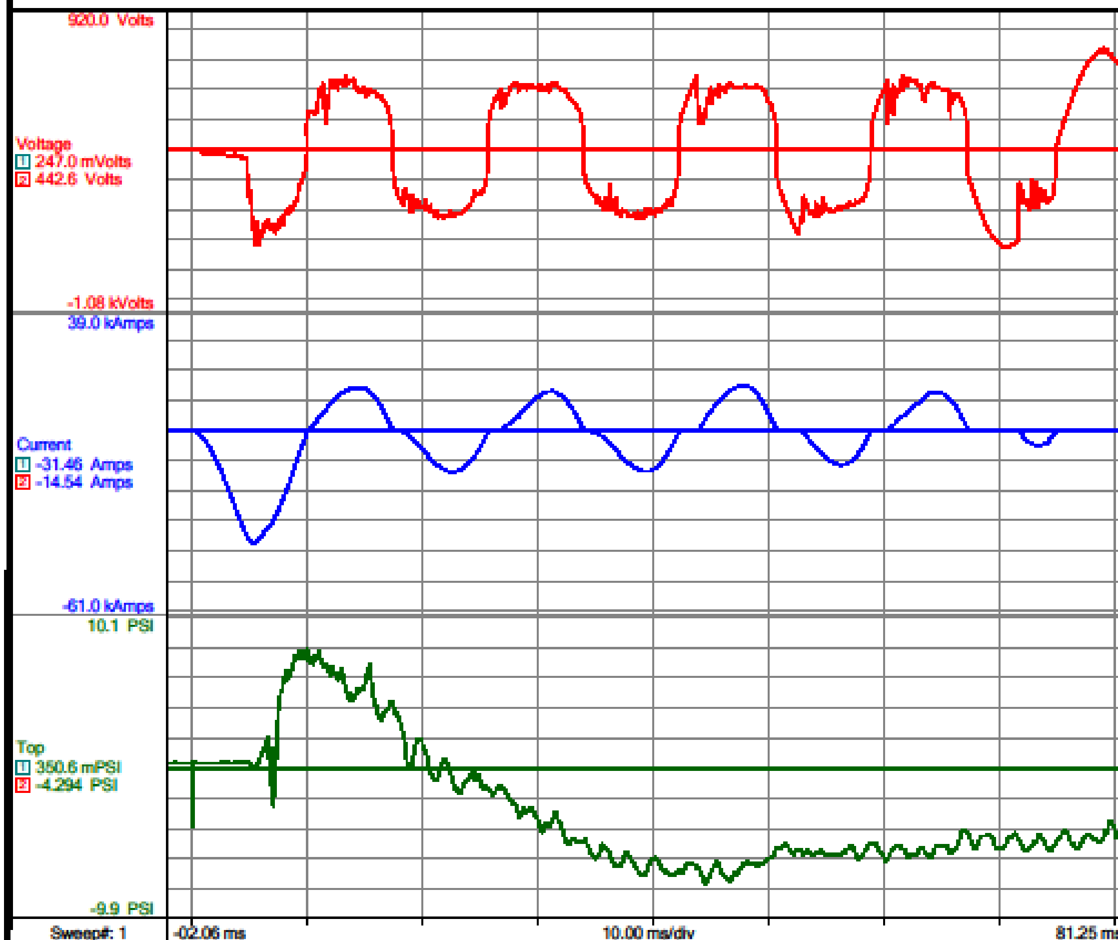
Oscillogram No.: HPL3-34432 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 11:16:40 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 91




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 184 Deg |
| Closing time (V0)+ | 8.508 m Sec |
| Peak Current (Ip) | -37.40 k Amperes |
| Time to Ip | 5.308 m Sec. |
| I²t | 9.602 M Amp^2sec |
| I Duration | 67.31 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

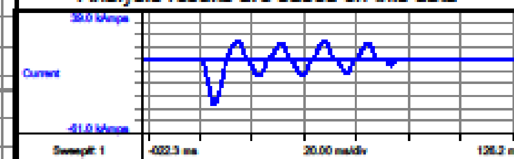
## Comment Section

20.66 kA

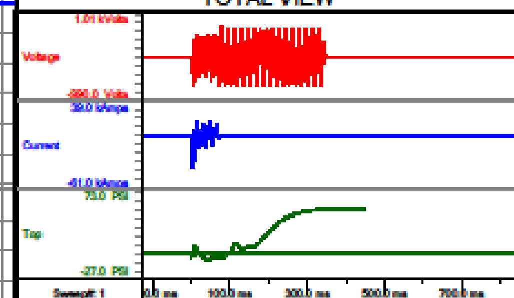
18 in.

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System:HBM GEN7T C/N [illegible]
VOLTAGE:100X Boyce Probe, C/N [illegible], 1% PLOT FILE:HPL3 CR_1_8
VOLTAGE:100X Boyce Probe, C/N [illegible], 1%
CURRENT:ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34432

Oscillogram No.: HPL3-34434 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 11:21:27 AM

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

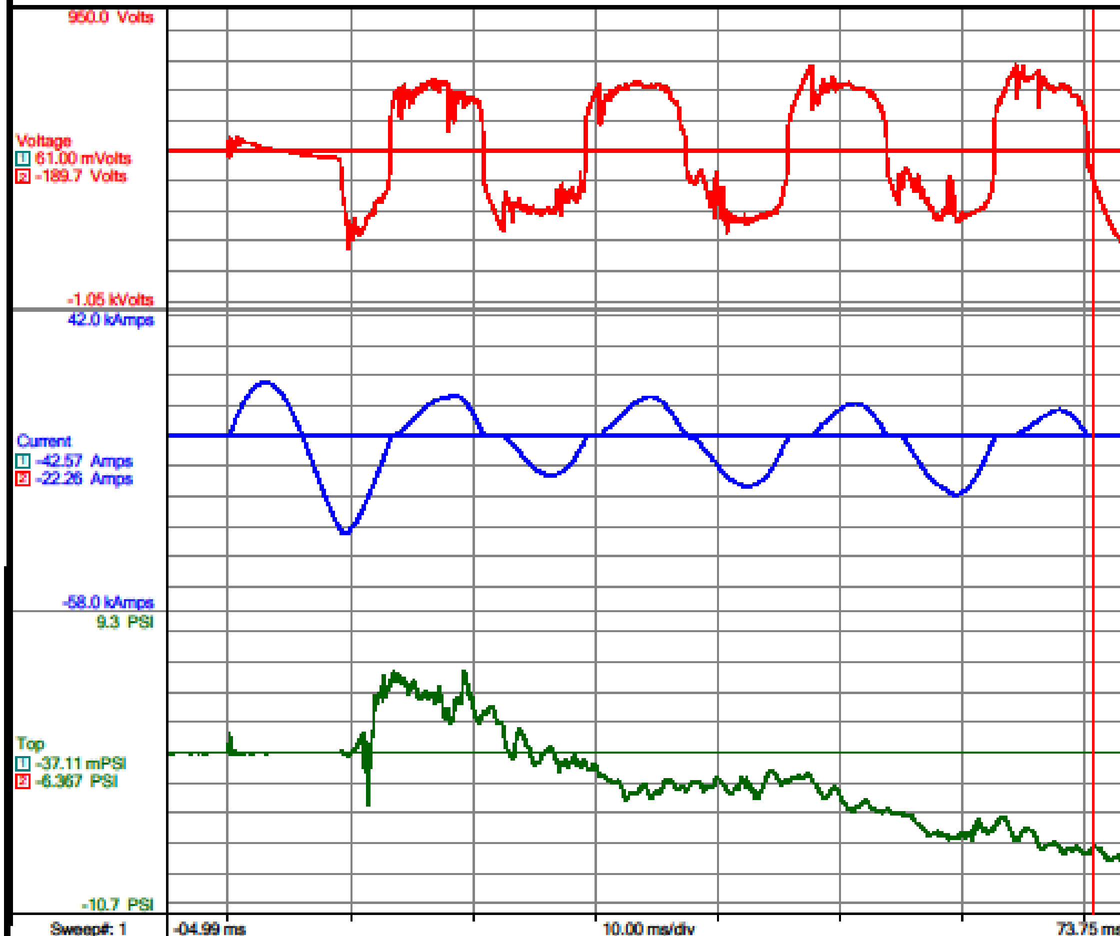
AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 92

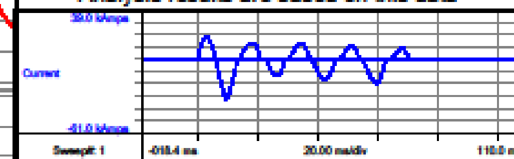
| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 110 Deg |
| Closing time (V0)+ | 5.082 m Sec |
| Peak Current (Ip) | -32.58 k Amperes |
| Time to Ip | 9.570 m Sec. |
| I²t | 8.850 M Amp^2sec |
| I Duration | 62.74 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

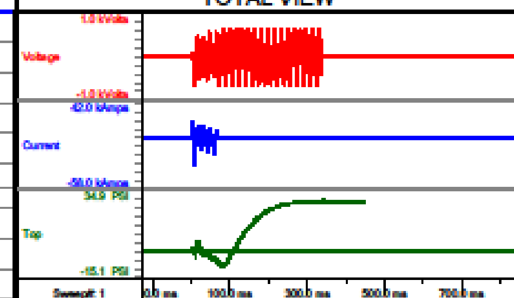
| Comment Section |
|---|
| 20.66 kA |
| 18 in. |
| - |




Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

OSC. NO.: HPL3-34434

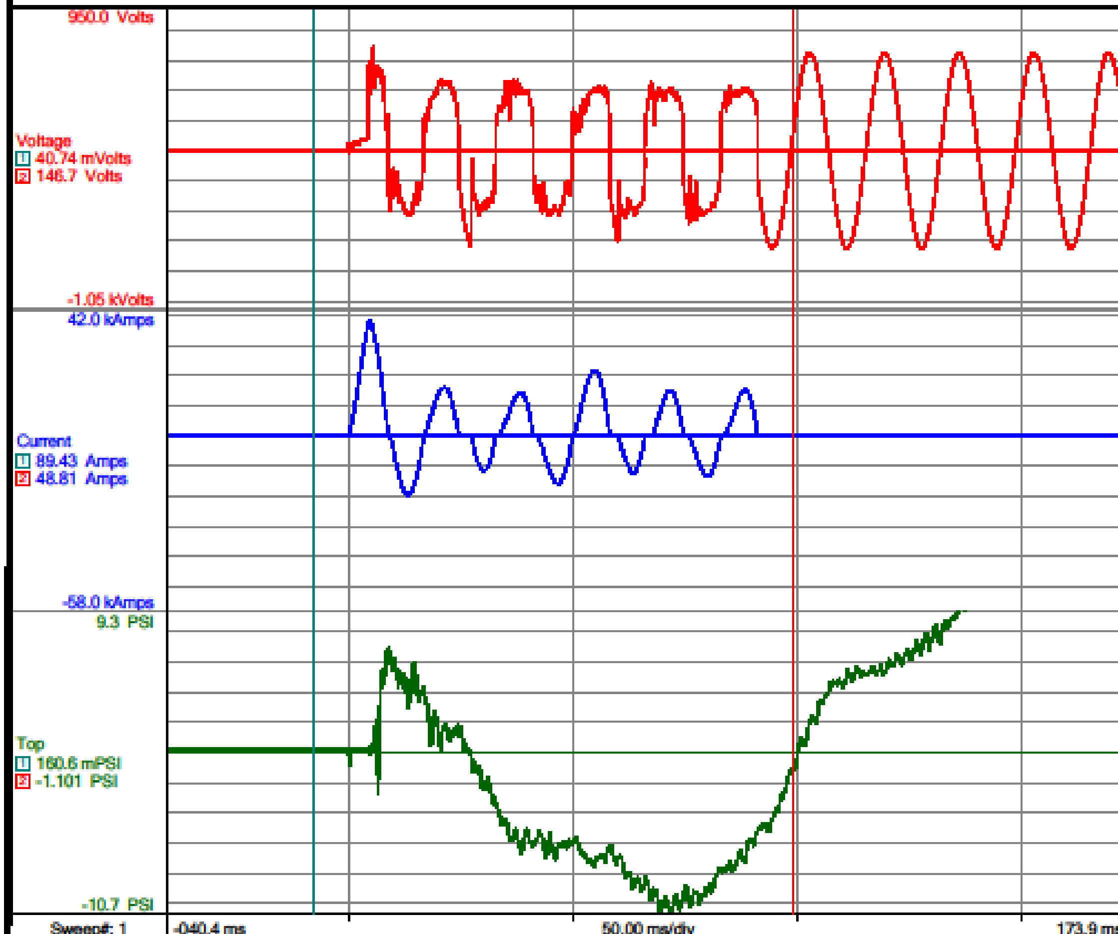
Oscillogram No.: HPL3-34435 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 11:25:44 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 93




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 30 Deg |
| Closing time (V0)+ | 1.369 m Sec |
| Peak Current (Ip) | 38.35 k Amperes |
| Time to Ip | 4.498 m Sec. |
| I²t | 14.04 M Amp^2sec |
| I Duration | 91.18 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

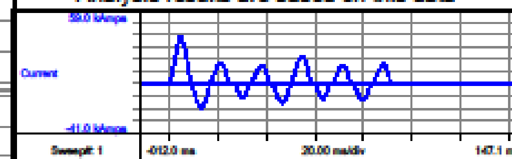
## Comment Section

20.66 kA

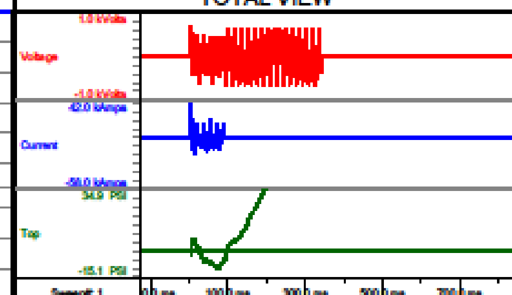
18 in.

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173

VOLTAGE 100X Scope Probe, C/N 131-008, 1% PLOT FILE HPL3 CR_1_8

VOLTAGE 100X Scope Probe, C/N 131-004, 1%

CURRENT ROGOWSKI COIL, C/N 045-445

NOTE: Channel offset removed for analysis,

but not for display.

OSC. NO.: HPL3-34435

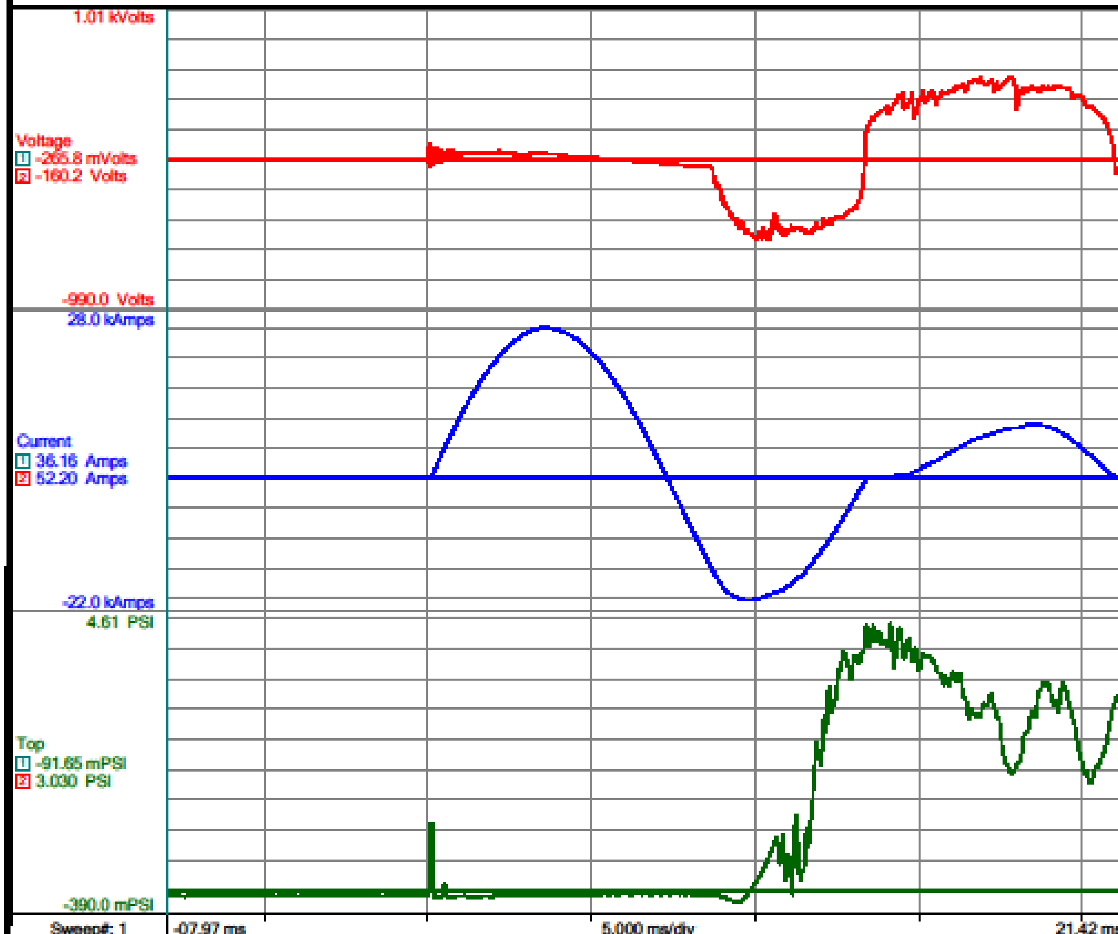
Oscillogram No.: HPL3-34436 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 11:31:02 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 94




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 93 Deg |
| Closing time (V0)+ | 4.322 m Sec |
| Peak Current (Ip) | 24.98 k Amperes |
| Time to Ip | 3.555 m Sec. |
| I²t | 3.577 M Amp^2sec |
| I Duration | 13.38 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

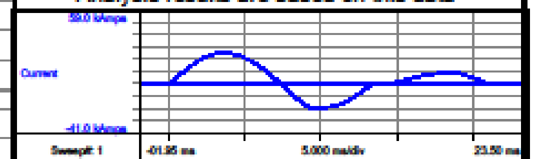
## Comment Section

20.68 kA

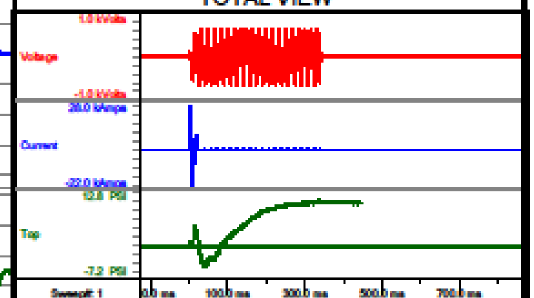
18 in.

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-175

VOLTAGE 100X Scope Probe, C/N 131-008, 1% PLOT FILE HPL3 CR_1_8

VOLTAGE 100X Scope Probe, C/N 131-004, 1%

CURRENT ROGOWSKI COIL, C/N 048-448

NOTE: Channel offset removed for analysis but not for display.

OSC. NO.: HPL3-34436

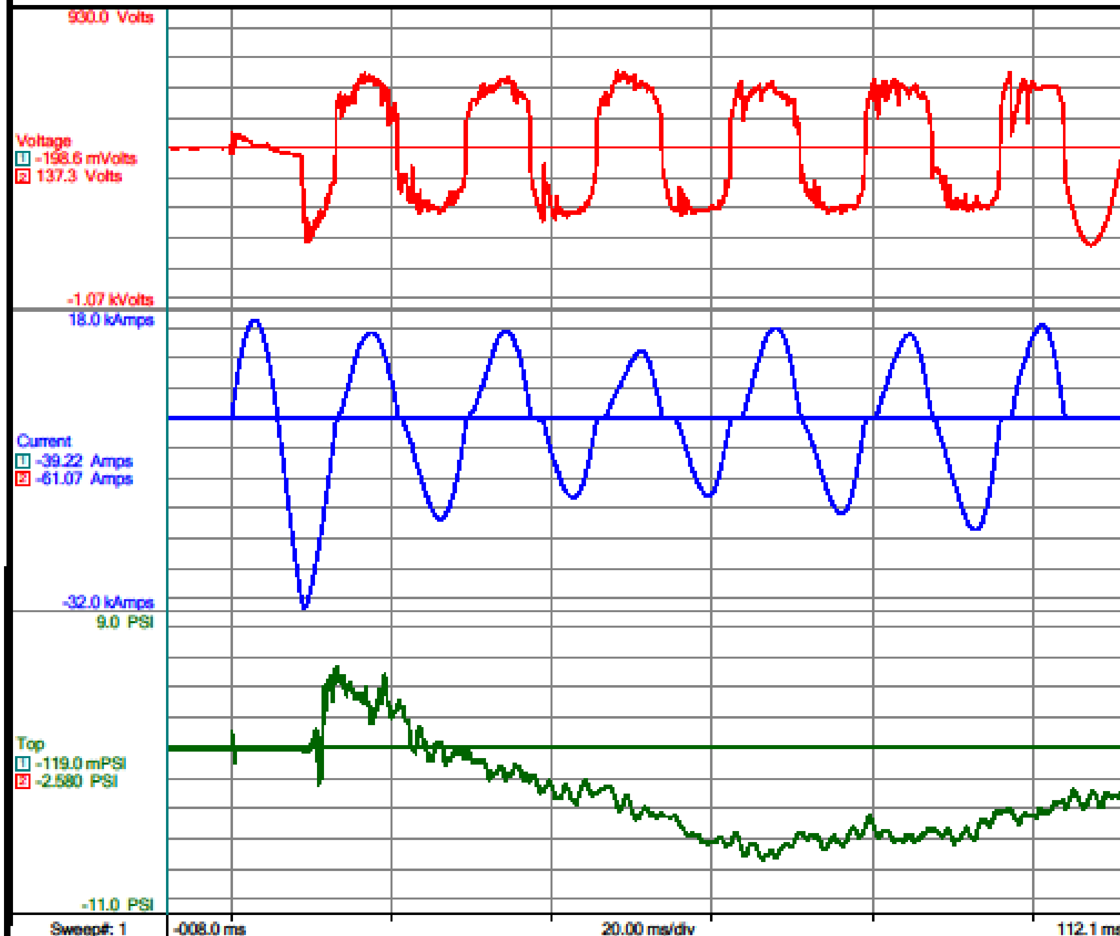
Oscillogram No.: HPL3-34437  OCV = 460 V
Date of Test: 9/30/2020  Time of Test: 11:35:12 AM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776  Calibration Date: 09/6/19
OCV = 485 V   Rms Sym Current = 25.33 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332  TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 95




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 113 Deg |
| Closing time (V0)+ | 5.221 m Sec |
| Peak Current (Ip) | -31.60 k Amperes |
| Time to Ip | 9.160 m Sec. |
| I²t | 12.45 M Amp^2sec |
| I Duration | 104.0 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

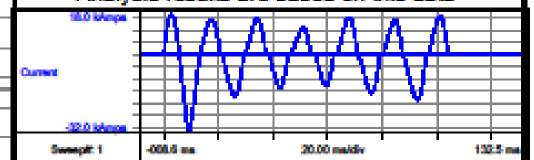
Comment Section

20.66 kA

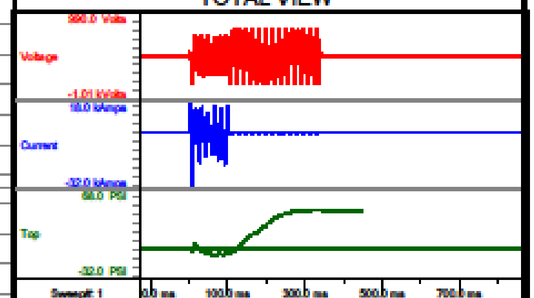
18 in.

-

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

OSC. NO.: HPL3-34437

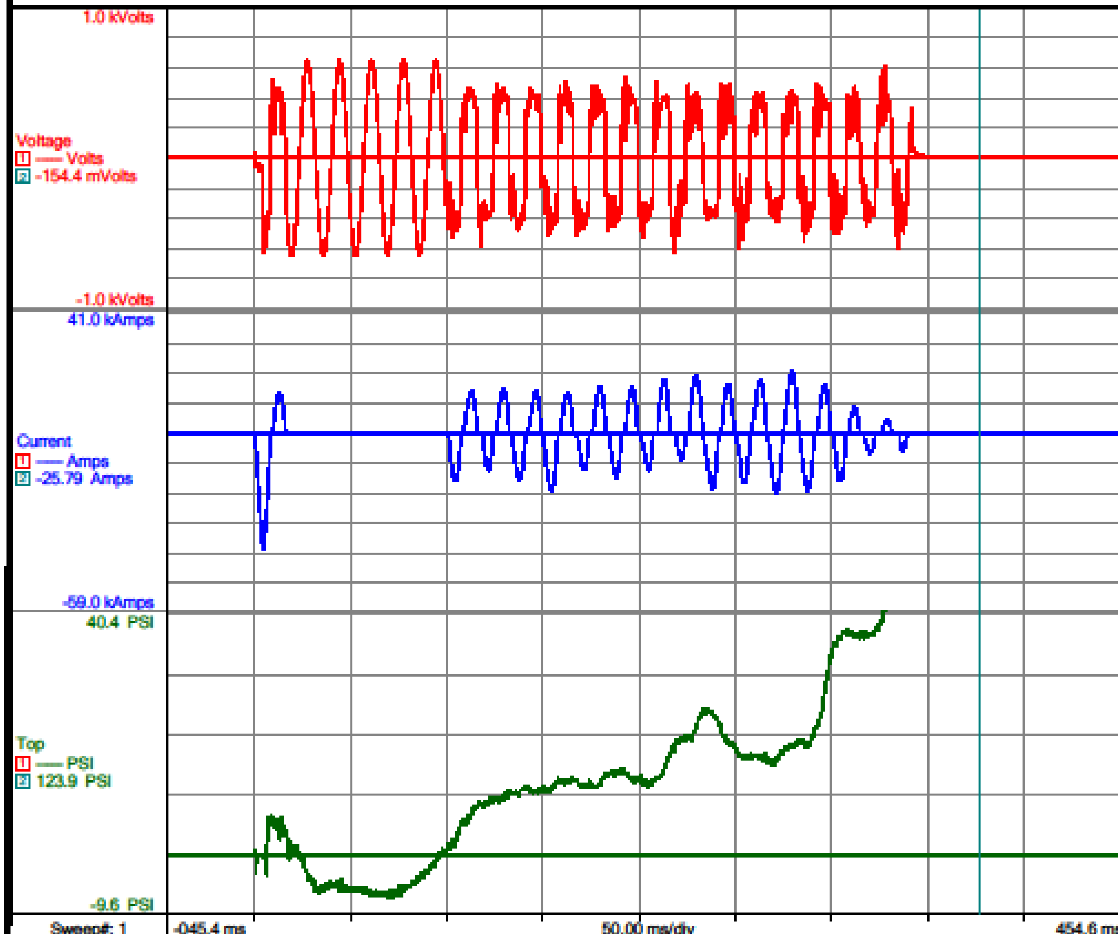
| |
|---|
| Oscillogram No.: HPL3-34438 OCV = 480 V<br>Date of Test: 9/30/2020 Time of Test: 12:13:41 PM |

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 96




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 154 Deg |
| Closing time (V0)+ | 23.81 µ Sec |
| Peak Current (Ip) | -38.30 k Amperes |
| Time to Ip | 4.430 m Sec. |
| I²t | 28.41 M Amp^2sec |
| I Duration | 307.8 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

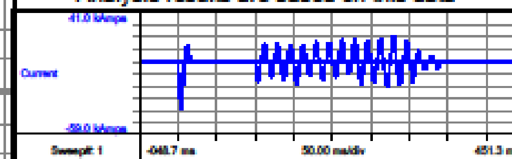
## Comment Section

20.68 kA

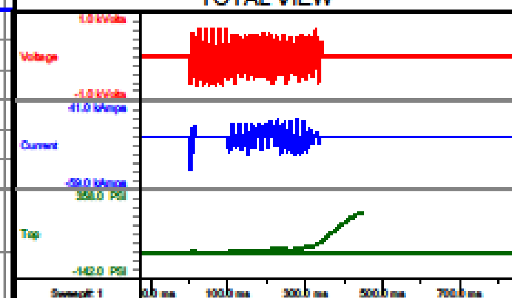
18 in.

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]

VOLTAGE 1000X Probe, CAL [illegible], 1% PLOT FILE [illegible]

VOLTAGE 1000X Probe, CAL [illegible], 1%

CURRENT ROGOWSKI COIL, CAL [illegible]

NOTE: Channel offset removed for analysis

but not for display.

**OSC. NO.: HPL3-34438**

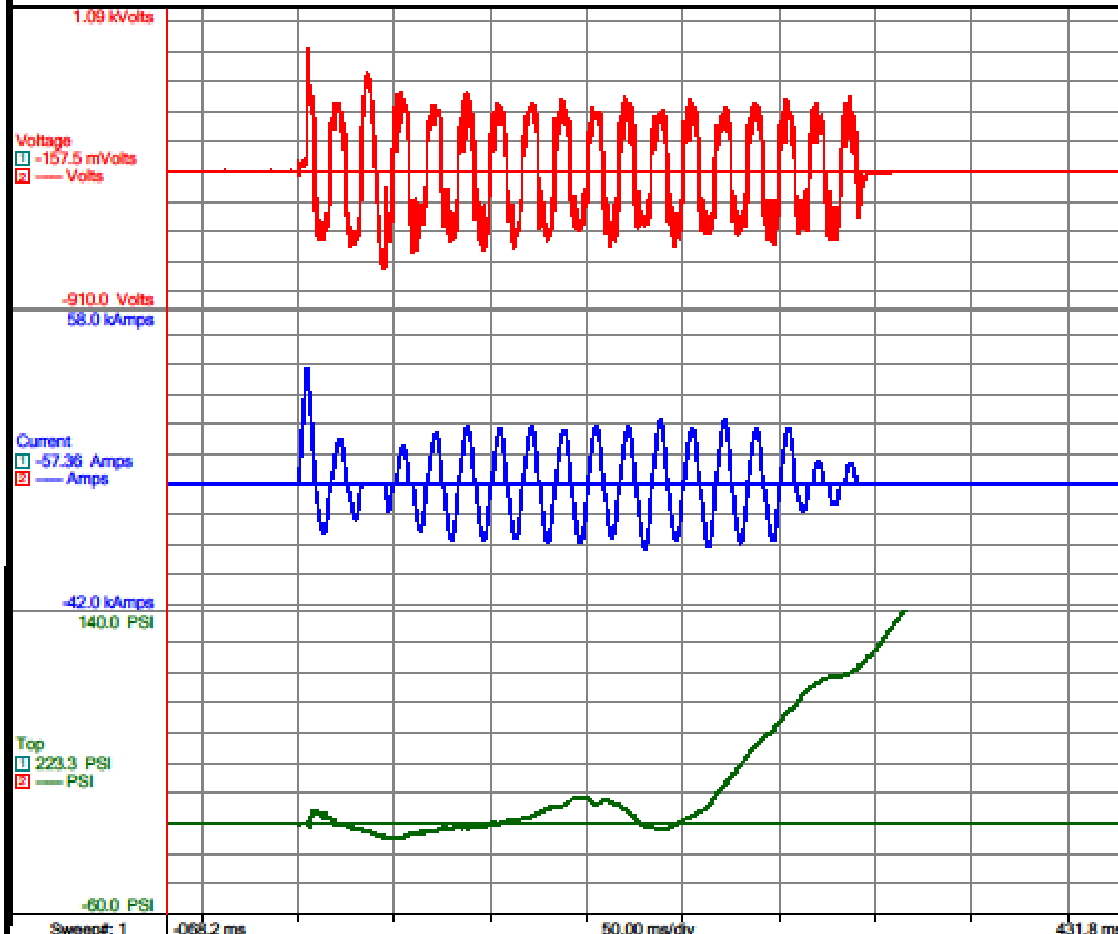
Oscillogram No.: HPL3-34439 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 12:23:02 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 97

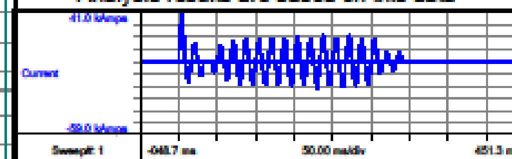



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 288 Deg |
| Closing time (V0)+ | 103.0 μ Sec |
| Peak Current (Ip) | 38.68 k Amperes |
| Time to Ip | 4.544 m Sec. |
| I²t | 41.20 M Amp^2sec |
| I Duration | 258.4 m Sec. |

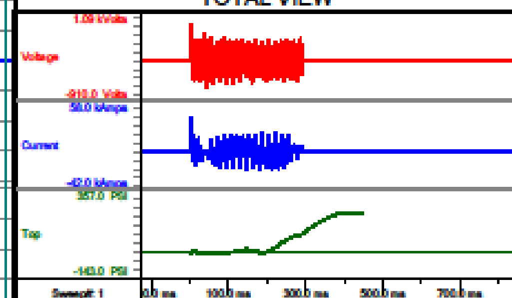
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 20.68 kA |
| 18 in. |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 363-173
VOLTAGE 100X Scope Probe, C/N 131-888, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 100X Scope Probe, C/N 131-804, 1%
CURRENT ROGOWSKI COIL, C/N 045-448
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34439

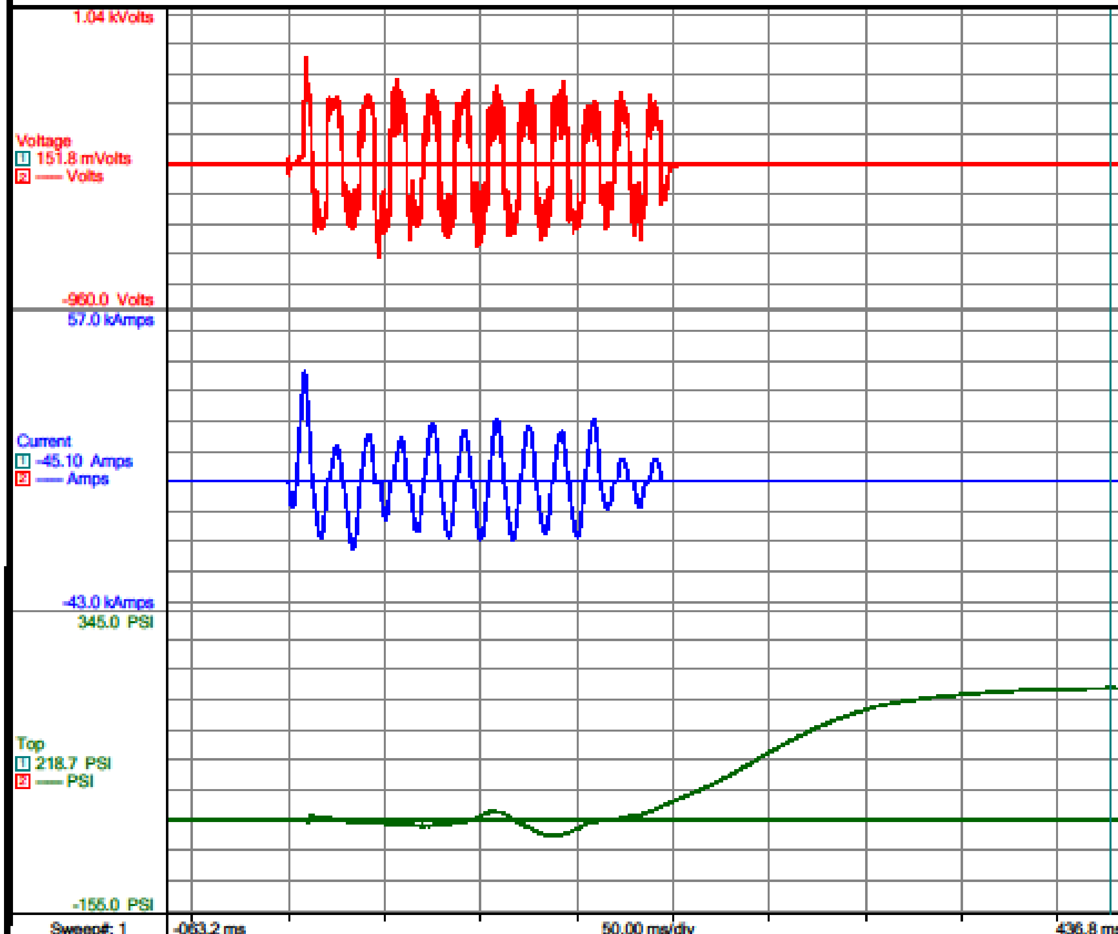
Oscillogram No.: HPL3-34440 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 12:33:11 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 98

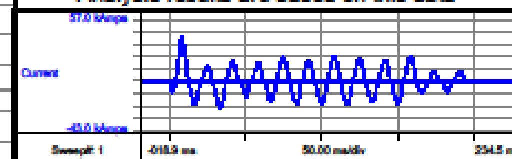



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 193 Deg |
| Closing time (V0)+ | 24.99 µ Sec |
| Peak Current (Ip) | 38.34 k Amperes |
| Time to Ip | 8.193 m Sec. |
| I²t | 25.92 M Amp^2sec |
| I Duration | 162.0 m Sec. |

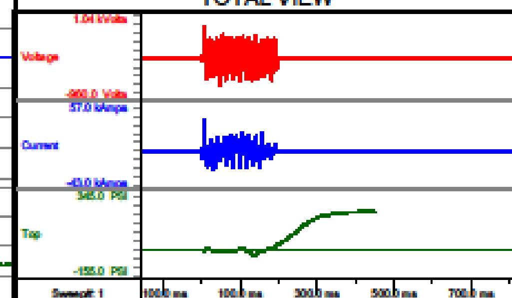
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 20.68 kA |
| 18 in. |
| - |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 383-173
VOLTAGE 1000X Bogge Probe, C/N 131-688, 1% PLOT FILE HPL3 CR_1_M
VOLTAGE 1000X Bogge Probe, C/N 131-604, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34440

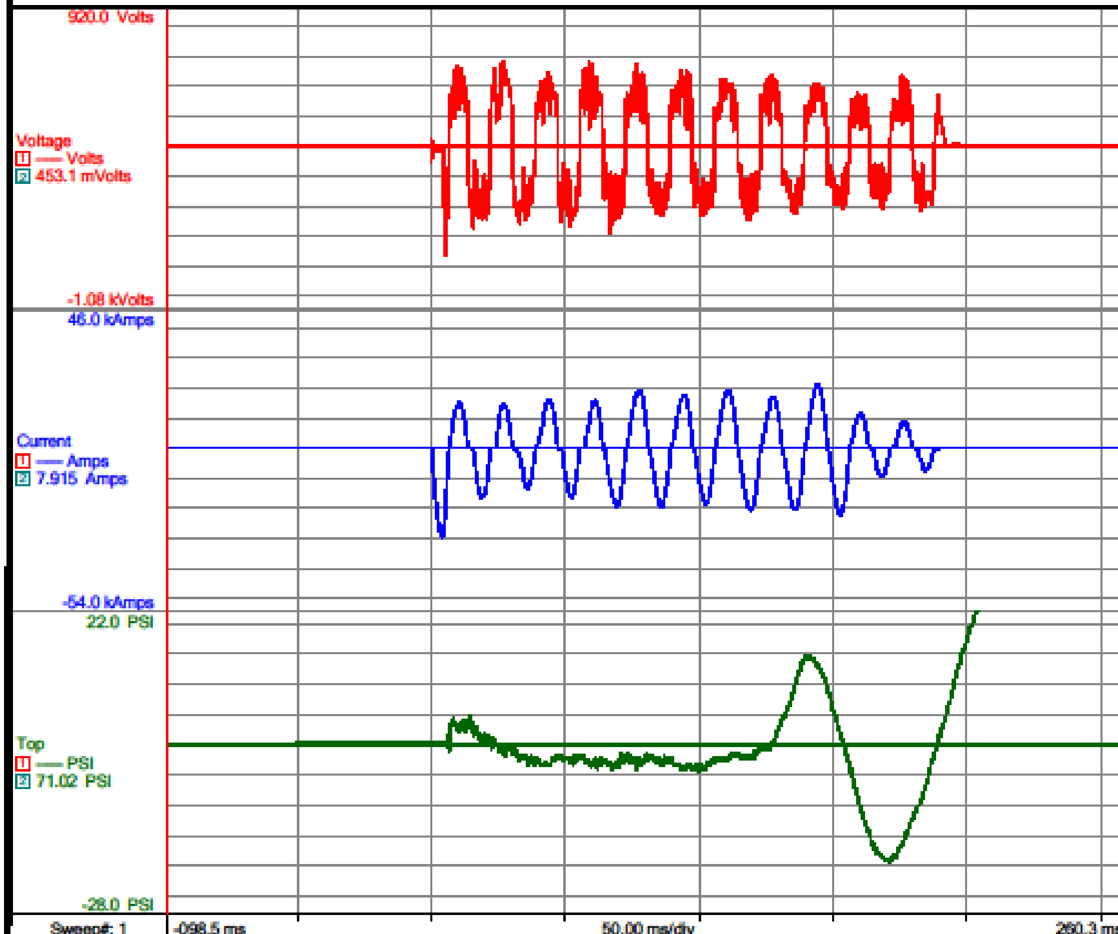
Oscillogram No.: HPL3-34441 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 12:44:02 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 99




| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 22 Deg |
| Closing time (V0)+ | 9.893 µ Sec |
| Peak Current (Ip) | -29.53 k Amperes |
| Time to Ip | 3.978 m Sec. |
| I²t | 25.70 M Amp^2sec |
| I Duration | 163.4 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

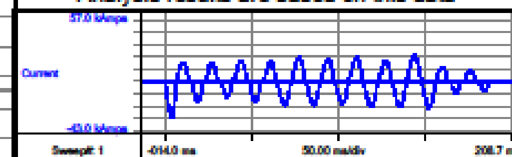
## Comment Section

20.66 kA

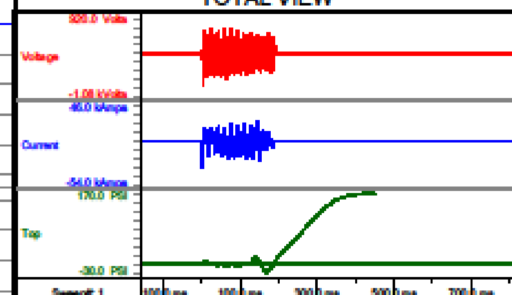
18 in.

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System [illegible]

VOLTAGE [illegible] Probe, C/N [illegible], 1% PLOT FILE [illegible]

VOLTAGE [illegible] Probe, C/N [illegible], 1%

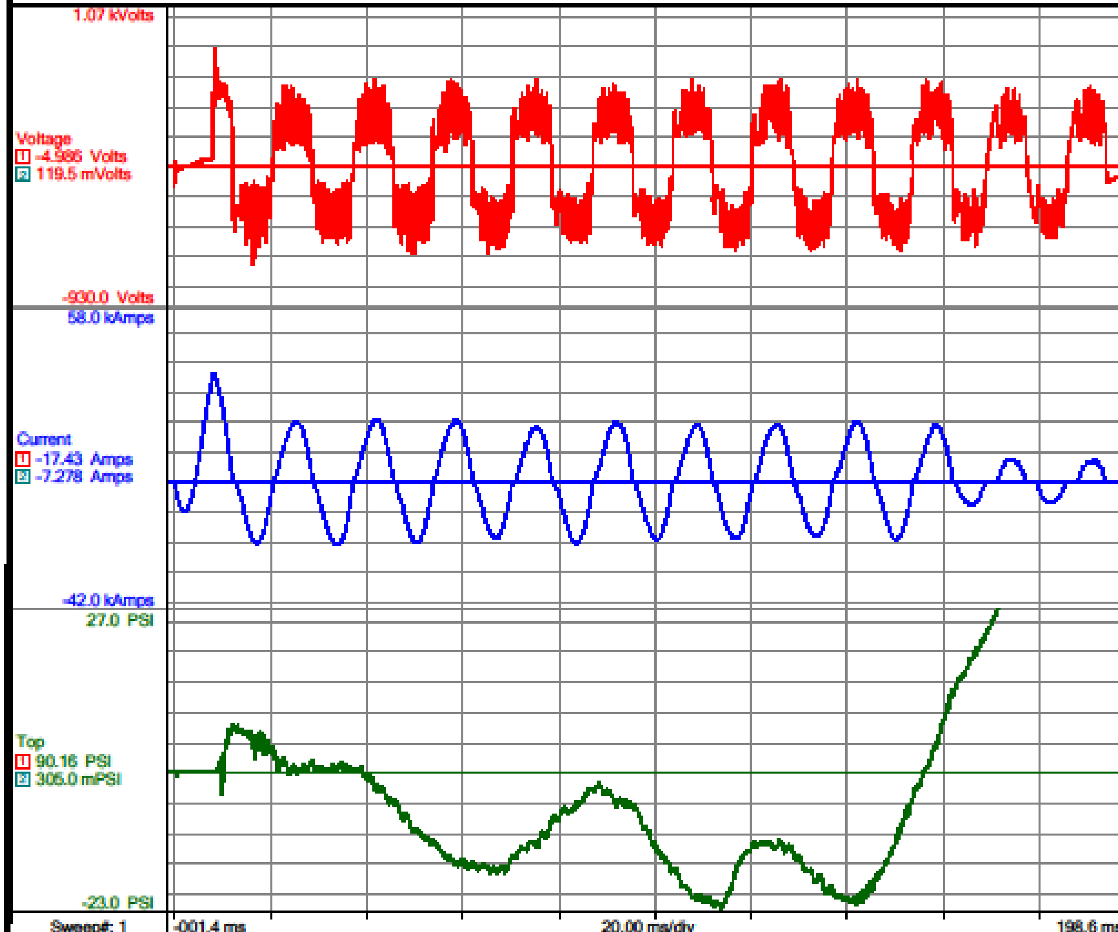
CURRENT [illegible] COIL, C/N [illegible]

NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-34441**

| | |
|---|---|
| Oscillogram No.: HPL3-34442 OCV = 480 V<br>Date of Test: 9/30/2020 Time of Test: 12:53:15 PM | **Schneider Electric**<br>High Power Laboratory, HPL3 Facility<br>Cedar Rapids, Iowa, USA |
| AVAILABLE CIRCUIT CHARACTERISTICS:<br>Osc. No: 23776 Calibration Date: 09/6/19<br>OCV = 485 V Rms Sym Current = 25.33 kA<br>Power Factor = 16% | |

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 100




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 343 Deg |
| Closing time (V0)+ | 74.49 μ Sec |
| Peak Current (Ip) | 38.11 k Amperes |
| Time to Ip | 8.139 m Sec. |
| I²t | 31.18 M Amp^2sec |
| I Duration | 182.0 m Sec. |

## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

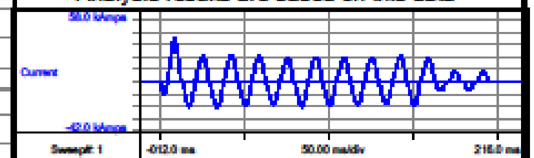
## Comment Section

20.68 kA

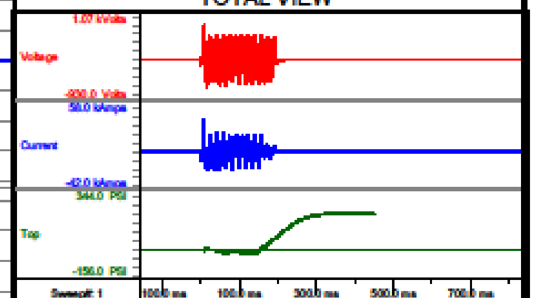
18 in.

-

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 063-173

VOLTAGE 1000X Scope Probe, C/N 131-830, 1% PLOT FILE HPL3 CR_1_M

VOLTAGE 1000X Scope Probe, C/N 131-804, 1%

CURRENT ROGOWSKI COIL, C/N 045-445

NOTE: Channel offset removed for analysis

but not for display.

**OSC. NO.: HPL3-34442**

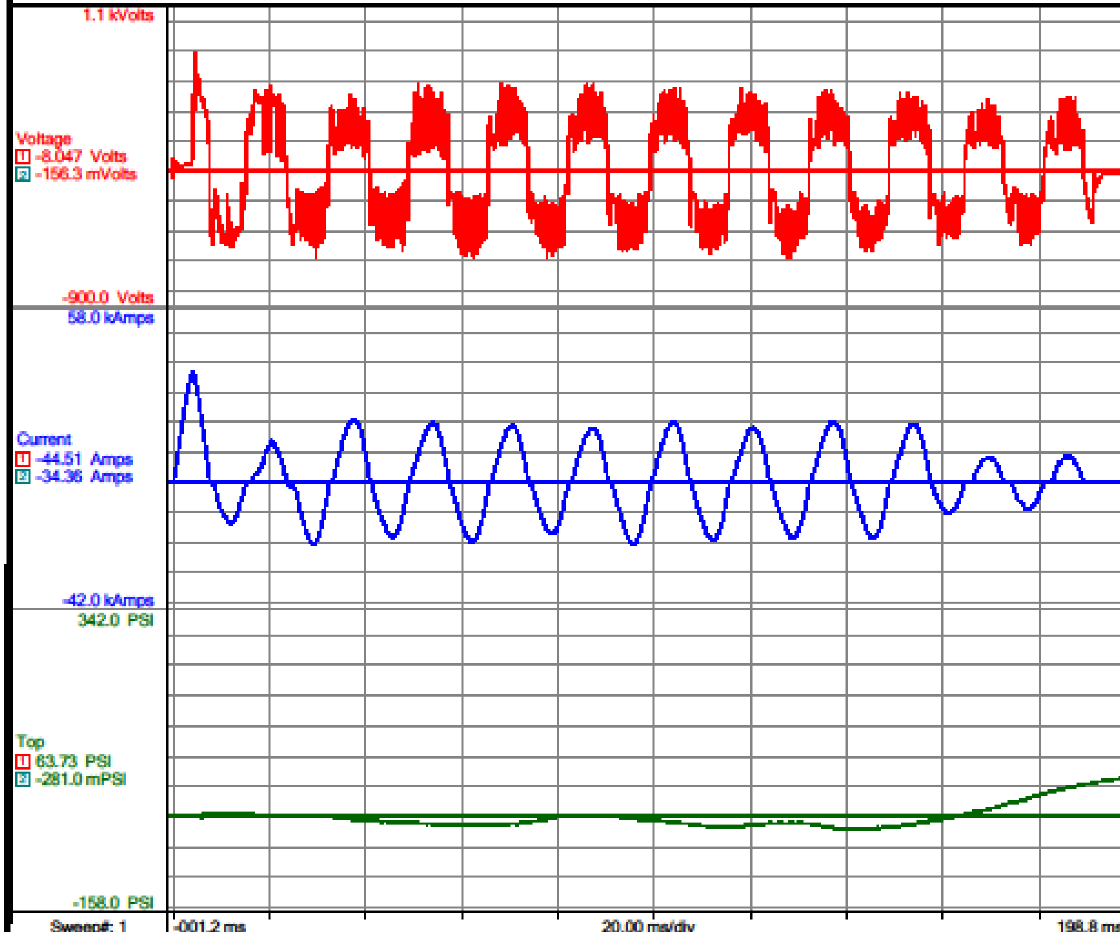
Oscillogram No.: HPL3-34443 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 12:59:28 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 101




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 99 Deg |
| Closing time (V0)+ | 27.22 µ Sec |
| Peak Current (Ip) | 38.85 k Amperes |
| Time to Ip | 3.999 m Sec. |
| I²t | 28.51 M Amp^2sec |
| I Duration | 164.5 m Sec. |

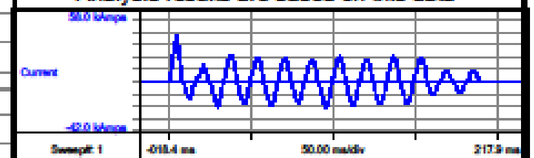
## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

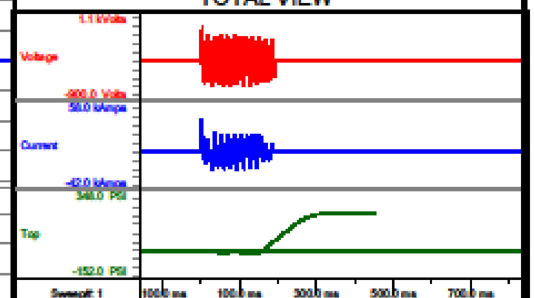
## Comment Section

20.66 kA
18 in.
with paint

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N [illegible]
VOLTAGE: 100X Scope Probe, C/N [illegible], 1% PLOT FILE HPL3 CR_1_[illegible]
VOLTAGE: 100X Scope Probe, C/N [illegible], 1%
CURRENT: ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-34443**

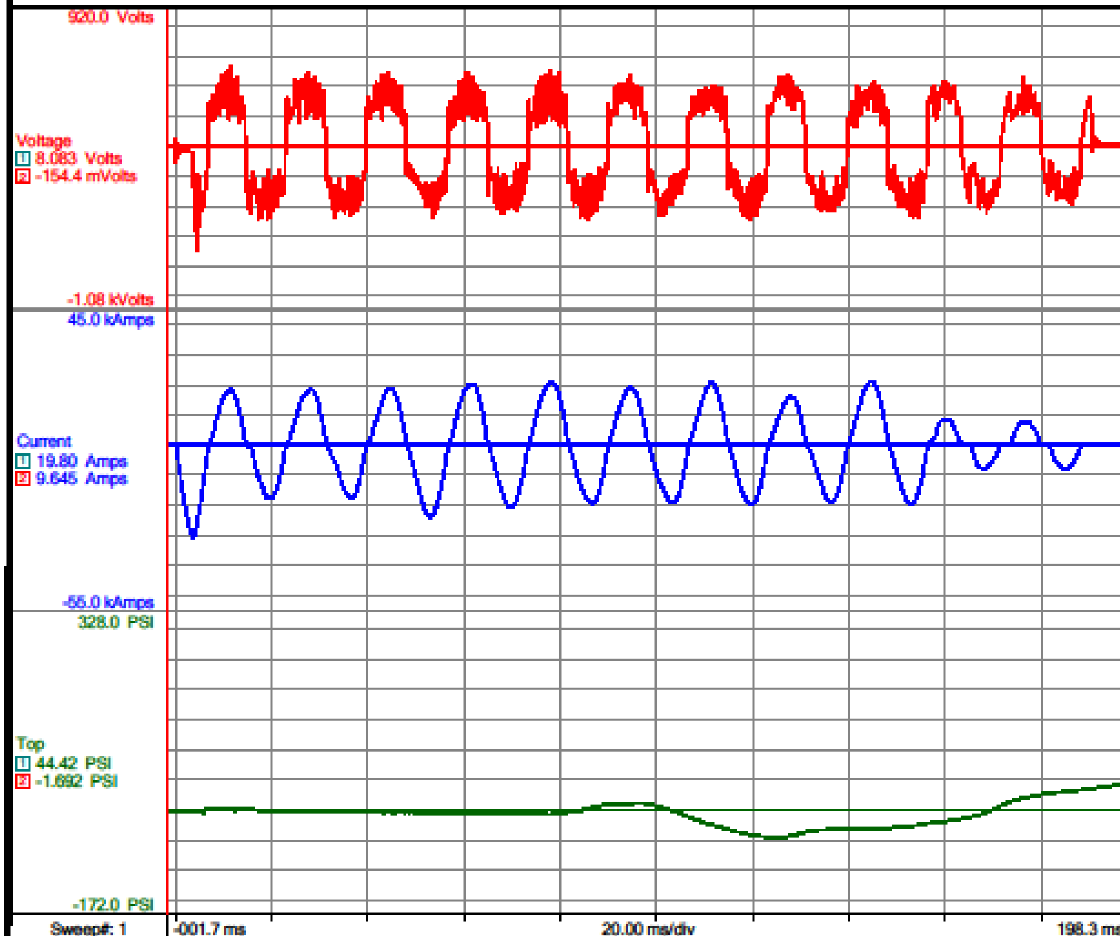
Oscillogram No.: HPL3-34444 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 1:04:15 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 102




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 171 Deg |
| Closing time (V0)+ | 32.42 μ Sec |
| Peak Current (Ip) | -30.91 k Amperes |
| Time to Ip | 3.643 m Sec. |
| I²t | 29.89 M Amp^2sec |
| I Duration | 156.4 m Sec. |

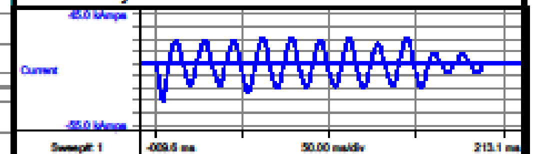
## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

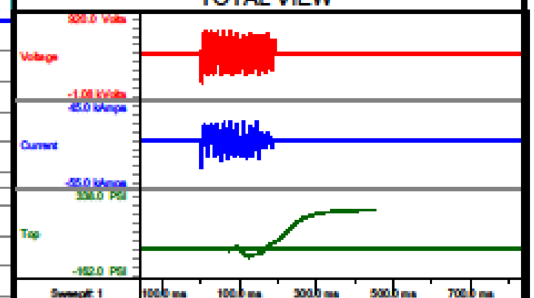
## Comment Section

20.66 kA
18 in.
with paint

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

[illegible]
[illegible] PLOT FILE HPL3 CR_1_8
[illegible]
[illegible]
[illegible]
[illegible]

OSC. NO.: HPL3-34444

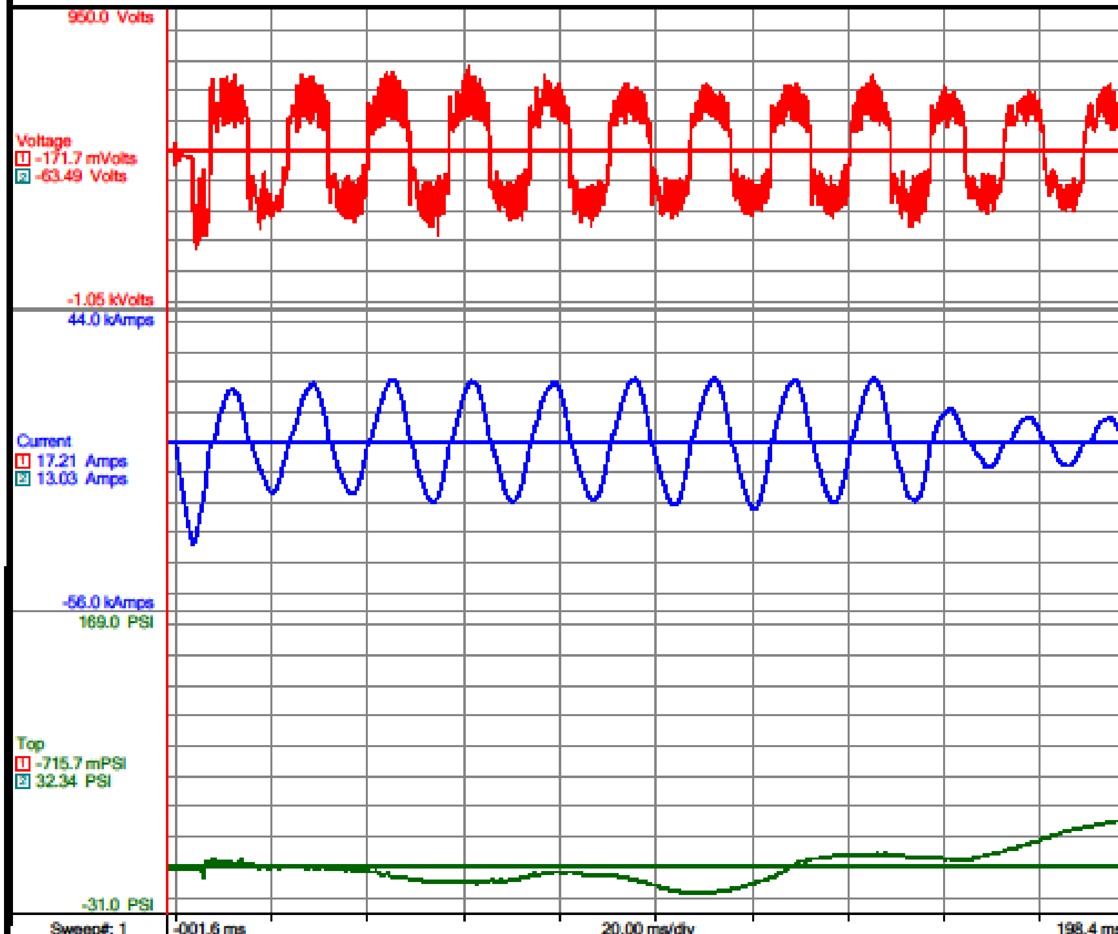
Oscillogram No.: HPL3-34445 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 1:09:12 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 103



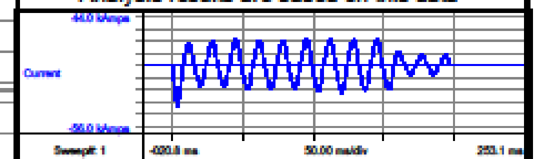

| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 228 Deg |
| Closing time (V0)+ | 272.8 µ Sec |
| Peak Current (Ip) | -34.05 k Amperes |
| Time to Ip | 3.798 m Sec. |
| I²t | 32.07 M Amp^2sec |
| I Duration | 184.3 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

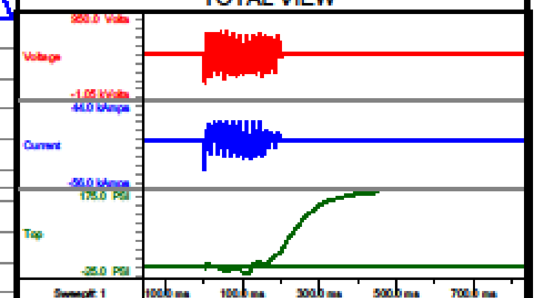
## Comment Section

20.66 kA
18 in.
with paint

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System:HBM GEN7T C/N 063-173
VOLTAGE:1000X Bugge Probe, C/N 131-080, 1%
PLOT FILE:HPL3 CR_1_M
VOLTAGE:1000X Bugge Probe, C/N 131-804, 1%
CURRENT:ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-34445**

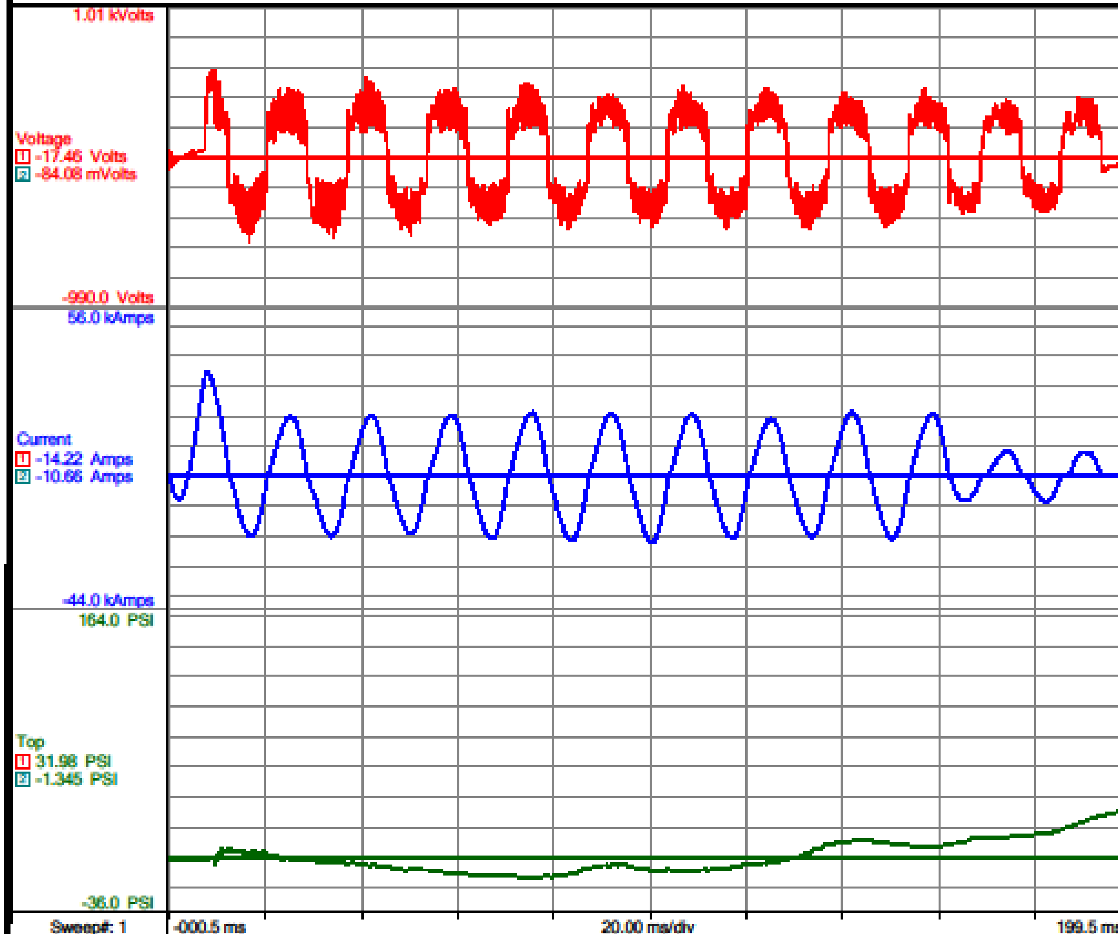
Oscillogram No.: HPL3-34446 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 1:13:25 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 104

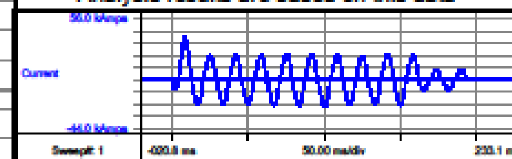



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 275 Deg |
| Closing time (V0)+ | 1.343 m Sec |
| Peak Current (Ip) | 34.80 k Amperes |
| Time to Ip | 7.862 m Sec. |
| I²t | 34.63 M Amp^2sec |
| I Duration | 162.1 m Sec. |

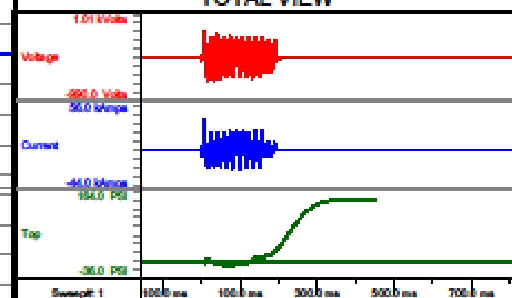
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 20.66 kA |
| 18 in. |
| with paint |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

OSC. NO.: HPL3-34446

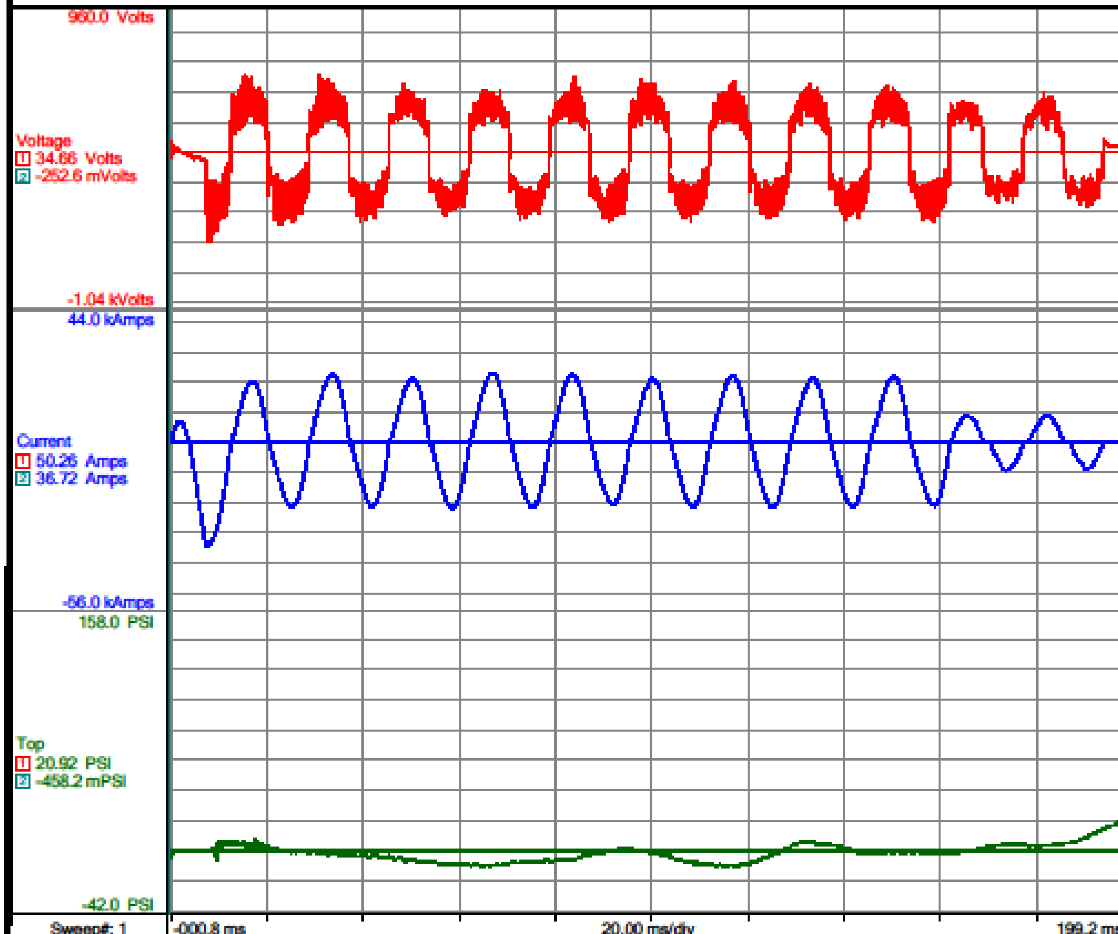
Oscillogram No.: HPL3-34447 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 1:17:57 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 105




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 236 Deg |
| Closing time (V0)+ | 689.9 μ Sec |
| Peak Current (Ip) | -34.92 k Amperes |
| Time to Ip | 7.528 m Sec. |
| I²t | 38.22 M Amp^2sec |
| I Duration | 162.0 m Sec. |

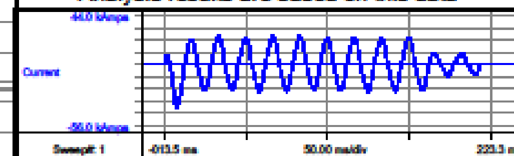
## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

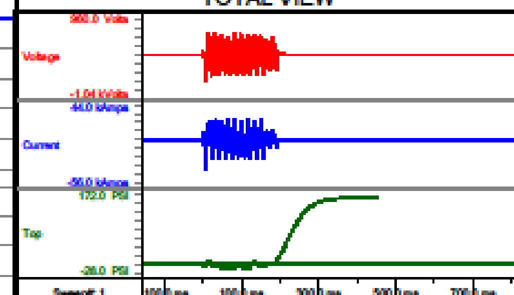
## Comment Section

20.68 kA
18 in.
with paint

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

## OSC. NO.: HPL3-34447

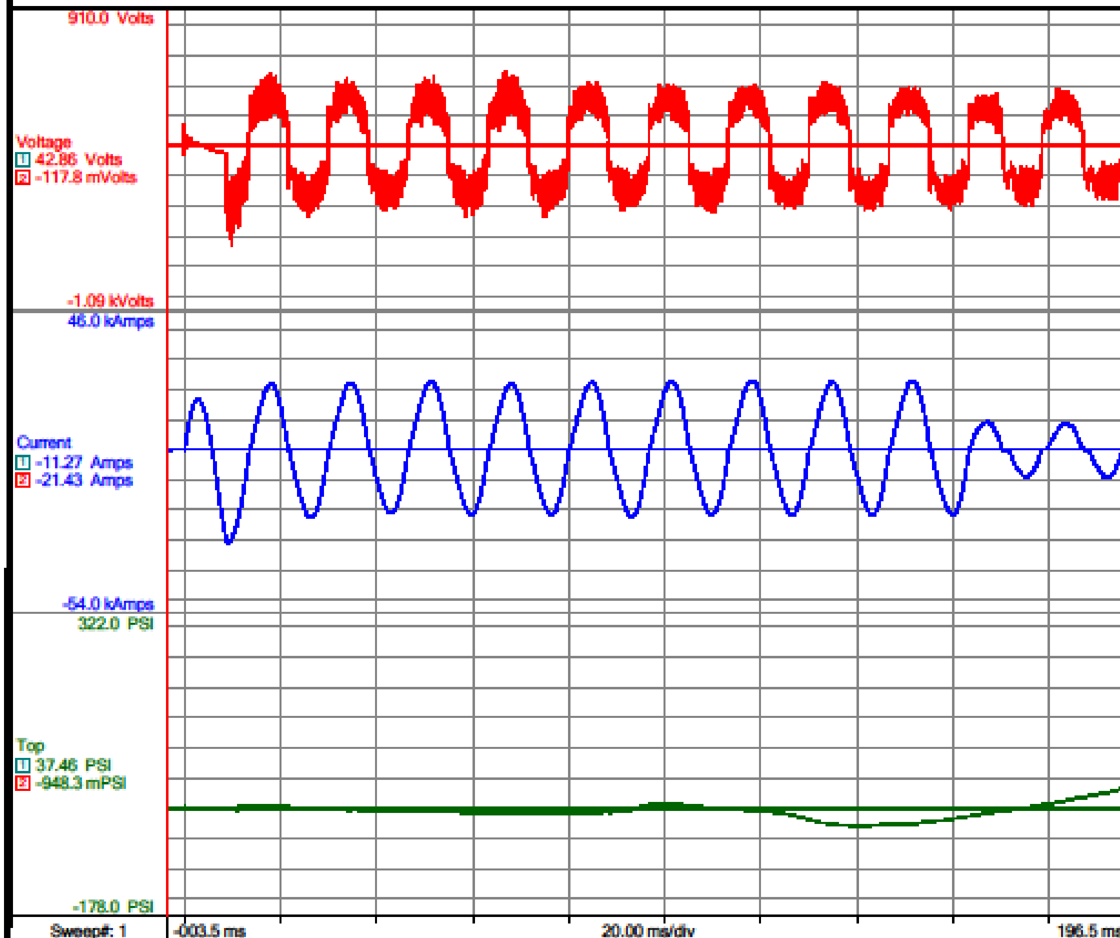
Oscillogram No.: HPL3-34448 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 1:21:55 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 106




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 237 Deg |
| Closing time (V0)+ | 1.118 m Sec |
| Peak Current (Ip) | -31.10 k Amperes |
| Time to Ip | 9.141 m Sec. |
| I²t | 39.54 M Amp^2sec |
| I Duration | 163.2 m Sec. |

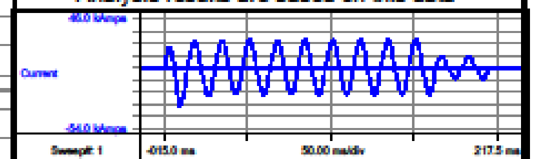
## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

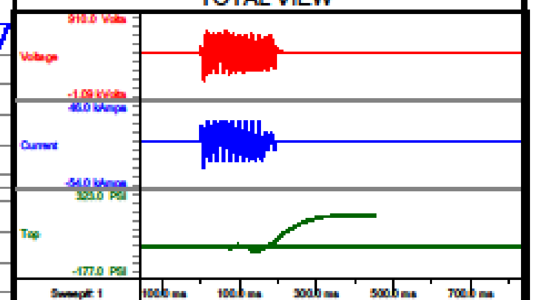
## Comment Section

20.66 kA
18 in.
with paint

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 003-173
VOLTAGE 100X Scope Probe, C/N 131-008, 1% PLOT FILE:HPL3 CR_1_0
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 045-448
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34448

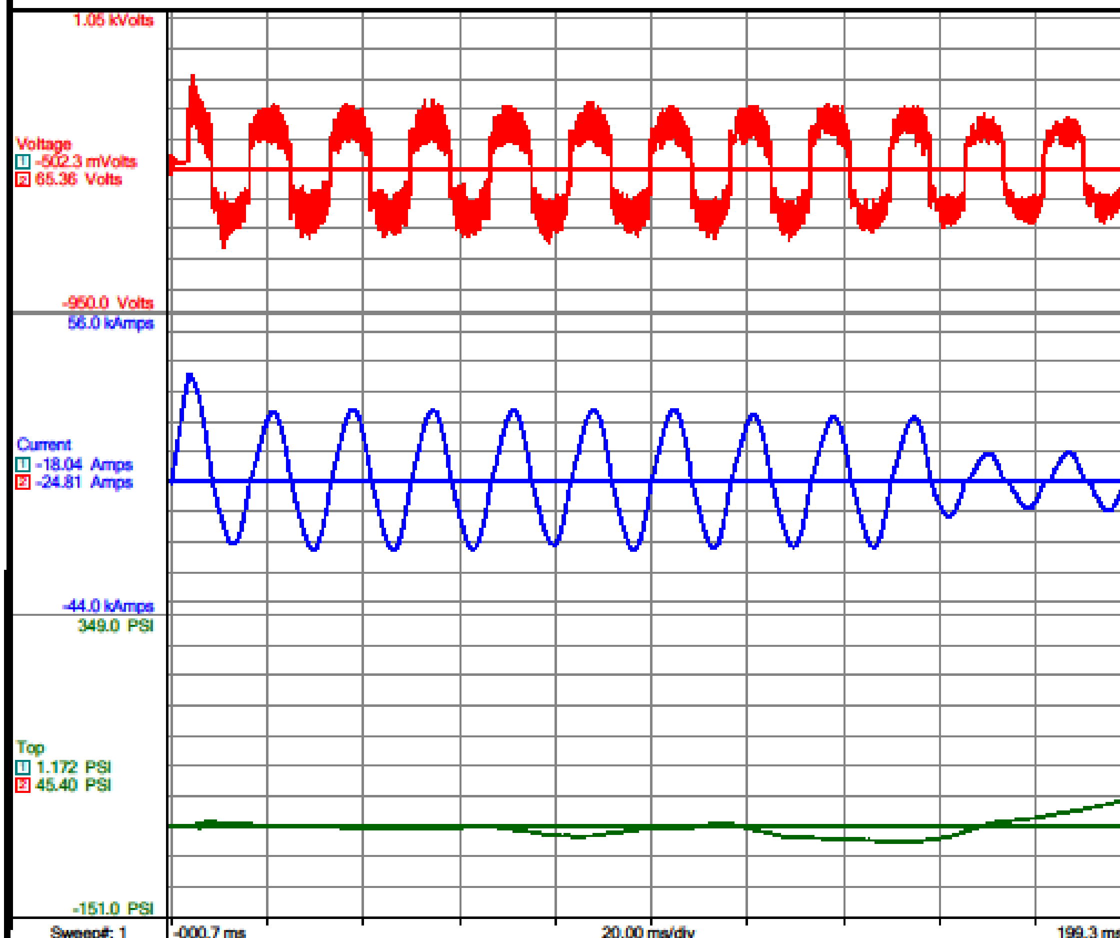
Oscillogram No.: HPL3-34449 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 1:29:38 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 107

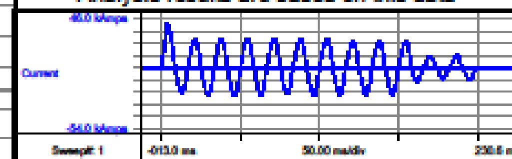



| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 70 Deg |
| Closing time (V0)+ | 302.5 µ Sec |
| Peak Current (Ip) | 35.80 k Amperes |
| Time to Ip | 3.985 m Sec. |
| I²t | 41.70 M Amp^2sec |
| I Duration | 165.1 m Sec. |

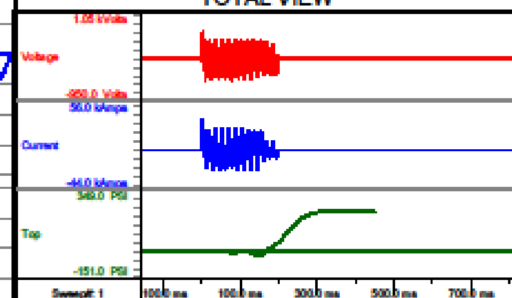
| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

| Comment Section |
|---|
| 20.68 kA |
| 18 in. |
| with paint |

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

Data Recording System:HBM GEN7T C/N [illegible]
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
VOLTAGE 100X Scope Probe, C/N [illegible], 1%
CURRENT ROGOWSKI COIL, C/N [illegible]
NOTE: Channel offset removed for analysis
but not for display.

PLOT FILE:HPL3 CR_1_M

OSC. NO.: HPL3-34449

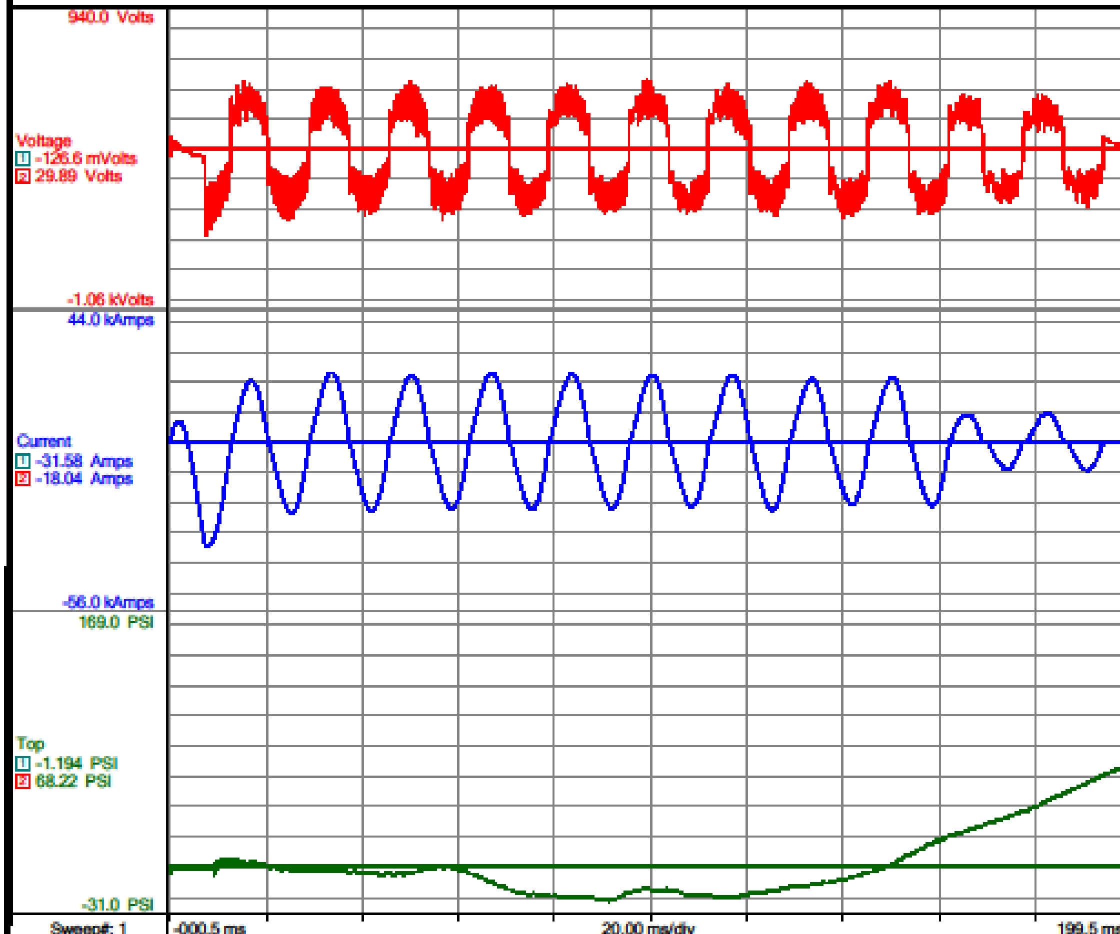
Oscillogram No.: HPL3-34450 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 1:33:34 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 108




## ANALYSIS RESULTS TABLE

| | |
|---|---|
| Closing Angle | 148 Deg |
| Closing time (V0)+ | 503.8 µ Sec |
| Peak Current (Ip) | -34.73 k Amperes |
| Time to Ip | 7.500 m Sec. |
| I²t | 40.41 M Amp^2sec |
| I Duration | 162.0 m Sec. |

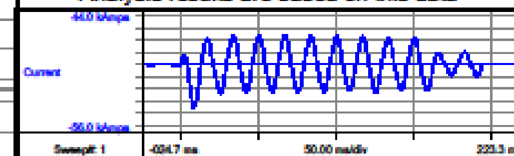
## Performance Observations

| | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

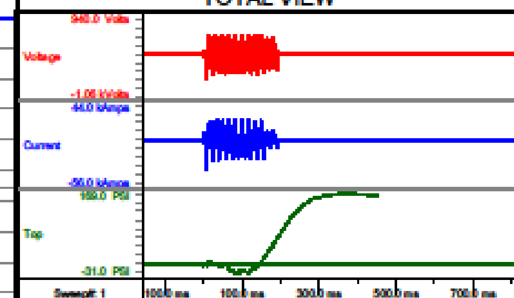
## Comment Section

20.66 kA
18 in.
with paint

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T C/N 083-173
VOLTAGE 100X Scope Probe, C/N 131-000, 1% PLOT FILE HPL3 CR_1_8
VOLTAGE 100X Scope Probe, C/N 131-004, 1%
CURRENT ROGOWSKI COIL, C/N 048-448
NOTE: Channel offset removed for analysis
but not for display.

**OSC. NO.: HPL3-34450**

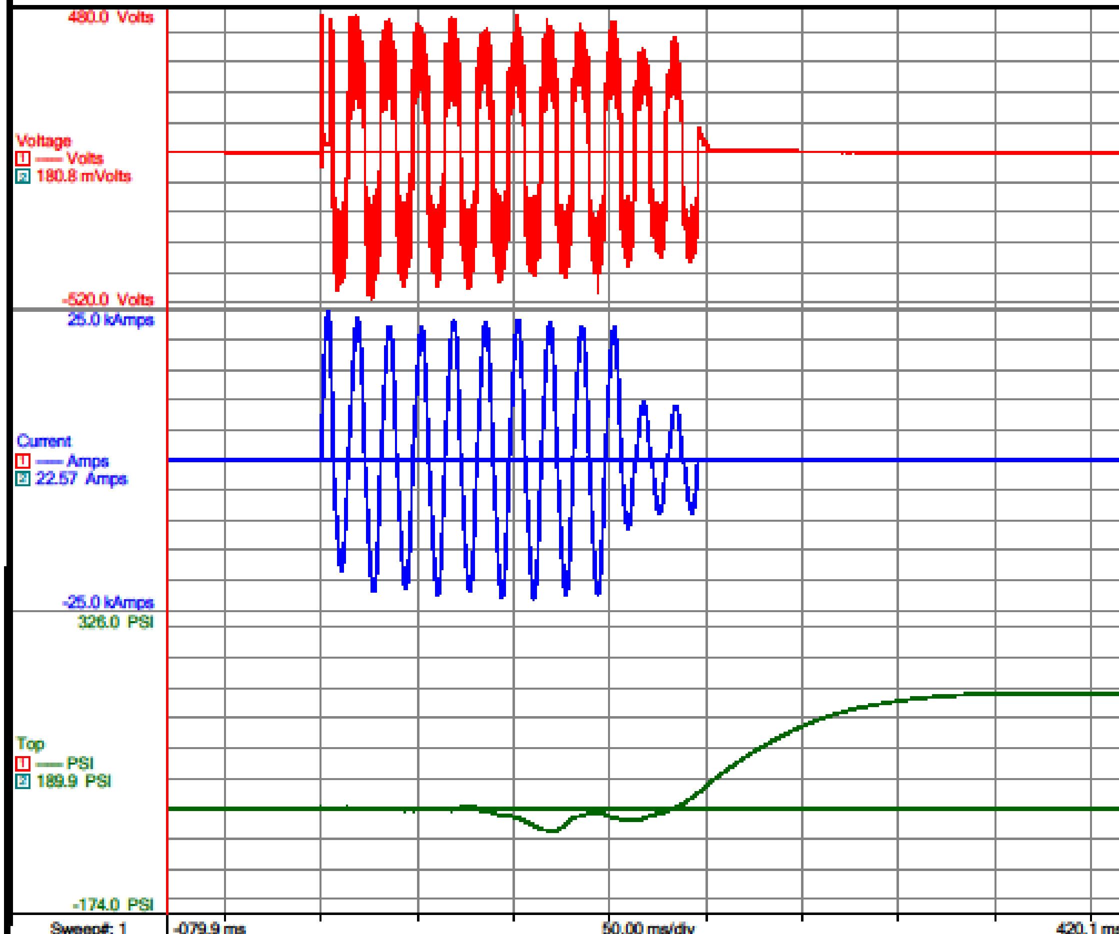
Oscillogram No.: HPL3-34451 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 1:38:59 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

Schneider Electric

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 109



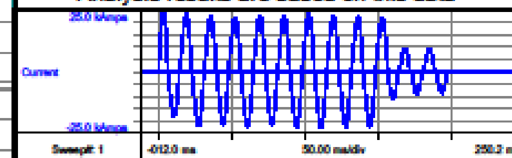

| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 84 Deg |
| Closing time (V0)+ | 1.113 m Sec |
| Peak Current (Ip) | 24.92 k Amperes |
| Time to Ip | 3.588 m Sec. |
| I²t | 38.28 M Amp^2sec |
| I Duration | 163.0 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

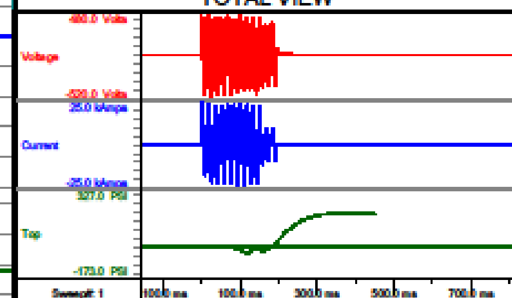
Comment Section

20.66 kA
18 in.
with paint

Analysis results are based on this data




TOTAL VIEW




INSTRUMENTATION DATA

[illegible]

OSC. NO.: HPL3-34451

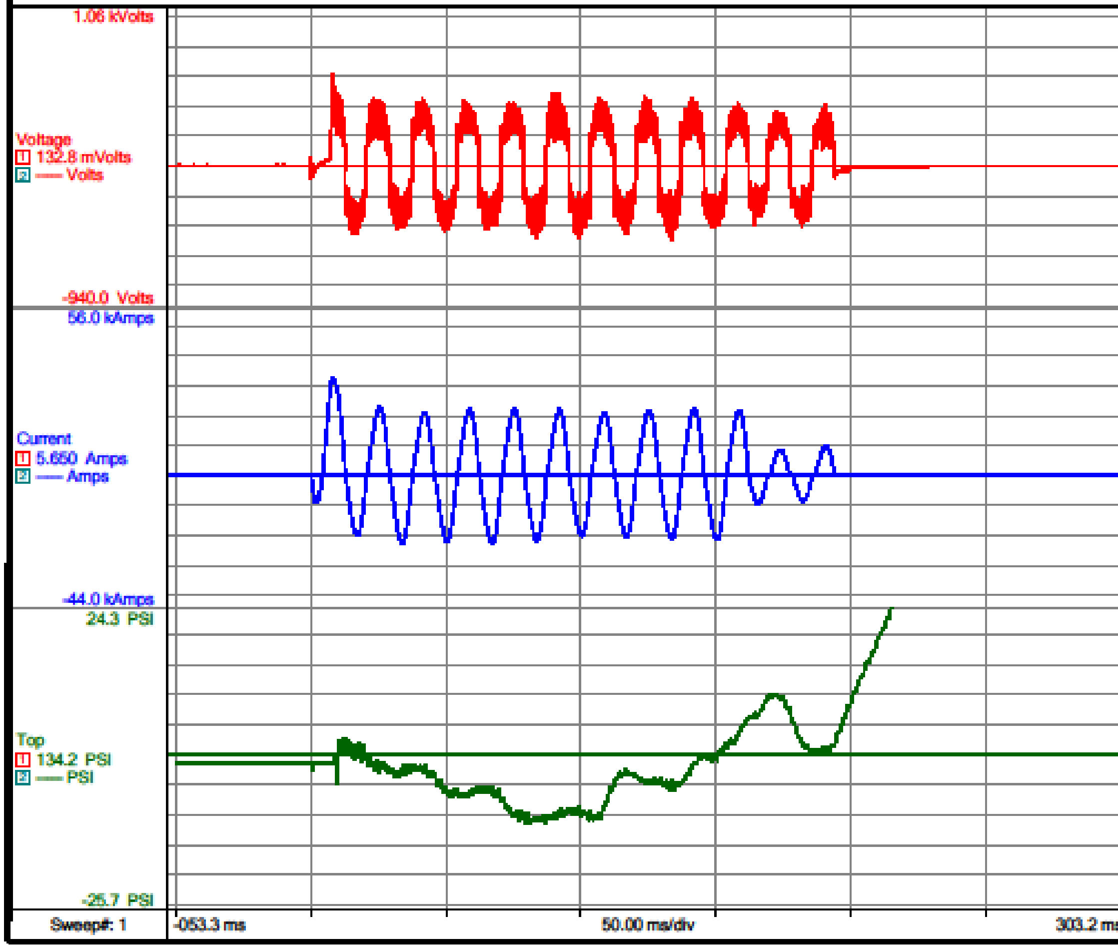
Oscillogram No.: HPL3-34452 OCV = 460 V
Date of Test: 9/30/2020 Time of Test: 1:42:41 PM

AVAILABLE CIRCUIT CHARACTERISTICS:
Osc. No: 23776 Calibration Date: 09/6/19
OCV = 485 V Rms Sym Current = 25.33 kA
Power Factor = 16%

**Schneider Electric**

High Power Laboratory, HPL3 Facility
Cedar Rapids, Iowa, USA

Project No.: 6000001332 TestFlow No.: UTK
Test Device: ARC FLASH
Sample No.: 110



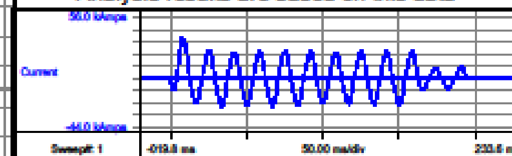

| ANALYSIS RESULTS TABLE | |
|---|---|
| Closing Angle | 338 Deg |
| Closing time (V0)+ | 522.4 μ Sec |
| Peak Current (Ip) | 32.99 k Amperes |
| Time to Ip | 7.772 m Sec. |
| I²t | 38.19 M Amp^2sec |
| I Duration | 182.3 m Sec. |

| Performance Observations | |
|---|---|
| Was the Breaker Tripped after the test? | NA |
| Could the Breaker be Reset? | NA |
| Did it have continuity in all poles? | NA |
| Was the Enclosure Fuse Opened? | NA |

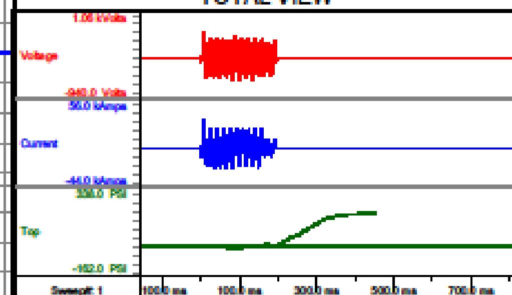
## Comment Section

20.66 kA
18 in.
with paint

## Analysis results are based on this data




## TOTAL VIEW




## INSTRUMENTATION DATA

Data Recording System HBM GEN7T CAN [illegible]
VOLTAGE 1000X Scope Probe, CAN [illegible], 1% PLOT FILE HPL3 [illegible]
VOLTAGE 1000X Scope Probe, CAN [illegible], 1%
CURRENT ROGOWSKI COIL, CAN [illegible]
NOTE: Channel offset removed for analysis
but not for display.

OSC. NO.: HPL3-34452

# APPENDIX B : FIGURES

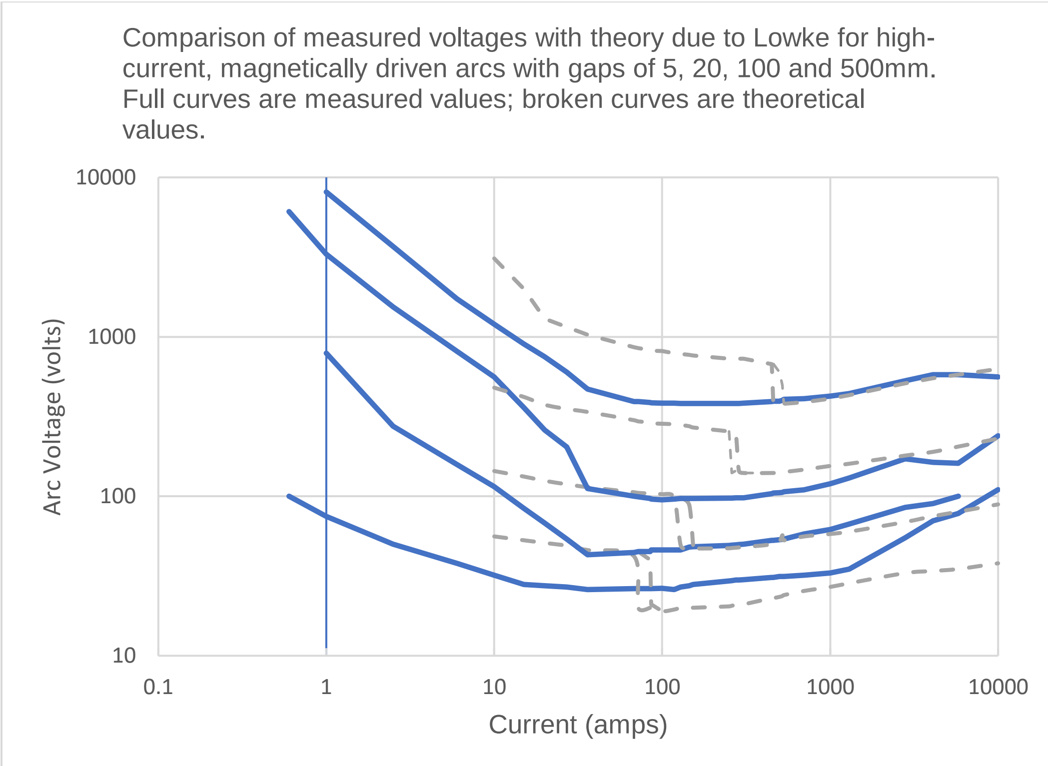



*Figure 1 - Measured Voltage vs. Theory from Lowke*

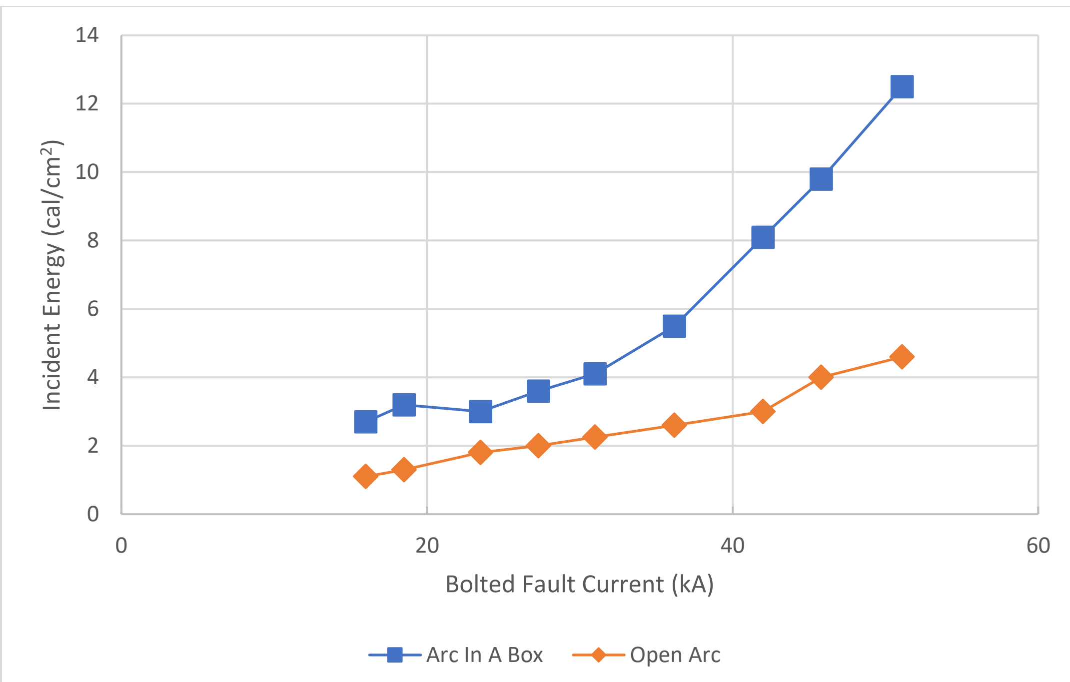



*Figure 2 - Incident Energy - Open Air vs. Arc In A Box*

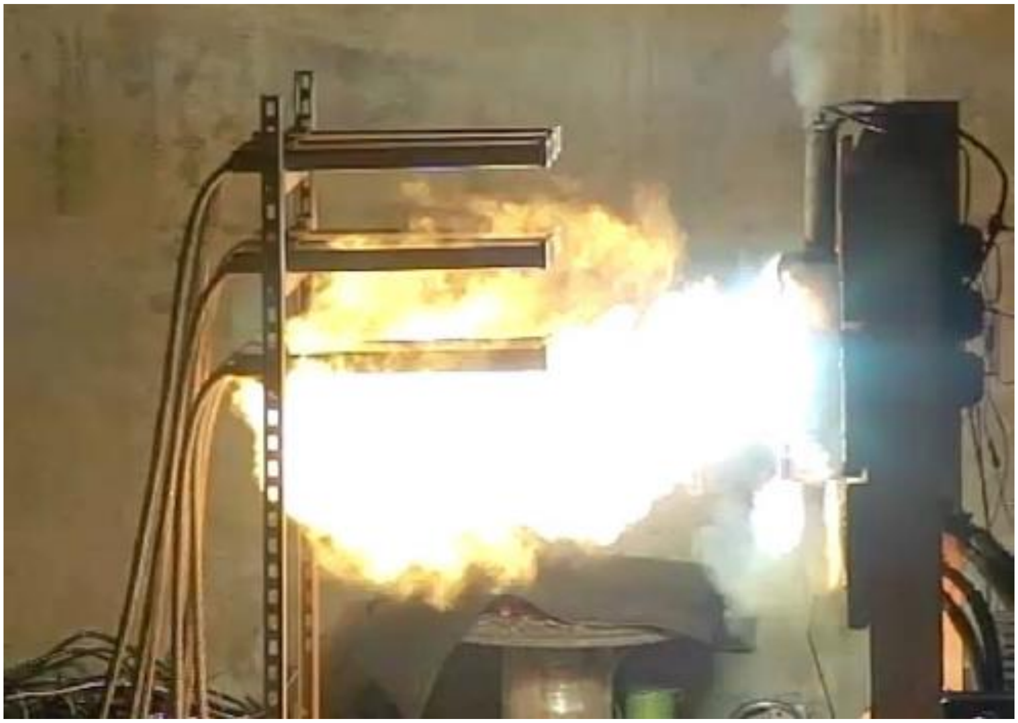


*Figure 3 - Arc Flash from a Meter Base*

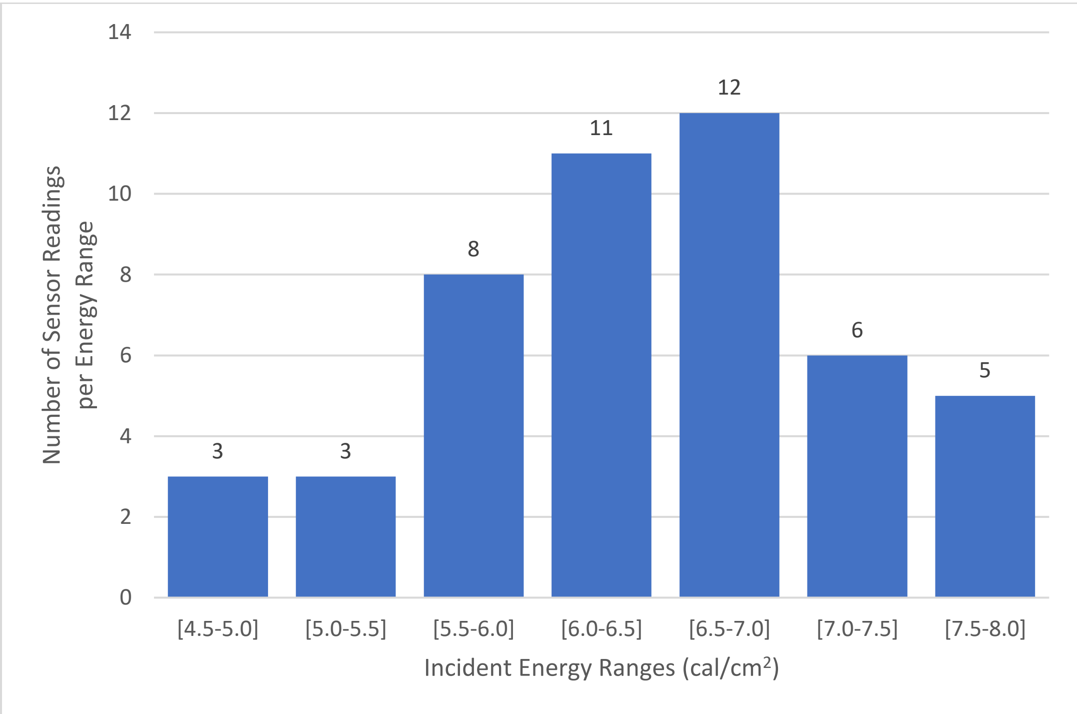



*Figure 4 - Sensor Readings per Energy Range*

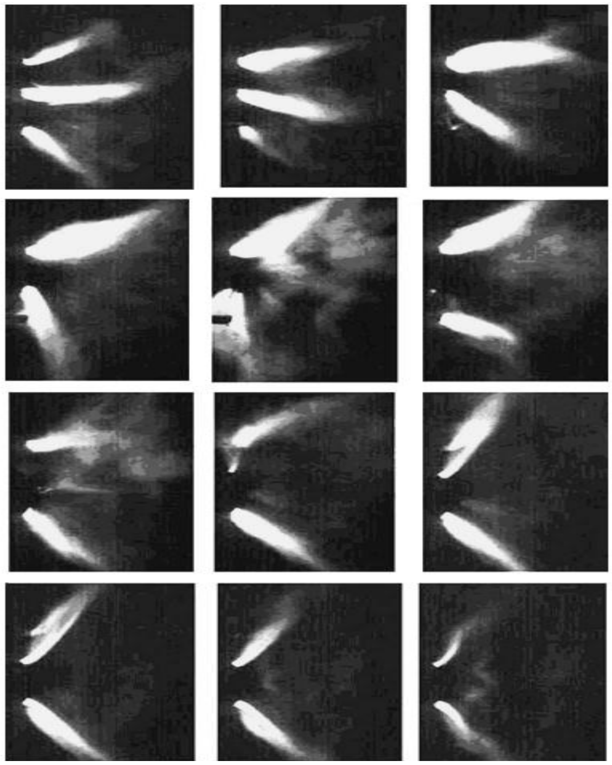


*Figure 5 - Arc Plume Evolution*

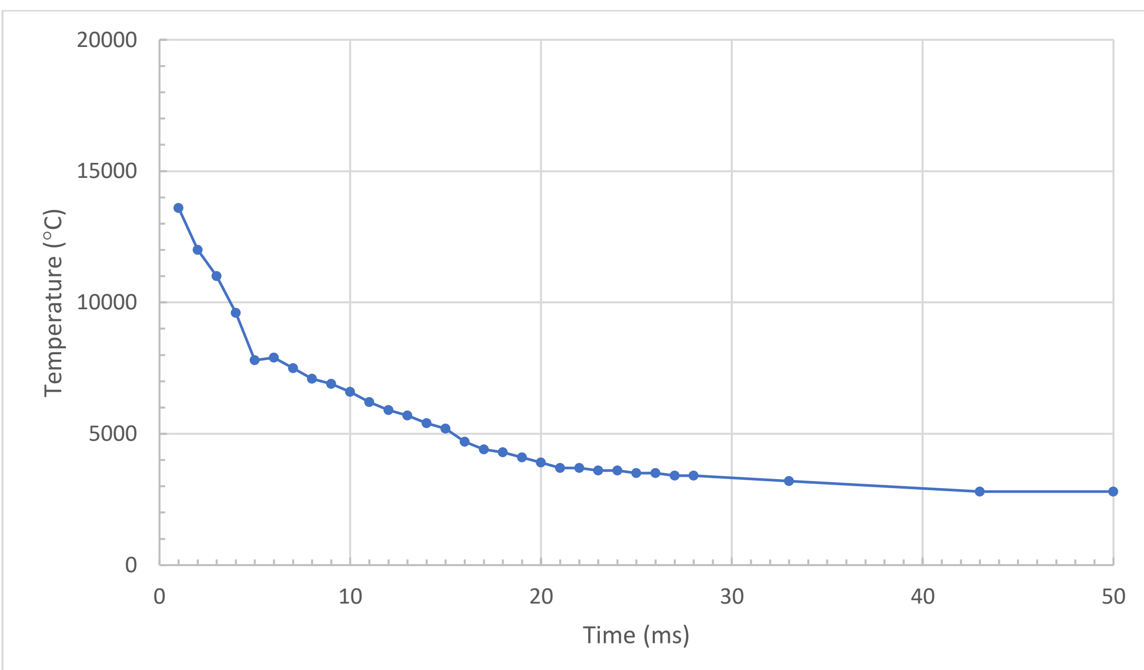
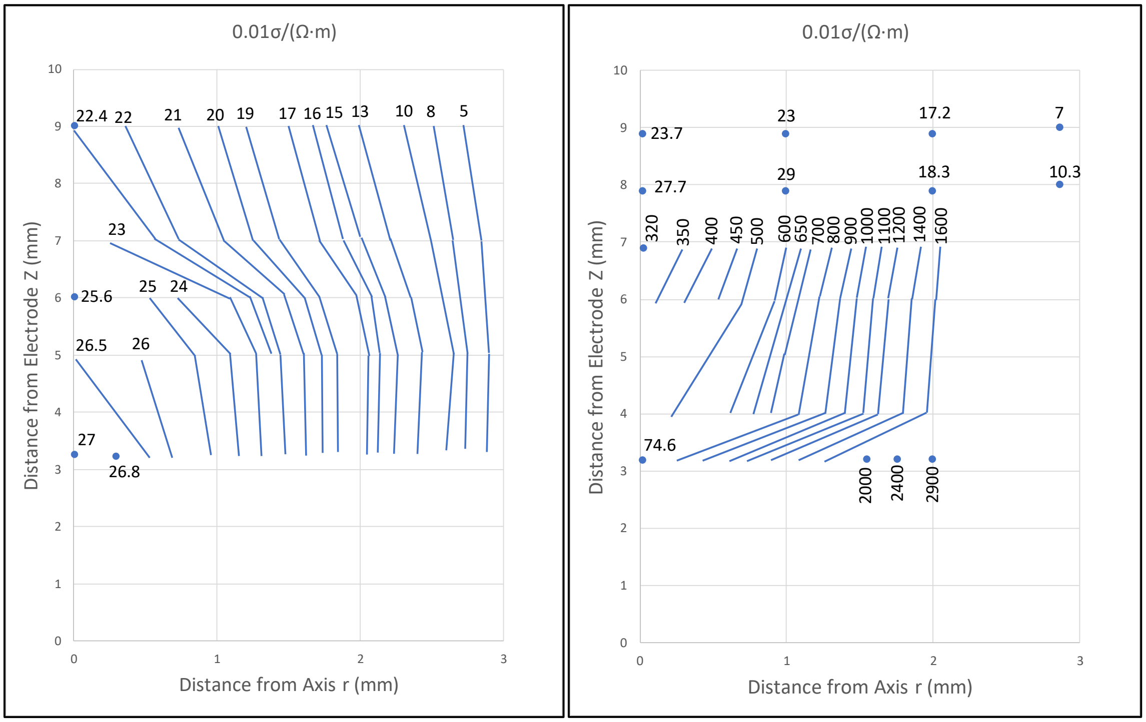



*Figure 6 - Arc Flash Temperature Development*




“un-contaminated plasma” “contaminated plasma”

*Figure 7 - Plasma Conductivities - Without vs. With Copper vapor*

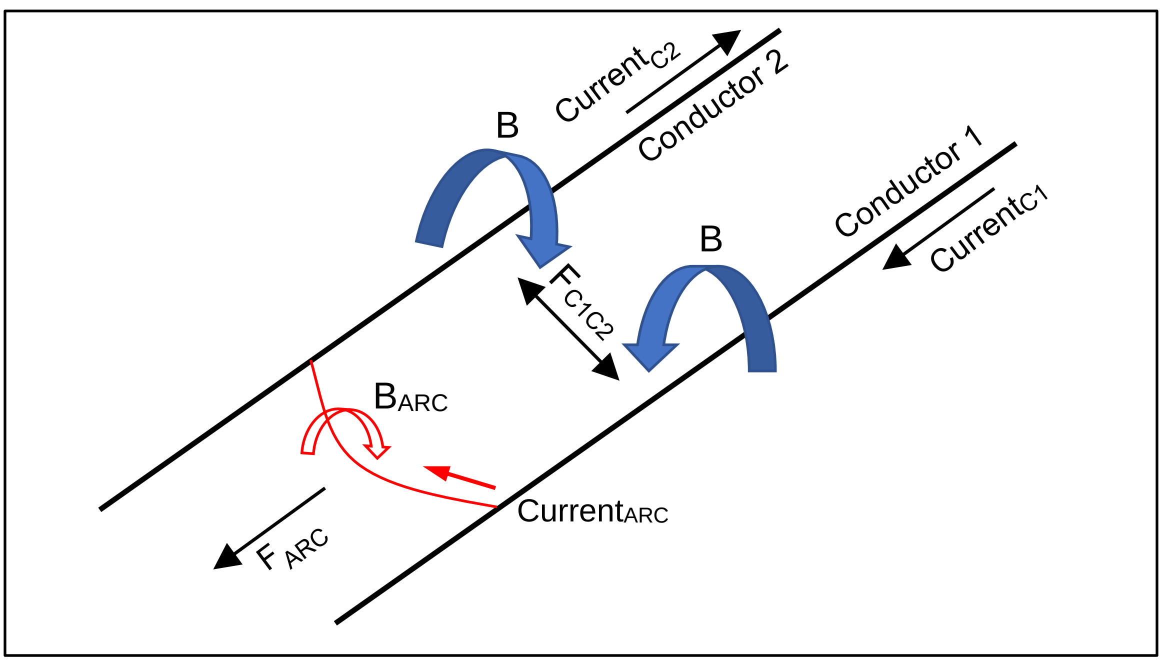



*Figure 8 - Arc Migration Due to the Lorentz Force*

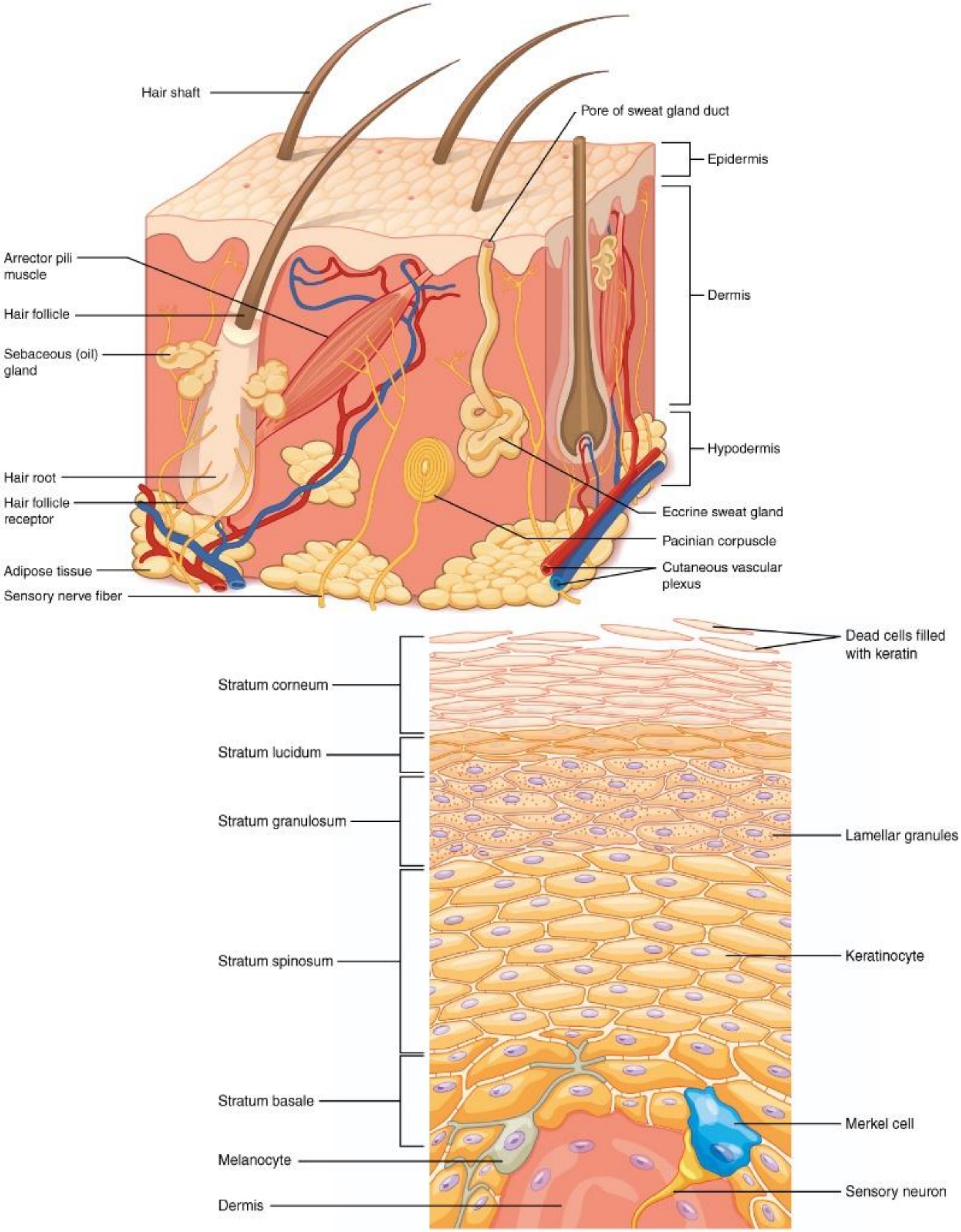



*Figure 9 - Structure and Layers of Human Skin*

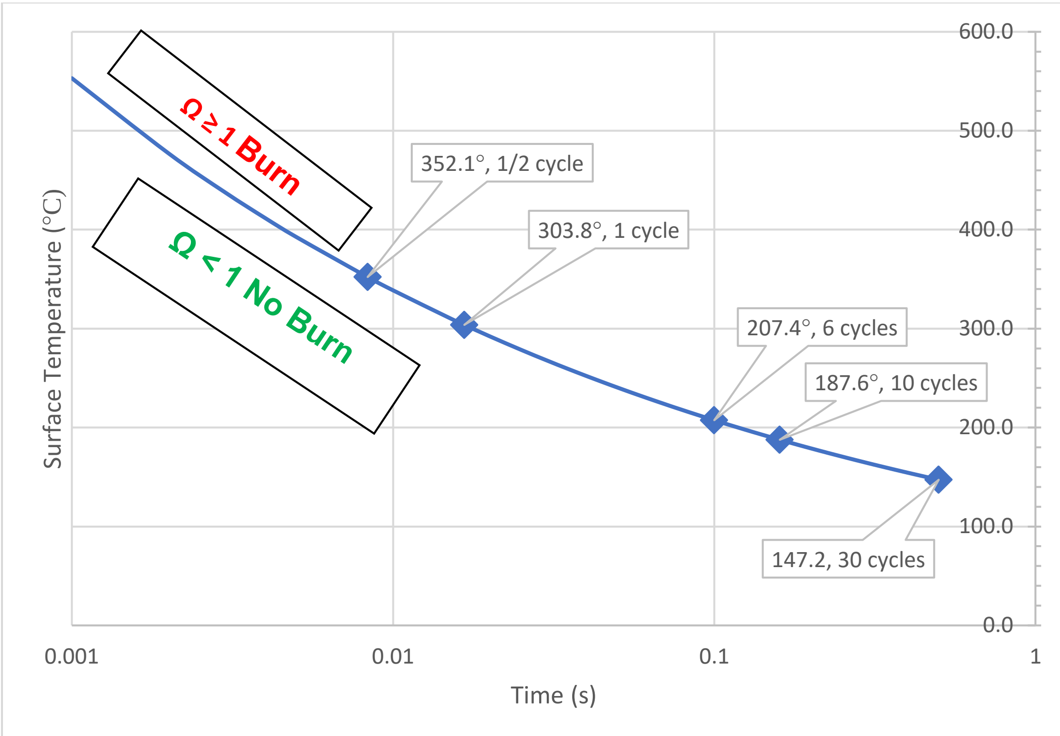



*Figure 10 - Deep Partial-Thickness Burns - Surface Temperature vs. Time*

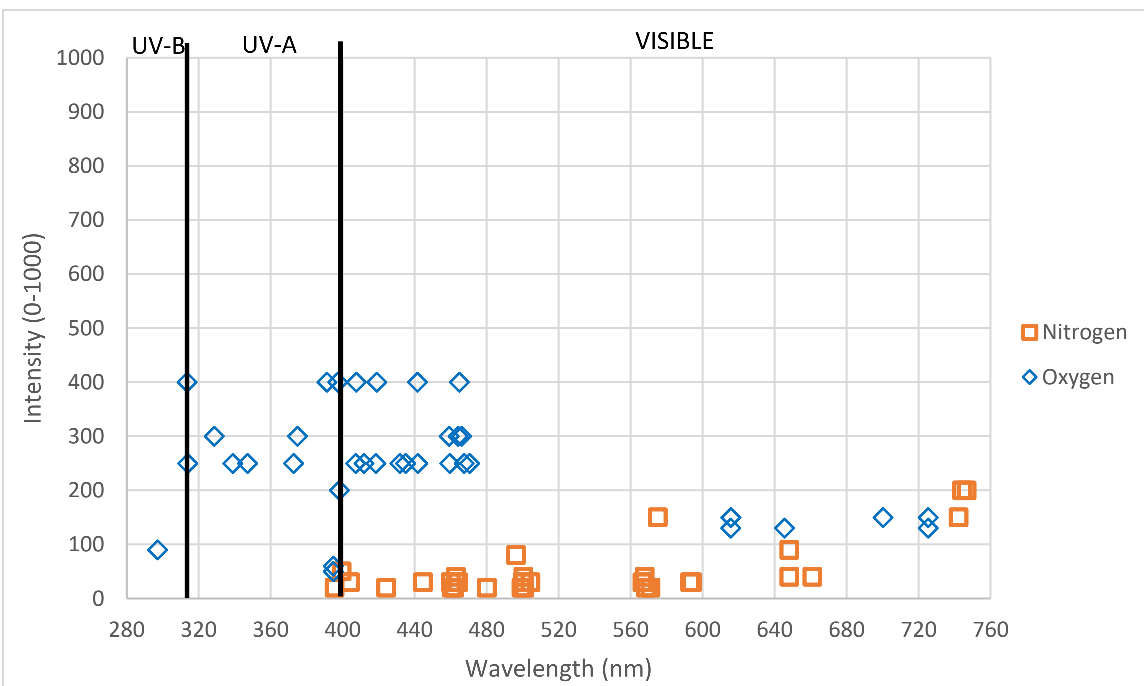



*Figure 11 - Spectra for Primary Constituents of Air*

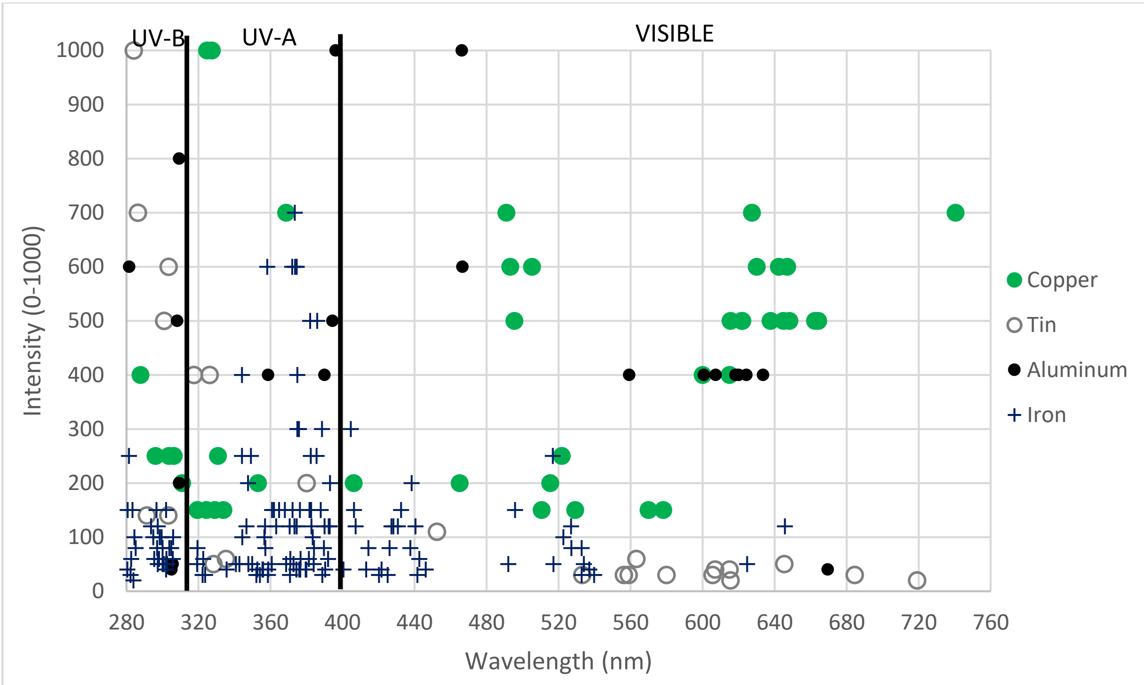



*Figure 12 - Spectra for Common Electrical Metals*

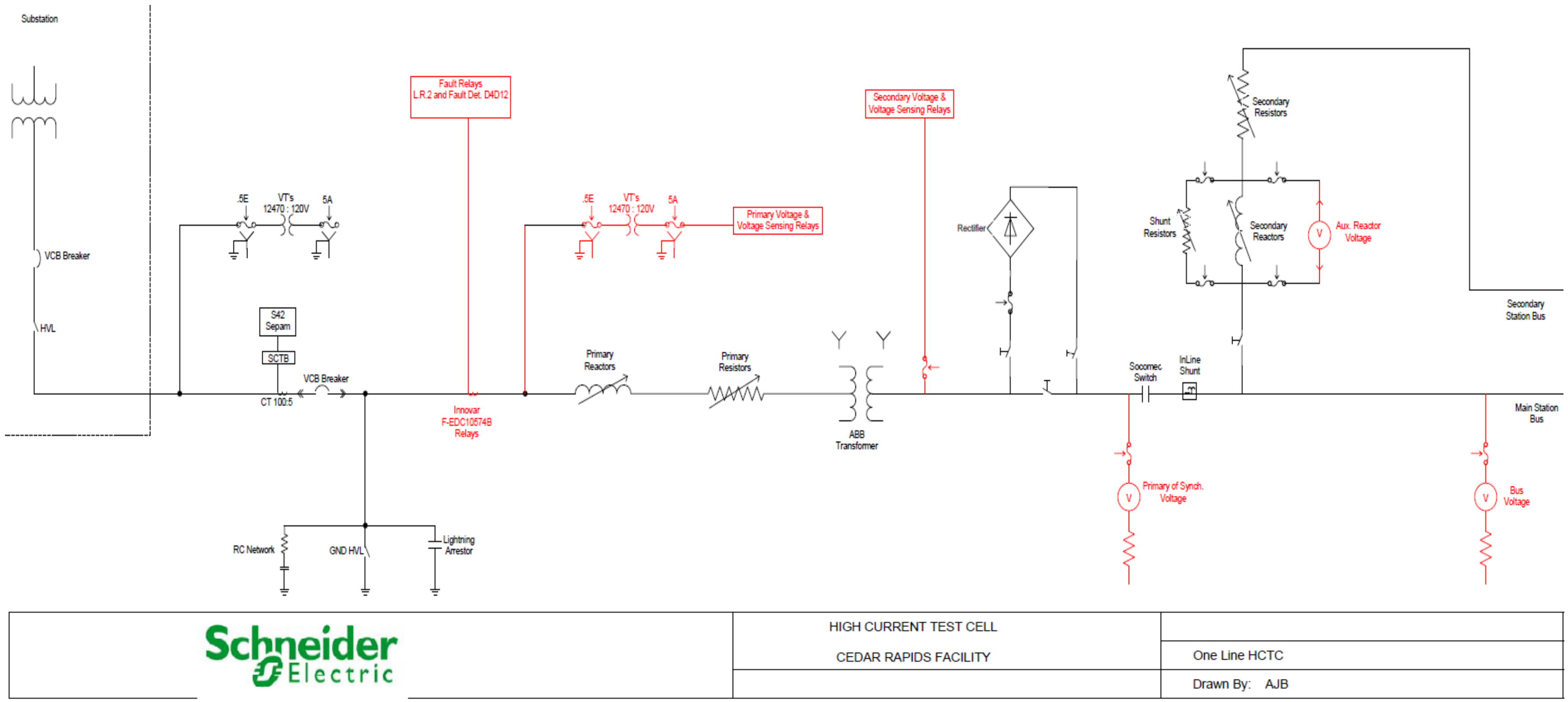



*Figure 13 - Test Cell One-line Diagram*

*Figure 14 - IEEE Vertical Conductors In A Box Test Article*

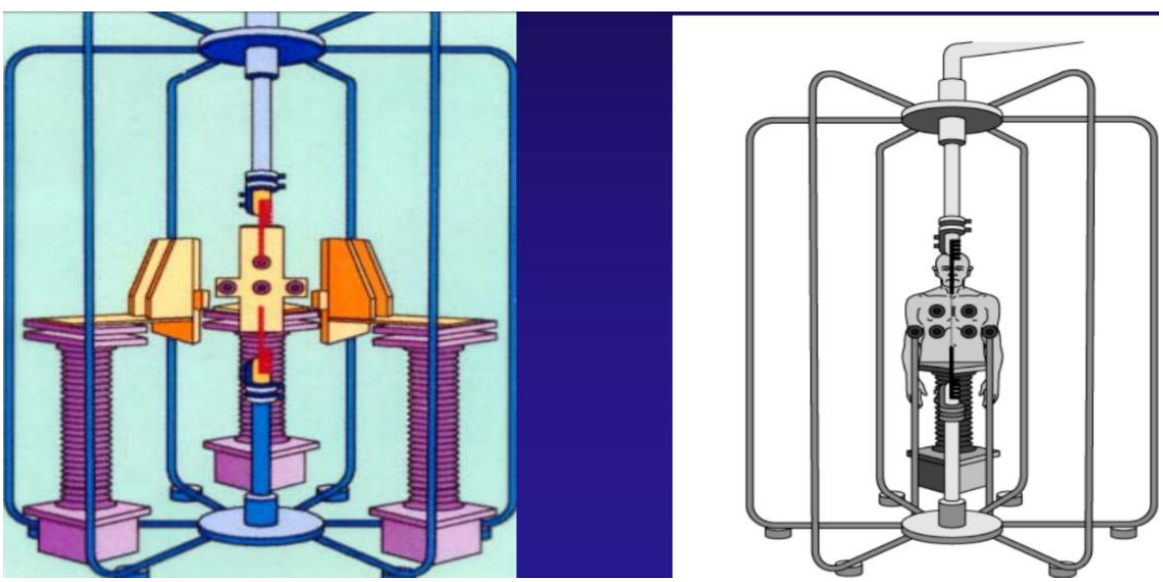


*Figure 15 - ASTM 1959 / 1958 Test Fixtures*

*Figure 16 - Single-phase Arc Flash Test Fixture*

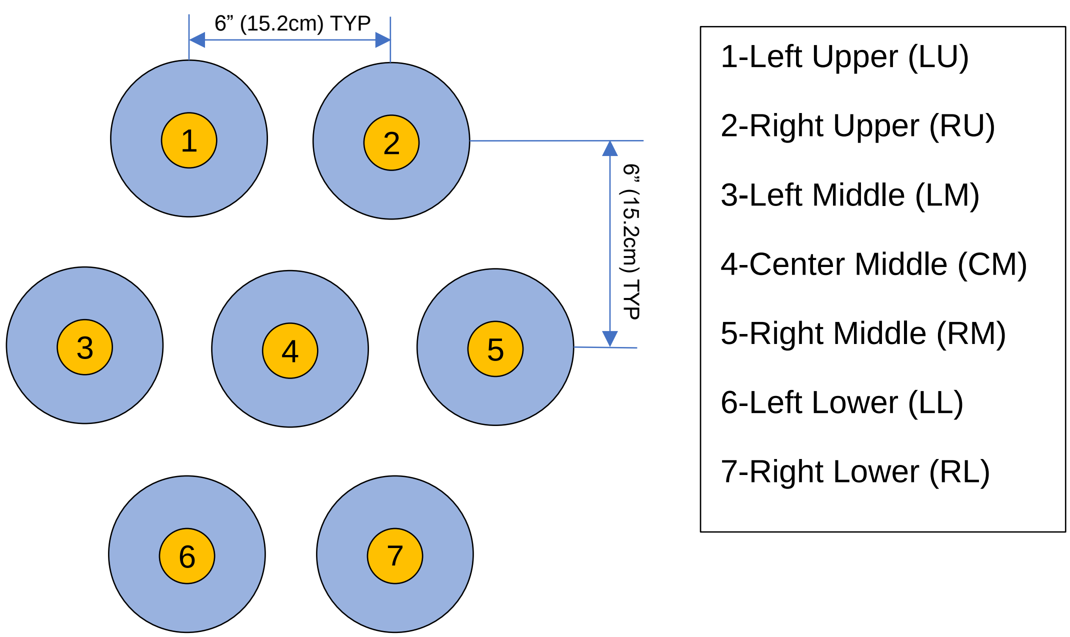



*Figure 17 - Calorimeter Arrangement - Facing Measurement Surfaces*

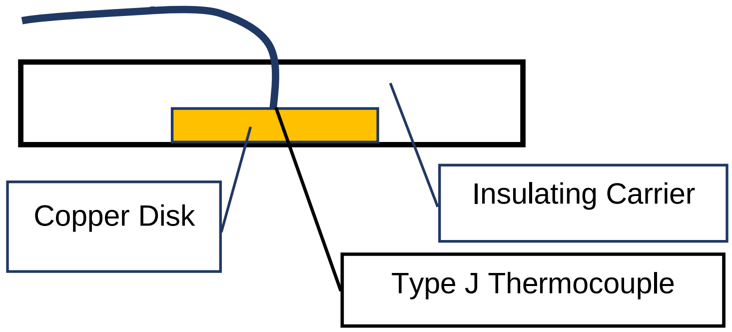



*Figure 18 - Copper Slug Calorimeter - Simplified Cross-Section*

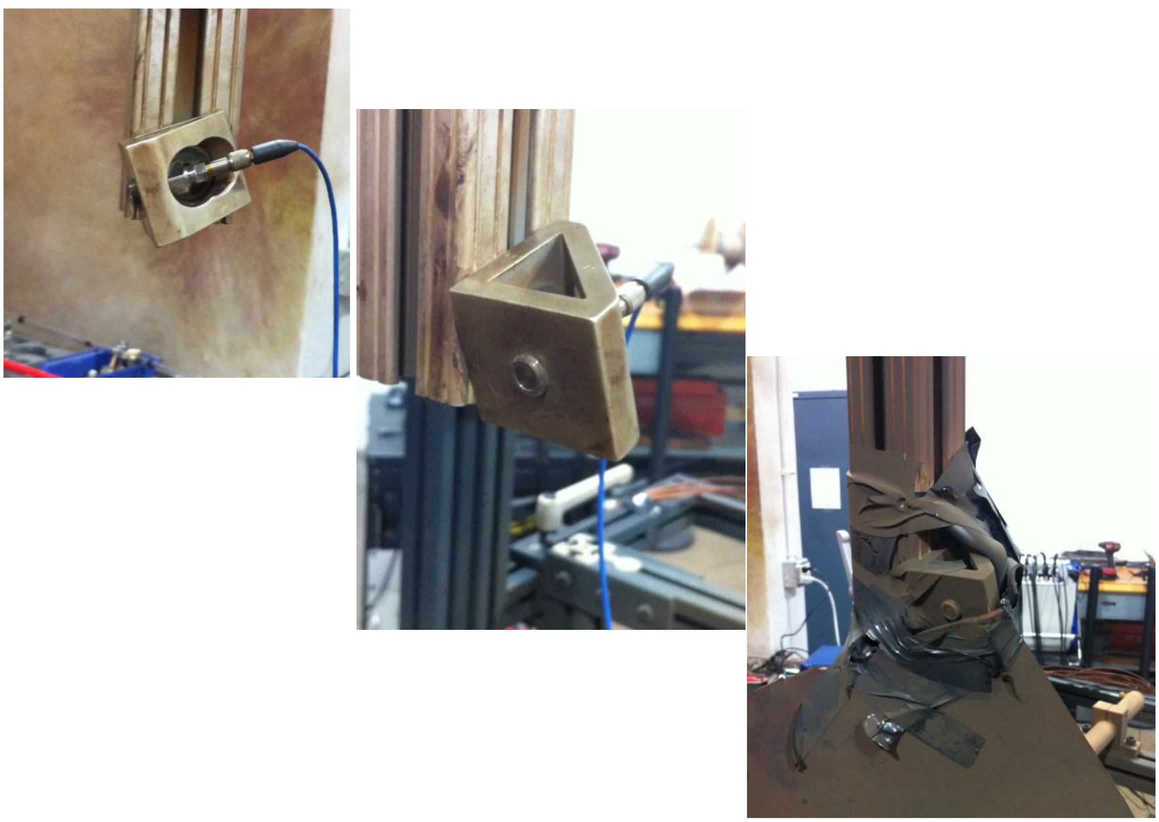


*Figure 19 - Blast Pressure Sensor Mounting and Cable Protection*

*Figure 20 - Initial Test Cell Configuration*

*Figure 21 - Close-up Showing Fuse Wire for Test Run #1*

*Figure 22 - Test Series #1 - Calorimeters at 12 inches*

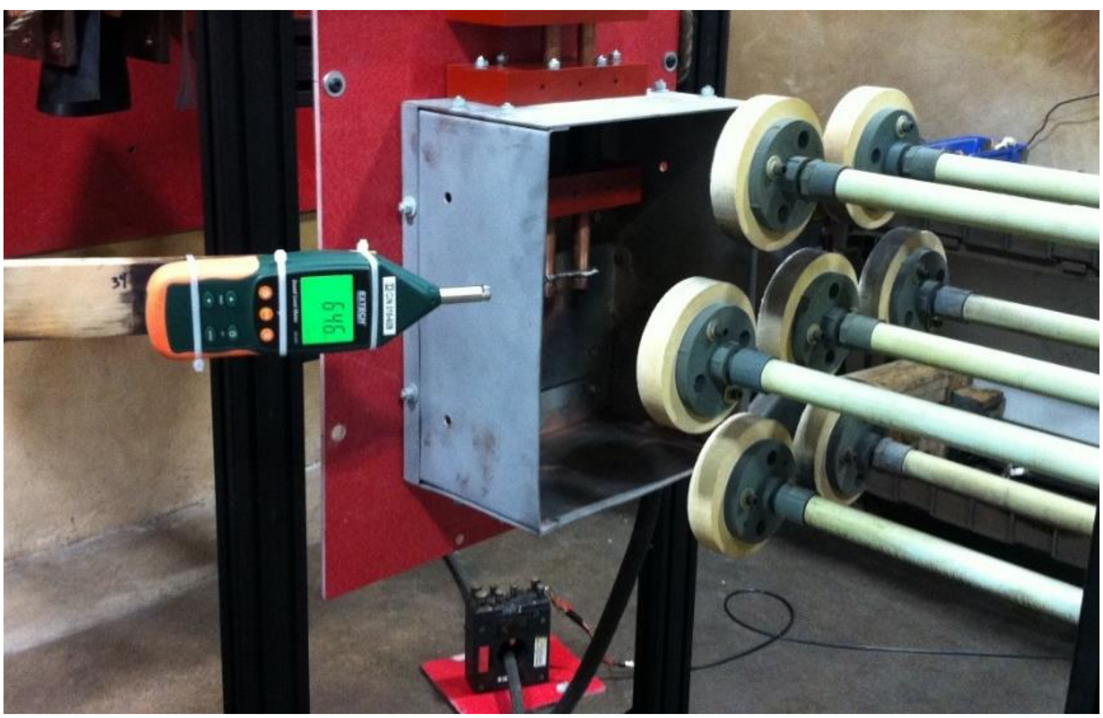


*Figure 23 - Handheld Sound Pressure Meter*

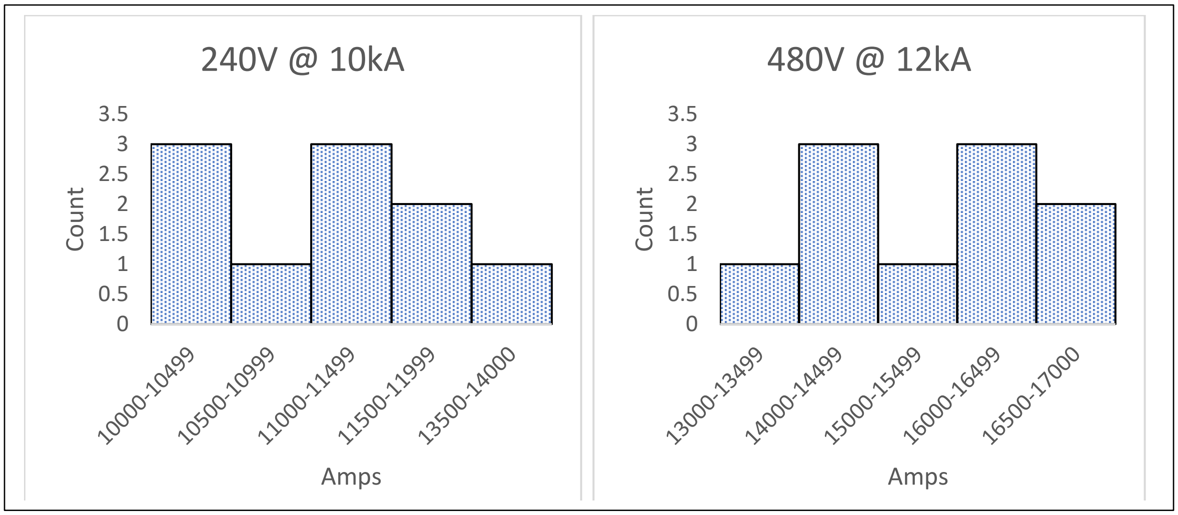



*Figure 24 - Probability Distributions - Series #1 - 10kA and 12kA Test Runs*

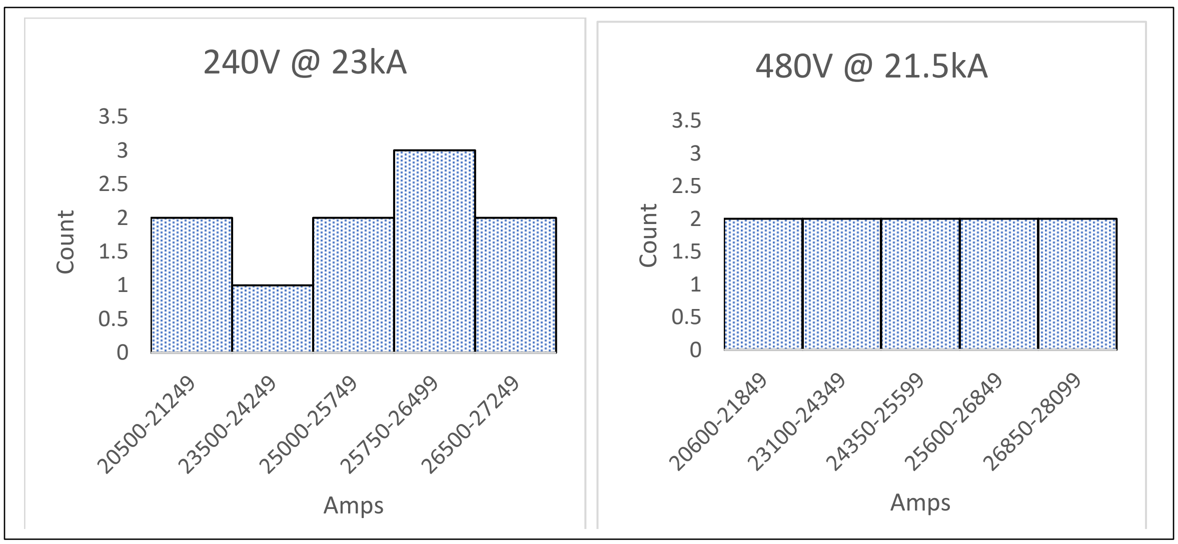



*Figure 25 - Probability Distributions - Series #1 - 23kA and 21.5kA Test Runs*

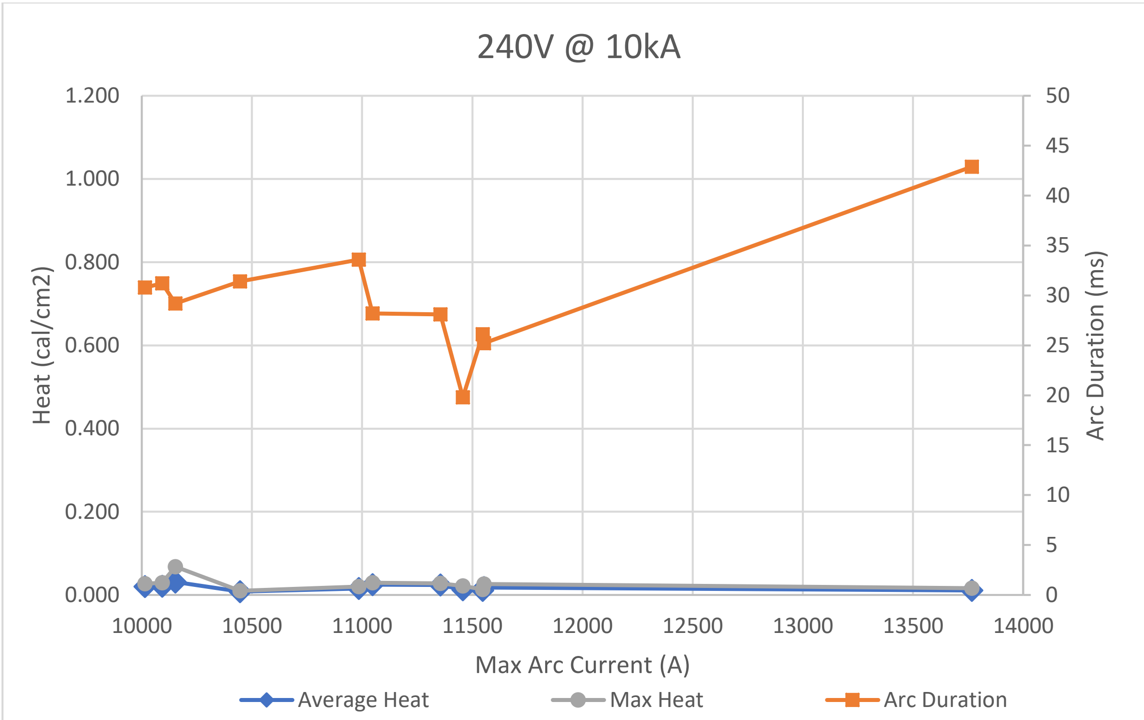



*Figure 26 - Heat & Arc Duration vs. Current - 240V @ 10kA*

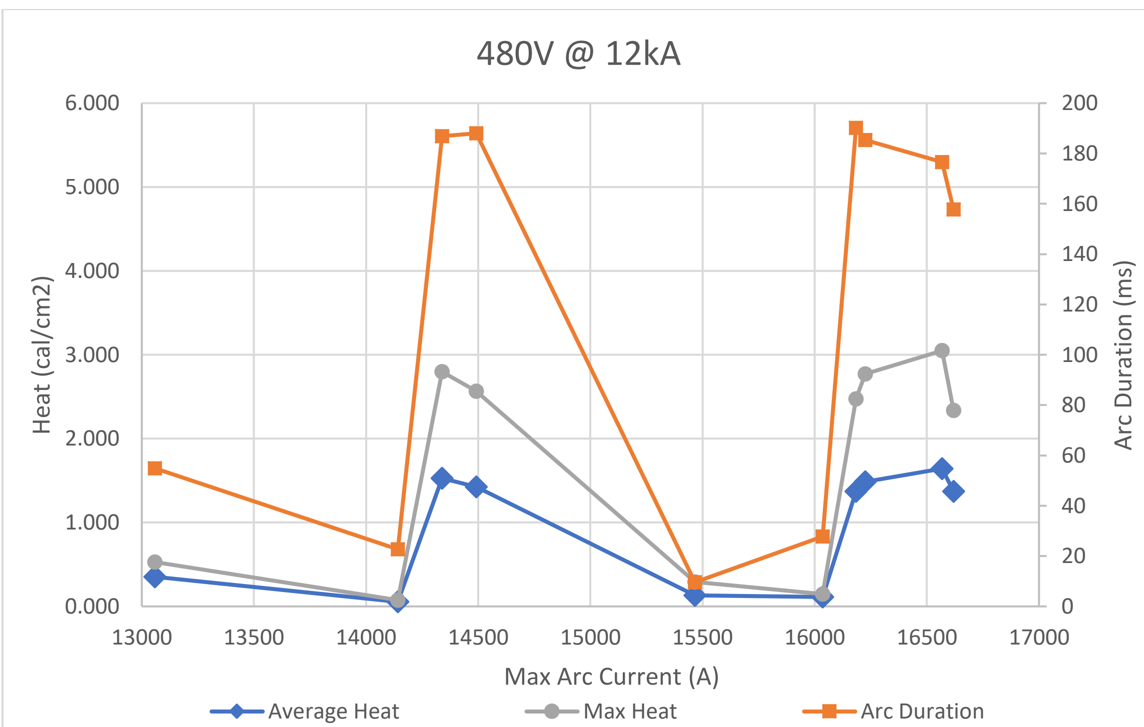



*Figure 27 - Heat & Arc Duration vs. Current - 480V @ 12kA*

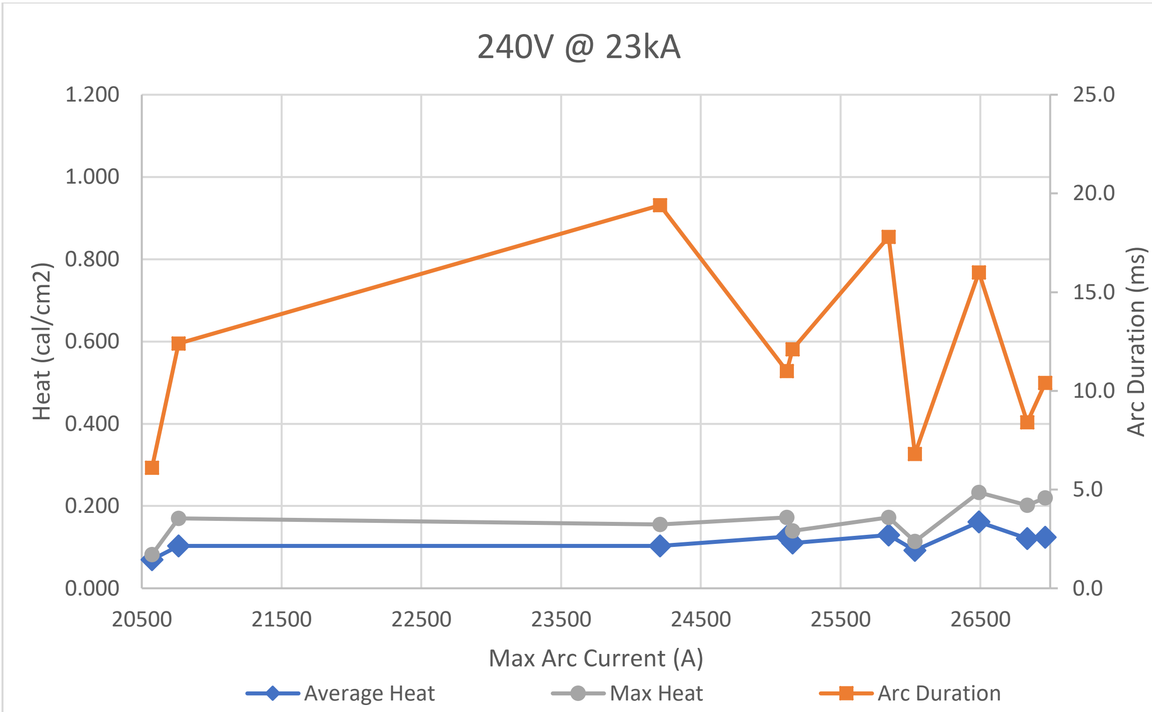



*Figure 28 - Heat & Arc Duration vs. Current - 240V @ 23kA*

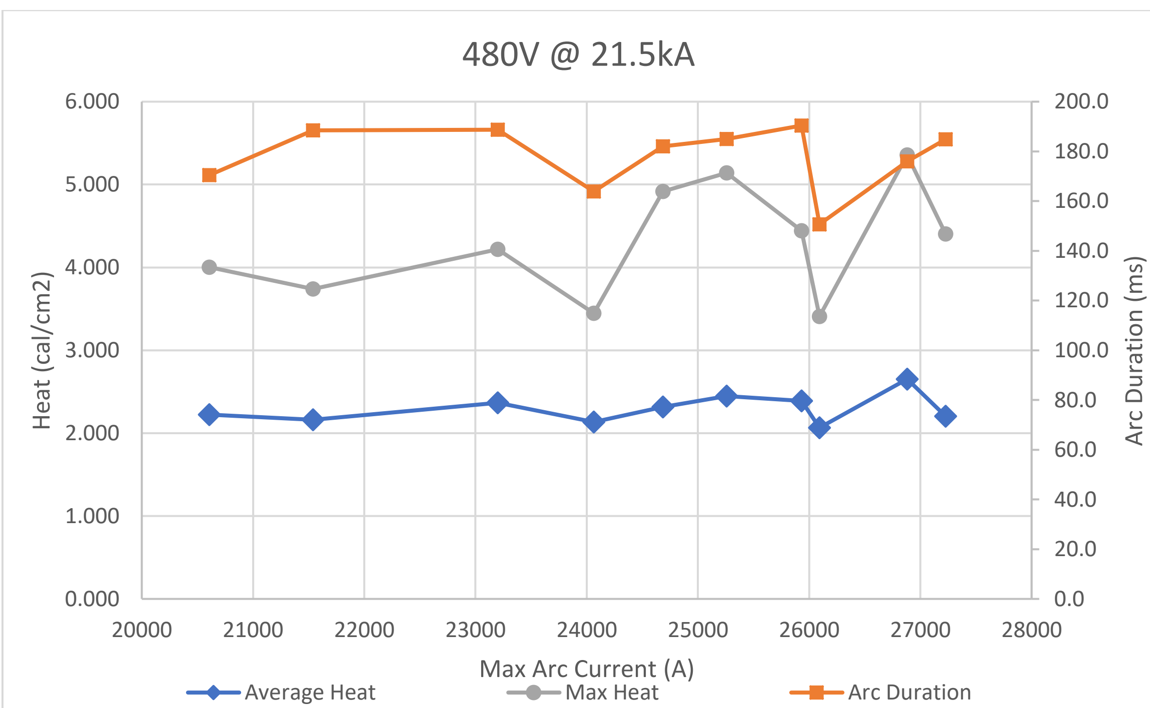



*Figure 29 - Heat & Arc Duration vs. Current - 480V @ 21.5kA*

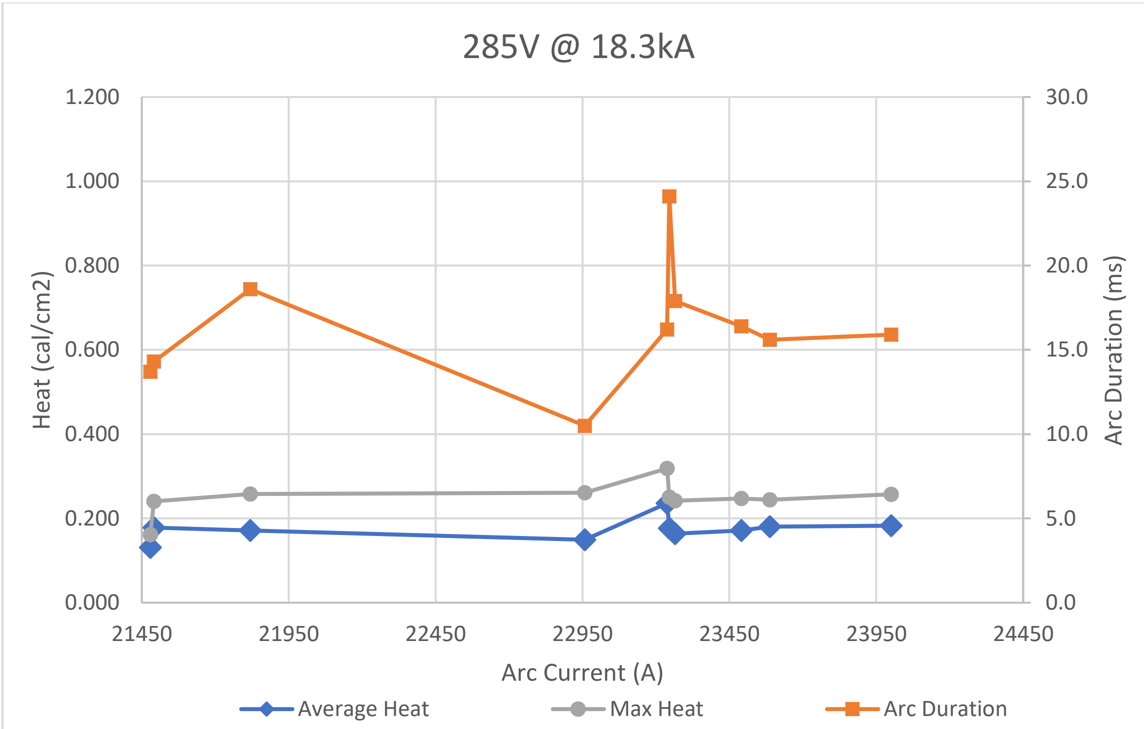



*Figure 30 - Heat & Arc Duration vs. Current - 285V @ 18.3kA*

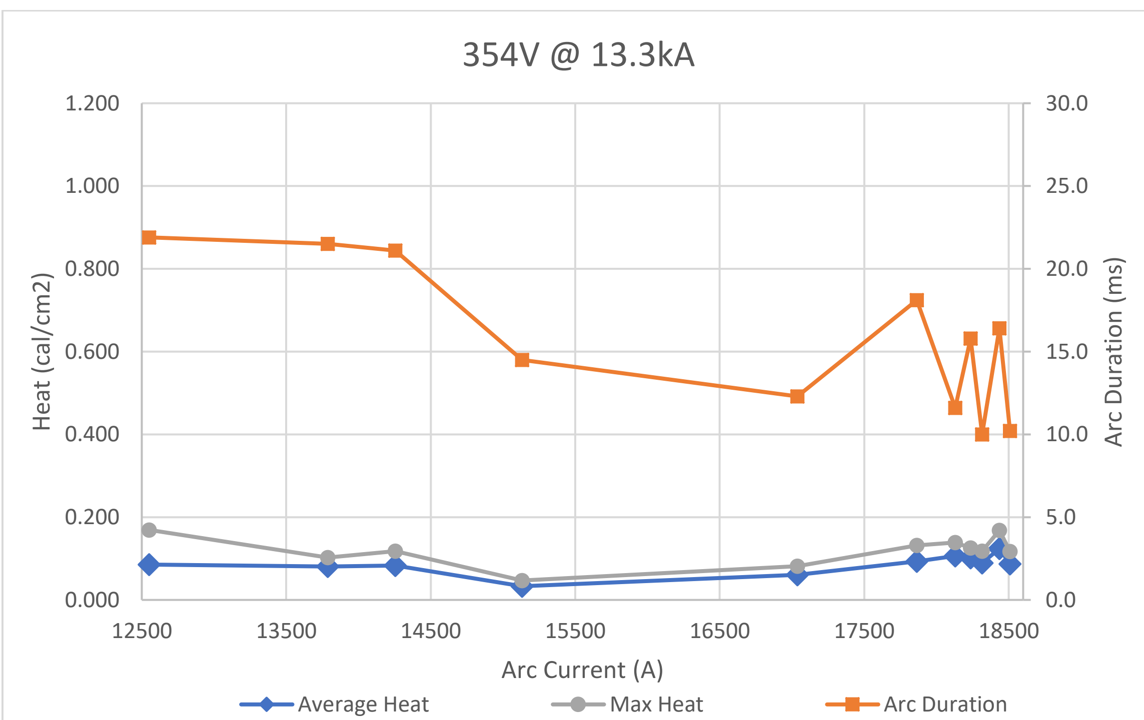



*Figure 31 - Heat & Arc Duration vs. Current - 354V @ 13.3kA*

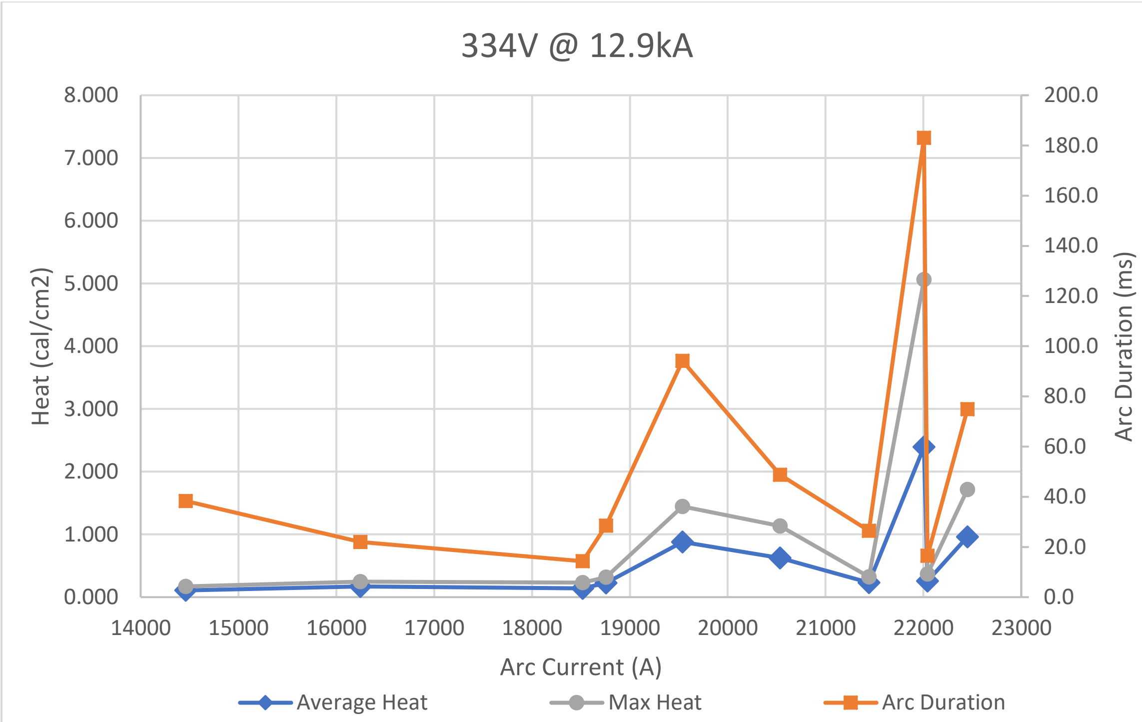



*Figure 32 - Heat & Arc Duration vs. Current - 334V @ 12.9kA*

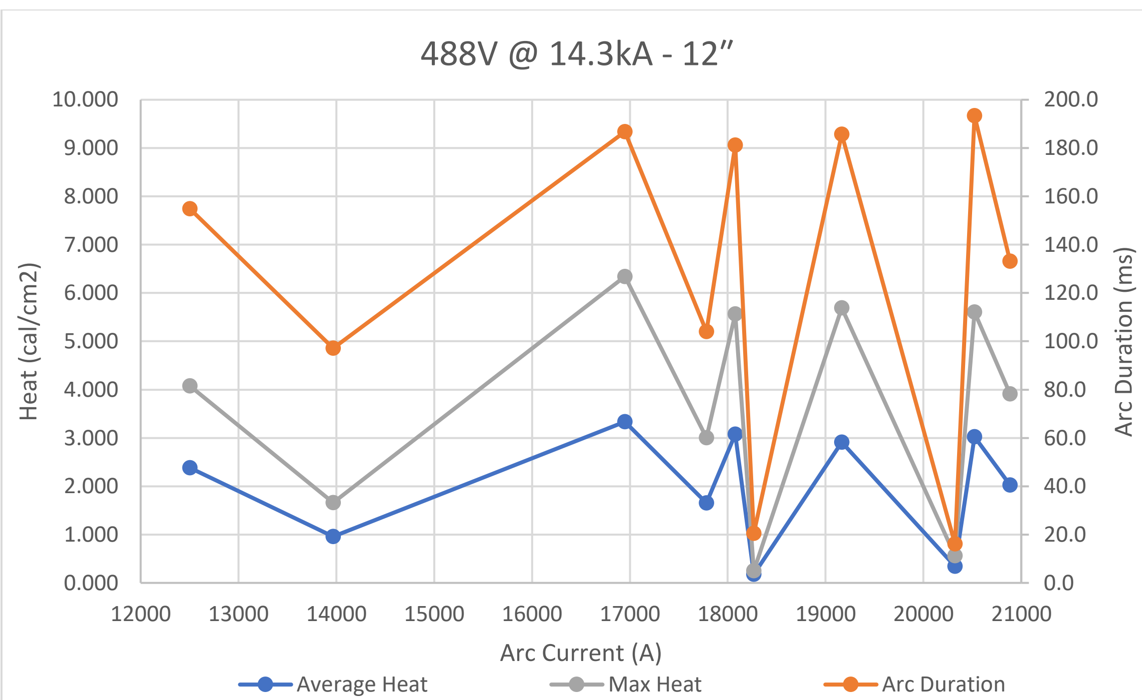



*Figure 33 - Heat & Arc Duration vs. Current - 488V @ 14.3kA - 12"*

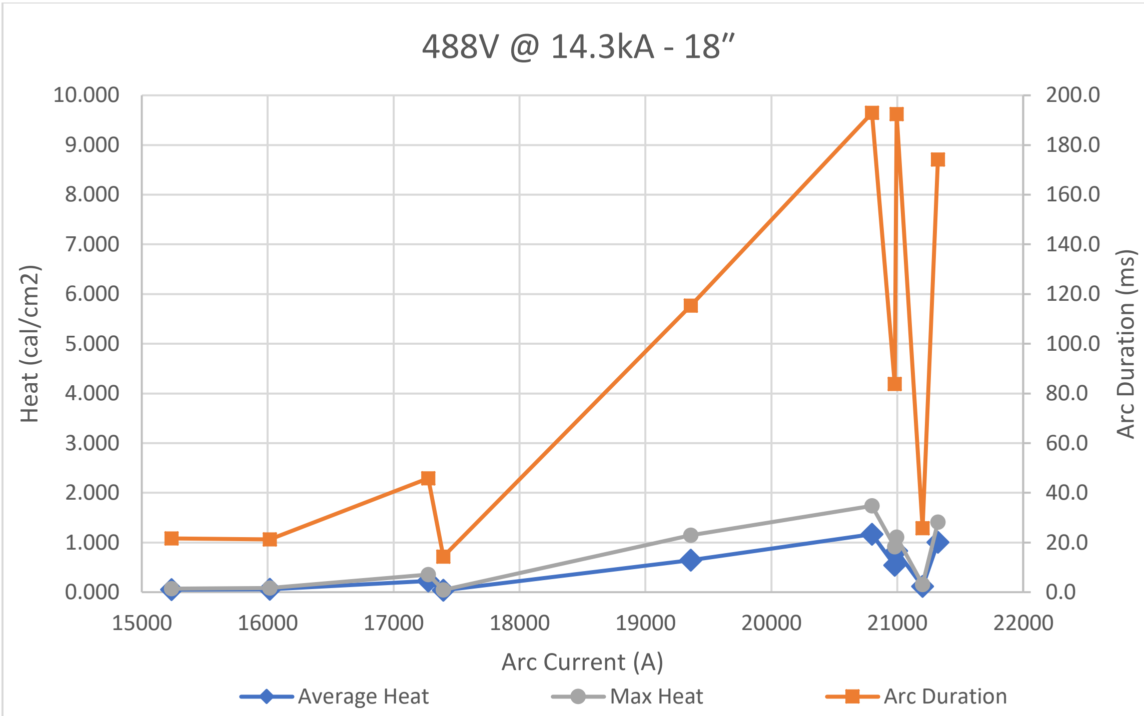



*Figure 34 - Heat & Arc Duration vs. Current - 488V @ 14.3kA - 18"*

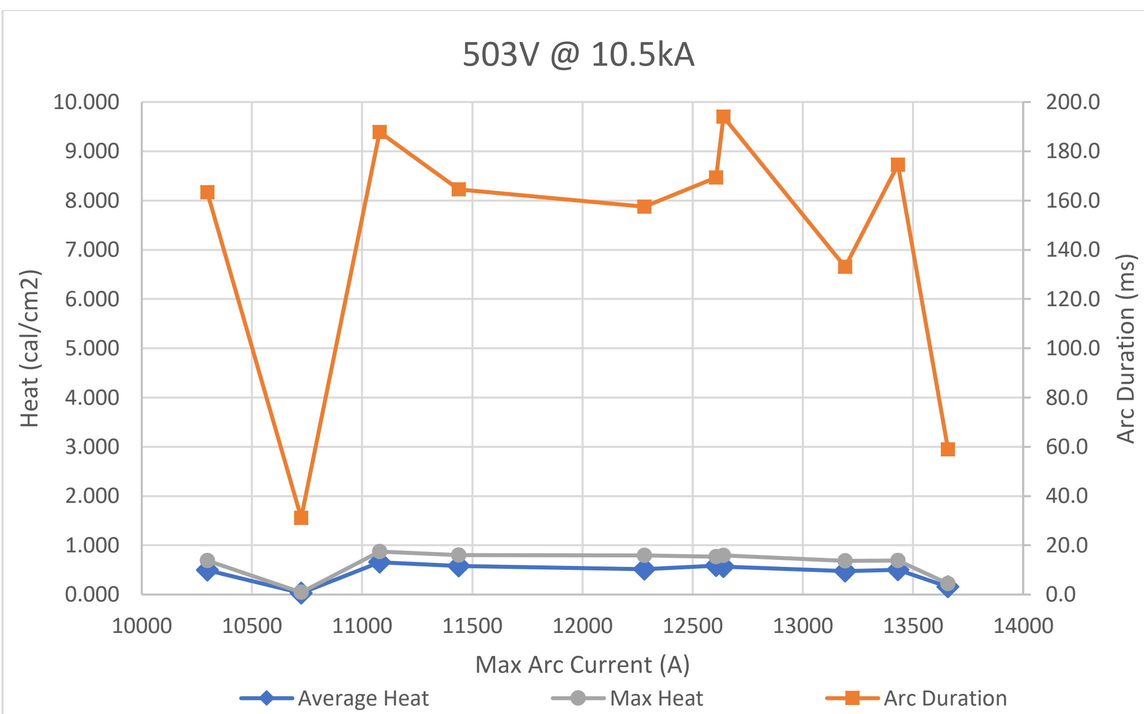



*Figure 35 - Heat & Arc Duration vs. Current - 503V @ 10.5kA*

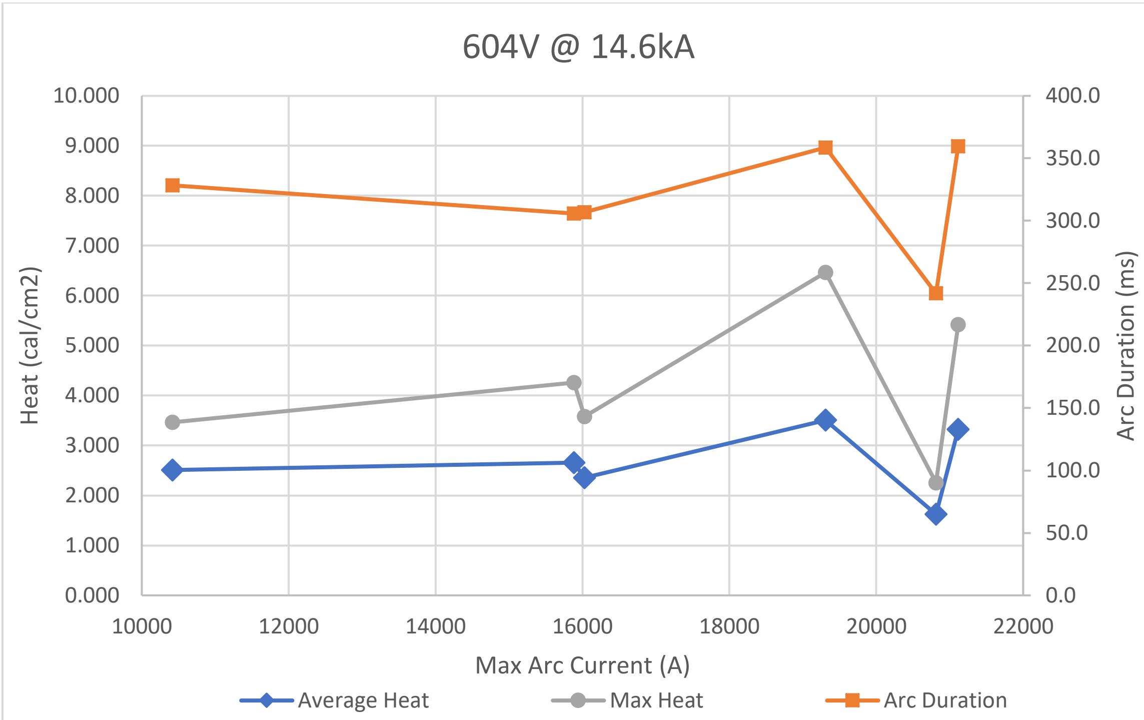



*Figure 36 - Heat & Arc Duration vs. Current - 604V @ 14.6kA*

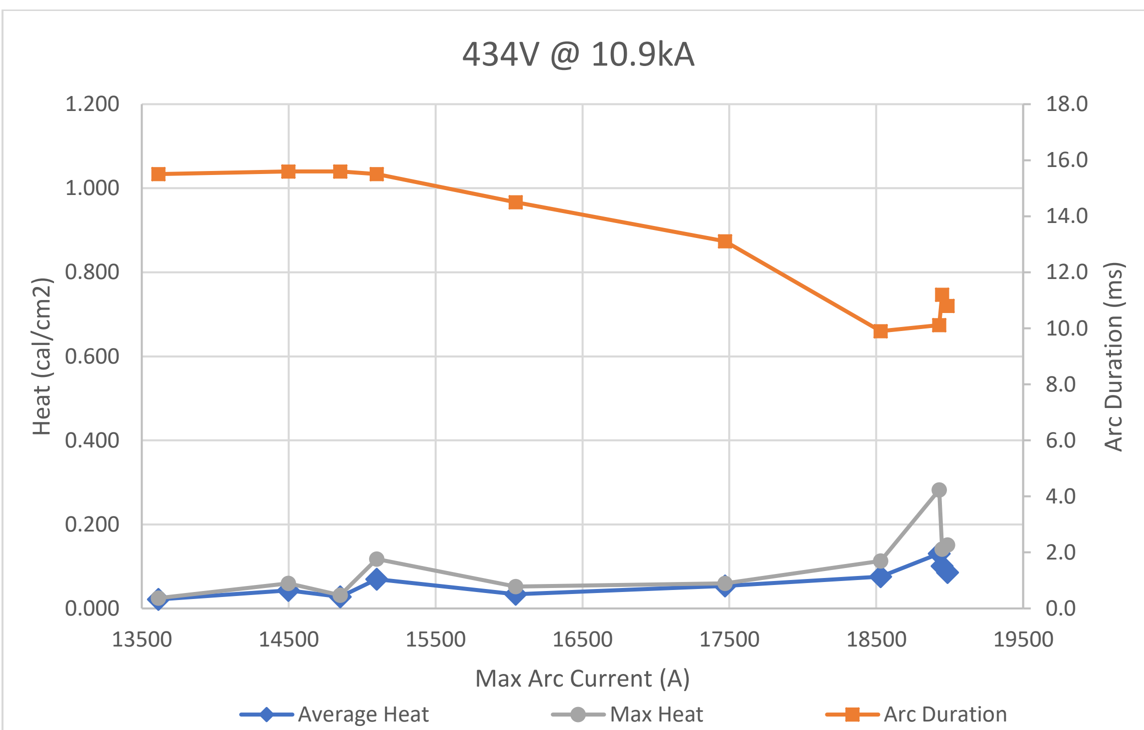



*Figure 37 - Heat & Arc Duration vs. Current - 434V @ 10.9kA*

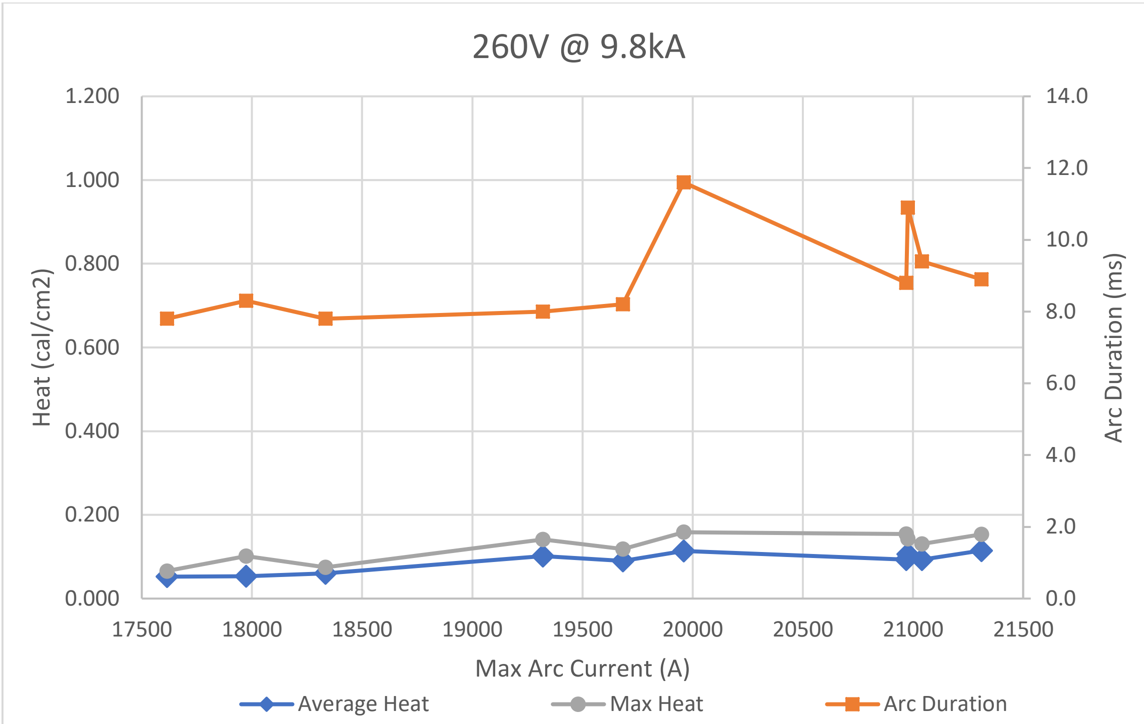



*Figure 38 - Heat & Arc Duration vs. Current - 260V @ 9.8kA*

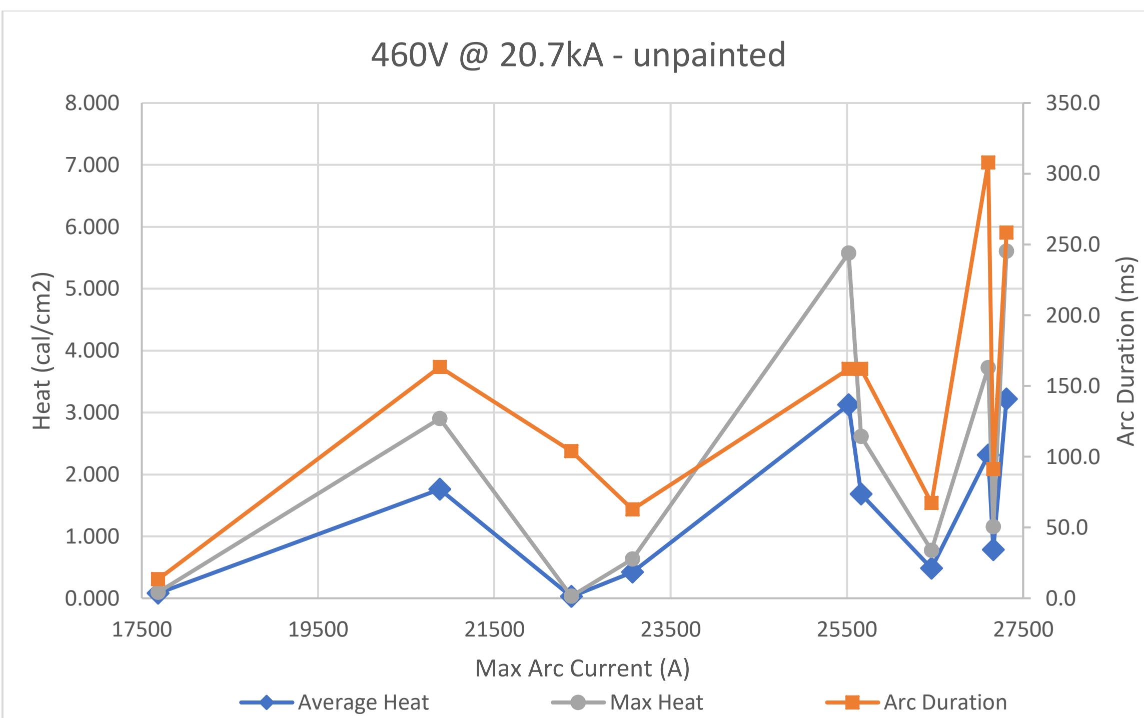



*Figure 39 - Heat & Arc Duration vs. Current - 460V @ 20.7kA – Unpainted*

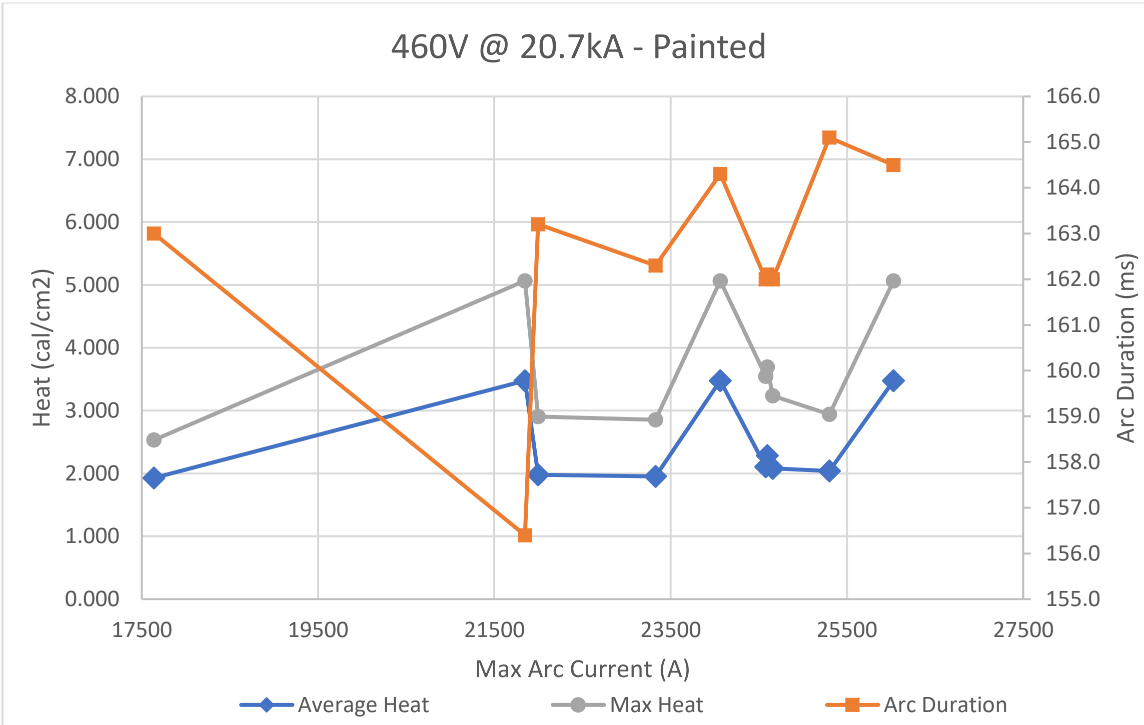



*Figure 40 - Heat & Arc Duration vs. Current - 460V @ 20.7kA – Painted*

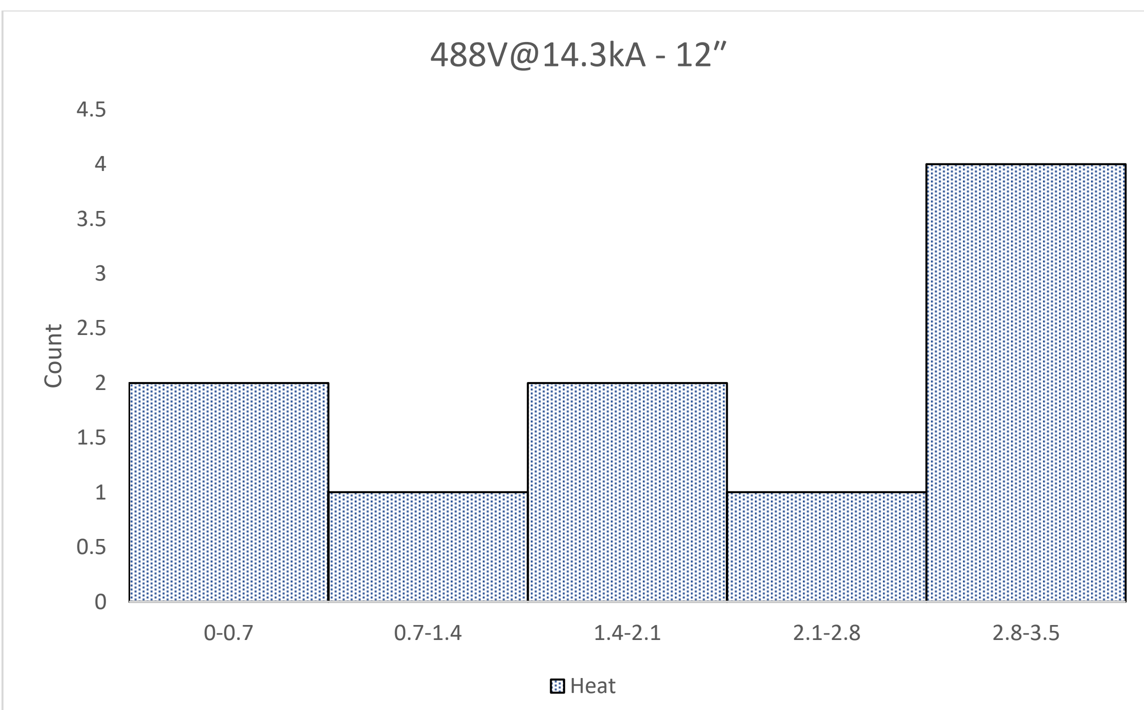



*Figure 41 - Probability Distribution of Heat Values - 488V @ 14.3kA - 12"*

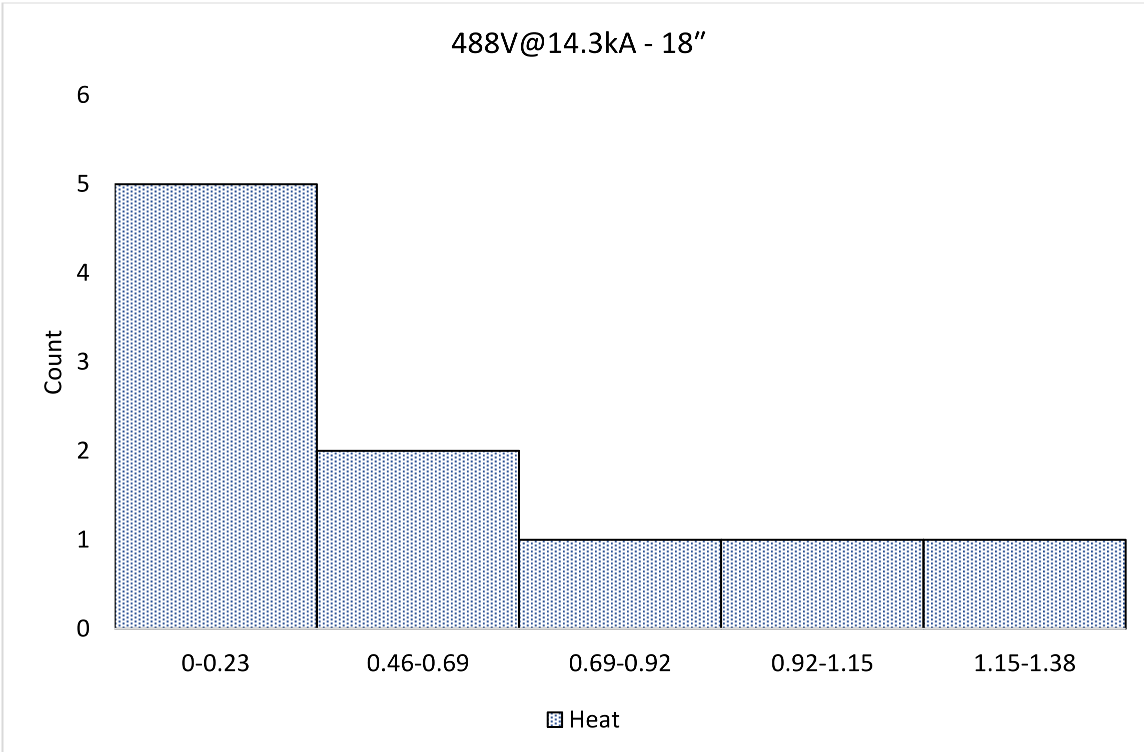



*Figure 42 - Probability Distribution of Heat Values - 488V @ 14.3kA - 18"*

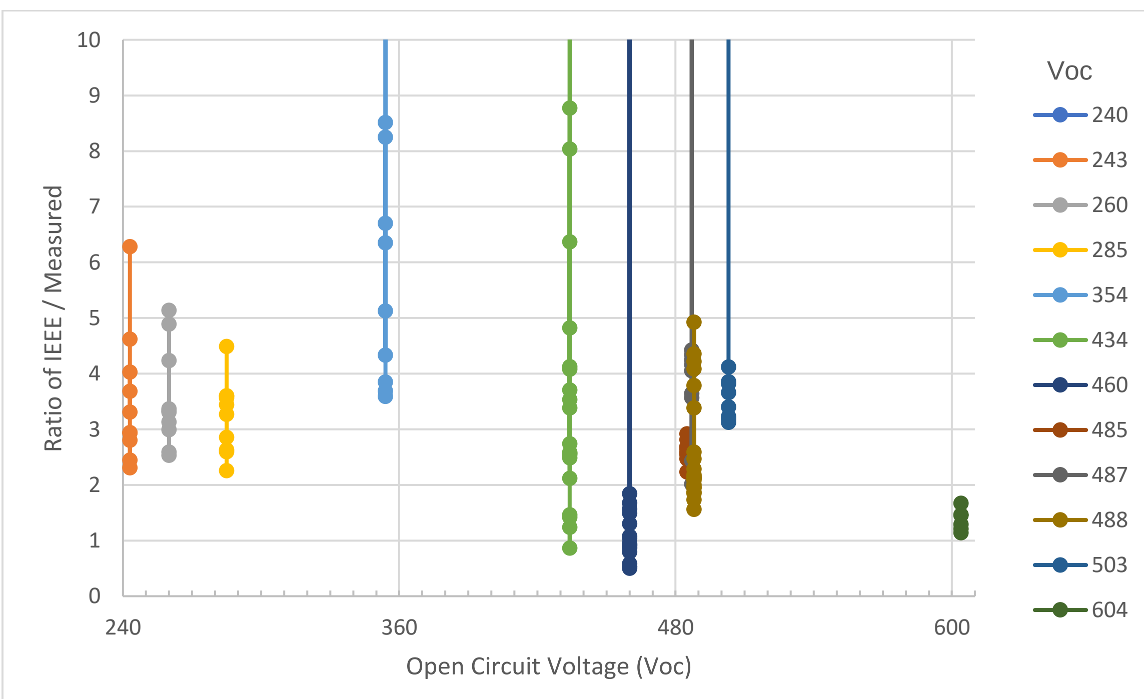



*Figure 43 - Corrected Heat vs IEEE 1584*

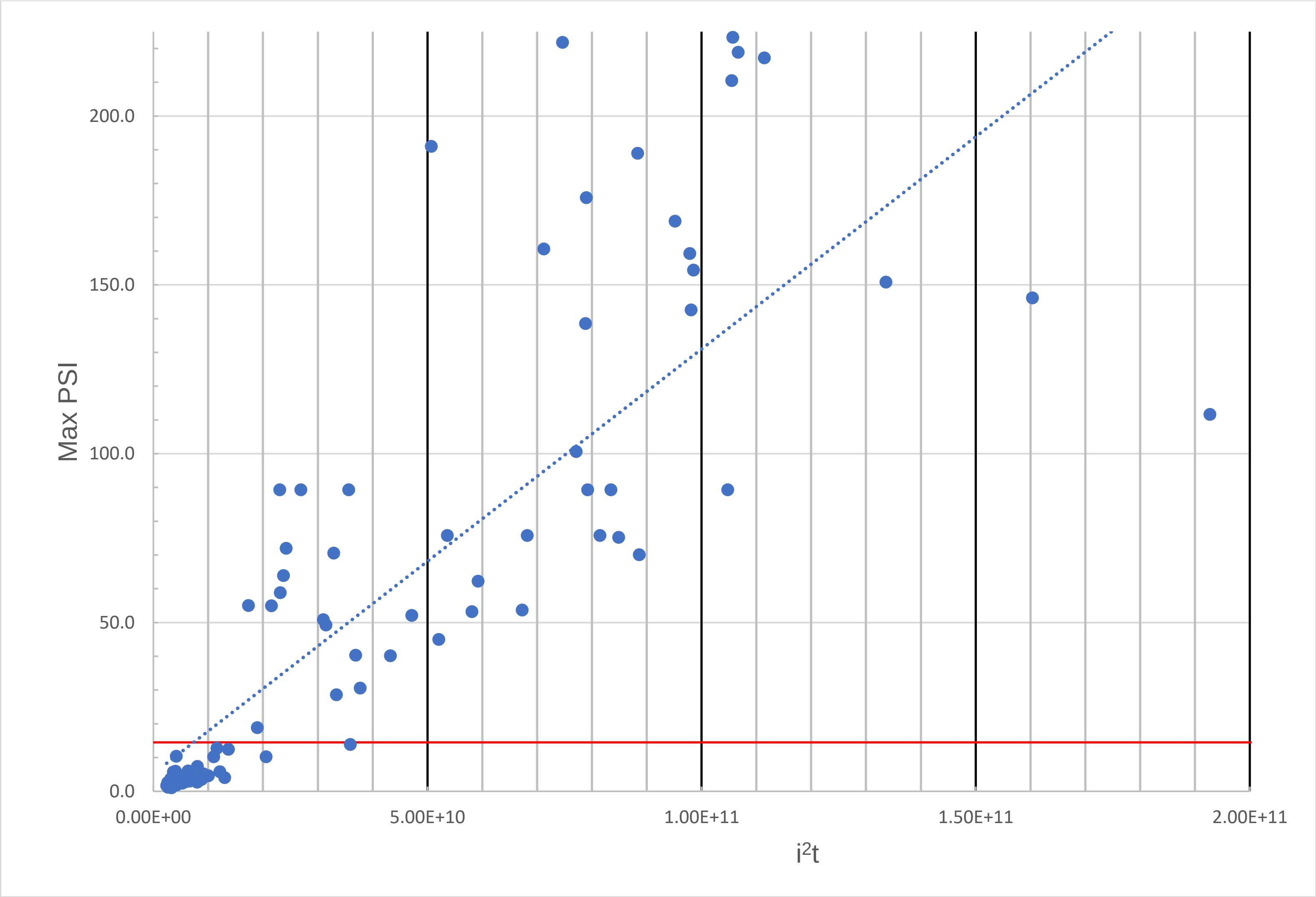



*Figure 44 - Blast Pressure at 18 Inches*

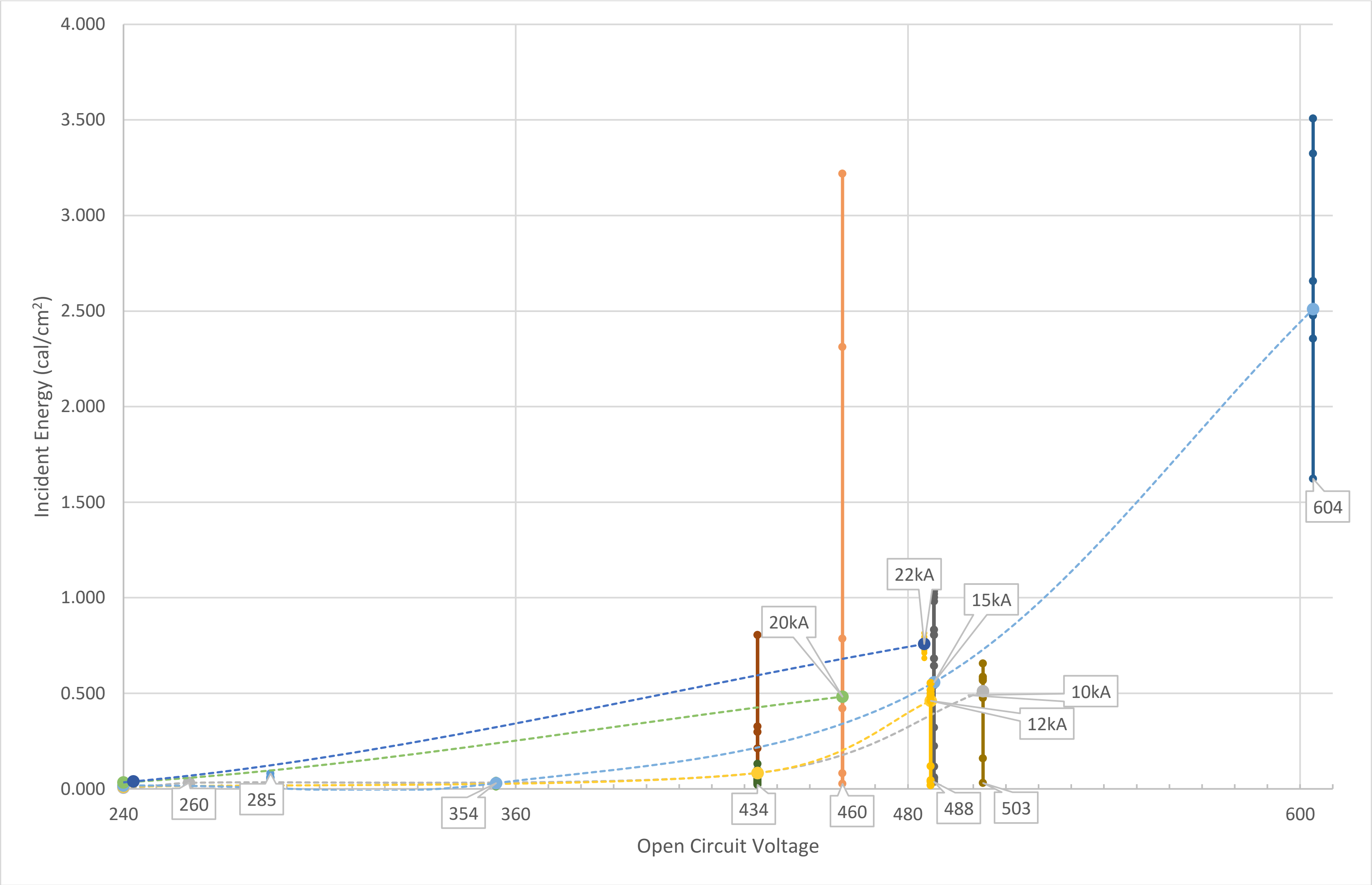



*Figure 45 - Incident Energy vs. Open Circuit Voltage and Available Current*

*Figure 46 - Post-Run Snapshots – Series #1 - #1, #2, #9*

*Figure 47 - Post-Run Snapshots – Series #1 - #14, #34*

*Figure 48 - Post-Run Snapshots - Series #2 - #76*

*Figure 49 - Post-Run Snapshots - Series #2 - #110*

*Figure 50 - Enlarged Clip of Series #1 Run 6 / 27880 - 240V Fusing Only*

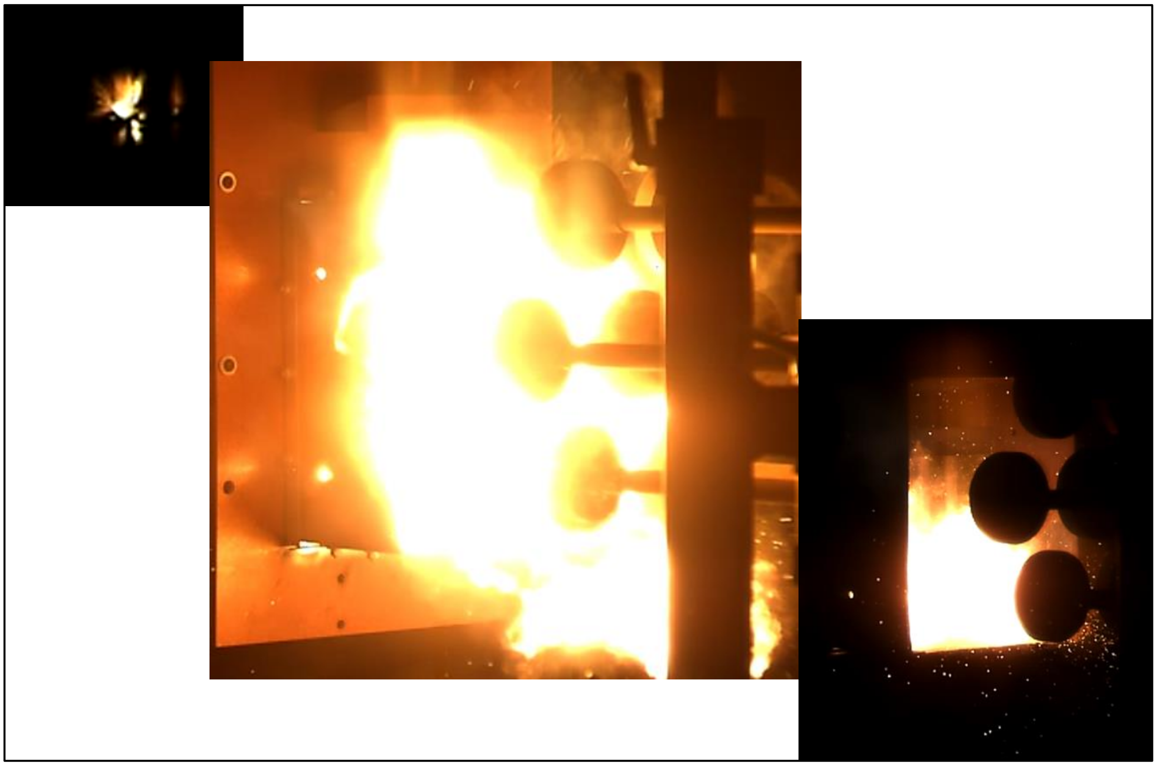
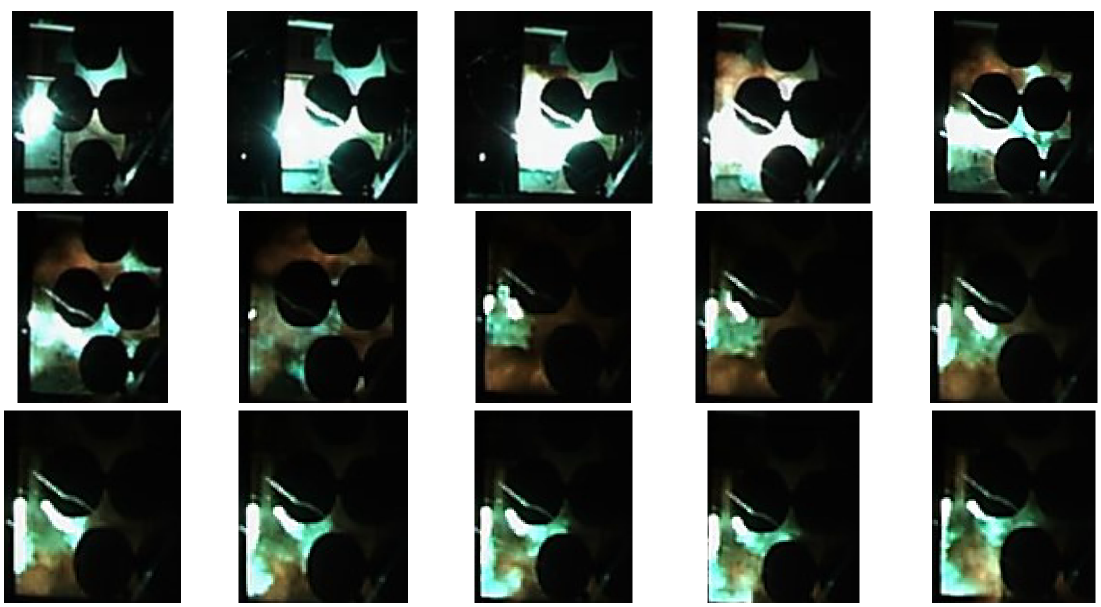


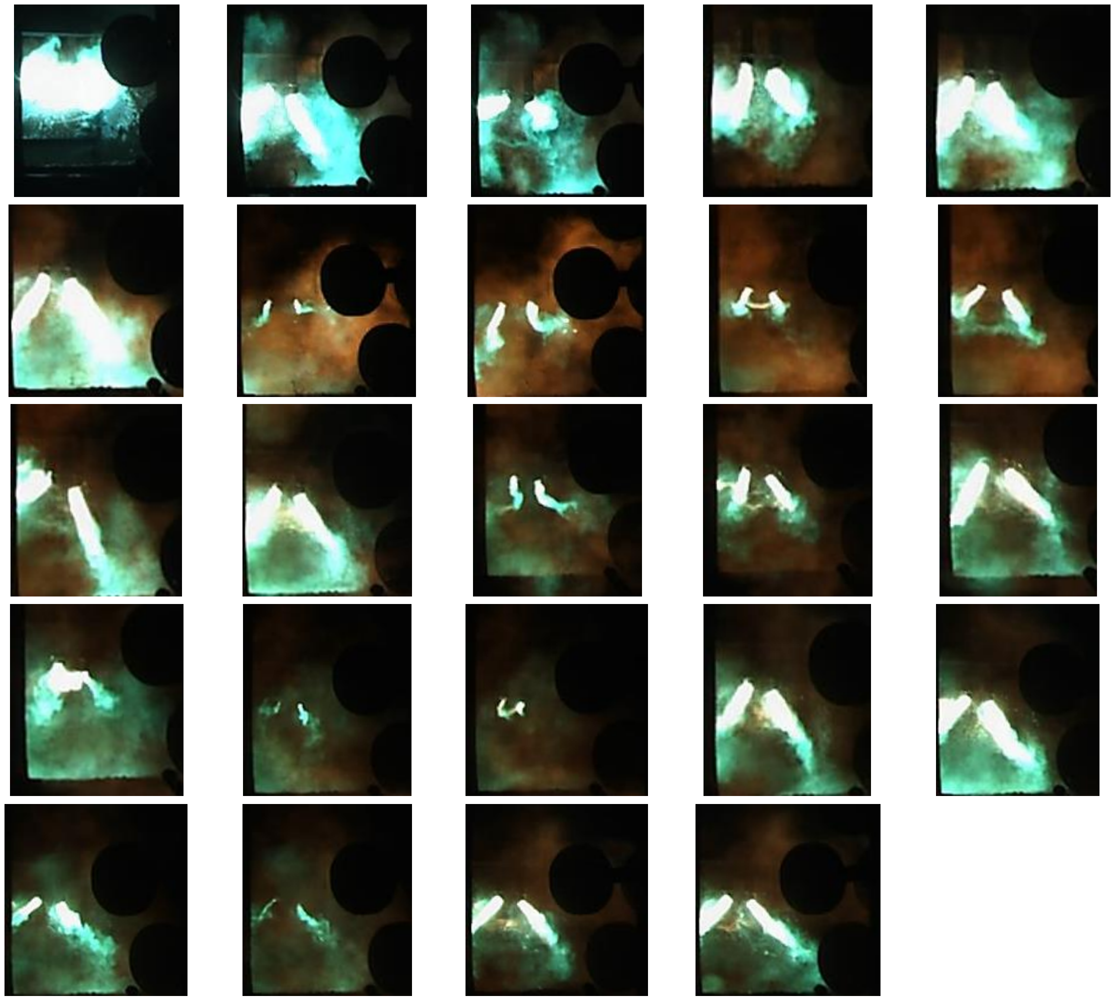
*Figure 51 - Clips of Series #1 Run 23 / 30036 - Flash Sequence Video*

*Figure 52 - Clips of Series #1 Run 35 / 30048 - Flash Sequence Video*



Clip order is left to right, top to bottom

*Figure 53 - Clips of Series #2 Run 68 / 34405 - Flash Sequence Video*



Clip order is left to right, top to bottom

*Figure 54 - Clips of Series #2 Run 68 / 34405 - Flash Sequence Video*

# APPENDIX C : TABLES

*Table 1 - Maximum Power in Three-Phase Arc (MW)*

| Bolted Fault (kA) | System Voltage (kV) | | | | | |
|---|---|---|---|---|---|---|
| | **0.48** | **2.4** | **4.2** | **7.2** | **13.2** | **14.5** |
| 1 | 0.42 | 2.0 | 3.6 | 6.3 | 11.4 | 29.8 |
| 2 | 0.83 | 4.2 | 7.2 | 12.5 | 2.8 | 59.6 |
| 3 | 1.25 | 6.2 | 10.8 | 18.7 | 34.8 | 910 |
| 5 | 2.08 | 10.3 | 18.0 | 31.2 | 57.1 | 149.2 |
| 10 | 4.15 | 20.8 | 36.0 | 62.3 | 114.2 | 295.5 |
| 15 | 6.23 | 31.1 | 54.0 | 93.4 | 171.3 | 447.7 |
| 20 | 8.3 | 41.5 | 72.0 | 120.5 | 228.3 | 596.7 |
| 30 | 12.5 | 62.2 | 108.0 | 186.8 | | |
| 40 | 16.6 | 83.0 | 144.0 | | | |
| 50 | 20.8 | 103.8 | 180.0 | | | |

*Table 2 - Arc Fault Data with 50kVA Transformer*

| Test | Primary Fuse Size | Arc Gap Length | | Arc Fault Current (A) | Pri. Fuse Blow? | Clearing Time | |
|---|---|---|---|---|---|---|---|
| | | (in) | (mm) | | | (ms) | (cycles) |
| 1 | 10KA | Bolted | Bolted | 9585 | Y | 108.92 | 6.5 |
| 2 | 10KA | 0.125 | 3.2 | 5148 | N | 8.2 | 0.5 |
| 3 | 10KA | 0.25 | 6.4 | 3852 | N | 6.58 | 0.4 |
| 4 | 20KA | 0.042 | 1.1 | 7347 | N | 9.44 | 0.6 |
| 5 | 10KA | 0.5 | 12.7 | 3444 | N | 6.12 | 0.4 |
| 6 | 10KA | 1.0 | 25.4 | 1446 | N | 2.6 | 0.2 |
| 7 * | 20KA | 0.125 | 3.2 | 7812 | N | 3.71 | 0.2 |
| 8 ** | 10KA | N/A | N/A | 10260 | Y | 44 | 2.6 |
| * 240V phase-to-phase fault in pedestal  ** 240V phase-to-phase fault in meter socket | | | | | | | |

*Table 3 - Arc Fault Data with 167kVA Transformer*

| Test | Primary Fuse Size | Arc Gap Length | | Arc Gap Voltage | Arc Fault Current (A) | Pri. Fuse Blow? | Clearing Time | |
|---|---|---|---|---|---|---|---|---|
| | | (in) | (mm) | | | | (ms) | (cycles) |
| 1 | 20KA | Bolted | Bolted | 5 | 11958 | Y | 150 | 9 |
| 2 | 20KA | 0.042 | 1.1 | 44 | 11892 | N | 7.23 | 0.4 |
| 3 | 20KA | 0.125 | 3.2 | 97 | 8109 | N | 7.1 | 0.4 |
| 4 | 20KA | 0.375 | 9.5 | 136 | 4131 | N | 3.45 | 0.2 |
| 5 ** | 20KA | N/A | N/A | 145 | 12120 | N | 19.1 | 1.1 |
| ** 240V phase-to-phase fault in meter socket | | | | | | | | |

*Table 4 - Skin Thickness versus Age Group*

| | | Age Group | | |
|---|---|---|---|---|
| **Body Region** | **Skin Layer** | **18-22** | **23-53** | **53-73** |
| Forehead | Epidermis | 0.203 | 0.244 | 0.108 |
| | Dermis (Corium) | 2.017 | 2.006 | 2.253 |
| Cheeks | Epidermis | 0.211 | 0.238 | 0.214 |
| | Dermis (Corium) | 1.352 | 1.824 | 1.359 |
| Anterior Neck | Epidermis | 0.094 | 0.130 | 0.084 |
| | Dermis (Corium) | 2.419 | 2.633 | 3.458 |
| Thorax (chest) | Epidermis | 0.176 | 0.132 | 0.086 |
| | Dermis (Corium) | 1.816 | 3.065 | 2.192 |
| Abdomen | Epidermis | 0.218 | 0.179 | 0.110 |
| | Dermis (Corium) | 2.981 | 3.075 | 2.548 |
| Anterior Arm | Epidermis | 0.150 | 0.113 | 0.092 |
| | Dermis (Corium) | 4.017 | 2.220 | 1.063 |
| Anterior Forearm | Epidermis | 0.107 | 0.113 | 0.092 |
| | Dermis (Corium) | 3.014 | 2.965 | 1.825 |
| Anterior Leg | Epidermis | 0.098 | 0.144 | 0.100 |
| | Dermis (Corium) | 3.330 | 4.805 | 2.026 |
| All thicknesses in millimeters (mm)<br>Source material lists first age range as “13-22”. In the U.S. electrical workers potentially exposed to arc flash will be minimum 18 years old. | | | | |

*Table 5 - Comparison of Skin Burn Classification Systems*

| **Trad.** | **Reed [111]** | **Lawton [112]** | **U.Roch./Knox [113]** |
|---|---|---|---|
| 1st | Below Threshold | Superficial | 1 – Cell damage without acidophilism<br>2 – Partial epidermal acidophilism<br>3 – Complete epidermal acidophilism |
| 2nd | Partial Thickness | Partial Thickness | 4 – Partial dermal-epidermal separation<br>5 – Complete dermal-epidermal separation |
| 3rd | Full Thickness | Deep Dermal | 6 – Superficial dermal<br>7 – Mid dermal<br>8 – Deep dermal<br>9 – Complete dermal to adipose border |
| | | | 10 – Adipose |

*Table 6 - Series #1 Run Numbers - Voltage/Current Settings*

| Series - Run | Oscillogram Number | Voc (RMS) | Available Current (RMS) | Comments |
|---|---|---|---|---|
| 1-1 | 27875 | 240 | 10.0kA | 18″ spacing |
| 1-2 | 27875 | 240 | 10.0kA | 12″ spacing |
| … | … | … | … | … |
| 1-11 | 27885 | 240 | 10.0kA | 12″ spacing |
| 1-12 | 30025 | 487 | 12.3kA | 12″ spacing |
| … | … | … | … | … |
| 1-21 | 30034 | 487 | 12.3kA | 12″ spacing |
| 1-22 | 30035 | 243 | 22.9kA | 12″ spacing |
| … | … | … | … | … |
| 1-31 | 30044 | 243 | 22.9kA | 12″ spacing |
| 1-32 | 30045 | 485 | 21.5kA | 12″ spacing |
| … | … | … | … | … |
| 1-41 | 30056 | 485 | 21.5kA | 12″ spacing |
| 1-42 | 30056 | 485 | 21.5kA | Video only |
| 1-43 | 30056 | 485 | 21.5kA | Video only |

*Table 7 - Series #2 Run Numbers- 12″ vs. 18″ - Voltage/Current Settings*

| Series - Run | Oscillogram Number | Voc (RMS) | Available Current (RMS) | Comments |
|---|---|---|---|---|
| 2-33 | 34367 | 488 | 14.3kA | 12″ spacing |
| … | … | … | … | … |
| 2-42 | 34376 | 488 | 14.3kA | 12″ spacing |
| 2-43 | 34377 | 488 | 14.3kA | 18″ spacing |
| … | … | … | … | … |
| 2-52 | 34386 | 488 | 14.3kA | 18″ spacing |

*Table 8 - Series #2 Run Numbers - Voltage/Current Settings*

| Series - Run | Oscillogram Number | Voc (RMS) | Available Current (RMS) | Comments |
|---|---|---|---|---|
| 2-1 | 34315 | 285 | 18.3kA | 12″ spacing |
| … | … | … | … | … |
| 2-11 | 34338 | 285 | 18.3kA | 12″ spacing |
| 2-12 | 34342 | 354 | 13.3kA | 12″ spacing |
| … | … | … | … | … |
| 2-22 | 34354 | 354 | 13.3kA | 12″ spacing |
| 2-23 | 34357 | 434 | 12.9kA | 12″ spacing |
| … | … | … | … | … |
| 2-32 | 34366 | 434 | 12.9kA | 12″ spacing |
| 2-53 | 34389 | 503 | 10.5kA | 18″ spacing |
| … | … | … | … | … |
| 2-62 | 34398 | 503 | 10.5kA | 18″ spacing |
| 2-63 | 34400 | 604 | 14.6kA | 18″ spacing |
| … | … | … | … | … |
| 2-69 | 34406 | 604 | 14.6kA | 18″ spacing |
| 2-70 | 34408 | 434 | 10. 9kA | 18″ spacing |
| … | … | … | … | … |
| 2-79 | 34417 | 434 | 10. 9kA | 18″ spacing |
| 2-80 | 34419 | 260 | 9.8kA | 12″ spacing |
| … | … | … | … | … |
| 2-89 | 34428 | 260 | 9.8kA | 12″ spacing |

*Table 9 - Series #2 Run Numbers - Unpainted vs. Painted - Voltage/Current Settings*

| Series - Run | Oscillogram Number | Voc (RMS) | Available Current (RMS) | Comments |
|---|---|---|---|---|
| 2-91 | 34432 | 460 | 20.7 | unpainted 18″ |
| … | … | … | … | … |
| 2-100 | 34442 | 460 | 20.7 | unpainted 18″ |
| 2-101 | 34443 | 460 | 20.7 | painted 18″ |
| … | … | … | … | … |
| 2-110 | 34452 | 460 | 20.7 | painted 18″ |

*Table 10 - 240V @ 10kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm$^2$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **1-1** | 27875 | 10446 | 31.4 | 0.008 | 0.008 | 0.005 | 0.008 | 0.010 | 0.010 | 0.008 |
| **1-2** | 27876 | 10153 | 29.2 | 0.018 | 0.020 | 0.020 | 0.028 | 0.031 | 0.033 | 0.068 |
| **1-3** | 27877 | 11457 | 18.1 | 0.022 | 0.012 | 0.016 | 0.010 | 0.009 | 0.009 | 0.007 |
| **1-4** | 27878 | 11547 | 26.1 | 0.012 | 0.013 | 0.008 | 0.011 | 0.013 | 0.010 | 0.011 |
| **1-5** | 27879 | 11553 | 18.5 | 0.014 | 0.013 | 0.016 | 0.015 | 0.019 | 0.026 | 0.024 |
| **1-6** | 27880 | 10015 | 30.7 | 0.019 | 0.027 | 0.013 | 0.018 | 0.017 | 0.023 | 0.022 |
| **1-7** | 27881 | 10093 | 30.7 | 0.017 | 0.029 | 0.012 | 0.019 | 0.021 | 0.022 | 0.026 |
| **1-8** | 27882 | 11047 | 28.2 | 0.029 | 0.027 | 0.023 | 0.029 | 0.017 | 0.027 | 0.023 |
| **1-9** | 27883 | 10985 | 33.6 | 0.014 | 0.017 | 0.011 | 0.019 | 0.014 | 0.020 | 0.015 |
| **1-10** | 27884 | 11355 | 27.9 | 0.023 | 0.028 | 0.016 | 0.028 | 0.023 | 0.022 | 0.026 |
| **1-11** | 27885 | 13768 | 26.3 | 0.015 | 0.016 | 0.007 | 0.009 | 0.009 | 0.010 | 0.009 |

*Table 11 - 487V @ 12.3kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm$^2$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **1-12** | 30025 | 14141 | 22.7 | 0.075 | 0.057 | 0.043 | 0.051 | 0.041 | 0.056 | 0.062 |
| **1-13** | 30026 | 14491 | 188.0 | 0.842 | 1.139 | 0.547 | 1.782 | 1.368 | 1.730 | 2.565 |
| **1-14** | 30027 | 16568 | 176.6 | 0.851 | 1.120 | 0.732 | 1.775 | 1.999 | 1.974 | 3.049 |
| **1-15** | 30028 | 15466 | 9.8 | 0.036 | 0.060 | 0.046 | 0.147 | 0.191 | 0.163 | 0.291 |
| **1-16** | 30029 | 16036 | 14.1 | 0.127 | 0.077 | 0.097 | 0.110 | 0.094 | 0.147 | 0.124 |
| **1-17** | 30030 | 14339 | 186.9 | 0.843 | 1.131 | 0.670 | 1.733 | 1.764 | 1.752 | 2.800 |
| **1-18** | 30031 | 16226 | 185.3 | 0.679 | 1.101 | 0.677 | 1.470 | 1.906 | 1.800 | 2.772 |
| **1-19** | 30032 | 16184 | 82.9 | 0.769 | 1.030 | 0.541 | 1.408 | 1.645 | 1.726 | 2.474 |
| **1-20** | 30033 | 13059 | 47.0 | 0.303 | 0.227 | 0.162 | 0.379 | 0.396 | 0.477 | 0.527 |
| **1-21** | 30034 | 16619 | 150.0 | 0.695 | 1.110 | 0.482 | 1.438 | 1.691 | 1.842 | 2.336 |

Arc durations in this group greater than 150ms estimated from raw data. Arc events terminated by test cell controller.

*Table 12 - 243V @ 22.9kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm²) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **1-22** | 30035 | 20573 | 6.1 | 0.071 | 0.081 | 0.044 | 0.068 | 0.071 | 0.070 | 0.082 |
| **1-23** | 30036 | 25115 | 11.0 | 0.158 | 0.077 | 0.111 | 0.125 | 0.080 | 0.172 | 0.156 |
| **1-24** | 30037 | 26031 | 6.8 | 0.114 | 0.091 | 0.056 | 0.114 | 0.066 | 0.099 | 0.103 |
| **1-25** | 30038 | 20764 | 12.4 | 0.098 | 0.080 | 0.059 | 0.105 | 0.094 | 0.170 | 0.115 |
| **1-26** | 30039 | 25844 | 17.8 | 0.172 | 0.084 | 0.080 | 0.125 | 0.126 | 0.167 | 0.150 |
| **1-27** | 30040 | 26837 | 8.4 | 0.118 | 0.068 | 0.089 | 0.135 | 0.073 | 0.202 | 0.161 |
| **1-28** | 30041 | 25156 | 12.1 | 0.140 | 0.086 | 0.092 | 0.111 | 0.079 | 0.134 | 0.128 |
| **1-29** | 30042 | 24208 | 19.4 | 0.100 | 0.070 | 0.074 | 0.103 | 0.085 | 0.155 | 0.137 |
| **1-30** | 30043 | 26965 | 10.4 | 0.103 | 0.108 | 0.088 | 0.128 | 0.083 | 0.220 | 0.138 |
| **1-31** | 30044 | 26489 | 16.0 | 0.117 | 0.123 | 0.120 | 0.174 | 0.136 | 0.233 | 0.226 |

*Table 13 - 485V @ 21.5kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm²) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **1-32** | 30045 | 27227 | 184.8 | 1.265 | 1.475 | 1.246 | 2.023 | 1.978 | 4.403 | 3.043 |
| **1-33** | 30046 | 24685 | 182.0 | 1.012 | 1.651 | 0.909 | 2.096 | 2.279 | 4.918 | 3.347 |
| **1-34** | 30047 | 26882 | 176.0 | 1.279 | 1.748 | 1.130 | 2.273 | 2.747 | 5.357 | 4.035 |
| **1-35** | 30048 | 25257 | 185.0 | 1.183 | 1.737 | 0.917 | 2.143 | 2.541 | 5.142 | 3.480 |
| **1-36** | 30049 | 24063 | 163.9 | 1.039 | 1.608 | 0.902 | 1.904 | 2.671 | 3.448 | 3.374 |
| **1-37** | 30050 | 25932 | 190.4 | 0.990 | 1.720 | 1.024 | 2.113 | 2.735 | 4.441 | 3.712 |
| **1-38** | 30051 | 23200 | 188.7 | 1.090 | 1.555 | 0.943 | 2.043 | 2.813 | 3.894 | 4.220 |
| **1-39** | 30052 | 26093 | 150.7 | 1.033 | 1.580 | 0.878 | 1.621 | 2.589 | 3.350 | 3.409 |
| **1-40** | 30053 | 20608 | 170.4 | 1.080 | 1.567 | 0.835 | 2.076 | 2.579 | 3.423 | 4.002 |
| **1-41** | 30054 | 21539 | 188.4 | 0.995 | 1.605 | 0.794 | 2.085 | 2.570 | 3.352 | 3.740 |

Arc durations in this group greater than 150ms estimated from raw data. Arc events terminated by test cell controller.

*Table 14 - 285V @ 18.3kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps | Arc Duration | Incident Energy (cal/cm²) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | (RMS) | (ms) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **2-1** | 34315 | 21491 | 14.3 | 0.208 | 0.109 | 0.097 | 0.240 | 0.168 | 0.225 | 0.200 |
| **2-2** | 34316 | 23238 | 16.2 | 0.318 | 0.167 | 0.201 | 0.311 | 0.188 | 0.274 | 0.194 |
| **2-3** | 34317 | 23246 | 24.1 | 0.205 | 0.151 | 0.115 | 0.229 | 0.123 | 0.250 | 0.162 |
| **2-4** | 34318 | 24001 | 15.9 | 0.211 | 0.134 | 0.127 | 0.243 | 0.153 | 0.257 | 0.155 |
| **2-5** | 34330 | 21479 | 13.7 | 0.160 | 0.096 | 0.094 | 0.161 | 0.107 | 0.156 | 0.145 |
| **2-6** | 34333 | 23588 | 15.6 | 0.242 | 0.152 | 0.124 | 0.244 | 0.160 | no data | 0.162 |
| **2-7** | 34334 | 23491 | 16.4 | 0.205 | 0.127 | 0.145 | 0.247 | 0.126 | no data | 0.178 |
| **2-8** | 34335 | 22958 | 10.5 | 0.141 | 0.117 | 0.118 | 0.261 | 0.104 | no data | 0.156 |
| **2-9** | 34336 | 23265 | 32.4 | omitted – no data | | | | | | |
| **2-10** | 34337 | 21819 | 17.9 | 0.163 | 0.111 | 0.115 | 0.242 | 0.127 | 0.194 | 0.194 |
| **2-11** | 34338 | 21491 | 18.6 | 0.178 | 0.136 | 0.146 | 0.203 | 0.100 | 0.178 | 0.258 |

*Table 15 - 354V @ 13.3kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps | Arc Duration | Incident Energy (cal/cm²) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | (RMS) | (ms) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **2-12** | 34342 | 18509 | 10.2 | 0.092 | 0.095 | 0.056 | 0.117 | 0.063 | 0.093 | 0.091 |
| **2-13** | 34343 | 17864 | 18.1 | 0.087 | 0.076 | 0.067 | 0.125 | 0.068 | 0.099 | 0.132 |
| **2-14** | 34344 | 14254 | 21.1 | 0.102 | 0.078 | 0.044 | 0.118 | 0.059 | 0.096 | 0.086 |
| **2-15** | 34345 | 12550 | 21.9 | 0.087 | 0.055 | 0.041 | 0.099 | 0.053 | 0.090 | 0.169 |
| **2-16** | 34346 | 18236 | 15.8 | 0.125 | 0.088 | 0.065 | 0.125 | 0.066 | 0.116 | 0.126 |
| **2-17** | 34349 | 15132 | 14.5 | 0.034 | 0.027 | 0.022 | 0.042 | 0.028 | 0.032 | 0.047 |
| **2-18** | 34350 | 18317 | 10.0 | 0.115 | 0.069 | 0.062 | 0.118 | 0.072 | 0.099 | 0.087 |
| **2-19** | 34351 | 17037 | 12.3 | 0.064 | 0.064 | 0.032 | 0.077 | 0.034 | 0.069 | 0.082 |
| **2-20** | 34352 | 18130 | 11.6 | 0.139 | 0.079 | 0.087 | 0.135 | 0.079 | 0.091 | 0.135 |
| **2-21** | 34353 | 18436 | 16.4 | 0.160 | 0.092 | 0.077 | 0.166 | 0.086 | 0.168 | 0.118 |
| **2-22** | 34354 | 13787 | 21.5 | 0.101 | 0.064 | 0.058 | 0.097 | 0.066 | 0.102 | 0.078 |

*Table 16 - 434V @ 12.9kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm$^2$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **2-23** | 34357 | 18757 | 28.5 | 0.277 | 0.148 | 0.113 | 0.291 | 0.197 | 0.319 | 0.243 |
| **2-24** | 34358 | 20533 | 48.8 | 1.132 | 0.357 | 0.247 | 0.702 | 0.685 | 0.878 | 0.378 |
| **2-25** | 34359 | 22043 | 16.5 | 0.370 | 0.147 | 0.184 | 0.340 | 0.201 | 0.328 | 0.218 |
| **2-26** | 34360 | 14461 | 38.3 | 0.104 | 0.108 | 0.060 | 0.121 | 0.065 | 0.120 | 0.171 |
| **2-27** | 34361 | 19538 | 94.1 | 1.447 | 0.511 | 0.389 | 1.004 | 0.859 | 1.197 | 0.764 |
| **2-28** | 34362 | 22006 | 183.0 | 5.060 | 1.574 | 0.940 | 2.494 | 2.761 | 2.770 | 1.157 |
| **2-29** | 34363 | 22450 | 74.9 | 1.718 | 0.701 | 0.398 | 1.158 | 0.972 | 1.253 | 0.539 |
| **2-30** | 34364 | 21443 | 26.4 | 0.323 | 0.196 | 0.170 | 0.303 | 0.187 | 0.291 | 0.168 |
| **2-31** | 34365 | 18516 | 14.3 | 0.158 | 0.100 | 0.083 | 0.161 | 0.078 | 0.232 | 0.166 |
| **2-32** | 34366 | 16244 | 22.0 | 0.177 | 0.122 | 0.096 | 0.246 | 0.112 | 0.249 | 0.186 |

*Table 17 - 503V @ 10.5kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm$^2$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **2-53** | 34389 | 13432 | 174.5 | 0.601 | 0.524 | 0.248 | 0.591 | 0.690 | 0.575 | 0.310 |
| **2-54** | 34390 | 12606 | 169.3 | 0.769 | 0.586 | 0.311 | 0.701 | 0.605 | 0.617 | 0.512 |
| **2-55** | 34391 | 12640 | 194.0 | 0.688 | 0.472 | 0.335 | 0.642 | 0.793 | 0.646 | 0.398 |
| **2-56** | 34392 | 10723 | 31.2 | 0.037 | 0.027 | 0.026 | 0.029 | 0.022 | 0.044 | 0.029 |
| **2-57** | 34393 | 10297 | 163.4 | 0.694 | 0.490 | 0.241 | 0.593 | 0.652 | 0.490 | 0.331 |
| **2-58** | 34394 | 11079 | 187.8 | 0.873 | 0.624 | 0.445 | 0.796 | 0.628 | 0.741 | 0.481 |
| **2-59** | 34395 | 13659 | 58.9 | 0.184 | 0.099 | 0.123 | 0.207 | 0.128 | 0.151 | 0.226 |
| **2-60** | 34396 | 12281 | 157.5 | 0.792 | 0.473 | 0.204 | 0.538 | 0.719 | 0.584 | 0.310 |
| **2-61** | 34397 | 11438 | 164.5 | 0.749 | 0.555 | 0.322 | 0.723 | 0.802 | 0.489 | 0.400 |
| **2-62** | 34398 | 13192 | 133.0 | 0.648 | 0.380 | 0.262 | 0.603 | 0.422 | 0.684 | 0.332 |

*Table 18 - 604V @ 14.6kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm²) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **2-63** | 34400 | 20814 | 241.8 | 2.188 | 1.534 | 0.830 | 1.684 | 2.255 | 1.937 | 0.932 |
| **2-64** | 34401 | 10418 | 328.4 | 3.467 | 2.484 | 1.030 | 2.763 | 3.434 | 2.722 | 1.672 |
| **2-65** | 34402 | No Data | | 3.910 | 2.333 | 1.140 | 2.623 | 3.161 | 2.453 | 1.710 |
| **2-66** | 34403 | 16028 | 306.8 | 3.580 | 2.181 | 1.038 | 2.708 | 3.334 | 2.296 | 1.358 |
| **2-67** | 34404 | 15885 | 305.7 | 4.261 | 2.526 | 1.043 | 2.545 | 3.891 | 2.721 | 1.605 |
| **2-68** | 34405 | 21116 | 359.6 | 5.421 | 3.007 | 1.407 | 3.551 | 4.342 | 3.386 | 2.157 |
| **2-69** | 34406 | 19308 | 358.5 | 6.465 | 2.858 | 1.196 | 3.578 | 5.113 | 3.337 | 2.000 |

*Table 19 - 434V @ 10.9kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm²) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **2-70** | 34408 | 14852 | 15.6 | 0.031 | 0.021 | 0.024 | 0.028 | 0.029 | 0.031 | 0.028 |
| **2-71** | 34409 | 18928 | 10.1 | 0.159 | 0.091 | 0.066 | 0.111 | 0.282 | 0.127 | 0.078 |
| **2-72** | 34410 | 18529 | 9.9 | 0.093 | 0.053 | 0.060 | 0.113 | 0.061 | 0.081 | 0.068 |
| **2-73** | 34411 | 18986 | 10.8 | 0.151 | 0.054 | 0.057 | 0.081 | 0.075 | 0.111 | 0.068 |
| **2-74** | 34412 | 13613 | 15.5 | 0.019 | 0.024 | 0.017 | 0.023 | 0.021 | 0.025 | 0.024 |
| **2-75** | 34413 | 18948 | 11.2 | 0.142 | 0.062 | 0.063 | 0.108 | 0.114 | 0.137 | 0.081 |
| **2-76** | 34414 | 14499 | 15.6 | 0.060 | 0.035 | 0.032 | 0.040 | 0.044 | 0.045 | 0.041 |
| **2-77** | 34415 | 17471 | 13.1 | 0.055 | 0.040 | 0.049 | 0.060 | 0.055 | 0.059 | 0.056 |
| **2-78** | 34416 | 15099 | 15.5 | 0.118 | 0.046 | 0.047 | 0.062 | 0.056 | 0.096 | 0.061 |
| **2-79** | 34417 | 16045 | 14.5 | 0.028 | 0.024 | 0.031 | 0.032 | 0.028 | 0.039 | 0.052 |

*Table 20 - 260V @ 9.8kA - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm$^2$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **2-80** | 34419 | 17614 | 7.8 | 0.066 | 0.035 | 0.043 | 0.066 | 0.044 | 0.054 | 0.058 |
| **2-81** | 34420 | 19959 | 11.6 | 0.143 | 0.076 | 0.090 | 0.158 | 0.103 | 0.131 | 0.094 |
| **2-82** | 34421 | 19683 | 8.2 | 0.096 | 0.066 | 0.066 | 0.118 | 0.096 | 0.094 | 0.092 |
| **2-83** | 34422 | 19320 | 8.0 | 0.142 | 0.083 | 0.057 | 0.125 | 0.083 | 0.095 | 0.127 |
| **2-84** | 34423 | 20977 | 10.9 | 0.104 | 0.101 | 0.072 | 0.132 | 0.078 | 0.115 | 0.143 |
| **2-85** | 34424 | 17974 | 8.3 | 0.073 | 0.038 | 0.024 | 0.058 | 0.032 | 0.101 | 0.048 |
| **2-86** | 34425 | 21311 | 8.9 | 0.150 | 0.091 | 0.057 | 0.154 | 0.091 | 0.137 | 0.123 |
| **2-87** | 34426 | 18334 | 7.8 | 0.060 | 0.064 | 0.042 | 0.075 | 0.058 | 0.063 | 0.062 |
| **2-88** | 34427 | 21040 | 9.4 | 0.131 | 0.080 | 0.069 | 0.114 | 0.070 | 0.103 | 0.087 |
| **2-89** | 34428 | 20969 | 8.8 | 0.085 | 0.077 | 0.068 | 0.101 | 0.081 | 0.088 | 0.154 |

*Table 21 - 488V @ 14.3kA - 12" Spacing - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm$^2$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **2-33** | 34367 | 16949 | 186.7 | 6.343 | 2.263 | 1.087 | 3.245 | 4.007 | 5.049 | 1.348 |
| **2-34** | 34368 | 13969 | 97.1 | 1.662 | 0.688 | 0.321 | 0.974 | 1.249 | 1.336 | 0.466 |
| **2-35** | 34369 | 20522 | 193.4 | 5.603 | 1.993 | 1.184 | 3.378 | 3.342 | 4.421 | 1.231 |
| **2-36** | 34370 | 20886 | 133.2 | 3.910 | 1.407 | 0.823 | 2.176 | 2.277 | 2.584 | 1.009 |
| **2-37** | 34371 | 19167 | 185.7 | 5.693 | 2.035 | 0.982 | 3.176 | 3.396 | 3.792 | 1.301 |
| **2-38** | 34372 | 18076 | 181.2 | 5.562 | 1.965 | 1.159 | 3.269 | 3.606 | 4.579 | 1.398 |
| **2-39** | 34373 | 17784 | 104.0 | 3.005 | 1.239 | 0.647 | 1.812 | 1.648 | 2.422 | 0.809 |
| **2-40** | 3474 | 12503 | 154.9 | 4.074 | 1.567 | 0.943 | 2.671 | 2.455 | 3.822 | 1.161 |
| **2-41** | 34375 | 20323 | 16.1 | 0.560 | 0.175 | 0.179 | 0.350 | 0.346 | 0.549 | 0.249 |
| **2-42** | 34376 | 18266 | 20.5 | 0.172 | 0.139 | 0.119 | 0.248 | 0.124 | 0.232 | 0.204 |

*Table 22 - 488V @ 14.3kA - 18" Spacing - Fault Current, Arc Duration, Incident Energy*

| Run # | Run Osc | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm²) UPPER 1 | UPPER 2 | MIDDLE 3 | MIDDLE 4 | MIDDLE 5 | LOWER 6 | LOWER 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| **2-43** | 34377 | 16016 | 21.2 | 0.062 | 0.052 | 0.050 | 0.068 | 0.039 | 0.082 | 0.053 |
| **2-44** | 34378 | 21323 | 174.2 | 1.411 | 0.999 | 0.497 | 1.166 | 1.356 | 0.936 | 0.646 |
| **2-45** | 34379 | 19361 | 115.4 | 1.143 | 0.543 | 0.277 | 0.678 | 0.724 | 0.784 | 0.358 |
| **2-46** | 34380 | 20799 | 192.9 | 1.737 | 0.990 | 0.590 | 1.481 | 1.205 | 1.367 | 0.794 |
| **2-47** | 34381 | 15235 | 21.7 | 0.042 | 0.046 | 0.046 | 0.042 | 0.038 | 0.056 | 0.073 |
| **2-48** | 34382 | 20980 | 83.8 | 0.914 | 0.494 | 0.268 | 0.639 | 0.675 | 0.545 | 0.257 |
| **2-49** | 34383 | 17396 | 14.3 | 0.044 | 0.033 | 0.031 | 0.036 | 0.024 | 0.044 | 0.044 |
| **2-50** | 34384 | 20995 | 192.5 | 1.107 | 0.777 | 0.443 | 0.969 | 1.009 | 0.866 | 0.652 |
| **2-51** | 34385 | 21200 | 25.8 | 0.155 | 0.083 | 0.094 | 0.134 | 0.097 | 0.141 | 0.115 |
| **2-52** | 34386 | 17276 | 45.8 | 0.293 | 0.157 | 0.142 | 0.240 | 0.187 | 0.356 | 0.194 |

*Table 23 - 460V @ 20.7kA - Unpainted - Fault Current, Arc Duration, Incident Energy*

| Run # | Run Osc | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm²) UPPER 1 | UPPER 2 | MIDDLE 3 | MIDDLE 4 | MIDDLE 5 | LOWER 6 | LOWER 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| **2-91** | 34432 | 27603 | 67.3 | 0.771 | 0.432 | 0.236 | 0.491 | 0.580 | 0.525 | 0.342 |
| **2-92** | 34434 | 26460 | 62.7 | 0.536 | 0.285 | 0.270 | 0.439 | 0.632 | 0.542 | 0.236 |
| **2-93** | 34435 | 23067 | 91.2 | 1.155 | 0.621 | 0.388 | 0.858 | 0.860 | 1.126 | 0.489 |
| **2-94** | 34436 | 27163 | 13.4 | 0.089 | 0.082 | 0.061 | 0.094 | 0.070 | 0.084 | 0.091 |
| **2-95** | 34437 | 17685 | 104.0 | 0.033 | 0.031 | 0.020 | 0.031 | 0.029 | 0.017 | 0.024 |
| **2-96** | 34438 | 22373 | 307.8 | 3.726 | 1.986 | 1.226 | 2.436 | 2.553 | 2.560 | 1.692 |
| **2-97** | 34439 | 27102 | 258.4 | 5.605 | 2.786 | 1.294 | 3.625 | 3.616 | 3.608 | 1.996 |
| **2-98** | 34440 | 27311 | 162.0* | 2.616 | 1.483 | 0.776 | 1.641 | 2.326 | 1.817 | 1.110 |
| **2-100** | 34441 | 25662 | 163.4* | 4.649 | 1.645 | 1.923 | 3.569 | 3.043 | 5.573 | 1.456 |

* Arc events terminated by test cell controller.
Arc durations = 150ms + not more than one cycle (16.7ms).

*Table 24 - 460V @ 20.7kA - Painted - Fault Current, Arc Duration, Incident Energy*

| Run | | Max Amps (RMS) | Arc Duration (ms) | Incident Energy (cal/cm$^2$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UPPER | | MIDDLE | | | LOWER | |
| # | Osc | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **2-101** | 34443 | 26030 | 164.5* | 4.954 | 2.377 | 2.120 | 4.235 | 3.777 | 5.066 | 1.809 |
| **2-102** | 34444 | 21848 | 156.4* | 4.954 | 2.377 | 2.120 | 4.235 | 3.777 | 5.066 | 1.809 |
| **2-103** | 34445 | 24064 | 164.3* | 4.954 | 2.377 | 2.120 | 4.235 | 3.777 | 5.066 | 1.809 |
| **2-104** | 34446 | 24596 | 162.1* | 3.694 | 1.677 | 1.502 | 2.712 | 2.298 | 2.679 | 1.431 |
| **2-105** | 34447 | 24659 | 162.0* | 3.234 | 1.707 | 1.133 | 2.441 | 2.333 | 2.536 | 1.185 |
| **2-106** | 34448 | 21997 | 163.2* | 2.908 | 1.611 | 1.272 | 2.214 | 2.435 | 2.309 | 1.105 |
| **2-107** | 34449 | 25301 | 165.1* | 2.943 | 1.654 | 1.361 | 2.238 | 2.409 | 2.371 | 1.289 |
| **2-109** | 34450 | 24578 | 162.0* | 3.546 | 1.599 | 1.254 | 2.276 | 2.523 | 2.477 | 1.069 |
| **2-110** | 34451 | 17638 | 163.0* | 2.532 | 1.540 | 1.419 | 1.995 | 2.298 | 2.510 | 1.207 |

* Arc events terminated by test cell controller.
Arc durations = 150ms + not more than one cycle (16.7ms).

*Table 25 - Blast Pressure at 18 Inches*

| Amps | Duration | $I^2t$ | MaxPSI | kPa | dbA |
|---|---|---|---|---|---|
| 17614 | 7.8 | 2.42E+09 | 1.7 | 11.9 | 175.5 |
| 18334 | 7.8 | 2.62E+09 | 2.6 | 18.2 | 179.2 |
| 17974 | 8.3 | 2.68E+09 | 1.2 | 8.5 | 172.6 |
| 13613 | 15.5 | 2.87E+09 | 1.9 | 12.9 | 176.2 |
| 19320 | 8 | 2.99E+09 | 2.9 | 20.3 | 180.1 |
| 19683 | 8.2 | 3.18E+09 | 3.7 | 25.5 | 182.1 |
| 14499 | 15.6 | 3.28E+09 | 2.6 | 18.0 | 179.1 |
| 15132 | 14.5 | 3.32E+09 | 1.0 | 7.1 | 171.1 |
| 18317 | 10 | 3.36E+09 | 2.7 | 18.7 | 179.4 |
| 18529 | 9.9 | 3.40E+09 | 4.0 | 27.3 | 182.7 |
| 14852 | 15.6 | 3.44E+09 | 2.0 | 13.8 | 176.8 |
| 12550 | 21.9 | 3.45E+09 | 1.6 | 10.9 | 174.8 |
| 18509 | 10.2 | 3.49E+09 | 2.6 | 17.8 | 179.0 |
| 15099 | 15.5 | 3.53E+09 | 3.8 | 25.9 | 182.2 |
| 17037 | 12.3 | 3.57E+09 | 1.5 | 10.4 | 174.3 |

*Table 25 Continued*

| Amps | Duration | $I^2t$ | MaxPSI | kPa | dbA |
|---|---|---|---|---|---|
| 10723 | 31.17 | 3.58E+09 | 2.9 | 19.9 | 180.0 |
| 18928 | 10.11 | 3.62E+09 | 5.8 | 39.7 | 185.9 |
| 16045 | 14.5 | 3.73E+09 | 2.7 | 18.6 | 179.4 |
| 18130 | 11.6 | 3.81E+09 | 2.7 | 18.8 | 179.5 |
| 20969 | 8.8 | 3.87E+09 | 3.4 | 23.2 | 181.3 |
| 18986 | 10.8 | 3.89E+09 | 4.7 | 32.1 | 184.1 |
| 17471 | 13.11 | 4.00E+09 | 3.5 | 23.8 | 181.5 |
| 18948 | 11.2 | 4.02E+09 | 5.9 | 40.9 | 186.2 |
| 21311 | 8.9 | 4.04E+09 | 3.5 | 24.0 | 181.6 |
| 13787 | 21.5 | 4.09E+09 | 2.0 | 13.6 | 176.6 |
| 21040 | 9.4 | 4.16E+09 | 3.1 | 21.6 | 180.7 |
| 17685 | 13.38 | 4.18E+09 | 10.4 | 71.6 | 191.1 |
| 14254 | 21.1 | 4.29E+09 | 1.9 | 13.4 | 176.5 |
| 17396 | 14.3 | 4.33E+09 | 3.4 | 23.7 | 181.5 |
| 19959 | 11.6 | 4.62E+09 | 3.7 | 25.2 | 182.0 |
| 20977 | 10.9 | 4.80E+09 | 3.4 | 23.5 | 181.4 |
| 18516 | 14.3 | 4.90E+09 | 3.4 | 23.4 | 181.4 |
| 15235 | 21.66 | 5.03E+09 | 3.4 | 23.1 | 181.3 |
| 18236 | 15.8 | 5.25E+09 | 2.4 | 16.6 | 178.4 |
| 16016 | 21.2 | 5.44E+09 | 4.5 | 31.2 | 183.9 |
| 22958 | 10.5 | 5.53E+09 | 3.1 | 21.7 | 180.7 |
| 18436 | 16.4 | 5.57E+09 | 3.2 | 22.3 | 181.0 |
| 17864 | 18.1 | 5.78E+09 | 2.8 | 19.5 | 179.8 |
| 16244 | 22 | 5.81E+09 | 4.9 | 33.7 | 184.5 |
| 21479 | 13.7 | 6.32E+09 | 6.1 | 42.0 | 186.4 |
| 21491 | 14.3 | 6.60E+09 | 3.0 | 20.9 | 180.4 |
| 20323 | 16.1 | 6.65E+09 | 5.0 | 34.6 | 184.8 |
| 18266 | 20.5 | 6.84E+09 | 4.7 | 32.3 | 184.2 |
| 14461 | 38.3 | 8.01E+09 | 2.7 | 18.9 | 179.5 |
| 22043 | 16.5 | 8.02E+09 | 7.4 | 51.2 | 188.2 |
| 23588 | 15.6 | 8.68E+09 | 4.0 | 27.5 | 182.8 |
| 23238 | 16.2 | 8.75E+09 | 3.5 | 24.3 | 181.7 |

*Table 25 Continued*

| Amps | Duration | $I^2t$ | MaxPSI | kPa | dbA |
|---|---|---|---|---|---|
| 21819 | 18.6 | 8.85E+09 | 3.7 | 25.8 | 182.2 |
| 23491 | 16.4 | 9.05E+09 | 4.1 | 28.1 | 183.0 |
| 24001 | 15.9 | 9.16E+09 | 5.2 | 35.6 | 185.0 |
| 23265 | 17.9 | 9.69E+09 | 4.6 | 31.5 | 184.0 |
| 18757 | 28.5 | 1.00E+10 | 4.6 | 31.8 | 184.0 |
| 13659 | 58.88 | 1.10E+10 | 10.2 | 70.4 | 190.9 |
| 21200 | 25.79 | 1.16E+10 | 12.7 | 87.9 | 192.9 |
| 21443 | 26.4 | 1.21E+10 | 5.8 | 40.2 | 186.1 |
| 23246 | 24.1 | 1.30E+10 | 4.1 | 28.3 | 183.0 |
| 17276 | 45.8 | 1.37E+10 | 12.4 | 85.7 | 192.6 |
| 10297 | 163.4 | 1.73E+10 | 55.1 | 379.6 | 205.6 |
| 13969 | 97.1 | 1.89E+10 | 18.9 | 130.2 | 196.3 |
| 20533 | 48.78 | 2.06E+10 | 10.2 | 70.5 | 190.9 |
| 11438 | 164.5 | 2.15E+10 | 55.0 | 379.3 | 205.6 |
| 11079 | 187.8 | 2.31E+10 | 89.3 | 615.8 | 209.8 |
| 13192 | 133 | 2.31E+10 | 58.9 | 405.8 | 206.1 |
| 12281 | 157.5 | 2.38E+10 | 63.9 | 440.5 | 206.9 |
| 12503 | 154.9 | 2.42E+10 | 72.0 | 496.5 | 207.9 |
| 12606 | 169.3 | 2.69E+10 | 89.3 | 615.8 | 209.8 |
| 12640 | 194 | 3.10E+10 | 50.8 | 350.6 | 204.9 |
| 13432 | 174.5 | 3.15E+10 | 49.3 | 339.9 | 204.6 |
| 17784 | 104 | 3.29E+10 | 70.6 | 486.7 | 207.7 |
| 23067 | 62.74 | 3.34E+10 | 28.6 | 197.4 | 199.9 |
| 10418 | 328.4 | 3.56E+10 | 89.3 | 615.8 | 209.8 |
| 19538 | 94.11 | 3.59E+10 | 13.9 | 95.8 | 193.6 |
| 20980 | 83.8 | 3.69E+10 | 40.4 | 278.2 | 202.9 |
| 22450 | 74.9 | 3.77E+10 | 30.6 | 210.8 | 200.5 |
| 19361 | 115.4 | 4.33E+10 | 40.1 | 276.7 | 202.8 |
| 26460 | 67.31 | 4.71E+10 | 52.1 | 359.5 | 205.1 |
| 17638 | 163 | 5.07E+10 | 191.1 | 1,317.3 | 216.4 |
| 22373 | 104 | 5.21E+10 | 45.0 | 310.0 | 203.8 |
| 16949 | 186.7 | 5.36E+10 | 75.8 | 522.8 | 208.3 |

*Table 25 Continued*

| Amps | Duration | $I^2t$ | MaxPSI | kPa | dbA |
|---|---|---|---|---|---|
| 20886 | 133.2 | 5.81E+10 | 53.2 | 366.8 | 205.3 |
| 18076 | 181.2 | 5.92E+10 | 62.3 | 429.3 | 206.6 |
| 27163 | 91.16 | 6.73E+10 | 53.7 | 370.1 | 205.3 |
| 19167 | 185.7 | 6.82E+10 | 75.8 | 522.8 | 208.3 |
| 20881 | 163.4 | 7.12E+10 | 160.6 | 1,107.6 | 214.9 |
| 21848 | 156.4 | 7.47E+10 | 221.8 | 1,529.5 | 217.7 |
| 15885 | 305.7 | 7.71E+10 | 100.7 | 694.0 | 210.8 |
| 16028 | 306.8 | 7.88E+10 | 138.5 | 955.2 | 213.6 |
| 21997 | 163.2 | 7.90E+10 | 175.9 | 1,212.5 | 215.7 |
| 21323 | 174.2 | 7.92E+10 | 89.3 | 615.8 | 209.8 |
| 20522 | 193.4 | 8.15E+10 | 75.8 | 522.8 | 208.3 |
| 20799 | 192.9 | 8.34E+10 | 89.3 | 615.8 | 209.8 |
| 20995 | 192.5 | 8.49E+10 | 75.2 | 518.7 | 208.3 |
| 23331 | 162.3 | 8.83E+10 | 188.9 | 1,302.7 | 216.3 |
| 22006 | 183 | 8.86E+10 | 70.1 | 483.0 | 207.7 |
| 24064 | 164.3 | 9.51E+10 | 168.9 | 1,164.3 | 215.3 |
| 24578 | 162 | 9.79E+10 | 159.3 | 1,098.2 | 214.8 |
| 24596 | 162.1 | 9.81E+10 | 142.6 | 983.1 | 213.8 |
| 24659 | 162 | 9.85E+10 | 154.4 | 1,064.6 | 214.5 |
| 20814 | 241.8 | 1.05E+11 | 89.3 | 615.8 | 209.8 |
| 25521 | 162 | 1.06E+11 | 210.5 | 1,451.5 | 217.2 |
| 25301 | 165.1 | 1.06E+11 | 223.3 | 1,539.7 | 217.7 |
| 25662 | 162 | 1.07E+11 | 218.9 | 1,509.0 | 217.6 |
| 26030 | 164.5 | 1.11E+11 | 217.2 | 1,497.7 | 217.5 |
| 19308 | 358.5 | 1.34E+11 | 150.8 | 1,039.9 | 214.3 |
| 21116 | 359.6 | 1.60E+11 | 146.2 | 1,007.8 | 214.0 |
| 27311 | 258.4 | 1.93E+11 | 111.7 | 769.8 | 211.7 |
| 27102 | 307.8 | 2.26E+11 | 223.3 | 1,539.7 | 217.7 |

*Table 26 - All Test Runs - Incident Heat Corrected to 18 Inches*

| Run | Max Amps (RMS) | Arc Dur. (ms) | Incident Energy (cal/cm$^2$) | | | | | | | Avg. | Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UPPER | | MIDDLE | | | LOWER | | | |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | |
| 240 Volts @ 10,000 Amps | | | | | | | | | | | |
| 1-1 | 10446 | 31.4 | 0.008 | 0.008 | 0.005 | 0.008 | 0.010 | 0.010 | 0.008 | 0.008 | 0.010 |
| 1-2 | 10153 | 29.2 | 0.006 | 0.006 | 0.006 | 0.012 | 0.010 | 0.011 | 0.022 | 0.010 | 0.022 |
| 1-3 | 11457 | 18.1 | 0.007 | 0.004 | 0.005 | 0.004 | 0.003 | 0.003 | 0.002 | 0.004 | 0.007 |
| 1-4 | 11547 | 26.1 | 0.004 | 0.004 | 0.003 | 0.005 | 0.004 | 0.003 | 0.004 | 0.004 | 0.005 |
| 1-5 | 11553 | 18.5 | 0.004 | 0.004 | 0.005 | 0.007 | 0.006 | 0.008 | 0.008 | 0.006 | 0.008 |
| 1-6 | 10015 | 30.7 | 0.006 | 0.009 | 0.004 | 0.008 | 0.005 | 0.007 | 0.007 | 0.007 | 0.009 |
| 1-7 | 10093 | 30.7 | 0.005 | 0.009 | 0.004 | 0.008 | 0.007 | 0.007 | 0.008 | 0.007 | 0.009 |
| 1-8 | 11047 | 28.2 | 0.009 | 0.009 | 0.007 | 0.013 | 0.005 | 0.009 | 0.007 | 0.008 | 0.013 |
| 1-9 | 10985 | 33.6 | 0.004 | 0.005 | 0.003 | 0.008 | 0.004 | 0.006 | 0.005 | 0.005 | 0.008 |
| 1-10 | 11355 | 27.9 | 0.007 | 0.009 | 0.005 | 0.012 | 0.007 | 0.007 | 0.008 | 0.008 | 0.012 |
| 1-11 | 13768 | 26.3 | 0.005 | 0.005 | 0.002 | 0.004 | 0.003 | 0.003 | 0.003 | 0.004 | 0.005 |
| 480 Volts @ 12,300 Amps | | | | | | | | | | | |
| 1-12 | 14141 | 22.7 | 0.024 | 0.018 | 0.014 | 0.023 | 0.013 | 0.018 | 0.020 | 0.018 | 0.024 |
| 1-13 | 14491 | 188.0 | 0.268 | 0.362 | 0.172 | 0.792 | 0.430 | 0.551 | 0.816 | 0.484 | 0.816 |
| 1-14 | 16568 | 176.6 | 0.271 | 0.356 | 0.230 | 0.789 | 0.628 | 0.628 | 0.970 | 0.553 | 0.970 |
| 1-15 | 15466 | 9.8 | 0.011 | 0.019 | 0.014 | 0.065 | 0.060 | 0.052 | 0.093 | 0.045 | 0.093 |
| 1-16 | 16036 | 14.1 | 0.040 | 0.025 | 0.030 | 0.049 | 0.030 | 0.047 | 0.039 | 0.037 | 0.049 |
| 1-17 | 14339 | 186.9 | 0.268 | 0.360 | 0.211 | 0.770 | 0.554 | 0.558 | 0.891 | 0.516 | 0.891 |
| 1-18 | 16226 | 185.3 | 0.216 | 0.350 | 0.213 | 0.653 | 0.599 | 0.573 | 0.882 | 0.498 | 0.882 |
| 1-19 | 16184 | 82.9 | 0.245 | 0.328 | 0.170 | 0.626 | 0.517 | 0.549 | 0.787 | 0.460 | 0.787 |
| 1-20 | 13059 | 47.0 | 0.096 | 0.072 | 0.051 | 0.168 | 0.124 | 0.152 | 0.168 | 0.119 | 0.168 |
| 1-21 | 16619 | 150.0 | 0.221 | 0.353 | 0.151 | 0.639 | 0.531 | 0.586 | 0.743 | 0.461 | 0.743 |
| 243 Volts @ 22,900 Amps | | | | | | | | | | | |
| 1-22 | 20573 | 6.1 | 0.023 | 0.026 | 0.014 | 0.030 | 0.022 | 0.022 | 0.026 | 0.023 | 0.030 |
| 1-23 | 25115 | 11.0 | 0.050 | 0.025 | 0.035 | 0.056 | 0.025 | 0.055 | 0.050 | 0.042 | 0.056 |
| 1-24 | 26031 | 6.8 | 0.036 | 0.029 | 0.018 | 0.051 | 0.021 | 0.032 | 0.033 | 0.031 | 0.051 |
| 1-25 | 20764 | 12.4 | 0.031 | 0.025 | 0.019 | 0.047 | 0.030 | 0.054 | 0.037 | 0.035 | 0.054 |

*Table 26 Continued*

| Run | Max Amps (RMS) | Arc Dur. (ms) | Incident Energy (cal/cm$^2$) | | | | | | | Avg. | Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UPPER | | MIDDLE | | | LOWER | | | |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | |
| 1-26 | 25844 | 17.8 | 0.055 | 0.027 | 0.025 | 0.056 | 0.040 | 0.053 | 0.048 | 0.043 | 0.056 |
| 1-27 | 26837 | 8.4 | 0.038 | 0.022 | 0.028 | 0.060 | 0.023 | 0.064 | 0.051 | 0.041 | 0.064 |
| 1-28 | 25156 | 12.1 | 0.045 | 0.027 | 0.029 | 0.049 | 0.025 | 0.043 | 0.041 | 0.037 | 0.049 |
| 1-29 | 24208 | 19.4 | 0.032 | 0.022 | 0.023 | 0.046 | 0.027 | 0.049 | 0.044 | 0.035 | 0.049 |
| 1-30 | 26965 | 10.4 | 0.033 | 0.034 | 0.028 | 0.057 | 0.026 | 0.070 | 0.044 | 0.042 | 0.070 |
| 1-31 | 26489 | 16.0 | 0.037 | 0.039 | 0.038 | 0.077 | 0.043 | 0.074 | 0.072 | 0.054 | 0.077 |
| 485 Volts @ 21,500 Amps | | | | | | | | | | | |
| 1-32 | 27227 | 184.8 | 0.403 | 0.469 | 0.392 | 0.899 | 0.622 | 1.401 | 0.968 | 0.736 | 1.401 |
| 1-33 | 24685 | 182.0 | 0.322 | 0.525 | 0.286 | 0.932 | 0.716 | 1.565 | 1.065 | 0.773 | 1.565 |
| 1-34 | 26882 | 176.0 | 0.407 | 0.556 | 0.355 | 1.010 | 0.863 | 1.705 | 1.284 | 0.883 | 1.705 |
| 1-35 | 25257 | 185.0 | 0.376 | 0.553 | 0.288 | 0.952 | 0.798 | 1.636 | 1.107 | 0.816 | 1.636 |
| 1-36 | 24063 | 163.9 | 0.331 | 0.512 | 0.283 | 0.846 | 0.839 | 1.097 | 1.074 | 0.712 | 1.097 |
| 1-37 | 25932 | 190.4 | 0.315 | 0.547 | 0.322 | 0.939 | 0.859 | 1.413 | 1.181 | 0.797 | 1.413 |
| 1-38 | 23200 | 188.7 | 0.347 | 0.495 | 0.296 | 0.908 | 0.884 | 1.239 | 1.343 | 0.787 | 1.343 |
| 1-39 | 26093 | 150.7 | 0.329 | 0.503 | 0.276 | 0.720 | 0.814 | 1.066 | 1.085 | 0.685 | 1.085 |
| 1-40 | 20608 | 170.4 | 0.344 | 0.499 | 0.262 | 0.923 | 0.810 | 1.089 | 1.274 | 0.743 | 1.274 |
| 1-41 | 21539 | 188.4 | 0.317 | 0.511 | 0.249 | 0.927 | 0.808 | 1.067 | 1.190 | 0.724 | 1.190 |
| 285 Volts @ 18,300 Amps | | | | | | | | | | | |
| 2-1 | 21491 | 14.3 | 0.066 | 0.035 | 0.031 | 0.107 | 0.053 | 0.072 | 0.064 | 0.061 | 0.107 |
| 2-2 | 23238 | 16.2 | 0.101 | 0.053 | 0.063 | 0.138 | 0.059 | 0.087 | 0.062 | 0.081 | 0.138 |
| 2-3 | 23246 | 24.1 | 0.065 | 0.048 | 0.036 | 0.102 | 0.039 | 0.080 | 0.051 | 0.060 | 0.102 |
| 2-4 | 24001 | 15.9 | 0.067 | 0.043 | 0.040 | 0.108 | 0.048 | 0.082 | 0.049 | 0.062 | 0.108 |
| 2-5 | 21479 | 13.7 | 0.051 | 0.031 | 0.030 | 0.072 | 0.034 | 0.049 | 0.046 | 0.045 | 0.072 |
| 2-6 | 23588 | 15.6 | 0.077 | 0.048 | 0.039 | 0.108 | 0.050 | 0.000 | 0.051 | 0.054 | 0.108 |
| 2-7 | 23491 | 16.4 | 0.065 | 0.040 | 0.045 | 0.110 | 0.040 | 0.000 | 0.057 | 0.051 | 0.110 |
| 2-8 | 22958 | 10.5 | 0.045 | 0.037 | 0.037 | 0.116 | 0.033 | 0.000 | 0.050 | 0.045 | 0.116 |
| 2-9 | omitted | | | | | | | | | | |
| 2-10 | 23265 | 17.9 | 0.052 | 0.035 | 0.036 | 0.108 | 0.040 | 0.062 | 0.062 | 0.056 | 0.108 |
| 2-11 | 21819 | 18.6 | 0.057 | 0.043 | 0.046 | 0.090 | 0.032 | 0.057 | 0.082 | 0.058 | 0.090 |

*Table 26 Continued*

| Run | Max Amps (RMS) | Arc Dur. (ms) | Incident Energy (cal/cm²) UPPER 1 | UPPER 2 | MIDDLE 3 | MIDDLE 4 | MIDDLE 5 | LOWER 6 | LOWER 7 | Avg. | Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 354 Volts @ 13,300 Amps | | | | | | | | | | | |
| 2-12 | 18509 | 10.2 | 0.029 | 0.030 | 0.018 | 0.052 | 0.020 | 0.029 | 0.029 | 0.030 | 0.052 |
| 2-13 | 17864 | 18.1 | 0.028 | 0.024 | 0.021 | 0.056 | 0.021 | 0.032 | 0.042 | 0.032 | 0.056 |
| 2-14 | 14254 | 21.1 | 0.033 | 0.025 | 0.014 | 0.052 | 0.019 | 0.031 | 0.027 | 0.029 | 0.052 |
| 2-15 | 12550 | 21.9 | 0.028 | 0.018 | 0.013 | 0.044 | 0.017 | 0.029 | 0.054 | 0.029 | 0.054 |
| 2-16 | 18236 | 15.8 | 0.040 | 0.028 | 0.020 | 0.056 | 0.021 | 0.037 | 0.040 | 0.034 | 0.056 |
| 2-17 | 15132 | 14.5 | 0.011 | 0.008 | 0.007 | 0.019 | 0.009 | 0.010 | 0.015 | 0.011 | 0.019 |
| 2-18 | 18317 | 10.0 | 0.037 | 0.022 | 0.019 | 0.052 | 0.023 | 0.032 | 0.028 | 0.030 | 0.052 |
| 2-19 | 17037 | 12.3 | 0.020 | 0.020 | 0.010 | 0.034 | 0.011 | 0.022 | 0.026 | 0.021 | 0.034 |
| 2-20 | 18130 | 11.6 | 0.044 | 0.025 | 0.027 | 0.060 | 0.025 | 0.029 | 0.043 | 0.036 | 0.060 |
| 2-21 | 18436 | 16.4 | 0.051 | 0.029 | 0.024 | 0.074 | 0.027 | 0.054 | 0.038 | 0.042 | 0.074 |
| 434 Volts @ 12,900 Amps | | | | | | | | | | | |
| 2-22 | 13787 | 21.5 | 0.032 | 0.020 | 0.018 | 0.043 | 0.021 | 0.033 | 0.025 | 0.027 | 0.043 |
| 2-23 | 18757 | 28.5 | 0.088 | 0.047 | 0.036 | 0.129 | 0.062 | 0.101 | 0.077 | 0.077 | 0.129 |
| 2-24 | 20533 | 48.8 | 0.360 | 0.113 | 0.078 | 0.312 | 0.215 | 0.279 | 0.120 | 0.211 | 0.360 |
| 2-25 | 22043 | 16.5 | 0.118 | 0.047 | 0.058 | 0.151 | 0.063 | 0.104 | 0.069 | 0.087 | 0.151 |
| 2-26 | 14461 | 38.3 | 0.033 | 0.034 | 0.019 | 0.054 | 0.020 | 0.038 | 0.055 | 0.036 | 0.055 |
| 2-27 | 19538 | 94.1 | 0.460 | 0.163 | 0.122 | 0.446 | 0.270 | 0.381 | 0.243 | 0.298 | 0.460 |
| 2-28 | 22006 | 183.0 | 1.610 | 0.501 | 0.295 | 1.108 | 0.868 | 0.882 | 0.368 | 0.805 | 1.610 |
| 2-29 | 22450 | 74.9 | 0.547 | 0.223 | 0.125 | 0.515 | 0.305 | 0.399 | 0.172 | 0.327 | 0.547 |
| 2-30 | 21443 | 26.4 | 0.103 | 0.062 | 0.053 | 0.135 | 0.059 | 0.093 | 0.053 | 0.080 | 0.135 |
| 2-31 | 18516 | 14.3 | 0.050 | 0.032 | 0.026 | 0.072 | 0.024 | 0.074 | 0.053 | 0.047 | 0.074 |
| 488 Volts @ 14,300 Amps | | | | | | | | | | | |
| 2-32 | 16244 | 22.0 | 0.056 | 0.039 | 0.030 | 0.109 | 0.035 | 0.079 | 0.059 | 0.058 | 0.109 |
| 2-33 | 16949 | 186.7 | 2.018 | 0.720 | 0.342 | 1.442 | 1.259 | 1.607 | 0.429 | 1.117 | 2.018 |
| 2-34 | 13969 | 97.1 | 0.529 | 0.219 | 0.101 | 0.433 | 0.392 | 0.425 | 0.148 | 0.321 | 0.529 |
| 2-35 | 20522 | 193.4 | 1.783 | 0.634 | 0.372 | 1.501 | 1.050 | 1.407 | 0.392 | 1.020 | 1.783 |
| 2-36 | 20886 | 133.2 | 1.244 | 0.448 | 0.259 | 0.967 | 0.715 | 0.822 | 0.321 | 0.682 | 1.244 |
| 2-37 | 19167 | 185.7 | 1.812 | 0.647 | 0.309 | 1.412 | 1.067 | 1.207 | 0.414 | 0.981 | 1.812 |

*Table 26 Continued*

| Run | Max Amps (RMS) | Arc Dur. (ms) | Incident Energy (cal/cm$^2$) | | | | | | | Avg. | Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UPPER | | MIDDLE | | | LOWER | | | |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | |
| 2-38 | 18076 | 181.2 | 1.770 | 0.625 | 0.364 | 1.453 | 1.133 | 1.457 | 0.445 | 1.035 | 1.770 |
| 2-39 | 17784 | 104.0 | 0.956 | 0.394 | 0.203 | 0.805 | 0.518 | 0.771 | 0.257 | 0.558 | 0.956 |
| 2-40 | 12503 | 154.9 | 1.297 | 0.499 | 0.296 | 1.187 | 0.771 | 1.216 | 0.370 | 0.805 | 1.297 |
| 2-41 | 20323 | 16.1 | 0.178 | 0.056 | 0.056 | 0.156 | 0.109 | 0.175 | 0.079 | 0.116 | 0.178 |
| 2-42 | 18266 | 20.5 | 0.055 | 0.044 | 0.037 | 0.110 | 0.039 | 0.074 | 0.065 | 0.061 | 0.110 |
| 2-43 | 16016 | 21.2 | 0.062 | 0.052 | 0.050 | 0.068 | 0.039 | 0.082 | 0.053 | 0.058 | 0.082 |
| 2-44 | 21323 | 174.2 | 1.411 | 0.999 | 0.497 | 1.166 | 1.356 | 0.936 | 0.646 | 1.002 | 1.411 |
| 2-45 | 19361 | 115.4 | 1.143 | 0.543 | 0.277 | 0.678 | 0.724 | 0.784 | 0.358 | 0.644 | 1.143 |
| 2-46 | 20799 | 192.9 | 1.737 | 0.990 | 0.590 | 1.481 | 1.205 | 1.367 | 0.794 | 1.166 | 1.737 |
| 2-47 | 15235 | 21.7 | 0.042 | 0.046 | 0.046 | 0.042 | 0.038 | 0.056 | 0.073 | 0.049 | 0.073 |
| 2-48 | 20980 | 83.8 | 0.914 | 0.494 | 0.268 | 0.639 | 0.675 | 0.545 | 0.257 | 0.542 | 0.914 |
| 2-49 | 17396 | 14.3 | 0.044 | 0.033 | 0.031 | 0.036 | 0.024 | 0.044 | 0.044 | 0.037 | 0.044 |
| 2-50 | 20995 | 192.5 | 1.107 | 0.777 | 0.443 | 0.969 | 1.009 | 0.866 | 0.652 | 0.832 | 1.107 |
| 2-51 | 21200 | 25.8 | 0.155 | 0.083 | 0.094 | 0.134 | 0.097 | 0.141 | 0.115 | 0.117 | 0.155 |
| 2-52 | 17276 | 45.8 | 0.293 | 0.157 | 0.142 | 0.240 | 0.187 | 0.356 | 0.194 | 0.224 | 0.356 |
| 503 Volts @ 10,500 Amps | | | | | | | | | | | |
| 2-53 | 13432 | 174.5 | 0.601 | 0.524 | 0.248 | 0.591 | 0.690 | 0.575 | 0.310 | 0.505 | 0.690 |
| 2-54 | 12606 | 169.3 | 0.769 | 0.586 | 0.311 | 0.701 | 0.605 | 0.617 | 0.512 | 0.586 | 0.769 |
| 2-55 | 12640 | 194.0 | 0.688 | 0.472 | 0.335 | 0.642 | 0.793 | 0.646 | 0.398 | 0.568 | 0.793 |
| 2-56 | 10723 | 31.2 | 0.037 | 0.027 | 0.026 | 0.029 | 0.022 | 0.044 | 0.029 | 0.030 | 0.044 |
| 2-57 | 10297 | 163.4 | 0.694 | 0.490 | 0.241 | 0.593 | 0.652 | 0.490 | 0.331 | 0.499 | 0.694 |
| 2-58 | 11079 | 187.8 | 0.873 | 0.624 | 0.445 | 0.796 | 0.628 | 0.741 | 0.481 | 0.655 | 0.873 |
| 2-59 | 13659 | 58.9 | 0.184 | 0.099 | 0.123 | 0.207 | 0.128 | 0.151 | 0.226 | 0.160 | 0.226 |
| 2-60 | 12281 | 157.5 | 0.792 | 0.473 | 0.204 | 0.538 | 0.719 | 0.584 | 0.310 | 0.517 | 0.792 |
| 2-61 | 11438 | 164.5 | 0.749 | 0.555 | 0.322 | 0.723 | 0.802 | 0.489 | 0.400 | 0.577 | 0.802 |
| 2-62 | 13192 | 133.0 | 0.648 | 0.380 | 0.262 | 0.603 | 0.422 | 0.684 | 0.332 | 0.476 | 0.684 |
| 604 Volts @ 14,600 Amps | | | | | | | | | | | |
| 2-63 | 20814 | 241.8 | 2.188 | 1.534 | 0.830 | 1.684 | 2.255 | 1.937 | 0.932 | 1.623 | 2.255 |
| 2-64 | 10418 | 328.4 | 3.467 | 2.484 | 1.030 | 2.763 | 3.434 | 2.722 | 1.672 | 2.510 | 3.467 |

*Table 26 Continued*

| Run | Max Amps (RMS) | Arc Dur. (ms) | Incident Energy (cal/cm²) UPPER 1 | UPPER 2 | MIDDLE 3 | MIDDLE 4 | MIDDLE 5 | LOWER 6 | LOWER 7 | Avg. | Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-65 | no data | | 0.688 | 3.910 | 2.333 | 1.140 | 2.623 | 3.161 | 2.453 | 1.710 | 2.476 |
| 2-66 | 16028 | 306.8 | 3.580 | 2.181 | 1.038 | 2.708 | 3.334 | 2.296 | 1.358 | 2.356 | 3.580 |
| 2-67 | 15885 | 305.7 | 4.261 | 2.526 | 1.043 | 2.545 | 3.891 | 2.721 | 1.605 | 2.656 | 4.261 |
| 2-68 | 21116 | 359.6 | 5.421 | 3.007 | 1.407 | 3.551 | 4.342 | 3.386 | 2.157 | 3.325 | 5.421 |
| 2-69 | 19308 | 358.5 | 6.465 | 2.858 | 1.196 | 3.578 | 5.113 | 3.337 | 2.000 | 3.507 | 6.465 |
| 434 Volts @ 10,900 Amps | | | | | | | | | | | |
| 2-70 | 14852 | 15.6 | 0.031 | 0.021 | 0.024 | 0.028 | 0.029 | 0.031 | 0.028 | 0.027 | 0.031 |
| 2-71 | 18928 | 10.1 | 0.159 | 0.091 | 0.066 | 0.111 | 0.282 | 0.127 | 0.078 | 0.131 | 0.282 |
| 2-72 | 18529 | 9.9 | 0.093 | 0.053 | 0.060 | 0.113 | 0.061 | 0.081 | 0.068 | 0.076 | 0.113 |
| 2-73 | 18986 | 10.8 | 0.151 | 0.054 | 0.057 | 0.081 | 0.075 | 0.111 | 0.068 | 0.085 | 0.151 |
| 2-74 | 13613 | 15.5 | 0.019 | 0.024 | 0.017 | 0.023 | 0.021 | 0.025 | 0.024 | 0.022 | 0.025 |
| 2-75 | 18948 | 11.2 | 0.142 | 0.062 | 0.063 | 0.108 | 0.114 | 0.137 | 0.081 | 0.101 | 0.142 |
| 2-76 | 14499 | 15.6 | 0.060 | 0.035 | 0.032 | 0.040 | 0.044 | 0.045 | 0.041 | 0.043 | 0.060 |
| 2-77 | 17471 | 13.1 | 0.055 | 0.040 | 0.049 | 0.060 | 0.055 | 0.059 | 0.056 | 0.053 | 0.060 |
| 2-78 | 11438 | 164.5 | 0.118 | 0.046 | 0.047 | 0.062 | 0.056 | 0.096 | 0.061 | 0.070 | 0.118 |
| 2-79 | 13192 | 133.0 | 0.028 | 0.024 | 0.031 | 0.032 | 0.028 | 0.039 | 0.052 | 0.034 | 0.052 |
| 260 Volts @ 9,800 Amps | | | | | | | | | | | |
| 2-80 | 17614 | 7.8 | 0.021 | 0.011 | 0.014 | 0.029 | 0.014 | 0.017 | 0.018 | 0.018 | 0.029 |
| 2-81 | 19959 | 11.6 | 0.045 | 0.024 | 0.028 | 0.070 | 0.032 | 0.042 | 0.030 | 0.039 | 0.070 |
| 2-82 | 19683 | 8.2 | 0.031 | 0.021 | 0.021 | 0.052 | 0.030 | 0.030 | 0.029 | 0.031 | 0.052 |
| 2-83 | 19320 | 8.0 | 0.045 | 0.026 | 0.018 | 0.056 | 0.026 | 0.030 | 0.040 | 0.034 | 0.056 |
| 2-84 | 20977 | 10.9 | 0.033 | 0.032 | 0.023 | 0.059 | 0.024 | 0.037 | 0.046 | 0.036 | 0.059 |
| 2-85 | 17974 | 8.3 | 0.023 | 0.012 | 0.007 | 0.026 | 0.010 | 0.032 | 0.015 | 0.018 | 0.032 |
| 2-86 | 21311 | 8.9 | 0.048 | 0.029 | 0.018 | 0.068 | 0.029 | 0.044 | 0.039 | 0.039 | 0.068 |
| 2-87 | 18334 | 7.8 | 0.019 | 0.020 | 0.013 | 0.033 | 0.018 | 0.020 | 0.020 | 0.021 | 0.033 |
| 2-88 | 21040 | 9.4 | 0.042 | 0.025 | 0.022 | 0.051 | 0.022 | 0.033 | 0.028 | 0.032 | 0.051 |
| 2-89 | 20969 | 8.8 | 0.027 | 0.024 | 0.021 | 0.045 | 0.025 | 0.028 | 0.049 | 0.031 | 0.049 |
| 2-90 | omitted | | | | | | | | | | |

*Table 26 Continued*

| Run | Max Amps (RMS) | Arc Dur. (ms) | Incident Energy (cal/cm²) UPPER 1 | UPPER 2 | MIDDLE 3 | MIDDLE 4 | MIDDLE 5 | LOWER 6 | LOWER 7 | Avg. | Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 460 Volts @ 20,700 Amps | | | | | | | | | | | |
| 2-91 | 26460 | 67.3 | 0.771 | 0.432 | 0.236 | 0.491 | 0.580 | 0.525 | 0.342 | 0.482 | 0.771 |
| 2-92 | 23067 | 62.7 | 0.536 | 0.285 | 0.270 | 0.439 | 0.632 | 0.542 | 0.236 | 0.420 | 0.632 |
| 2-93 | 27163 | 91.2 | 1.155 | 0.621 | 0.388 | 0.858 | 0.860 | 1.126 | 0.489 | 0.785 | 1.155 |
| 2-94 | 17685 | 13.4 | 0.089 | 0.082 | 0.061 | 0.094 | 0.070 | 0.084 | 0.091 | 0.081 | 0.094 |
| 2-95 | 22373 | 104.0 | 0.033 | 0.031 | 0.020 | 0.031 | 0.029 | 0.017 | 0.024 | 0.026 | 0.033 |
| 2-96 | 27102 | 307.8 | 3.726 | 1.986 | 1.226 | 2.436 | 2.553 | 2.560 | 1.692 | 2.311 | 3.726 |
| 2-97 | 27311 | 258.4 | 5.605 | 2.786 | 1.294 | 3.625 | 3.616 | 3.608 | 1.996 | 3.218 | 5.605 |
| 2-98 | 25662 | 162.0 | 2.616 | 1.483 | 0.776 | 1.641 | 2.326 | 1.817 | 1.110 | 1.681 | 2.616 |
| 2-99 | 20881 | 163.4 | 2.583 | 1.399 | 0.751 | 1.593 | 2.049 | 2.900 | 1.035 | 1.759 | 2.900 |
| 2-100 | 25521 | 162.0 | 4.649 | 1.645 | 1.923 | 3.569 | 3.043 | 5.573 | 1.456 | 3.123 | 5.573 |
| 2-101 | 26030 | 164.5 | 4.954 | 2.377 | 2.120 | 4.235 | 3.777 | 5.066 | 1.809 | 3.477 | 5.066 |
| 2-102 | 21848 | 156.4 | 4.954 | 2.377 | 2.120 | 4.235 | 3.777 | 5.066 | 1.809 | 3.477 | 5.066 |
| 2-103 | 24064 | 164.3 | 4.954 | 2.377 | 2.120 | 4.235 | 3.777 | 5.066 | 1.809 | 3.477 | 5.066 |
| 2-104 | 24596 | 162.1 | 3.694 | 1.677 | 1.502 | 2.712 | 2.298 | 2.679 | 1.431 | 2.285 | 3.694 |
| 2-105 | 24659 | 162.0 | 3.234 | 1.707 | 1.133 | 2.441 | 2.333 | 2.536 | 1.185 | 2.081 | 3.234 |
| 2-106 | 21997 | 163.2 | 2.908 | 1.611 | 1.272 | 2.214 | 2.435 | 2.309 | 1.105 | 1.979 | 2.908 |
| 2-107 | 25301 | 165.1 | 2.943 | 1.654 | 1.361 | 2.238 | 2.409 | 2.371 | 1.289 | 2.038 | 2.943 |
| 2-108 | 24578 | 162.0 | 3.546 | 1.599 | 1.254 | 2.276 | 2.523 | 2.477 | 1.069 | 2.106 | 3.546 |
| 2-109 | 17638 | 163.0 | 2.532 | 1.540 | 1.419 | 1.995 | 2.298 | 2.510 | 1.207 | 1.929 | 2.532 |
| 2-110 | 23331 | 162.3 | 2.855 | 1.814 | 1.268 | 2.098 | 2.329 | 2.088 | 1.225 | 1.954 | 2.855 |

# VITA

John Francis Wade is a practicing engineer with over thirty-five years of experience. He has been a Registered Professional Engineer since 1992 and is past Treasurer of the Alabama Society of Professional Engineers. Mr. Wade added Fire Protection certification in 2018.

During 13 years at United Controls Corp., a small software and systems integration firm, Mr. Wade was technical lead in creation of a new business unit serving public and municipal utilities SCADA instrumentation and telemetry needs. In this capacity, he was responsible for UL 508A/698A instrument control panel standards enforcement, especially related to equipment constructed for hazardous locations.

While supporting NASA at Marshall Space Flight Center for Teledyne-Brown Engineering, he was a member of the International Space Station Ground Operations team and later was ARES First Stage Operations liaison. During his 10-year tenure with Teledyne-Brown, he was twice proposal manager for successful bid efforts.

Working for BWX Technologies, both at the Clinch River and Nuclear Fuel Services (NFS) divisions, Mr. Wade has supported production operations engineering and project activities. As group lead for the Electrical and Instrumentation team at NFS he is responsible for workplace electrical safety including arc flash hazard analysis and procedures implementing NFPA 70E. In his Advisory engineer capacity, Mr. Wade provides technical oversight for junior engineers, designers, automation specialists, contract staff, and engineer interns. He has spear-headed such system innovations as cataloging plant-wide Electrical and Instrumentation equipment, modernizing electrical system documentation, and industrial human factors improvements.

Mr. Wade is the author or co-author of several industry papers on telemetry, controls, and operations; and author of the first editions of the NASA ISS Crew Procedure Authoring Tool training manual that is still in use.

Mr. Wade holds B.S. (In Cursu Honorum) and M.S. degrees in Electrical Engineering and is a Doctoral candidate in Electrical Engineering - Fire Protection at the University of Tennessee. He is an Eagle Scout, and a member of Alpha Lambda Delta, Phi Kappa Phi, Etta Kappa Nu, and Tau Beta Pi honor societies.  He is a recipient of the ARES 1-X Mission Manager's Flight Commendation, and NASA Letter of Commendation for International Partner Training.

Mr. Wade is an avid Amateur Radio operator, SCUBA diver, and plays classical guitar. He currently resides in east Tennessee with his wife Shawna.