University of Southern Queensland
Faculty of Health, Engineering and Sciences

Arc Flash Protection of a Low Voltage Motor Control Centre

A dissertation submitted by

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Abstract

This dissertation seeks to investigate the arc flash hazard incident energy levels throughout the section of the power network that includes the Low Voltage Motor Control Centre (MCC) P6512 at Cristal Pigment Australia's Kemerton Plant, in Western Australia. It involved researching common industry practice for arc flash hazard studies, and following the requirements set out in the NFPA 70E (2012) and IEEE 1584 (2002) standards.

An audit of all associated plant and equipment was carried out. The power network of the plant was modelled, and a short-circuit evaluation conducted. The network's protection was studied to establish whether it provided the necessary protection/coordination between devices. Finally, with the aid of arc flash analysis calculation software ('Power Tools for Windows'), the arc flash study was conducted.

The result of this research has shown that the most dangerous location within the power network is the wiring (and connections) between the low voltage terminals of the MCC 22kV/415VAC supply transformer and the main Air Circuit Breaker (ACB) of the MCC. This is due to the location and type of the upstream protective device in use (i.e. a 22kV fuse upstream of the HV termination of the transformer). When calculated, the clearing time of this fuse was found to be greater than 14 seconds, by which time life could be lost and irreparable damage would occur.

It is recommended that this 22kV fuse should be replaced with a circuit breaker and relay. Calculations showed this could potentially reduce the clearing time to less than 0.75 seconds (an arc flash hazard/risk category of 3). A further recommendation would be to also incorporate an optical arc flash detection system, which could reduce this clearing time even further (to an arc flash hazard/risk category of 1).

Disclaimer

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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______________________________ (Signature)

30th October 2014 __________(Date)

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1. Introduction

Arcing faults occur when electric current passes through vapour between two conducting materials. The resulting high arc temperatures can cause fatal burns, even when standing several metres from the arc. The electric arc also can shower droplets of molten metal in the surrounding area, causing a further hazard. The arcing fault current is smaller than a bolted short-circuit because the vapour acts as an impedance between the conducting materials. This effect is generally more significant at a low voltage (e.g. 415VAC) level than at the higher voltages, and may substantially increase the protective device operating times when compared to bolted faults. The concussive effect of the accompanying arc-blast presents an additional hazard.

1.1 Statement of Task

The goal of this dissertation is to gain an understanding of the requirements of Arc Flash Protection, to carry out a study on a Low Voltage Motor Control Centre (MCC), and to make recommendations for ensuring the protection levels and operating procedures are to an adequate standard for the protection of plant and personnel (when compared to the standard). For the purposes of this research, the MCC to be studied is located at Cristal Pigment Australia's Kemerton TiO_2 manufacturing plant.

1.2 Objectives

Key objectives of the research are as follows:

- Choose the most appropriate “potentially at risk” switchroom/MCC.
- Research relevant standards, codes, and legislation.
- Paper review of the description and physics of low voltage arc formation and quenching; and correlate and compare to standards, codes and legislative requirements.
- Carry out power and quality surveys to provide a basis for the determination of arc flash values, and hazard assessment for equipment, hazardous area/s and plant in general.
- Carry out a risk and criticality assessment of the equipment and related hazardous zone/s.
- Determine fault levels and arc flash significance.
- Review site switching procedures and user PPE requirements.
- Review whether it may be best to upgrade or replace equipment by carrying an out technical and safety cost benefit analysis between upgrading current equipment against the replacement with the latest equipment (MCCs) on the market.
- Report findings and make recommendations.

1.3 Abbreviations

The following abbreviations are used in this document:

Table 1-1: Abbreviations

Abbreviation	Term Description
AFB	Arc Flash Boundary
HV	High Voltage
IE	Incident Energy (Arc Flash)
MV	Medium Voltage
MCC	Motor Control Centre
LV	Low Voltage
SLD	Single Line Diagram
PPE	Personal Protective Equipment
TCC	Time-current Characteristic Curves
WD	Working distance

1.4 Definitions

Table 1-2: Definitions

Term	Definition
Arc Flash Hazard	A dangerous condition related to the potential release of energy due to an electric arc.
Bolted Fault Current	Initial symmetrical three phase rms short-circuit current (including motor contributions).
Arcing Fault Current	A fault current flowing through an electrical arc plasma.

Term	Definition
Arc Flash Boundary	An approach distance to live exposed conductors where the incident energy falls to 1.2 cal/cm^2, which corresponds to the onset of second degree burns. An alternative definition is: The distance from live conductors within which a person could receive a second degree burn or greater.
Arc Flash Incident Energy	The amount of energy normal to a surface at a specified distance from the arc source, usually the working distance.
Working Distance	The distance between the arc source and the workers chest or face.
Gap	The spacing between bus bars or conductors at the arc location.
Personal Protective Equipment	Protective clothing to be worn when the working distance is within the arc flash boundary.

2. Background

Incidents and accidents within industry often place a massive burden on a company's profitability. A death at work creates many issues (beside the obvious), including a low morale within the workforce, and a massive rise in insurance premiums, while also opening up a company for litigation. An Arc Flash Protection assessment is increasingly being recognised as a safety priority in Australian manufacturing, and also generally within the electrical industry. It forms one proactive way of assisting in the reduction of incidents and accidents, which can cause plant downtime and/or, in a worst case, employee injury or death.

2.1 Arc Flash

Since the advent of wide-spread electrification early last century, people have been aware of the dangers of electricity in the form of electric shock from coming into contact with "Live" electrical components. However, it is only recently that society is paying more emphasis on the damage and injury that may occur due to an electrical arc flash incident. In fact, the first time a correlation was made between that of electrical arc flash incidents and personal burn injuries was only in 1982, as presented by Ralph H. Lee (1982, p. 246) in his paper on "The Other Electrical Hazard: Electric Arc Blast Burns". Lee stated that "Electric arc burns make up a substantial portion of the injuries from electrical malfunctions". Up until this time, most people did not fully appreciate the hazardous nature of arc flash event.

As more study and literature has been carried out, it has now become incumbent, as electrical workers, to consider the potential hazard of arc flash, and avoiding it has become one of the main challenges to be confronted within the electrical industry. The emotional and financial cost of an arc flash event can be extensive, and thus arc flash should be considered in conjunction with any current, or future, power network design.

2.1.1 What is arc flash?

In his book "Arc Flash Hazard Analysis and Mitigation", Jay C. Das (2012, p. 2) explains that "Electrical arcing signifies the passage of current through what has previously been air". An arc is plasma current that occurs as the result of a difference in voltage between two points, where this voltage exceeds in value that of the insulating strength limit of the air (or gas) between those particular points (*ABB SACE* 2013). The arc is created in the vapour of conductive metal, creating a circuit, which electrically links the two termination points across the gap. Given the right conditions, this arc (plasma current) continues to carry the electrical current until either the protective device in the circuit operates, or the impedance (ionisation of the air) between the two points becomes too great to sustain the arc. Therefore, it should be noted that once started, an arc can be self-sustaining.

To fully appreciate the origin of an electric arc, it is worthwhile looking at what occurs when a circuit breaker is opened. As the circuit breaker's contacts part, the resistance at the contact point increases. This in turn generates heat. The heat assists the air between the contacts to ionise, allowing the current to be maintained (in the form of a plasma discharge). The arc is extinguished when the voltage level at the ends of the arc contain enough energy to counteract the amount of heat that is being dissipated, while also having the capability to maintain appropriate temperature. One way of extinguishing the arc earlier is by elongating and cooling the arc (*ABB SACE* 2013).

However, an arc is also generally caused as a consequence of a short-circuit between a live termination and an earth (or different phases). That is, the arc is initiated by a short between points which are at different voltage levels. In these examples, the short-circuit provides a low impedance, which produces a high fault current (depending on the voltage differential, and the circuit characteristics). This current can cause overheating in the bus bars and associated cabling, to a point where it can eventually melt conductors. The result is a condition that is similar to those previously described during the operation of a circuit breaker. An arc will subsequently be created, and will continue until either the circuit's protection operates (disconnecting supply), or the conditions required for stability exist.

The term "arc flash" is given to the event where an unpredicted arc is generated. This arc can have the potential to cause external burns and injuries to people, as well as the subsequent potential damage to surrounding infrastructure. The intense temperature that can be generated by an arc, can cause fatal burns to a person within a distance of 5 feet (1.52 m), and major burns up to 10 feet (3.05 m) (*Lee* 1982). The arc can produce temperatures and pressures that can vaporise metal and shower the immediate area around the arc with droplets of the molten material.

Figure 2-1 shows an example of an arc flash.

Figure 2-1: Arc Flash (*Jennings* 2014)

2.1.2 Common causes of arc flash

Arc flash can quite often be inadvertently caused as a result of a human error (i.e. by a worker working on or near the vicinity of live equipment). This can be due to a mistake, such as accidently dropping a non-insulated spanner (or other tool) across live bus bars, or by closing a live isolation switch onto an earthed cable.

However, arc flash can also occur when safe clearances are compromised. There are several other common reasons why arc flash occur.

In their reference manual “Practical Arc Flash Protection for Electrical Safety Engineers & Technicians”, IDC Technologies (2013) lists several common reasons for arc flash. Some of these include:

- Dust or other impurity build up on insulators may provide a path for a current. This can cause an arc discharge path across the surface and can quite often be the cause of fires.
- Corrosion can be the cause of impurities or oxidation of materials, which can cause increases in the resistance of the contacts of conductor terminations (e.g. corrosion of switch contacts).
- Contamination can occur within switching mechanisms, which can cause the air gap to be compromised, leading to arcing.
- Vapour condensation or water ingress can result in current tracking across insulators or between air gaps.
- Voltage spikes can cause a strike over between isolators, due to the gap distance not being sufficient.

- Poorly designed and maintained equipment, incorrect work practices and structural failure of insulating materials can also cause arcing.

2.1.3 Arc flash hazards

There are a number of hazards that are directly related to an arc flash event. These include:

- Electric shock
- Thermal burns
- Projectiles
- Blast and pressure waves
- Intense light
- Intense sound
- Fire
- Effects due to powerful magnetic fields and plasma
- Toxic gases and vapours

The extent to which these hazards are dangerous is dependent on a few different factors:

1. The amount of the arc current
2. The length of time that the arc exists
3. Other volatile and/or flammable materials that may be present in the immediate vicinity of the arc flash event

2.1.3.1 Arc current

The arc current is governed by the amount of impedance at the point at which the arc flash occurs. That is, the fault (arc) current is considerably less at the end of a distribution network than it is nearer to the source. This is due to the extent of the circuit's impedance at the fault's location. Therefore, a short-circuit fault at the end of circuit is much less dangerous than it would be at its supply.

It should be noted that although arc energy is related to the short-circuit bolted fault level at a given point, the arc fault current will be less in value due to the arc's own impedance.

2.1.3.2 Arc time

Another important factor in reducing the severity of the hazard, is the time it takes to clear the fault. Obviously, the faster the protective device operates, the greater the chance of less damage taking place. A circuit breaker that can clear a fault within 4 cycles reduces the damage potential by 60%, when compared to a circuit breaker that takes 10 cycles (*IDC Technologies* 2013).

It should be noted that although it has previously been stated (in 2.1.3.1 above) that the arc current value of a fault will be less due to the distance from its source (which is true), this situation may still have a significant impact on the damage that can occur. The reason for this is that the circuit's protective device is also likely to be a fair distance from the fault location. In this case, this lower fault current could cause a delay in the operation of the protective device, allowing the arc flash event to continue for longer than that of a fault closer to the protective device. Thus, there can be a significant increase in damage even though the arc current is lower.

2.1.3.3 Hazardous materials

Another important factor is the housekeeping of the immediate vicinity of a possible a possible arc flash event. This is especially important in locations such as switchrooms, where storage (or placement) of flammable and explosive materials could exasperate the damage caused by the arc flash event itself.

When designing a power network, or even when auditing a location as part of an arc flash study, it is worthwhile to also look at the surrounding area. Besides looking at the obvious (such as the storage of dangerous goods), it is worthwhile to consider what may happen if an event took place. This may include looking at the work that may be performed in, or at the equipment in operation, in the adjacent area.

2.1.4 Properties of an arc flash

When an arc is initiated by a fault, it is never static. Powerful electromagnetic fields are created due to the fault current, which causes the arc to shift away from the supply point. As previously stated, the arc causes a rapid heating of the surrounding air, which triggers the air to vehemently expand. This, in turn, can result in parts being propelled outward from the fault location, which can cause subsequent damage to adjacent workers and/or infrastructure.

To provide some perspective of the danger of an arc flash event, the following describes some of the effects that occur (*IDC Technologies* 2013):

- The temperature produced by the arc can be in the region of 20,000°C (35,000°F). This is as much as 4 times that expected on the surface of the sun.
- The pressure created by the intense heating effect of the arc can result in a blast of hot air, much like that experienced in an explosion. It can cause a rapid expansion in any surrounding uncontained gas, which may cause parts and other equipment to be forced outward at high speed, causing significant damage to the adjacent area.
- The temperature surrounding the arc can force metals to change states from a solid to a vapour, which subsequently causes them to increase in volume. For example, the expansion rate of copper from a solid to a vapour is as much as 67,000 times (*Das* 2012). Due to this pressure created during the arc flash, and the expansion of the vaporising metal, these vaporised metal droplets can be expelled in a vast expanse adjacent to the fault source.

- Further to the vapour spread of the copper residue that is stated above, if not contained this has the potential to cause other creepage infringements. This can include, but not be limited to, initiating arc flash events on other nearby infrastructure.

It should be noted that the temperature and pressures produced by an arc are dependent on the arc voltage, and on the current and duration of the arc. However, in the case of a low voltage fault, once an arc of a length of 75-100mm is stable, it can remain active for a prolonged time (*IDC Technologies* 2013).

Figure 2-2 illustrates he effects that can occur when an arc flash takes place.

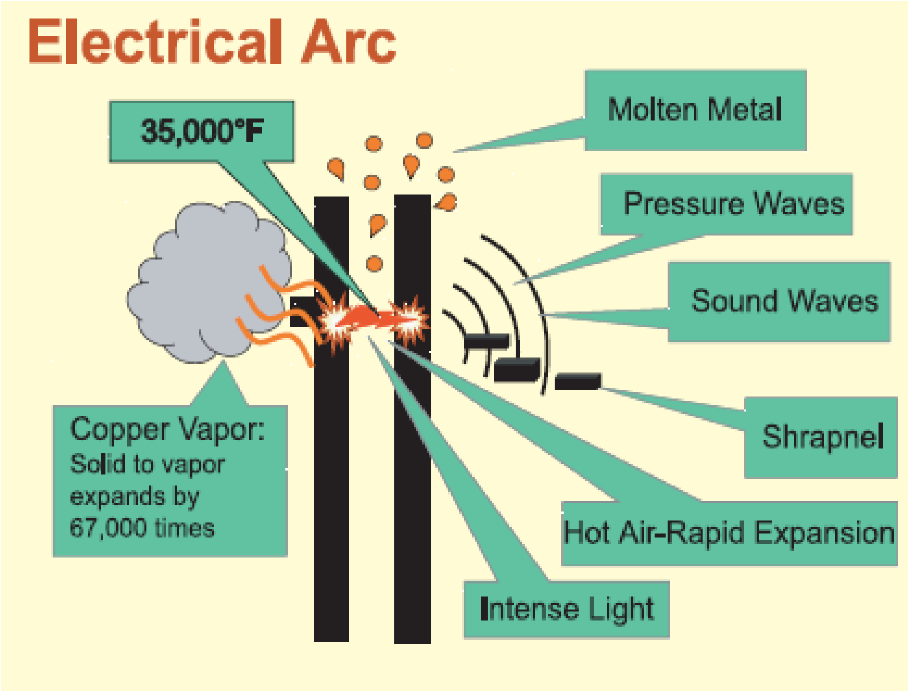


Figure 2-2: Electric Arc Model (*Cooper Bussmann* 2014, p. 117)

2.1.4.1 The effect of an arc fault within an enclosure

When the arc flash takes place within a panel or enclosure (such as in a Motor Control Centre or Switchboard), the effects described above are magnified. This can be best described in the following four phases (*Das* 2012):

- Phase 1 – Compression

  The air surrounding the arc overheats, which in turn heats up the rest of the air within the closed-in cabinet (due to convection and radiation). Rapidly the internal pressure increases.

- Phase 2 – Expansion

  Eventually the pressure becomes too great to be contained within the enclosure. A component (or part) will give way causing a rapid release of the superheated air, vapour and shrapnel. If there is not a possible release path for this pressure (for example, where "explosion vents/ducting are employed), potentially the cabinet could blow apart. After the initial explosion, the pressure will subside.

  Phase 3 – Emission

  The pressure of the superheated air will continue at a constant level while the arc still persists.

  Phase 4 – Thermal

  The temperature of the components within the enclosure will eventually near that of the arc itself. This will remain fairly constant until the arc is extinguished. Toxic fumes and vapours will continue to be released (as all metals and insulating materials may continuously melt and expand).

If work was being carried out on an enclosure, such as a Motor Control Centre (MCC) or switchboard, one would expect that either a panel door or side panel will be open. If a fault were then to occur in this enclosure, the effects described above will be concentrated toward the open side of the enclosure, thus inflicting maximum injury and damage. To assist in limiting this type of result, quite often new MCCs are now designed and fitted with ducting to divert any potential arc flash (pressure and temperature) away from these access points.

It should be noted that past statistical data shows that most arc flash incidents occur when an operator or worker is working on a piece of equipment with its doors open (see Table 2-1).

Table 2-1: Statistics of Arc Flash Incidents (*Das* 2012, p. 28)

Accident Occurrence	Percentage
When the operator or worker is working with equipment doors open	65
When the operator or worker happens to be in front of a closed door and the equipment is not arc resistant	10
When the operator or worker is not present at all and the equipment is not arc resistant	25

2.1.5 How location affects the hazard

The outcome of an arc flash incident can be greatly affected by its location. As previously stated, an incident involving an enclosure can be more severe when compared to an incident in an open area. In an open area the incident energy of the arc flash is allowed to disperse evenly in all directions, thus reducing the severity of the effect at any one point. This is vastly different to that resulting from a small enclosed space (such as a MCC or switchboard); where the resultant arc flash incident energy will be concentrated toward the open, or weakest, side. In this case, the personal exposure of a worker located in front of this opening can be perilous.

It should be noted that it is quite normal for a worker/operator to perform switching or fault finding on an MCC while it is still energised. In this scenario, the worker could possibly be within a ruler length of a potential arc flash. Therefore, it is vital that a risk assessment has been carried out on the work before starting. It is also important that any written procedures/instructions are followed, the correct tools (meters, leads etc.) for the work are used, and are used correctly, and that the necessary personal protective equipment (PPE) is worn, to reduce any possible exposure to an incident.

2.1.6 The personal consequence of an arc flash occurrence

The result of an individual's involvement in an arc flash incident can be severe, and any required treatment may impact the casualty for years. The casualty could require ongoing skin grafts, which could possibly require rehabilitation over many months. This may affect the casualty's quality of life, and also on their current or future employment (if they can return to work at all).

Some of the direct costs of an arc flash incident include:

- Casualty treatment costs that may exceed $1,000,000/case (*IDC Technologies* 2013)
- Litigation fees
- Production losses from downtime
- Equipment replacement cost and/or repair
- Fines
- Accident investigation cost
- Increase in insurance premiums

The total cost of an arc flash event can be between $8-10M US (*Weigel* 2014). However, the emotional and/or psychological impact can be much more.

2.2 Arc Flash Hazard Studies – Codes and Standards

The next step in reducing the potential impact of an arc flash incident is to perform a study (or analysis) of an installation (regardless of whether it is based on a current or a proposed future installation). This study involves methodically investigating the installation, and determining the significance of a hypothetical arc flash event occurring within that installation. To successfully guide oneself through the requirements of the study, some research has previously been carried out. The result is provided in the form of a document, known as a standard.

Codes and standards are produced to ensure products and installations comply with a certain level of functionality, and ultimately, safety. They are a massive collection of accumulated knowledge and expertise and are a guide to safe practice. They are the tools used to establish the norms in management procedures and they underpin a consumers expectations that goods and services will be safe, reliable and fit-for-purpose. In the electrical industry, this is usually provided by the Australian Standards, which are usually consistent with the IEC standards. These standards provide a way of ensuring that engineering results remain consistent. Unfortunately, at present, Australia does not yet have its own standard to cover the mitigation of the impact of arc flash event.

2.2.1 Australian industry and Arc flash standards

Australian industry is constantly striving for safer work places, to reduce their exposure to production downtime and loss time incidents and/or injuries. Therefore, it was only a matter of time before "arc flash" was investigated as a potential area in reducing a business' risk exposure. Currently, there are two standards that are commonly used in performing arc flash hazard analysis and studies; IEEE 1584 (IEEE Guide for performing Arc-Flash Hazard) and NFPA 70E (an offshoot of the USA's National Electrical Code – which is similar to Australia's "Wiring Rules" Standard: AS/NZS3000). Both of these standards have limitations, and are not entirely appropriate for the Australian work place, but in the absence of guidance from the IEC, they have been adopted (particularly within multinational companies) as Australia's defacto standards (*Willis* 2010).

However, as previously pointed out, Australia does not have a standard directly concerning the potential personal impact of an arc flash, but it does have a guideline that concerns the selection, use and maintenance of personal protective equipment for electrical hazards (Energy Networks Association (ENA) – NENS 09−2006). This guideline contains formulae for calculating the Heat Flux value (in cal/cm^2) of single phase and three phase faults, and a table for determining the minimum PPE that should be used. However, it does not consider the actual arcing current, and it assumes that all faults only have a fault duration of 0.1 seconds (*Energy Networks Association* 2006).

It should also be noted that the Australian Wiring Rules Standard AS/NZS3000: 2007 does consider and has provision for determining the fault duration of an arcing fault. This is primarily for the purpose of limiting the damage that can potentially occur to a switchboard, in the advent of potential internal arcing faults (Clause 2.5.5). However, the calculations involved are based on an assumption that the arcing current is normally between 30 and 60% of the prospective short-circuit current (*Standards Australia* 2007). This not only does not consider the actual arcing current, but also does not consider the personal impact of a fault.

In his presentation to the 2010 Electrical Arc Flash Forum, Peter Willis (2010) explains that with regards to arc flash hazard studies, the challenges that the Australian end-user face include:

- Grasping the meaning of “Arc Flash Hazard Study”. There are ambiguities in the standards, with no real guidance from the USA standards organisation on how to tackle these. Thus, there is scope for indecision, and therefore a possibility of non-conformity between different studies.

- Working with the foreign standards in the Australian workplace and working through their inconsistencies. This relies on the user taking the international standard and trying to apply it to their own situation. In doing so, the user will be required to make some of their own assumptions.
- Working without access to any recognised Australian or IEC Standard. Obviously, if guided by an Australian Standard, the user will feel confident that the work is within the guidelines set out solely for the Australian industry.
- Trying to limit the concerns with the problems associated within the IEEE 1584 and NFPA 70E.

It should be noted that in conjunction with the standards IEEE 1584 and NFPA 70E, a range of arc flash software tools are available. These programs enable simple design checks for arc flash, and are very useful in conjunction with any arc flash hazard study. However, these software packages still do not consider some of the problems that are encountered within the IEEE 1584 standard, with some basic engineering principles having been neglected. Peter Willis (2010) notes that these include:

- The relationship of switchgear segregation with arc propagation and the identification of protection clearing locations
- The risk assessment process to match various activities with the appropriate hazard controls
- The treatment of multiple sources, staged protection clearing and motor contribution
- The correct application of the hierarchy of controls
- The roles of Personal Protective Equipment (PPE)

2.2.2 The difference between the standards IEEE 1584 and NFPA 70E

As it has been pointed out, the standards are a guide on performing arc flash calculations and implementing appropriate safety requirements.

The NFPA 70E standard was primarily established for use by employees, employers and the US Occupational Safety and Health Administration (OSHA). Contained within this standard is a section which relates to the potential dangers of workers working on or near to energised equipment. This standard provides a method of calculating the incident energy at a point in a circuit through the use of "a theoretical value of power dissipated by arcing faults" (*IDC Technologies* 2013). This results in a generally conservative figure and is based on work carried out by Ralph Lee.

However, to calculate incident energy, the IEEE 1584 standard uses empirical equations, which have been derived from actual laboratory testing. This method results in a much more realistic value and helps to restrict the working limitations that would be put in place if the NFPA 70E result were to be used. However, one should be aware that the equations used are a result of laboratory testing, which may differ to the conditions one might be presented with in the field.

Unfortunately, both standards do not adequately address the hazards of arc flash. However, they do provide a model from which these hazards can then be addressed (e.g. PPE requirements etc.).

Table 2-2 describes the limitations of all Incident Energy and Arc Flash Boundary calculation methods as set out in Informative Annex D (Table D.1), in NFPA 70E.

Table 2-2: Limitation of calculation methods (*NFPA 70E* 2012, p. 63)

Section	Source	Limitations/Parameters
D.2, D.3, D.4	Ralph Lee Paper	Calculates arc flash boundary for an arc in open air; conservative over 600 V and becomes more conservative as voltage increases
D.5	Doughty/Neal Paper	Calculates incident energy for three-phase arc on systems rated 600 V and below; applies to short-circuit currents between 16 kA and 50 kA
D.6	Ralph Lee Paper	Calculates incident energy for three-phase arc in open air on systems rated above 600 V; becomes more conservative as voltage increases
D.7	IEEE Std. 1584	Calculates incident energy and arc flash boundary for: • 208 V to 15 kV; • Three-phase; • 50 Hz to 60 Hz; • 700 A to 106,000 A short-circuit current; and • 13 mm to 152 mm conductor gaps
D.8	ANSI/IEEE C2 NESC, Section 410 and Table 410.2	Calculates incident energy for open air phase-to-ground arcs 1 kV to 500 kV for live-line work.

2.3 Arc Flash Hazard Study deliverables

Once completed, an arc flash hazard study should provide an insight into the potential damage that may occur in the event of an incident. This should provide direction to what precautions should be taken to assist in mitigating the risk of exposing people to injury. Using this information, work procedures can be developed to ensure the safety of plant equipment and the personnel who work on them.

Some of the deliverables that should be expected from an arc flash hazard study should include:

- An accurate Single Line Diagram (SLD) of the sites electrical distribution
- A review of the sites protection system, and any updating as required
- A value for the fault level at the point within the network being studied
- An estimated value for the arcing current and the incident energy
- A figure for the flash protection boundary
- A determination of the hazard/risk category at the point studied
- A educated statement of the necessary Personal Protective Equipment (PPE) for certain tasks – based upon the calculated incident energy at a determined working distance

2.4 Cristal Pigment Australia, Kemerton

2.4.1 Company profile

Cristal is the second largest producer of Titanium Dioxide (TiO_2) in the world. Cristal operates eight TiO2 manufacturing plants across five continents, with locations in Ashtabula, Ohio; Baltimore, Maryland; Salvador, Bahia; Stallingborough, UK; Thann, France; Yanbu, Saudi Arabia; Bunbury, Australia; and a mine site in Paraiba, Brazil (*Cristal* 2014).

TiO_2 is a bright white powder, which is made from titanium ore and has the ability to pigment virtually any material. Its opacity, brightness and durability have made it a vital addition to paint formulas. Although this is its primary function, TiO_2 is also used is diverse products, such as printing inks, paper, ceramics, glass, leather, synthetic fibres and colour formulated art paints (*Cristal Pigments Australia* 2014).

Cristal has several sites in Western Australia. These include a Mineral Sands Mine in Wonnerup, a Heavy Mineral Separation Plant in Bunbury, a TiO_2 Manufacturing Plant in Kemerton Industrial Park, Wellesley, a TiO_2 Finishing and Packaging Plant in Australind, and a Warehouse in Henderson. The three latter sites comprise Cristal Pigments Australia. Of these, the two facilities at Kemerton and Australind form the Cristal Pigments “Bunbury Operations”, which are used to produce and package TiO_2 for Cristal.

The Kemerton Plant is located 24km north of Bunbury in the Kemerton Industrial Park. This plant is the proposed site for the arc flash hazard study that is to be conducted as part of this dissertation.

2.4.2 Arc flash protection study of a motor control centre

The Kemerton plant is a manufacturing plant, while the Australind plant is a packaging plant. The manufacturing plant is 25 years old, while the packaging plant is over 50 years. The motor control centres (MCCs) in both plants have had limited arc flash assessment carried out, and they are unlikely to provide the necessary arc flash protection. As such, there is an internal company drive to conduct a survey of the site's switchrooms (and operation methods), to assess their potential arc flash fault levels, and to make recommendations to reduce the risk of damage and injury to equipment and personnel.

As it is a very large commitment to perform an arc flash study on the plant as a whole, it was proposed that in this project the study would be confined to one switchroom (Electrical Distribution Centre - EDC). The chosen MCC is located in a switch room at the Kemerton facility. The switch room has the identifier of EDC K4, while the LV MCC's tag reference is P6512. This particular MCC was selected as its layout is not too complex, thus hopefully permitting the completion of this study to occur within the time frame that has been allowed.

Figure 2-3 shows the MCC that will be the subject of the Arc Flash Hazard Study in this dissertation.

Figure 2-3: MCC P6512 – Located in EDC K4

3. Methodologies

From the outset, it should be noted that for this particular study, it will be accepted that the arc flash calculations will be conducted in-line with the analysis method of the IEEE 1584 (IEEE Guide for performing Arc-Flash Hazard) Standard. This decision was formed by the perception of a more accurate result, while also considering the limitations of the look-up tables provided in the NFPA 70E (USA National Electrical Code) Standard. If used, the NFPA 70E would be based around a more generous value for fault current. This would likely make any study recommendation prohibitive, especially where work is carried out near energised equipment. That is, the result would likely mean that there would be more obstructions that would need to be in place to conduct one's work. In some cases, it would prevent work from being carried out at all. Therefore, a level of common sense has been taken in making the decision to use IEEE1584 Standard.

3.1 Modelling of the Power System

The first step in any arc flash hazard study is to produce a model of the power system. The power system model is important to aid in the calculation of the prospective fault levels at the different locations within the power network. This model also becomes a useful tool in the design, planning, maintenance and operations of the power system.

To accurately complete a meaningful Arc Flash Hazard study, the power system must first be modelled as accurately as possible. Reliable results can only be achieved if reliable, accurate data is first utilised in the power system modelling.

3.1.1 Data collection and system modelling

Data collection is one of the most important aspects of the arc flash study. It also forms one of the more time consuming elements of the study. However, if the data collected is not accurate, the study will not reflect the actual installation, which will subsequently affect the results of the following arc flash hazard analysis.

Much of the data required for an arc flash hazard study is also comparable to that required when performing a short-circuit and protection coordination study. These studies require having up-to-date information about the plant, and its electrical equipment, to assist in creating an accurate single line diagram (SLD) of the network.

It should be noted that the accuracy of this information is of the upmost importance, as arc flash energies may be worse at lower fault currents, especially as the clearing times for the current protective devices may be significantly long.

It is also important to look at the location of the equipment that is involved in the power network, to ensure their location does no increase any perceived hazard or risk. The layout of the equipment may affect access, and therefore may provide a barrier to personnel trying to flee an arc flash event. The adjacent area may also be deemed hazardous, which could cause further problems in the advent of an arc flash scenario.

3.1.1.1 Power system modelling data

The following items need to be addressed to successfully complete the Power System modelling:

i. The location of equipment within the power system need to be identified.
ii. All equipment data needs to be collected, including:
    - Voltage rating, size (in MVA), impedance, X/R ratio
    - Protective device features, including the type of device, the existing settings for relays, circuit breakers and trip units, the current rating, their time-current curve (TCC) characteristics, and their clearing time
    - Conductor and cable data is required to calculate its impedance. The cable route and support method needs to be verified as well as the cables length
    - Other data on subsidiary power system equipment, including the type of equipment, the grounding type, and the number of phases
    - The current power system connections, and consideration of any possible alternatives
iii. The supply authority (or network provider) is required to be contacted to request the fault MVA and power angle or *X/R* ratio at the point of supply (see application form in Appendix E).

For an example, Table 3-1 shows the data that would be required for protective devices.

Table 3-1: Protective device data (*IDC Technologies* 2013, p. 107)

Protective Device Description	**Data to gather**
Relay	Type, CT ratio, pickup setting, delay time and setting time
Fuse	Type, amp rating, voltage, peak up through current
Breaker	Type, fault clearing time, pickup setting, delay curve, delay setting

3.1.1.2 Arc flash study data

For the completion of the Arc Flash study itself, other information will also be required. This information may include:

i. The type of enclosure in which the equipment is installed
ii. The gap distance between any live conductors, or bus bars
iii. The approximate working distance for the equipment
iv. The location in which the equipment is placed (e.g. whether it is in or adjacent to a hazardous area)

It is important to analyse site plans and look into any known hazardous areas. Perform a hazardous area study adjacent to the location of the MCC. Anywhere where there is a potential for a worker or other equipment to be exposed to another known hazard, caused in part due to a hypothetical arc flash incident, should have a risk assessment performed.

3.1.2 Power System Single Line Diagram (SLD)

A SLD is a simplified representation of the three-phase power system. It is used for documenting and communicating information about the power system.

Once all the power system data has been collected, a SLD of the power network can be prepared. The single line diagram will show the power distribution arrangement of the network, with the relative placement of all the electrical equipment in the network.

The SLD will display all equipment belonging to the power network. These can include:

- Transformers
- Transmission lines
- Distribution circuit
- Electrical system grounding
- Current limiting devices
- Voltage correction or stabilization capacitors
- Switchgear
- Motor control centres (MCC's)
- Switchboards
- Protective devices
- Feeders or bus bars
- Motors down to 400V level

In the case of Cristal Pigments, SLDs for electrical networks have previously been created. These drawing will need to be sourced and reviewed against the current system, to ensure they are up-to-date.

3.2 Short-Circuit Analysis

3.2.1 Data required for short-circuit study

The next step is to perform a short-circuit study on the network. Once all the information has been collated, the equipment data is added to the SLD. Using this "combined" information, the designer should now be able to determine the bolted fault current level.

The data required to carry out a short-circuit analysis includes information on the equipment type, voltage, MVA/kVA, impedance, X/R Ratio, and phase/connection (*IDC Technologies* 2013).

When calculating for maximum and minimum short-circuit currents, the following is also required:

- The maximum and minimum Utility three-phase short-circuit contribution an R/X to a short-circuit at the PCC (Point of Common Coupling).
- The value of the voltage factor 'c' used to calculate the Utility contribution to be able to determine the short-circuit currents. Note that for this particular project, the Utility contribution voltage factor "c" was not used.
- The Initial symmetrical rms short-circuit current (I''_{k3}). The calculation of short-circuit currents should be in-line with that presented in AS3851 (1991) – *The calculation of short-circuit currents in three-phase a.c. systems*.
- Cable calculations (where necessary) to ensure compliance with AS3008 (2009). This involves verifying cable de-ratings, cable capacity and cable fault ratings.

- Consideration of all potential sources. These may include utilities, generators and motors greater than 37 kW (due to a motors ability to store energy in their magnetic circuit).

Note: Some equipment in the network may not require an arc flash hazard assessment, but their data will still likely be required to perform the short-circuit study.

3.2.2 Determine the possible modes of operation

The next step is to review the system to ensure an understanding of all its possible modes of operation. That is, it may be possible to change the configuration of the network by introducing new supplies. It is imperative that both the maximum and minimum short-circuit current levels are calculated for all operating modes. These figures are likely to be different when two different modes are utilised.

IEEE 1584 (2002, p. 7) lists the following example modes of operation:

- One or more utility feeders in service
- Utility interface substation secondary bus tie breaker open or closed
- Unit substation with one or two primary feeders
- Unit substation with two transformers with secondary tie opened or closed
- MCC with one or two feeders, one or both energised
- Generators running in parallel with the utility supply or in standby

3.2.3 Determine the bolted fault currents

Once all information is available, the initial bolted symmetrical rms short-circuit current (I''_{k3}) for each point of interest can be determined. This calculation should be in-line with that presented in AS3851 (1991). There is commercially available software to calculate the bolted fault current. In fact, for a simple radial system for up to 600V, suitable software is available with the purchase of the IEEE 1584. However, for a simple system, it can be just as easy to do the calculations by hand.

NOTE: Fault studies examine prospective system current levels under various fault conditions. These studies will typically look at a maximum and a minimum fault level for the protective equipment selection, to ensure that equipment protection settings will operate. The study will also typically look at the bolted three-phase and single-phase to ground fault levels as these are required for various protection devices.

3.3 Protection System Study

The function of a protection device involves three pivotal requirements. These include safeguarding the power network to maintain continuity of supply, minimising the damage that may happen if a fault occurs, and adequately protecting the safety of personnel. To provide this, the protective device needs to be able to display the following attributes (*IDC Technologies* 2013):

- Selectivity – To only isolate the equipment that is under fault.
- Stability – To operate in such a manner that its operation does not contribute to expanding the loss of supply to other "healthy" circuits.
- Sensitivity – To ensure that it picks up a fault in the minimum time possible (this involves the accuracy of the device's settings)

- Speed – To ensure is operation is quick enough to limit damage to the equipment and to personnel.
- Reliability – To ensure that it does operate when a fault occurs.
- Economical – To provide maximum protection at minimal cost.

With respect to the arc flash hazard analysis, the protection of the power network has a substantial impact on the potential incident energy at any given point of the installation. Incorrect protective devices, or devices with incorrectly settings, can not only cause issues with coordination, but also has a major influence on the disconnection (clearing) time of the circuit's supply. This can have a significant impact on the damage that may occur due to an arc flash incident.

However, it is also the responsibility of the electrical designer to attempt to design a network which has the best chance of maintaining supply. Therefore, coordination of protection within the network is vitally important. If a fault occurs on a piece of equipment, it should operate the nearest upstream protective device. This will minimise the area of the outage experienced, while ensuring damage is limited. Hence, the current protection system needs to be thoroughly investigated to ensure it is designed for the best possible result, while also being designed in accordance with the requirements of section 2.5 (Protection against overcurrent) of the Australian Standard AS/NZS 3000:2007 (Wiring Rules).

To carry out a phase overcurrent coordination study of the protection system, information is required on all of the phase overcurrent protective devices (e.g. fuses, circuit breakers etc.) within the network. The make, model and device settings are required so technical information can be sourced for their Time-Current Characteristic Curves (TCC). Armed with this information the study can commence.

The TCCs of all of the interconnected devices should be modelled on a common graph and common scale (at a common voltage base) to consider coordination. After considering the existing protection settings, proposals should be made where there are opportunities to optimise the protection settings of the network's protective devices (to provide improved circuit protection). Mal-grading of the devices with upstream protection should also be considered and if found, rectified where possible.

For grading purposes, only the largest outgoing protective device on the MCC needs to be considered. This is because this will be the item that has the greatest chance of mal-grading with the incoming air circuit breaker of the MCC. However, it is good practice to check the grading of all downstream devices that are fed from the MCC.

3.4 Arc Flash Analysis

The first actual step of the arc flash analysis study is to calculate the arcing short-circuit current. The value of the arcing short-circuit current is generally substantially different to that of the bolted short-circuit current due to the impedance at the fault location. That is, a bolted short-circuit infers that the short is the result of a solid connection, where as an arcing short is the result of plasma crossing a gap.

3.4.1 Non-linear nature of arcing short-circuit current

It should be noted that the arcing short-circuit current cannot be easily derived from the bolted short-circuit current. One would expect that it could easily be calculated as a percentage of the bolted current, but this is not the case, due to the variations that can occur in the value of the impedance of the fault.

Generally speaking, the higher the value of the bolted short-circuit current, the greater the percentage change when compared to that of the arcing short-circuit current value. Jim Phillips (2011) indicates the reason for this is due to the relationship between the arc and the bolted short-circuit impedances. As a high value of bolted short-circuit current indicates low circuit impedance, introducing the arc impedance has a greater effect on the overall impedance, and thus a greater effect on the reduction in current. However, if the circuit impedance is already high, the introduction of the arc impedance will not have as great of an influence on the fault current.

3.4.2 Why use a three phase model

The main reason the IEEE 1584 standard is based on a three-phase model is due to the fact that although many faults begin as a single-phase to ground fault, the resulting flash event usually propagates to three-phase fault. Thus, as a three-phase fault is generally likely, and that its calculation result is more conservative, the three-phase model has been subsequently adopted by the IEEE.

3.4.3 Determine the arcing currents

As previously discussed, the amount of damage that is the result of an arc flash can be decreased by limiting the arcing current and the time taken to operate a circuit's protective device. IEEE 1584 (2002) calculates the predicted three-phase arcing current using two different equations, one where the system voltage is < 1 kV and another where this voltage is > 1 kV.

Note: If the system voltage is > 15 kV, the Lee equations are required.

For system voltages < 1 kV, use:

$$logI_a = K + 0.662(logI_{bf}) + 0.0966V + 0.000526G + 0.5588V(logI_{bf}) - 0.00304G(logI_{bf})$$

where;

l_a is the arcing current (kA)

K is -0.153 for open configurations (not enclosed), or -0.097 for box configurations (enclosed)

I_{bf} is the bolted fault current for the three-phase fault (symmetrical RMS; kA)

V is the system voltage (kV)

G is the gap between the conductors (or bus bars; mm)

In instances where the system voltage is ≥ 1 kV (but less than 15 kV), the following formula is used instead:

$$logI_a = 0.00402 + 0.983logI_{bf}$$

Note: The open and box configurations are not required in this case.

Once the value for $logI_a$ has been found I_a is easily found by using the formula:

$$I_a = 10^{logI_a}$$

The IEEE 1584 (2002) indicates that two arcing current values should be determined. The first value is based on the figure for 100% of the arcing current. However, a second value of 85% of the arcing current is also required. These values are crucial when investigating the arc flash duration.

From the equation for system voltages below 1 kV, it can be noticed that the gap distance between conductors has a role in the magnitude of the arcing current. In the case of this project, this gap spacing is derived from that given in Table 2 in the IEEE 1584 (2002) standard.

Table 2 from the IEEE 1584 (2002) standard has been replicated below in Table 3-2:

Table 3-2: Classes of equipment and typical bus gaps as given in Table 2 of IEEE 1584 (2002, p. 9)

Classes of equipment	Typical bus gaps (mm)
15 kV switchgear	152
5 kV switchgear	104
Low-voltage switchgear	32
Low-voltage MCC's and panelboards	25
Cable	13
Other	Not required

3.4.4 Determine of arc flash duration

It has already been suggested that the time taken for a fault to be cleared can have a major impact on the damage caused by that fault. Needless to say, if there was a person is in the vicinity of the fault, this duration can be the difference between life and death. The longer the fault is permitted to exist the greater the total incident energy. The aim is to minimise this by setting the protection in order to keep this time to a minimum (without causing nuisance tripping).

To determine the clearing time of the protection device, the device's TCC is used. The two estimated arcing current values (85% and 100%) are superimposed onto the TCC as vertical lines. The arc flash duration is simply read from the TCC, where the "worst case" estimation for the arcing current (shown as a vertical line) crosses the clearing (upper) line of the protection time-current curve (i.e. the crossing with the greatest duration in time). It is important to note that fuse manufacturers don't always give the clearing time on their TCC. Quite often they only give their pre-melt time. In these cases, the total clearing time curve will need to be calculated and added to the TCC.

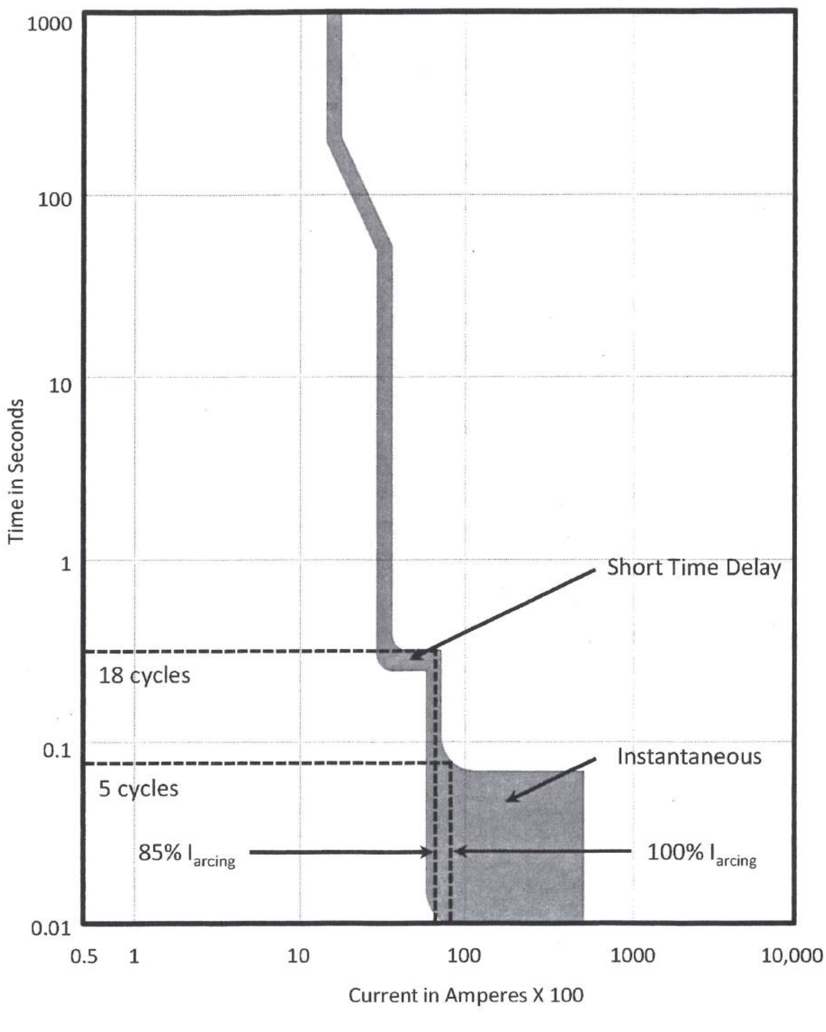


Figure 3-1: Working out arc duration (*Phillips* 2011, p. 126)

3.4.5 Limitation of damage of a switchboard to an arcing fault

Clause 2.5.5.3 in the Wiring Rules standard – AS3000 (2007) states that "*Protective devices shall be provided to limit, as far as practicable, the harmful effects of a switchboard internal arcing fault by automatic disconnection*". AS3000 (2007) suggests that the arcing fault should be considered as between 30 and 60% of the expected short-circuit current, and to limit the potential damage to the switchboard, a calculated clearing time (based on the 30% value of the prospective fault current) shall not be exceeded.

The calculated clearing time is given in AS3000 (2007) as:

$$\text{Clearing time } t = \frac{k_e \times I_r}{{I_f}^{1.5}}$$

where;

t is the clearing time (seconds)

I_f is 30% of the prospective fault current (A)

I_r is the current rating of the switchboard (A)

k_e is a constant of 250, based on acceptable volume damage

This clearing time needs to be determined and compared to the fault duration time found as part of the procedure in section 3.4.4, to ensure compliance.

3.5 Determining Incident Energy

To determine the appropriate level of personal protective equipment (PPE) required to perform a certain task (work) within the arc flash protection boundary, the incident energy of a potential fault first needs to be calculated. The incident energy value is the most critical element of the arc flash study procedure, as it defines what can be done and how.

3.5.1 Incident energy

The IEEE 1584 (2002) defines in clause 3.14 the incident energy as "*The amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event*". In general terms, the incident energy is the thermal energy that is experienced at a pre-determined distance (known as working distance). It is expressed in joules per square centimetre (J/cm^2), but as the NFPA 70E look-up tables use calories per square centimetre (cal/cm^2) to quantify the Hazard Risk Category, it is common to convert this to cal/cm^2 by dividing the J/cm^2 value by 4.148.

3.5.2 Select the working distances

To carry out the incident energy calculation, the working distance needs to be known. The IEEE 1584 (2002) defines in clause 3.17 that the working distance is "*The dimension between the possible arc point and the head and body of the worker positioned in place to perform the assigned task*".

The working distances from equipment at different voltage classes are given in the IEEE 1584 (2002) standard, in Table 3. This table has been replicated on the below in Table 3-3:

Table 3-3: Classes of equipment and typical working distances as given in Table 3 of IEEE 1584 (2002, p. 9)

Classes of equipment	**Typical working distance[a] (mm)**
15 kV switchgear	910
5 kV switchgear	910
Low-voltage switchgear	610
Low-voltage MCC's and panelboards	455
Cable	455
Other	To be determined in the field

[a] Typical working distance is the sum of the distance between the worker standing in front of the equipment, and from the front of the equipment to the potential arc source inside the equipment.

3.5.3 Determine the incident energy (≤ 15 kV)

Clause 5.3 in IEEE 1584 (2002) shows how the incident energy can be calculated. The first step is to calculate the log of the normalised incident energy at a normalised working distance of 610mm and arc time of 0.2 seconds using the following formula:

$$logE_n = K_1 + K_2 + 1.081(logI_a) + 0.0011G$$

where;

E_n is the normalised incident energy (J/cm^2)

l_a is the arcing current (kA)

G is the gap between the conductors (or bus bars; mm)

K_1 is -0.792 for open configurations (no enclosure), or -0.555 for box configurations (enclosed equipment)

K_2 is 0 for ungrounded and high-resistance grounded systems, or -0.113 for grounded systems

To find the normalised incident energy use the formula:

$$E_n = 10^{logE_n}$$

The incident energy calculation relies on a distance exponent that has been determined in IEEE 1584 (2002) in Table 3. This table has been replicated on the following page in Table 3-4.

Table 3-4: Factors for equipment and voltage classes as given in Table 4 of IEEE 1584 (2002, p. 12)

System voltage (kV)	**Equipment type**	**Typical gap between conductors (mm)**	**Distance x factor**
0.208 to 1	Open air	10 to 40	2.000
	Switchgear	32	1.473
	MCC and Panels	25	1.641
	Cable	13	2.000
> 1 to 5	Open air	102	2.000
	Switchgear	13 to 102	0.973
	Cable	13	2.000
> 5 to 15	Open air	13 to 153	2.000
	Switchgear	153	0.973
	Cable	13	2.000

Finally, to find the actual incident energy use the formula:

$$E = 4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D^x}\right)$$

where;

E is the incident energy (J/cm^2)

C_f is a calculation constant (1.0 for voltages above 1 kV, and 1.5 for voltages at or below 1 kV)

E_n is the normalised incident energy (J/cm^2)

t is the arcing time (seconds)

D is the distance from the possible arc point to the person (mm)

x is the distance exponent from Table 3-4

Note: As previously stated, to change the incident energy value above from J/cm^2 to cal/cm^2, divide the result by 4.184.

The calculations that are given in IEEE1584 are based on the use of protective devices that are not current limiting. Current limiting devices are designed to begin to interrupt the short-circuit current within the first quarter of a cycle, which will limit the peak value of the short-circuit current. This also impacts the value of the potential arc flash incident energy. Therefore, the IEEE1584 base their results on a more generous (conservative) figure, to ensure that the maximum possible incident energy is evaluated.

3.5.4 Determine the arc flash-protection boundary (≤ 15 kV)

The best form of protection from the potential damage and injury that can be caused by an arc flash incident is distance. The further the distance from the location of the arc flash, the less the value of the incident energy. In fact, the incident energy decreases exponentially as distance increases. This is the concept used by the NFPA 70E standard when it assesses the requirement of personal protective equipment within the arc flash-protection boundary.

The arc flash-protection boundary is defined in Article 100 (Definitions) of NFPA 70E (2012) as "*an approach limit at a distance from a prospective arc source within which a person could receive a second degree burn if an electrical arc flash were to occur*". NFPA goes on further to give this as an incident energy value of 5 J/cm^2 (1.2 cal/cm^2).

There are a few methods for calculating the arc flash-protection boundary. These include:

- 4 Foot Rule (*NFPA 70 E* 2012) – This is based on a boundary distance of 4 feet, where a calculation has not been performed. It is assumed the available bolted short-circuit fault current is greater than 50kA and that the protective device will clear within 2 cycles.
- Lee Equations – These two equations were published by Ralph Lee in 1982. One is determined using the transformer MVA, while the other uses the short-circuit MVA value. The difference between the two equations is due to the difference in value of the constant multiplier:

  Transformer MVA method

  $$D_C = (53 \times MVA_{tr} \times t)^{0.5}$$

  Short-circuit MVA method

  $$D_C = \left(2.65 \times MVA_{bf} \times t\right)^{0.5}$$

  NOTE: D_C is the distance (arc flash-protection boundary) from the arc source in feet.

- IEEE1584 – This equation provides the most detailed calculation method of the arc flash-protection boundary as it is based on the prospective incident energy previously calculated. Unlike the two methods previously discussed, this method considers the arcing short-circuit current and not the bolted short-circuit, hence providing a more accurate result.

After considering the three methods discussed above, this dissertation will employ the IEEE1584 procedure as it is the most comprehensive. In a similar fashion to those equations for determining the incident energy, it uses the normalised incident energy value. In doing so, it therefore allows for all of the arc flash considerations.

From Clause 5.5 in the IEEE1584 (2002), the arc flash-protection boundary formula is given as:

$$D_B = \left[4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{E_B}\right)\right]^{\frac{1}{x}}$$

where;

D_B is the distance of the boundary from the arcing point (mm)

C_f is a calculation constant (1.0 for voltages above 1 kV, and 1.5 for voltages at or below 1 kV)

E_n is the normalised incident energy (J/cm^2)

E_B is the incident energy at the boundary distance (J/cm^2)

t is the arcing time (seconds)

x is the distance exponent from Table 3-4

NOTE: As previously discussed, the incident energy at the arc flash-protection boundary should be 5.0 J/cm^2 (1.2 cal/cm^2), therefore E_B should be set at this value.

3.5.5 Determine the arc flash hazard/risk category and PPE selection

One of the final requirements of the arc flash study is to use the look-up tables in the NFPA 70E standard to determine the arc flash category level at the work location (that is, at the working distance from the potential arc flash), and subsequently decide on the Personal Protective Equipment (PPE) necessary. This requirement is generally the main reason why a study is completed in the first case.

The NFPA 70E standard uses two methods of deciding upon the arc flash level. One is based on the Analysis method, which is the calculation method performed using the formulae in the IEEE 1584, the other is based on the Study method, which uses the Hazard Risk Category Classification Table in the NFPA 70E. As this dissertation employs the Analysis method, this will be the one that is followed.

The following Arc Flash Hazard/Risk Category table shows the relationship between the incident energy value and the arc flash category:

Table 3-5: Arc Flash Hazard/Risk Category Table

Hazardous Risk Category	Incident Energy Value (cal/cm^2)
0	0.0 to 1.2
1	1.2 to 4.0
2	4.0 to 8.0
3	8.0 to 25.0
4	25.0 to 40.0
Not categorized - Dangerous	40.0 to 999.0

Once the hazard risk category has been decided, Table 130.7(C)(16) in NFPA 70E is used to determine the requirement for PPE. This table has been replicated below:

Table 3-6: Protective Clothing and Personal Protective Equipment (PPE), Table 130.7(C)(16), NFPA 70E (2002)

Hazardous Risk Category	Incident Energy Value (cal/cm^2)
0	**Protective Clothing, Nonmelting or Untreated Natural Fiber (i.e., untreated cotton, wool, rayon, or silk, or blends of these materials) with a Fabric Weight of at Least 4.5 oz/yd^2** Shirt (long sleeve) Pants (long) **Protective Equipment** Safety glasses or safety goggles (SR) Hearing protection (ear canal inserts) Heavy duty leather gloves (AN) (*See Note 1.*)

Hazardous Risk Category	Incident Energy Value (cal/cm^2)
1	**Arc-Rated Clothing, Minimum Arc Rating of 4 cal/cm^2** (*See Note 3.*) Arc-rated long-sleeve shirt and pants or arc-rated coverall Arc-rated face shield or arc flash suit hood Arc-rated jacket, parka, rainwear, or hard hat liner (AN) **Protective Equipment** Hard Hat Safety glasses or safety goggles (SR) Hearing protection (ear canal inserts) Heavy duty leather gloves (*See Note 1.*) Leather work shoes (AN)
2	**Arc-Rated Clothing, Minimum Arc Rating of 8 cal/cm^2** (*See Note 3.*) Arc-rated long-sleeve shirt and pants or arc-rated coverall Arc-rated flash suit hood (*See Note 2.*) or arc-rated face shield and arc-rated balaclava Arc-rated jacket, parka, rainwear, or hard hat liner (AN) **Protective Equipment** Hard Hat Safety glasses or safety goggles (SR) Hearing protection (ear canal inserts) Heavy duty leather gloves (*See Note 1.*) Leather work shoes (AN)

Hazardous Risk Category	Incident Energy Value (cal/cm^2)
3	**Arc-Rated Clothing Selected so That the System Arc Rating Meets the Required Minimum Arc Rating of 25 cal/cm^2** (*See Note 3.*) Arc-rated long-sleeve shirt (AR) Arc-rated pants (AR) Arc-rated coverall (AR) Arc-rated arc flash suit jacket (AR) Arc-rated arc flash suit pants (AR) Arc-rated flash suit hood Arc-rated gloves (*See Note 1.*) Arc-rated jacket, parka, rainwear, or hard hat liner (AN) **Protective Equipment** Hard Hat Safety glasses or safety goggles (SR) Hearing protection (ear canal inserts) Leather work shoes (AN)
4	**Arc-Rated Clothing Selected so That the System Arc Rating Meets the Required Minimum Arc Rating of 40 cal/cm^2** (*See Note 3.*) Arc-rated long-sleeve shirt (AR) Arc-rated pants (AR) Arc-rated coverall (AR) Arc-rated arc flash suit jacket (AR) Arc-rated arc flash suit pants (AR) Arc-rated flash suit hood Arc-rated gloves (*See Note 1.*) Arc-rated jacket, parka, rainwear, or hard hat liner (AN) **Protective Equipment** Hard Hat Safety glasses or safety goggles (SR) Hearing protection (ear canal inserts) Leather work shoes (AN)

AN: as needed (optional). AR: as required. SR: selection required.

Notes:

(1) *If rubber insulating gloves with leather protectors are required by Table (C)(9), additional leather or arc-rated gloves are not required. The combination of rubber insulating gloves with leather protectors satisfies the arc flash protection requirement.*

(2) *Face shields are to have wrap-around guarding to protect not only the face but also the forehead, ears, and neck, or, alternatively, an arc-rated arc flash suit hood is required to be worn.*

(3) *Arc rating is defined in Article 100 and can be either the arc thermal performance (ATPV) value or energy of break open threshold (E_{BT}). ATPV is defined in ASTM F 1959, Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing, as the incident energy on a material, or a multilayer system of materials, that results in a 50 percent probability that sufficient heat transfer through the tested specimen is predicted to cause the onset of a second-degree skin burn injury based on Stoll curve, in cal/cm^2. E_{BT} is defined in ASTM F 1959 as the incident energy on a material or material system that results in a 50 percent probability of breakopen. Arc rating is reported as either ATPV or EBT, whichever is the lower value.*

NOTE: Where the incident energy exceeds 40 cal/cm^2, no work should be carried out whilst the electrical equipment in energised. Although personal protective equipment manufacturers believe they can provide arc-rated PPE up to 100 cal/cm^2, the blast from an arc flash incident at these levels would be of a major concern.

3.5.6 Arc flash warning labels

Finally, the NFPA standard requires that electrical equipment, such as switchboards and motor control centres (that may require operation, maintenance, or servicing while energised), be labelled. The label should (at a minimum) contain the following information (*NFPA 70E*, 2002, Clause 130.5 (C)):

(1) At least one of the following:
   a. Available incident energy and corresponding working distance
   b. Minimum arc rating of clothing
   c. Required level of PPE
   d. Highest Hazard/Risk Category (HRC) for the equipment

(2) Nominal system voltage

(3) Arc flash boundary

3.6 Assumptions for the Arc Flash Hazard Study

(1) This study will only consider the risk of injury to a worker in the vicinity of the live equipment. The area's hazardous zoning will also be considered.

(2) NFPA 70E (2012) allows the determination of an arc flash hazard by the following methods :
   - Arc flash 'analysis' based on the IEEE 1584 formulae, referred to in Annex D.7 of NFPA 70E (2012).
   - NFPA 70E 'look-up' Table 130.7(C)(15)(a) Hazard/Risk Category, which is based on various criteria, such as the risk involved in the task performed, the type of switchgear, and the position of the doors (i.e. doors open or closed). This method is only valid for defined short-circuit current magnitudes and durations.

As the extent to which the 'look-up' table may be used is highly restrictive, it is therefore not used in this dissertation. Only the results of the arc-flash 'analysis' method are presented in this document.

The arc-flash 'analysis' method assumes there is no barrier between the bare conductors and the worker (i.e. the doors are considered open).

(3) The worker will be assumed to be stationary during the entire arc flash incident up to a time limit of 10 seconds at which they are able to move away to a safe distance.

(4) It will be assumed that the proposed protection settings provided in the power study report (and the time-current characteristic curves) will be implemented as part of the recommendations.

(5) Settings, where not known, will be applied at the maximum available to ensure the worst result will be provided and if acceptable, would ensure compliance.

(6) Some cable lengths have been estimated due to the difficulty in following the cables in-situ.

(7) IEEE 1584 only requires an allowance to be made for a motor fault contribution to the arc for motors greater than 37kW. However, this report considers all connected motor loads (regardless of the size of the motor) up to a level where the load on the system is in-line with the metered maximum demand current of the motor control centre. A load flow assessment will be conducted using software to confirm the 'normal' connected motor load.

(8) The study does not consider the damage to electrical installations (terminations, other electrical control and protection devices nearby, cables/buses) that could lead to supply interruptions that affect plant productivity and output profitability.

3.7 Power Tools for Windows (PTW) software

Due to the complexity of the calculations required at all levels of the power system model to perform the arc flash analysis, an arc flash calculation software was sourced and used in this dissertation. “Power Tools for Windows” is a software produced by SKM Systems Analysis Incorporated, in California, USA. This software is considered by industry as the most comprehensive arc flash analysis software on the market today, and takes into account all the requirements contained in both the NFPA 70E and IEEE 1584 standards.

The “Power Tools for Windows” PTW32 software (Version 7.0.3.6) was used to model the power network, and to calculate the subsequent short-circuit and arcing currents, incident energy, arc flash-protection boundary, and hazard risk category at various points within the network.

Validation of the “Power Tools for Windows” software was completed using a spreadsheet (produced in excel) that was configured with all the equations and requirements of IEEE 1584. However, to enable it to be kept simple, the motor contribution needed to be turned off in the “Power Tools for Windows” software (as this was too difficult to simulate in the spreadsheet). A screen shot of the spreadsheet can be found in Appendix J.

4. Research Results and Recommendations

4.1 Research Component

4.1.1 Power Tools for Windows (PTW) software Arc Flash settings and assumptions

The PTW arc flash studies were conducted to Standard NFPA 70E (2012), Annex D.7, using the IEEE 1584-2002 formulas for the Arc Flash Analysis Method.

The following user selectable study set-up parameters were used:

- The global maximum arcing duration was set to 20.0 sec. Even though the IEEE 1584 (2002) states that "*It is likely that a person exposed to an arc flash will move away quickly if it is physically possible and two seconds is a reasonable maximum time for calculations*"; for the purposes of indicating the actual disconnection time of a protection device, this setting was set higher.
- For voltages below 1000V, 100% and 85% of arcing current were used to calculate the incident energy. The highest incident energy of these two is reported by PTW. It should be noted that a reduction in arcing current may result in a longer trip time resulting in a higher incident energy.

- Asynchronous motors contribute the equivalent of locked rotor current at rated voltage for 2.5 cycles (0.05 seconds). Motor protection devices do not trip during the arc-flash analysis period. PTW was set at 3 cycles (0.06 seconds) for the purposes of this dissertation.
- As this report only focuses on one motor control centre, a lumped load has been allowed for in the PTW model to reflect the remaining load on other motor control centres and switchboards onsite. This load was based on the load flow of the metered maximum demand current that was found at each individual motor control centre.
- The “Cleared Fault Threshold” setting was set at 80%. This means that after 80% of the initial total arcing current has been cleared; the arc is extinguished, because the remaining 20% of initial arcing current is not considered capable of sustaining the arc.
- In accordance with IEEE 1584 (2002), earth fault relay trip times were not considered. Although many arcing faults are initiated by single phase to earth faults, the fault can quickly escalate to three phase faults with three times the incident energy.
- The PTW set up parameters included the specific values of ‘gap’ and ‘working distance’ for Equipment Type, according to Tables 3 and 4 of IEEE 1584. That is, the ‘arc gap’ for the 415VAC MCC was set to 32 mm, and for the 415VAC distribution boards and control panels it was set to 25 mm. NOTE: The IEEE 1584 tables were reproduced previously in Chapter 3 (Tables 3-3 and 3-4).

4.1.2 Data collection

An integral part of the arc flash study is the collection of all necessary data. Information was gathered from various sources, including from drawings, protection settings spreadsheets, cable schedules, and from site visits.

Appendix B shows the high level in-house Single Line Diagrams (SLDs). It should be noted that other SLDs were also used, but have not been included. However, the information from these diagrams were considered within the PTW SLD model.

Appendix D contains various detail for the on-site electrical equipment, which is required to build the PTW system model. This includes:

- Information on the various cables (length, size type)
- Data for the main protection devices (fuse sizing and type, and the motor control centre incomer air circuit breaker size and settings)
- The 22kV to 415V AC transformer P6507 (supply transformer to the P6512 MCC) nameplate and tap setting information

Appendix E comprises the Utility (Western Power) application for the maximum and minimum Utility three-phase short-circuit contribution an R/X to a short-circuit at the PCC (Point of Common Coupling). It also displays the spreadsheet that was sent with the application. It should be noted however, that the Utility Company was not forthcoming with the necessary information, and for the purposes of completing this dissertation, the information collected during a load study in 2013 was used.

NOTE: It is assumed that no significant changes to the Utility contribution has occurred in the last 12 months.

Appendix F contains all of the protective device time-current characteristic curves (from manufacturers' datasheets) for the electrical equipment that is supplied from the P6512 motor control centre. These curves were used to create the protective device models in PTW.

4.1.3 Presentation of arc flash analysis results

This dissertation presents the arc flash analysis results in PTW single line diagrams and spreadsheet formats.

4.1.3.1 PTW Single Line Diagrams

PTW single line diagrams are included in Appendix G and show the following results:

- Arc flash analysis results
- Protection device type and settings

Figure 4-1 is an example of the power network from the Utility PCC to the 415VAC Motor Control Centre P6512 showing:

- The arc-flash analysis results adjacent to buses; and
- The type and settings adjacent to protection devices

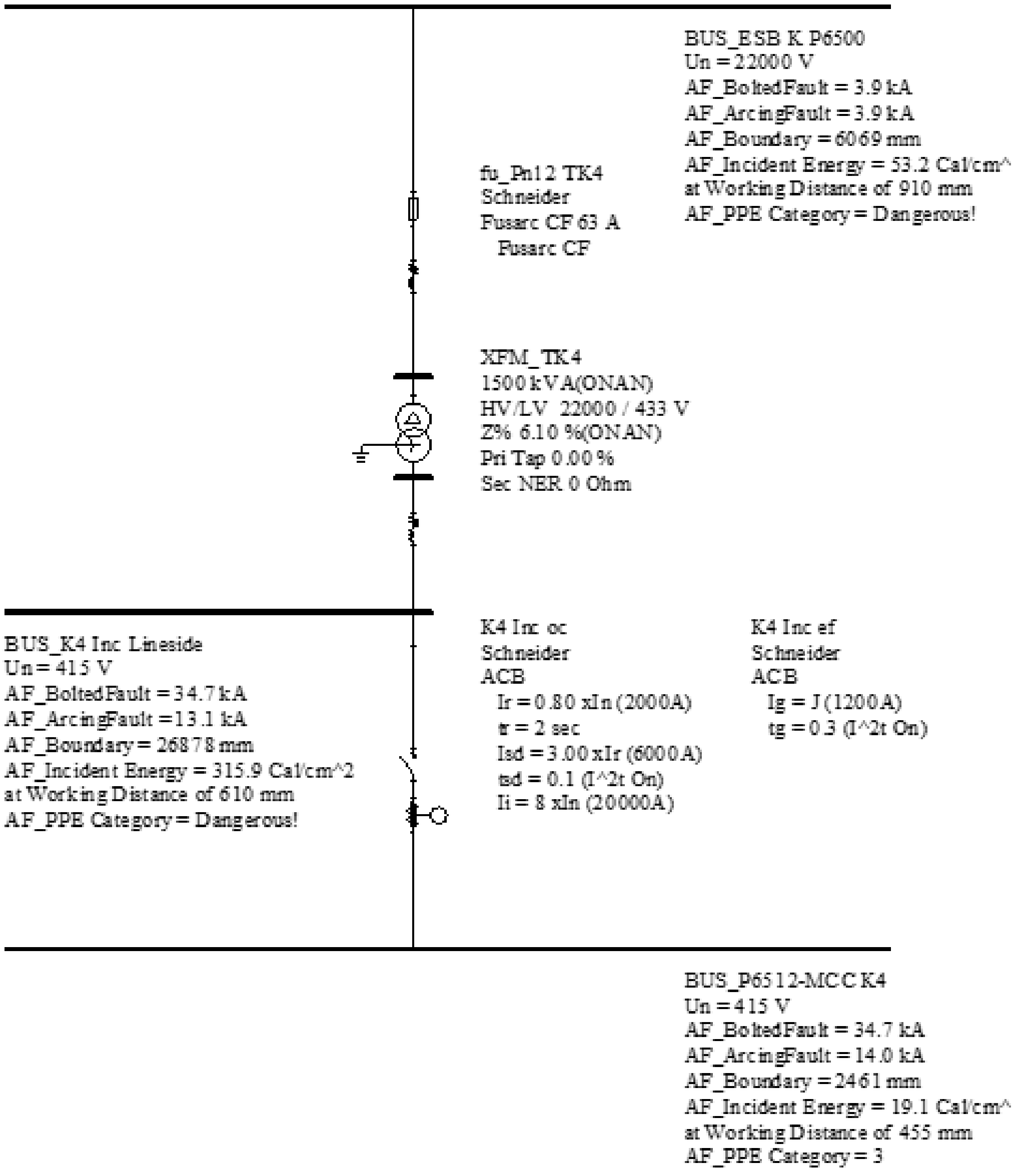


Figure 4-1: PTW Single Line Diagram and Arc Flash Analysis results for the existing power network (up to MCC P6512)

Figure 4-1 also illustrates the higher incident energy of 315.9 cal/cm^2 at the incomer tier (*BUS_K4 Inc Lineside*) compared to the lower incident energy of 19.1 cal/cm^2 for the remainder of the MCC (*BUS_P6512-MCC K4*).

The reason for this difference is that a short circuit in the incomer tier relies on the upstream 22kV 63A fuse (*fu_Pnl 2 TK4*) for the fault clearance. The remaining tiers of the MCC have the benefit of faster clearance of short-circuits effected by the MCC Incomer Air Circuit Breaker (ACB - *K4 inc oc*).

Specifically, the clearance of short-circuit currents is as follows:

- Faults in the Incomer tier are cleared by the upstream fuse, *fu_Pnl 2 TK4*
- Faults elsewhere in the switchboard are cleared by the incomer Air Circuit Breaker (ACB), *K4 inc oc*

Crucial to this concept is the premise that an arcing fault initially on the load side terminals of the Incomer ACB could propagate to the line side terminals of the Incomer ACB.

In Figure 4-1, the PTW bus, *BUS_K4 Inc Lineside*, represents the line side terminals of the MCC P6512 Incomer ACB. PTW bus, *BUS_P6512-MCC K4*, represents the load side terminals of the MCC P6512 Incomer ACB. Furthermore, this PTW bus represents the entire main busbar of the P6512 motor control centre.

The concept described above for the Incomer tier also applies to the remainder of the switchboard. Thus, an arcing fault initially on the load side terminals of any one of the switchboard's outgoing circuit breakers could propagate to the line side terminals of that breaker. This explains the absence of individual outgoing protective devices from the arc flash hazard analysis.

For the arc flash hazard analysis, the following fault clearance scenarios apply:

- An arcing fault in the MCC P6512 Incomer tier is cleared by the upstream 22kV 63A Fuse at 22kV switchboard P6500
- An arcing fault on the MCC P6512 main busbar is cleared in a shorter time by the MCC P6512 Incomer ACB,
- An arcing fault on any of the MCC P6512 tiers, other than the incomer tier, is also cleared by the MCC P6512 Incomer ACB.

This results in there being two incident energy levels associated with any motor control centre/switchboard:

- A higher incident energy for an arcing fault on the Incomer tier/circuit
- A lower incident energy for an arcing fault for all other tiers/circuits

4.1.3.2 Arc Flash Analysis result spreadsheet

All PTW Arc Flash Analysis result spreadsheets are located in Appendix G for all main bus locations in the MCC P6512 power network. The results shown in the example above are shown below, generated in spreadsheet form.

See Table 4-1 below for these results displayed in a spreadsheet format.

Table 4-1: Arc Flash Analysis results for the existing power network (up to MCC P6512)

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_ESB K P6500	Pnl 7 Sub K Inc oc	22.00	3.94	3.94	2.50	2.50	1.451	0.080	Yes	SWG	152	6069	910	53	Dangerous! (*N11)
BUS_K4 Inc Lineside	fu_Pnl 2 TK4	0.415	34.71	13.08	28.17	10.61	14.77	0.000	Yes	SWG	32	26878	610	316	Dangerous! (*N3)
BUS_P6512-MCC K4	K4 Inc oc	0.415	34.71	13.98	27.00	10.88	0.507	0.000	Yes	PNL	25	2461	455	19	Category 3 (*N3)

For a description of the terms used in the previous Table 4-1, see the legend associated below.

Legend:

Protective Device Name	Location of arcing fault
Bus kV	Bus nominal voltage
Bus Bolted Fault (kA)	3 phase initial symmetrical bolted rms
Bus Arcing Fault (kA	3 phase arcing fault current
Prot Dev Bolted Fault (kA)	3 phase bolted fault current through protective device
Prot Dev Arcing Fault (kA)	3 phase arcing fault current through protective device
Trip. Delay Time (sec)	Protective device operate time
Breaker Opening Time/Tol (sec)	Time from breaker receipt of trip signal to breaker arc extinguish
Ground	Considered earthed when ratio of 1P to Earth / 3P => 5%
Equip Type	Type of switchgear, panel, air, or cable
Gap (mm)	Spacing between bare bus bars or conductors at the arc location

Arc Flash Boundary (mm)	An approach distance to live exposed conductors where the incident energy falls to 1.2 cal/cm^2 which corresponds to the onset of a second degree burn
Working Distance (mm)	The distance between the arc source and the worker's chest or face
Incident Energy (cal/cm^2)	The amount of energy normal to a surface at a specific distance from the arc source, usually the working distance
PPE Level	Protective clothing to be worn when the Working Distance is within the Arc Flash Boundary

Note: The code in PPE Level Column indicates:

- (*N3) – Arcing Current Low Tolerances used (i.e. the 85% arcing current level has been used)
- (*N11) - Out of IEEE 1584 range, Lee equation used (i.e. the nominal voltage is greater than 15kV)

4.1.4 Protection device phase overcurrent grading

A phase overcurrent coordination study was completed prior to finalising the arc flash study. This is primarily due to the dependence of the arc flash analysis on the phase overcurrent protection characteristics.

The time-current characteristic curves for all switchboards form Appendix H.

Phase overcurrent protection settings were checked to achieve the best grading possible while providing fast fault clearing times to limit the arc flash hazard. The MCC incomer phase overcurrent protection settings were checked to grade with the largest outgoing protection device on the MCC. That is, the largest drive on MCC P6512 (G601A) was checked from the supply point at the Utility PCC, where the other equipment had its grading only checked from MCC P6512 onwards. The time-current characteristic curves used for the grading of this drive (G601A) are shown in Figure 4-2 below.

The phase overcurrent settings were all found to be sufficient and no mal-grading was found. This is important to check as phase overcurrent mal-grading can result in a larger outage than would have occurred if grading had been achieved.

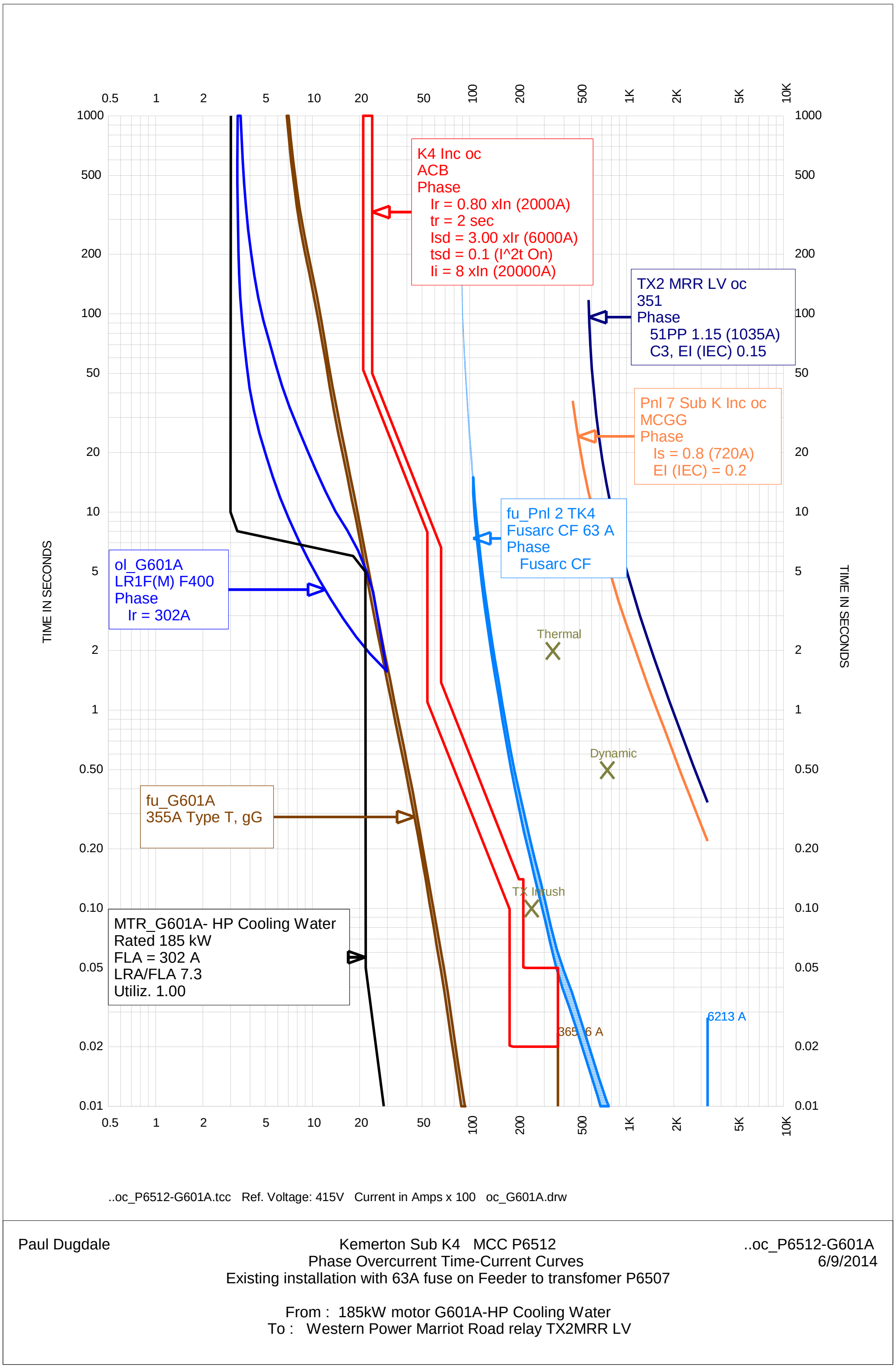


Figure 4-2: Grading of existing network to largest drive on Sub K4 MCC (P6512)

4.1.5 Short-circuit Analysis

The minimum and maximum short-circuit currents were calculated at all switchboards using the AS 3851 methodology.

Motor contribution was included, with a lumped load used to reflect the 'normal' operational load installed. This lumped load was based on actual metered maximum demand current values at each motor control centre (MCC).

The Western Power network contribution to a three phase bolted fault at the 22kV Utility busbars at Marriott Road substation was previously given as:

I"k3 = 4.26 kA, 3P X/R = 19.6

The short-circuit calculation results for all switchboards are presented in the single line diagram and spreadsheet format in Appendix G. These single line diagrams and spreadsheets show the maximum initial symmetrical rms three phase (I"k3) short-circuit current results at all switchboards.

The maximum calculated short-circuit current was also checked to ensure that it is below the switchboard rated short-time withstand current for all switchboards.

4.2 Arc Flash Analysis results and recommendations

4.2.1 Arc Flash Analysis results

As previously discussed, Appendix G includes a series of single line diagrams and tables with arc flash analysis results and protection device type and settings for all switchboards/MCCs. The arc flash was checked on both the minimum and maximum Utility contribution levels. The results indicated that the arc flash result was significantly worse when the minimum Utility contribution value was employed.

Note: As the arc flash results are worse using the minimum Utility contribution, all further discussion and recommendations (and their subsequent arc flash results) will be based on the use of this contribution.

4.2.2 Switchboards/MCCs where the Incident Energy exceeds 8 cal/cm^2 (for the existing installation)

The only locations where the incident energy exceeds 8 cal/cm^2 was at:

- The incoming tier of the 415 VAC motor control centre P6512 – Incident energy calculated at 315.87 cal/cm^2
- All the other tiers the 415 VAC motor control centre P6512 – Incident energy calculated at 19.07 cal/cm^2

An incident energy value between 8 and 25 cal/cm^2 requires a PPE level 3. PPE above level 2 is considered uncomfortable and very restrictive.

Above 40 cal/cm^2 it is too dangerous to work near the electrical equipment, and no PPE will assist the worker in the advent of an arc flash incident. In this case, the only answer is to isolate the supply before working adjacent to the electrical equipment.

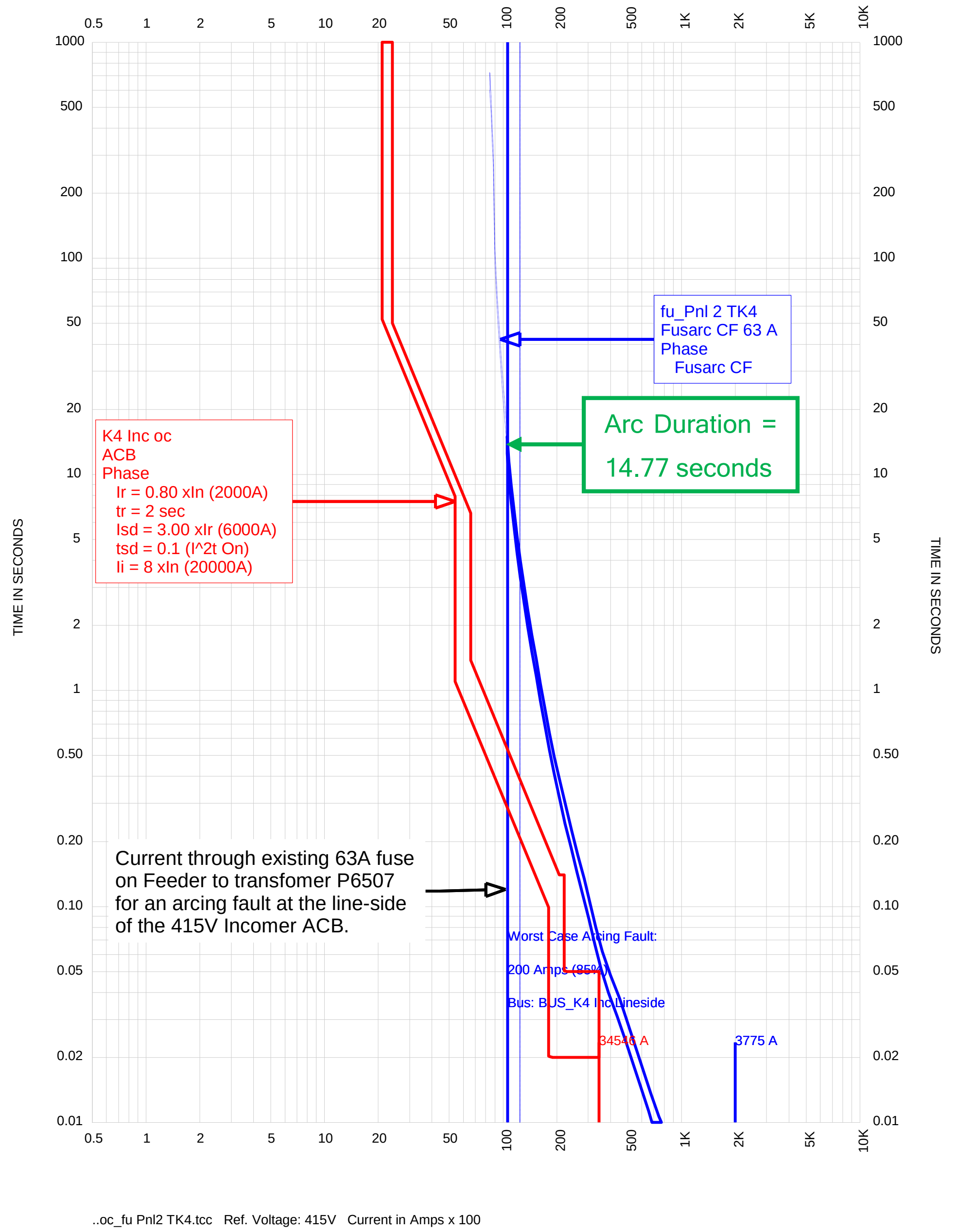
4.2.3 Existing arc flash result at incoming tier of the LV Motor Control Centre P6512

As discussed above, it would be considered dangerous to work on the incoming tier of the MCC. The incoming tier is protected by a 22kV fuse located on the supply side of the 22kV/415V MCC supply transformer (P6507 - *XFM_TK4*).

When the fuse's time-current characteristic curve was assessed against the arcing current (both at 85% and 100% of arcing current), it was found that in the worst case (i.e. at 85% arcing current) the fuse would take 14.77 seconds to clear the fault. This is unacceptable, as it is assumed a person would not survive an arc duration of greater than 2 seconds. Hence the 'dangerous' hazard/risk category.

Figure 4-3 shows a plot of the time-current characteristic curve for the upstream existing 22kV fuse against the 85% and 100% arcing current value. The solid and dashed blue vertical lines in above Figure 4-3 represent the 85% and 100% of the arcing current through the 22kV fuse for an arcing fault at the line side of the MCC ACB.

NOTE: The 100% of the arcing current through the 22kV fuse is used to when calculating the maximum incident energy (315.9 cal/cm^2).



Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Existing installation with 63A fuse on Feeder to transfomer P6507

..oc_fu Pnl2 TK4
6/9/2014

Blue curve - 22kV 63A fuse on Feeder to 1.5 MVA transformer P6507.
Red curve - 415V Incomer ACB to MCC P6512.
Blue solid / dashed vertical lines represent 85 % / 100% of current through the 63A fuse
for an arcing fault on the line-side of the Incomer ACB.

Figure 4-3: Existing Sub K4 MCC (P6512) Feeder TCC

4.2.4 Limitation of damage of MCC P6512 to an arcing fault

As previously stated, Clause 2.5.5.3 in the Wiring Rules standard – AS3000 (2007) states that "*Protective devices shall be provided to limit, as far as practicable, the harmful effects of a switchboard internal arcing fault by automatic disconnection*".

Using the calculation given in AS3000 (2007), and after determining from documentation that the busbar current rating of the MCC is 2400A, the maximum clearing time required for the 22kV supply fuse could be calculated.

NOTE: From the arc flash results the calculated bolted short-circuit current at the MCC is 34.71 kA.

Thus, the calculated clearing time is:

$$\text{Clearing time } t = \frac{k_e \times I_r}{{I_f}^{1.5}} = \frac{250 \times 2400}{(34710 \times 0.03)^{1.5}} = 17.85 \text{ seconds}$$

where;

t is the clearing time (seconds)

I_f is 30% of the prospective fault current (A)

I_r is the current rating of the switchboard (A)

k_e is a constant of 250, based on acceptable volume damage

As the maximum clearing time of the fault during an arc flash was determined to be 14.77 seconds, the MCC complies with the requirements of Clause 2.5.5.3 (AS3000).

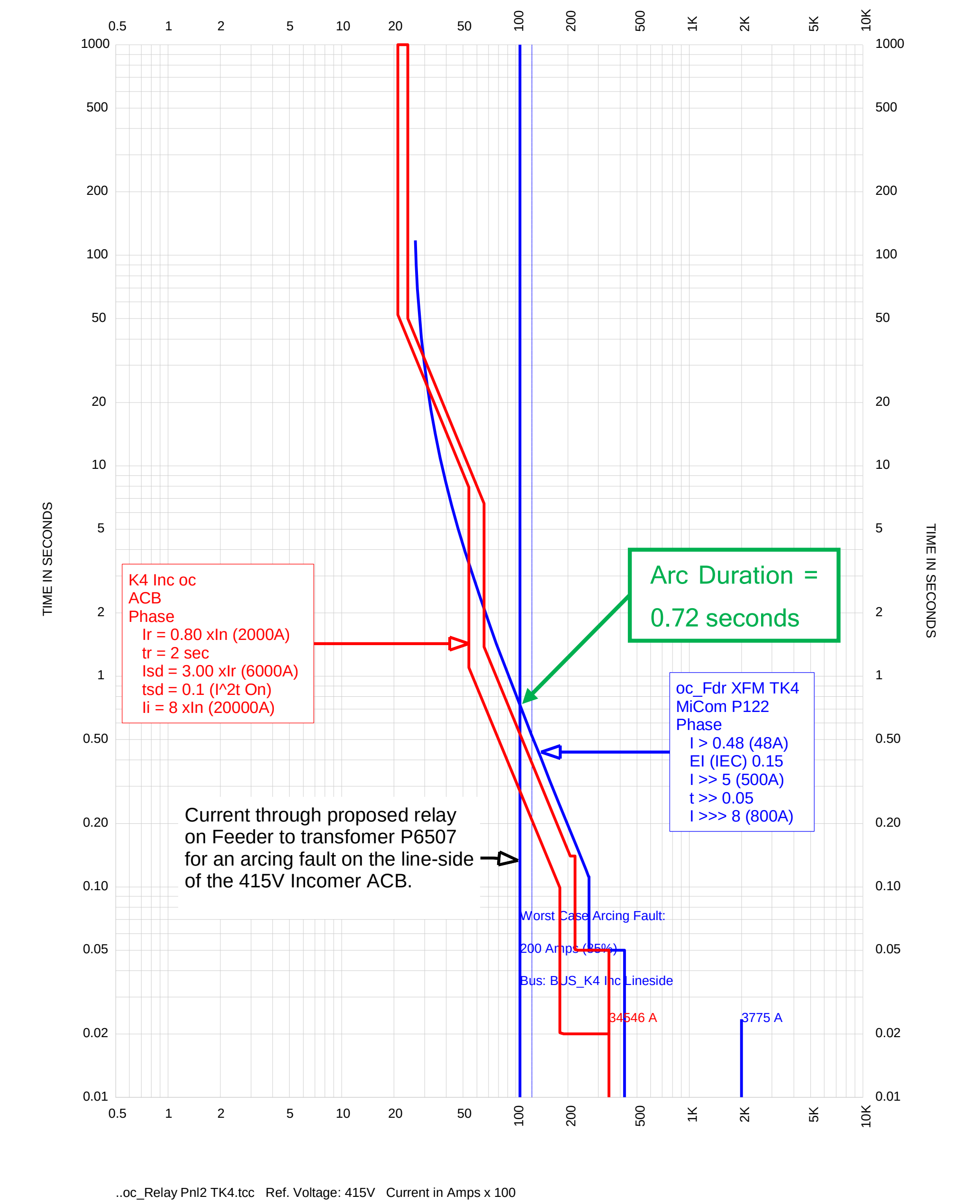
4.2.5 Proposed replacement of the 22kV supply fuse with an ACB & Relay

One way to reduce the arc duration and enable a fault to be cleared (disconnected/isolated) in a faster time, would be to consider replacing the 22kV supply fuse with a circuit breaker and relay. For the purpose of checking the viability of this recommendation, the MiCom P122 Relay (Schneider Electric) was considered (see Figure 4-4 below).

Figure 4-4: MiCom P122 Relay (*Schneider Electric* 2014)

Firstly, the MiCom's time-current characteristic curve was modelled in PTW and checked that it graded with the MCC's downstream ACB. When the TCC was assessed against the arcing current (both at 85% and 100% of arcing current), it was found that in the worst case (i.e. at 85% arcing current) it would take 0.72 seconds for it to clear the fault. This is much better result, and decreases the hazard/risk category down to a level 3 and an incident energy value of 20.2 cal/cm^2.

Figure 4-5 shows a plot of the new time-current characteristic curve for an upstream circuit breaker and relay (MiCom P122) against the 85% and 100% arcing current value.



Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with relay on Feeder to transformer P6507.

..oc_Relay Pnl2 TK4
14/9/2014

Blue curve - 22kV relay on Feeder to 1.5 MVA transformer P6507.
Red curve - 415V Incomer ACB to MCC P6512.
Blue solid / dashed vertical lines represent 85 % / 100% of current through the 22kV relay
for an arcing fault on the line-side of the Incomer ACB.

Figure 4-5: Proposed Sub K4 MCC (P6512) Feeder TCC

4.2.6 VAMP Optical Arc Protection Scheme

An optical arc detection scheme sensing both arc, as well as a high current, can detect a fault and interrupt the current in an appropriate 22kV circuit breaker within 0.1 seconds of a fault initiation. This is conditional on the optical arc detection scheme being wired with an intertrip to its respective 22kV transformer feeder circuit breaker. The 0.1 second interval is made up of 20ms optical arc detection time, plus 80ms circuit breaker total time from trip initiation to arc extinction (Interposing relay operating time = 20ms, circuit breaker tripping time = 60ms). Figure 4-6 below shows a typical installation.

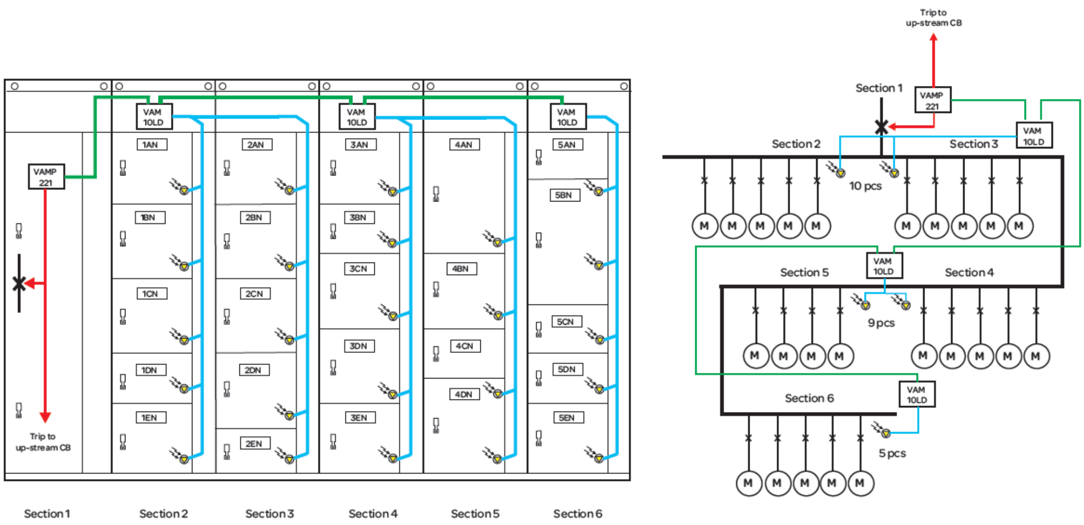


Figure 4-6: Typical installation of the VAMP 221 Arc Flash Protection System (*Schneider Electric* 2013)

A further recommendation for the proposed upgrade to the 22kV supply protection, would be to consider including the optical detection scheme with the proposed circuit breaker and MiCom P122 relay. This option would further decrease the fault clearance duration, which in this particular instance, could potentially reduce the hazard/risk category to a level 1 and an incident energy value of 2.9 cal/cm^2.

NOTE: If a decision was made to install a VAMP arc flash detection system, it would also be worthwhile to also consider the installation of a bypass or service switch for maintenance purposes.

4.2.7 LV Motor Control Centre Arc Flash installation proposal comparison

Tables 4-2 and 4-3 below shows the comparison between the different options for the two most hazardous areas discussed above (i.e. the incoming tier protection for the LV MCC and the protection for the rest of the MCC).

Table 4-2: Arc Flash Analysis results for the existing power network (up to the incoming tier of MCC P6512)

Component	Field	Scenario (minimum Utility fault contribution)		
		Existing 22kV fuse protection	Proposed 22kV ACB and Relay	Proposed 22kV ACB and Relay, with Arc detection
BUS_K4 Inc Lineside	Iu = (A)	2400	2400	2400
BUS_K4 Inc Lineside	Icw = (kA)	50	50	50
BUS_K4 Inc Lineside	Un = (V)	415	415	415
BUS_K4 Inc Lineside	AF_BoltedFault = (kA)	34.7	32.9	32.9
BUS_K4 Inc Lineside	AF_ArcingFault = (kA)	13.1	12.5	14.7
BUS_K4 Inc Lineside	AF_Boundary = (mm)	26878	4156	1123
BUS_K4 Inc Lineside	AF_Incident Energy = (Cal/cm^2)	315.9	20.2	2.9
BUS_K4 Inc Lineside	at Working Distance of (mm)	610	610	610
BUS_K4 Inc Lineside	AF_PPE Category =	Dangerous!	3	1

Table 4-3: Arc Flash Analysis results for the existing power network (up to the remaining tiers of MCC P6512)

Component	**Field**	**Scenario (minimum Utility fault contribution)**		
		Existing 22kV fuse protection	**Proposed 22kV ACB and Relay**	**Proposed 22kV ACB and Relay, with Arc detection**
BUS_P6512-MCC K4	Iu = (A)	2400	2400	2400
BUS_P6512-MCC K4	Icw = (kA)	50	50	50
BUS_P6512-MCC K4	Un = (V)	415	415	415
BUS_P6512-MCC K4	AF_BoltedFault = (kA)	34.7	32.9	32.9
BUS_P6512-MCC K4	AF_ArcingFault = (kA)	13.1	13.4	15.7
BUS_P6512-MCC K4	AF_Boundary = (mm)	3048	2630	1089
BUS_P6512-MCC K4	AF_Incident Energy = (Cal/cm^2)	19.7	21.3	5.0
BUS_P6512-MCC K4	at Working Distance of (mm)	455	455	455
BUS_P6512-MCC K4	AF_PPE Category =	3	3	2

4.3 Arc Flash Warning Labelling

A requirement of the NFPA 70E is to provide arc flash warning labelling for electrical equipment, such as switchboards and motor control centres (that may require operation, maintenance, or servicing while energised).

This dissertation has designed labelling which conforms to the requirements of NFPA 70E (2012), and can be found in Appendix I. For convenience, an example of one of the arc flash warning labels (for the Incoming Supply Tier of MCC K4 - P6512) is displayed in Figure 4-7 below.

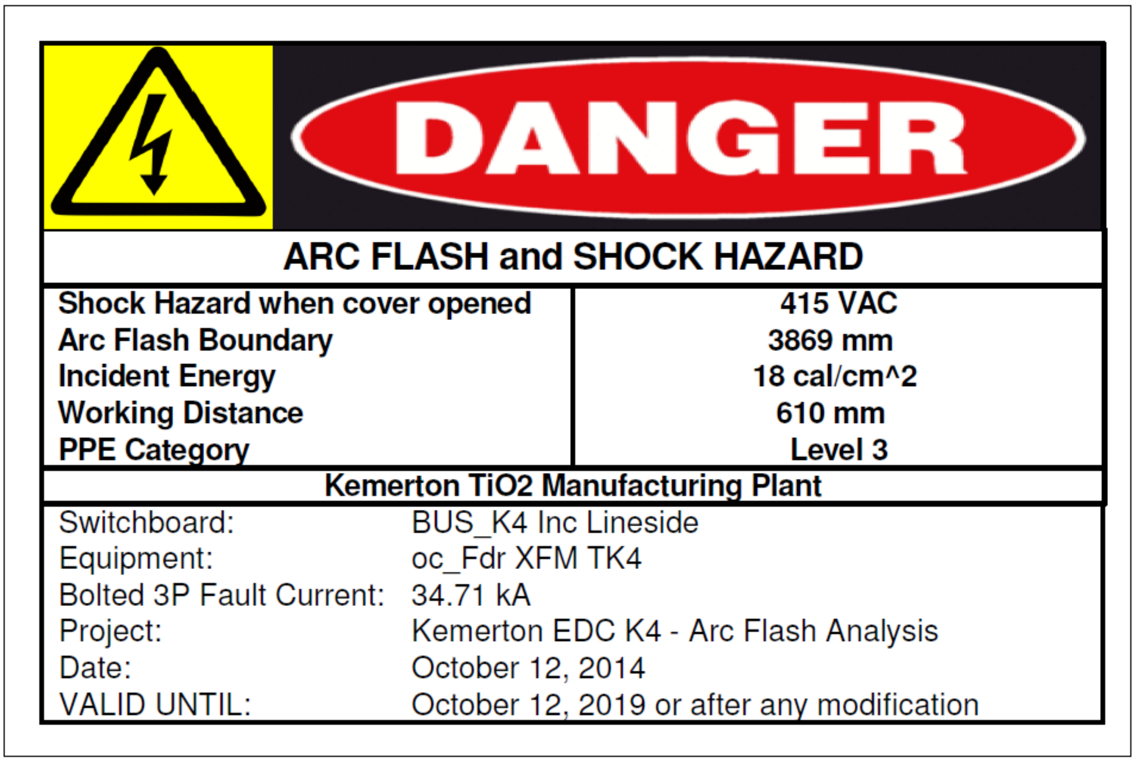


Figure 4-7: Arc Flash Label for Incoming Supply Tier of MCC K4 (P6512)

4.4 Critical Risks/Issues and Hazardous Area investigation

There are three main critical risks/issues with regards to an arc flash incident. These include:

- Fatality – Depending on the incident energy and the location of a worker to the fault, there is a potential chance of a death. A fatality can cause morale issues within the workforce, and may decrease the public's perception of the company, from being an "employer of choice" to a place to avoid. It can also cause insurance premium increases, and the company may be fined in court (if it was deemed preventable).
- Major Infrastructure Damage – Obviously with the energy that can be generated by an arc flash incident, there is an obvious potential for equipment damage. However, the initial fault can also quickly progress (or cascade) from just involving the initial equipment (that was under fault), to other infrastructure nearby. An example of this could be how a single phase fault can quickly escalate to a three phase fault, due to metal vapour shorting out between phases, caused by the arc flash. Another example could be where the arc flash blast pressure and temperature could damage adjacent equipment. In some instances this may be under pressure itself and contain hazardous/flammable materials (e.g. piping transporting gas). This may in turn, cause secondary damage to plant and equipment. This will cause production downtime, insurance premium increases, and lost profit. It can also involve the workforce losing their job for an extended period (while repairs are made,) or even in extreme cases, the complete closure of the company.

- Reputation – Finally, an arc flash event can cause irreparable damage to a company's reputation. Imagine if the arc flash involved damage to a section of plant that may contain a major hazardous material. If released, this material may have an impact on the environment, and/or on the public's health. These type of situations can damage a company's environmental reputation for many years.

Due to the reasons given above, as part of the data collection exercise for this dissertation, the adjacent area to the LV motor control centre P6512 was investigated for any potential items that may become hazardous or dangerous in the advent of an arc flash incident. This included reviewing the site's current hazardous area location drawing '000A2143' (see Figures 4-8 and 4-9) and the current site hazardous area classification report "WP04066-EE-RP-0002" (Rev 4, 2012).

The Hazardous area documents show that the MCC P6512 is located within a bricked switchroom (designated K4) outside any known hazardous area zone. A visual of the surrounding area shows the area is void of any potential hazardous materials or piping containing hazardous or dangerous materials. The housekeeping within the switchroom itself is very good and there is no storage of any form of dangerous goods.

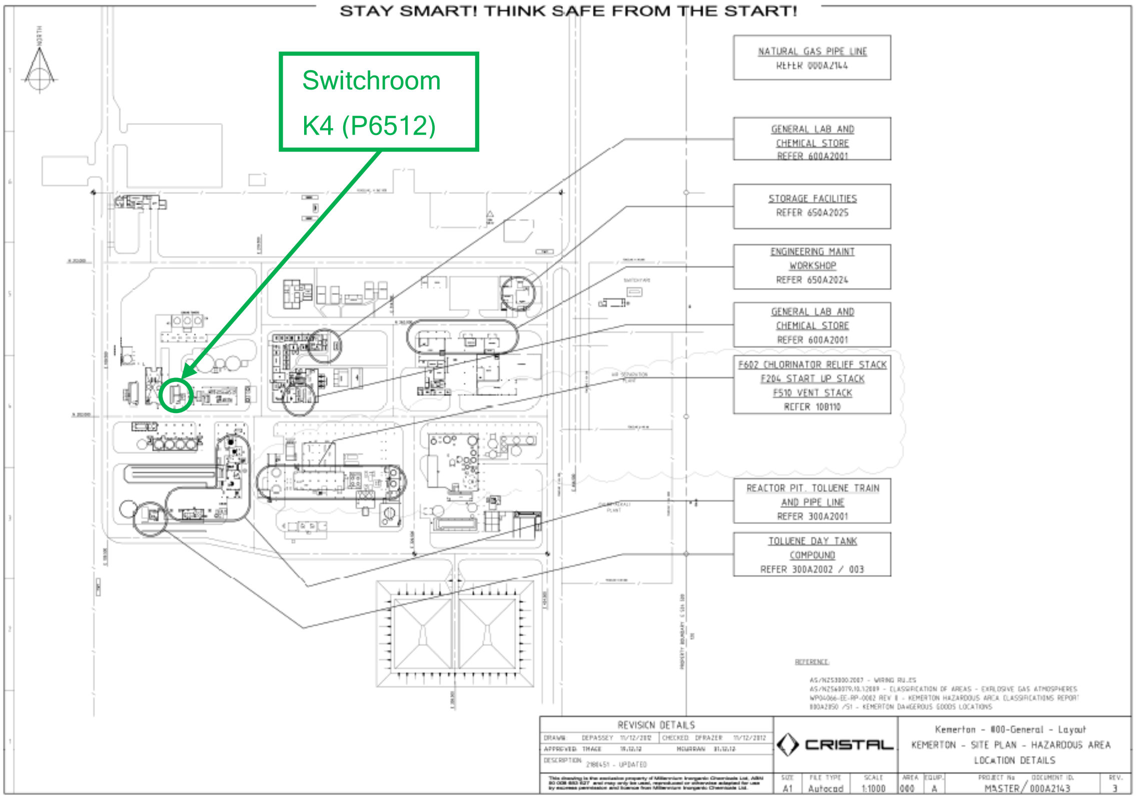


Figure 4-8: Hazardous Area Location Detail Drawing 000A2143 (*Cristal* 2012)

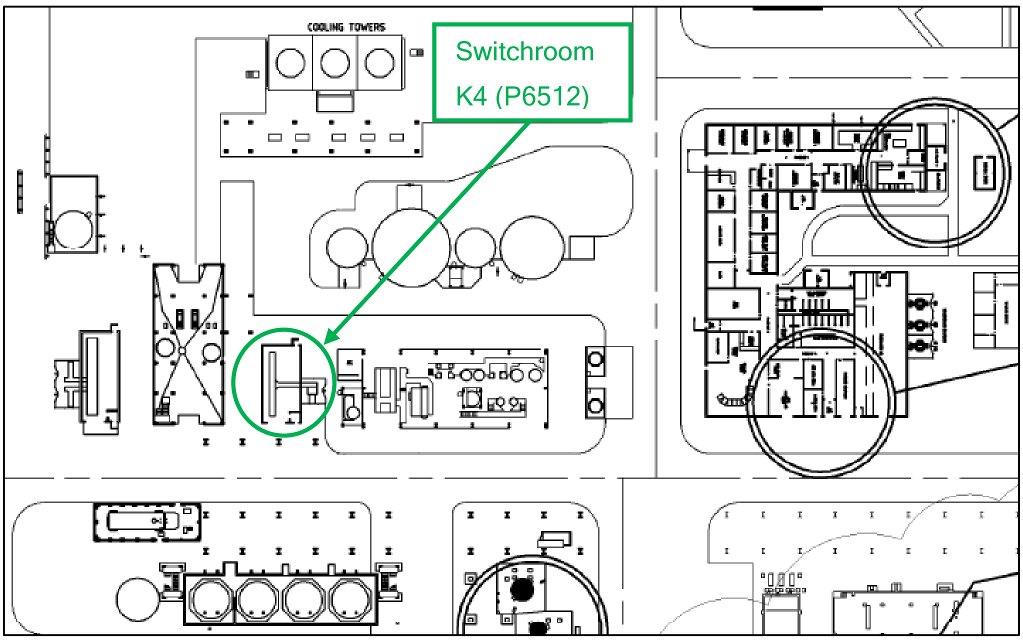


Figure 4-9: Extract of Hazardous Area Drawing 000A2143 (*Cristal* 2012)

After considering all the information available, it is believed that if an arc flash occurred, it would be contained to the switchroom. Thus, any damage and any probable lost production would also be contained to the power supply requirements of the items that are supplied by this MCC. It should be noted however, implementing the recommendations described previously will also assist to limit the damage and impact of an arc flash incident.

As the vicinity of this switchroom is in a non-volatile area, a further recommendation could be to install arc flash ductwork to the MCC to guide hazardous arc flash energies to a safer location. Should this recommendation be considered, it would require further investigation to evaluate the cost impact versus the safety benefit.

5. Conclusions and Further Work

This dissertation has shown that the most dangerous point in the power network is at the incoming tier of the Low Voltage Motor Control Centre (MCC – P6512). In its current configuration, the Incident Energy value at this location was calculated at 315.9 cal/cm^2. The maximum incident energy level permitted for workers to perform their duties (while wearing appropriate PPE), when the MCC is ‘live’ (energised), is set at 40 cal/cm^2 in the NFPA 70E (2012) standard. This means that the motor control centre would have to be de-energised for completion of any work (even inspections). This would impact production and create downtime; subsequently influencing the company’s sales and profit margin.

When this result was investigated further, it was found that this was primarily due to the nearest upstream protective device (for a fault in this location) comprising a 63A fuse located in the site’s 22kV switchroom (on the supply side of the 22kV/415VAC MCC supply transformer), more than 500 metres away. The time-current characteristic (TCC) curve of the fuse, plus the distance from the fault, influences the ability of the fuse to clear the fault within a reasonable time. At the current potential arcing current, it has been shown that this duration would be as much as 14.77 seconds.

The IEEE 1584 (2012) standard indicates that a person is unlikely to survive a duration of greater than 2 seconds. It is a recommendation of this dissertation to consider replacing the upstream 22kV 63A fuse with a circuit breaker and relay (MiCom P122). Further calculations indicated that this would reduce the incident energy value from 315.9 to 20.2 cal/cm^2. This would lower the hazard risk category from 'dangerous' to a level of 3, permitting work on the proviso that the appropriate PPE has to been worn (as indicated in NFPA 70E).

However, a hazard/risk category of 3 still involves wearing clothing which is very restrictive, and quite uncomfortable. A further recommendation would be to install an arc flash optical detection system, which can operate in a fraction of the time (approximately 100ms) as that of the trip characteristic of the fuse or the circuit breaker/relay alone. This system should be used in conjunction with the circuit breaker/relay selection. Calculations have shown that the incident energy for this option could be lowered to as much as 2.9 cal/cm^2. This would involve a further reduction of the PPE requirement to a hazard/risk level of 1, which requires minimal PPE and thus allows more freedom for the worker to enable them to complete their task(s).

5.1 Further Work

The original main premise of this dissertation was to investigate the safety aspect of working within the vicinity of a Low Voltage Motor Control Centre. When the dissertation specification document was developed, opportunities for further related research were also envisaged. These included equipment risk and criticality assessments, and carrying out a technical and safety cost benefit analysis for replacement of existing equipment. Unfortunately, not all of these items in the agreed programme could be completed in the time allotted. Nevertheless, the overall project aim of providing an understanding of what is an arc flash, the performing of a hazard study, and the recommendation of options for improvement of the current dangerous arc flash hazard levels have been fulfilled.

Further work, whether the recommendations are implemented or not, should include:

- Assessing the site's current PPE requirements and any 'Work Instruction' documentation with regards to work carried out within the switchroom (K4), and in the vicinity of the MCC P6512. This should include updating the documents to ensure they comply with the results found in this dissertation, and to keep in-line with the current adopted workplace standards (e.g. NFPA 70E).

- A review could be carried out to find out what the technical, safety, and financial impact of making the changes recommended in this dissertation. For instance, it may be more financially beneficial to replicate the MCC using new equipment, which may have already had arc flash consideration in their design. That is, the cost of having the plant on an extended shutdown to upgrade the existing network equipment, may be offset by installation of new equipment (which may or may not need such an extended shutdown).
- This dissertation concentrated only on 20% of the site's electrical infrastructure. Four additional switchrooms containing motor control centres exist on-site. After considering the results found while conducting this project, it would be prudent to recommend extended the scope to include the remaining plant.
- This research was carried out on the assumption that the enclosure/cabinet doors and access panels were open and that there was no impedance to the path of the arc flash incident energy. It may be worth investigating whether credit can be given with regards to the arc flash hazard/risk category, where these enclosure/cabinet doors are closed or sealed. Currently, it would appear that this has been taken into account in some ways in the look-up tables in the NFPA 70E standard, but it would appear that there is limited information in other documents. However, AS/NZS3439.1 (2002) does discuss internal arcing-fault (Internal Arc Classification – IAC) tests of low voltage switchgear assemblies in Annex ZD, which may be used in the future to investigate this option.

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Appendix A Project Specification

University of Southern Queensland

FACULTY OF HEALTH, ENGINEERING AND SCIENCES

ENG4111/4112 Research Project 2014
PROJECT SPECIFICATION

FOR: **Paul Nicholas DUGDALE**

TOPIC: ARC FLASH PROTECTION OF A LOW VOLTAGE MOTOR CONTROL CENTRE (MCC)

SUPERVISORS: Andreas Helwig
Tim Mace, I/E Reliability Superintendent, Cristal Pigment Australia

06 Feb 2014

SPONSERSHIP: Cristal Pigment Australia

PROJECT AIM: To gain an understanding of the requirements of Arc Flash Protection, carry out a study on a Low Voltage Motor Control Centre (MCC), and make recommendations for ensuring the protection levels and operating procedures are to an adequate standard for the protection of plant and personnel.

PROGRAMME: **Issue B, 19th March 2014**

1. Choose the most appropriate "potentially at risk" switch room/MCC
2. Research relevant standards, codes, and legislation.
3. Paper review of the description and physics of low voltage arc formation and quenching; and correlate and compare to standards, codes and legislative requirements.
4. Carry out power and quality surveys to provide a basis for the determination of arc flash values, and hazard assessment for equipment, hazardous area/s and plant in general.
5. Carry out a risk and criticality assessment of the equipment and related hazardous zone/s.
6. Determine fault levels and arc flash significance.
7. Review site switching procedures and user PPE requirements.
8. Review whether it may be best to upgrade or replace equipment by carrying an out technical and safety cost benefit analysis between upgrading current equipment against the replacement with the latest equipment (MCCs) on the market.
9. Report findings and make recommendations.

AGREED: __________ (student) __________ __________ (supervisors)

29 / 01 / 2014 ___ / ___ / 2014 29 / 1 / 2014

Examiner: __________ ___ / ___ / 2014

Appendix B Drawings

Appendix B.1 Site HV/MV Power Distribution Single Line Drawing (SLD)

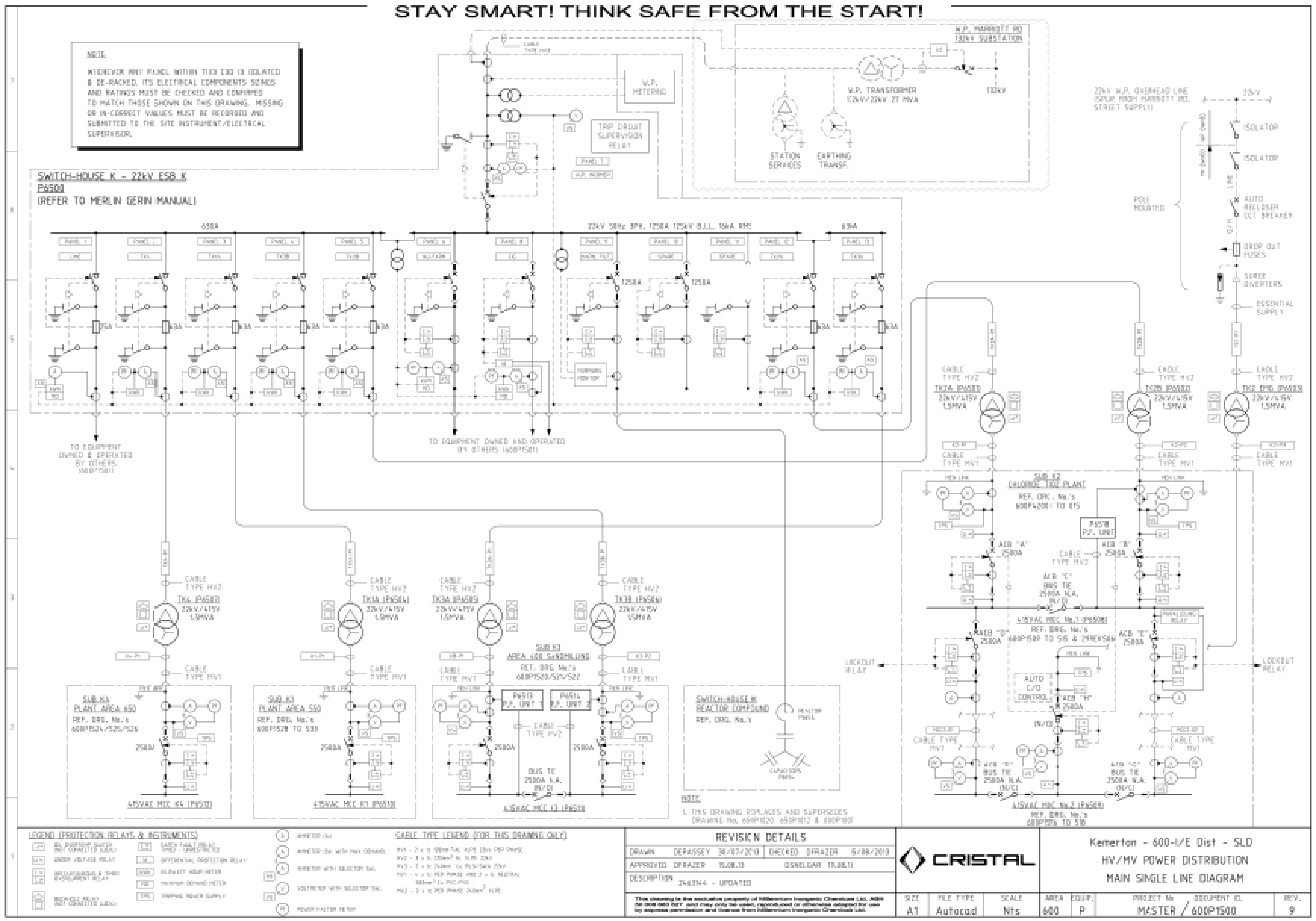


Figure B-1: Kemerton HV/MV Power Distribution Main Single Line Diagram 600P1500 (*Cristal* 2013)

Appendix B.2 LV Motor Control Centre Single Line Diagrams

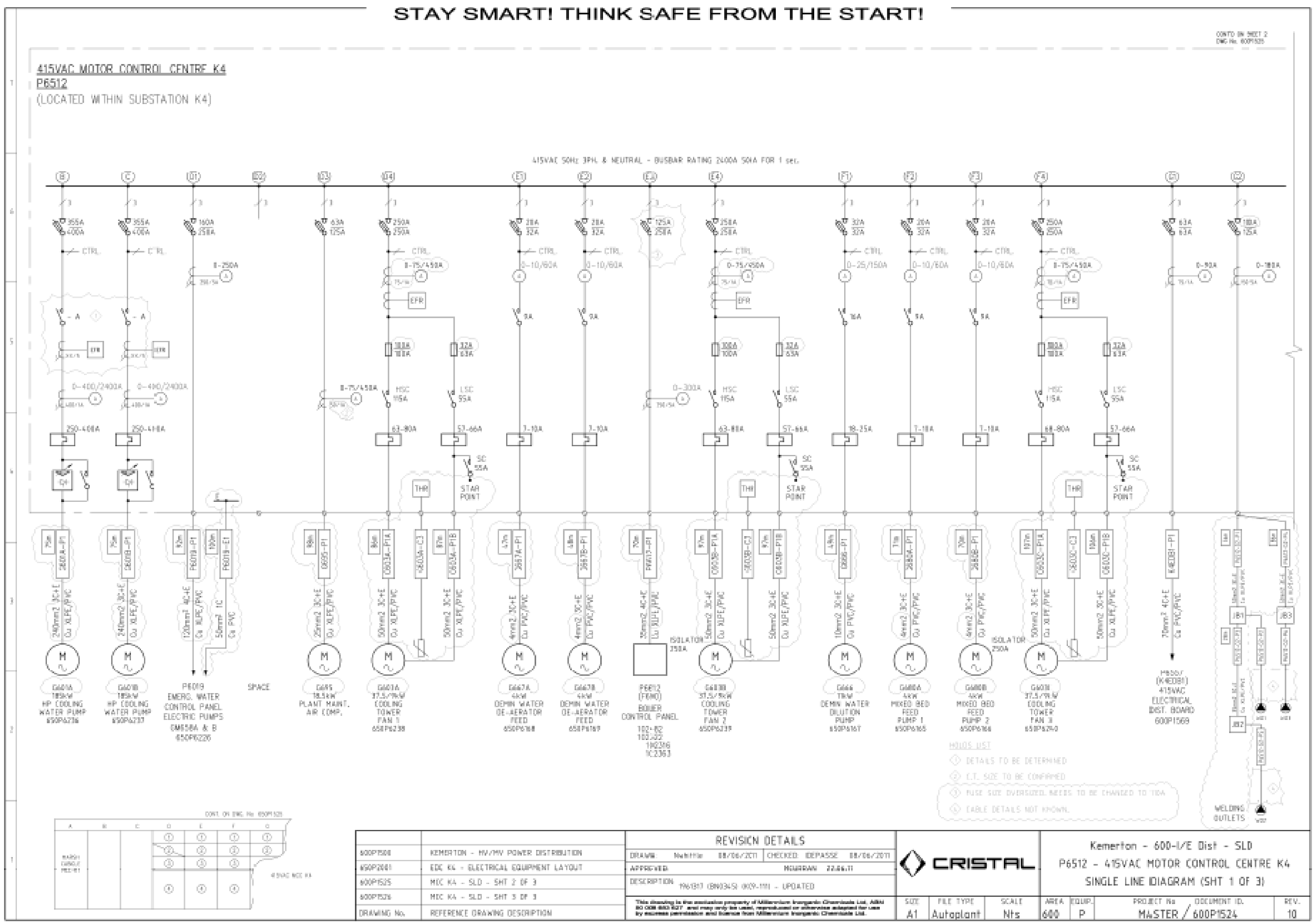


Figure B-2: P6512 – 415VAC Motor Control Centre K4 Single Line Diagram 600P1524 – Sheet 1 of 3 (*Cristal* 2011)

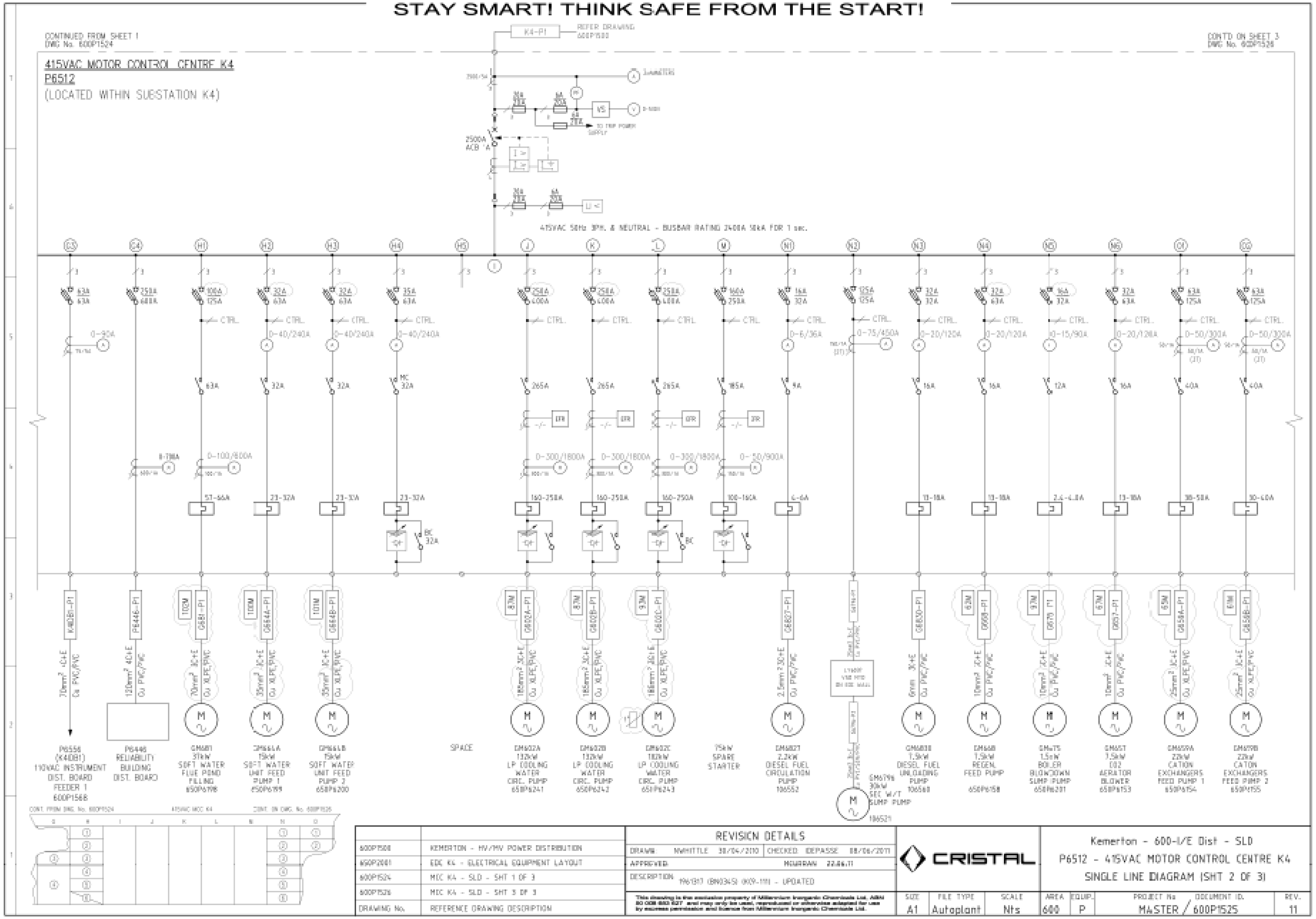


Figure B-3: P6512 – 415VAC Motor Control Centre K4 Single Line Diagram 600P1525 – Sheet 2 of 3 (*Cristal* 2011)

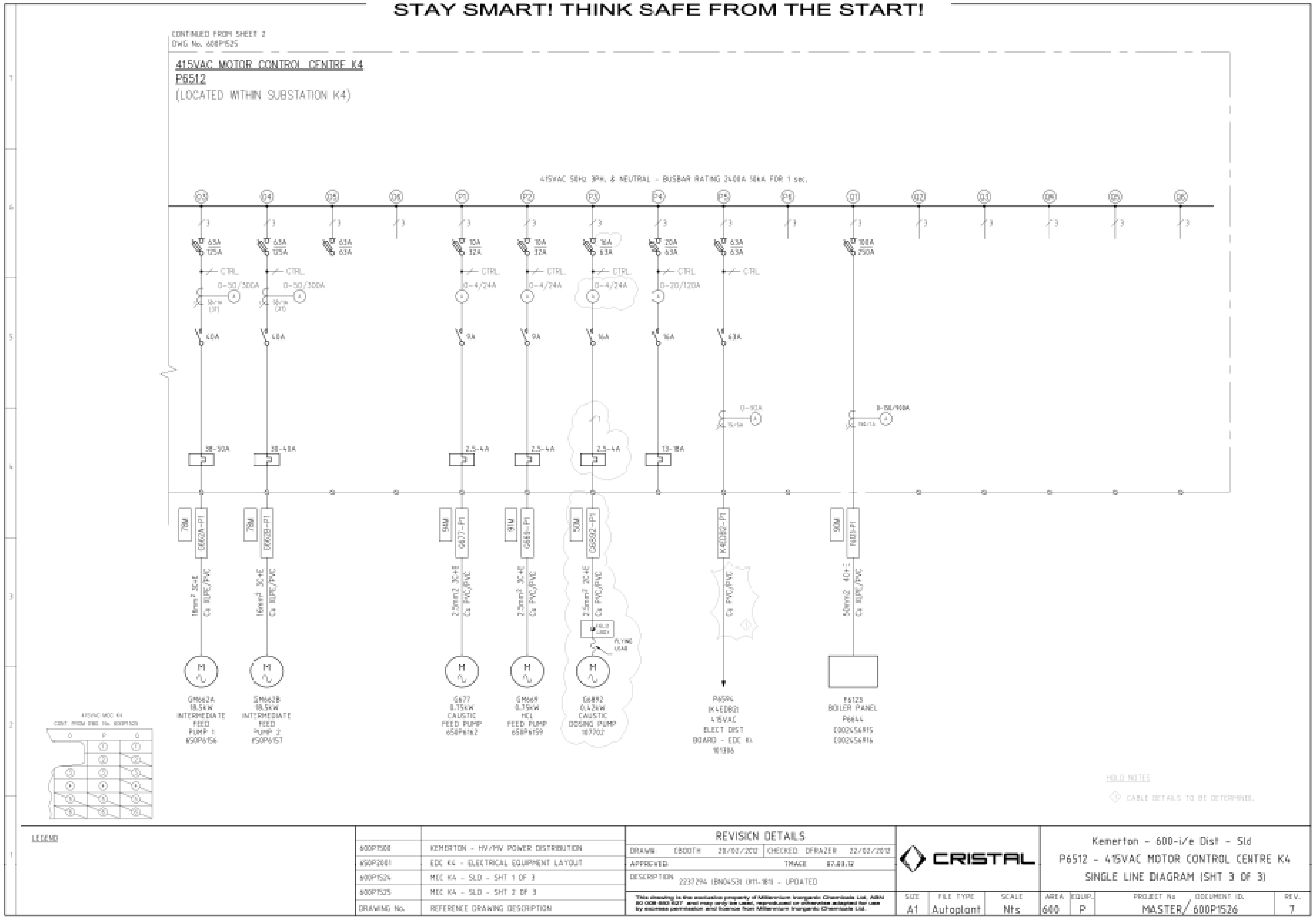


Figure B-4: P6512 – 415VAC Motor Control Centre K4 Single Line Diagram 600P1526 – Sheet 3 of 3 (*Cristal* 2012)

Appendix C Risk Assessment

This following risk assessment has been developed for the task of removing a panel of the MCC to inspect the bus bar sizing and gap spacing.

Table C-1: Electrocution hazard

Description of Hazard	People at risk	Number at risk	Parts of body	Risk level
Electrocution from live equipment	Persons working within MCC	1	All	High

Categories	Short term controls	Long term controls	Completion Details
Elimination	N/A		Employer: Cristal Pigments Prepared by: Paul Dugdale Date: 03/06/14 Signature: _______________ Date: _______________
Substitution	If possible, ring the switchboards manufacturer for the information needed		
Isolation	If possible, isolate MCC power before removing any access panels.		
Engineering	N/A	Install a safety relay/trip to any access panels that will automatically isolate main circuit breaker when an access panel is opened.	
Administrative	Review document management system on General arrangement drawings for the MCC. Use a standby person while conducting work.	Draft up a general arrangement of the MCC for future use.	
PPE	Wear gloves		

Additional Notes: This work is not permanent. The access panel will only be removed long enough to retrieve the information required to conduct the hazard study.

Table C-2: Arc Flash incident

Description of Hazard	People at risk	Number at risk	Parts of body	Risk level
Arc Flash incident due to short	All Persons within 3 metres of the open access panel of the MCC	≤2	All	High

Categories	Short term controls	Long term controls	Completion Details
Elimination	N/A		Employer: Cristal Pigments Prepared by: Paul Dugdale Date: 03/06/14 Signature: _______________ Date: _______________
Substitution	If possible, ring the switchboards manufacturer for the information needed		
Isolation	If possible, isolate MCC power before removing any access panels.		
Engineering	N/A	Install a safety relay/trip to any access panels that will automatically isolate main circuit breaker when an access panel is opened.	
Administrative	Review document management system on General arrangement drawings for the MCC. Use a standby person while conducting work - more than 5 metres from the access panel and off to one side.	Draft up a general arrangement of the MCC for future use.	
PPE	Wear gloves, fire resistant clothing, and a helmet with a face shield. Do not use a metal ruler or tape to take measurements.		

Additional Notes: This work is not permanent. The access panel will only be removed long enough to retrieve the information required to conduct the hazard study.

Table C-3: Muscle injury

Description of Hazard	People at risk	Number at risk	Parts of body	Risk level
Muscle injury due to incorrect lifting techniques when removing access panel	All Persons lifting	1-2	Back and other muscles	Moderate

Categories	Short term controls	Long term controls	Completion Details
Elimination	N/A		Employer: Cristal Pigments Prepared by: Paul Dugdale Date: 03/06/14 Signature: ______________ Date: ______________
Substitution	Use lifting device if possible		
Isolation	N/A		
Engineering		Install a hinge on access doors so there is not a need to remove the access panel in the future.	
Administrative	Review lifting technique before attempting the lift. Bend at the knees and hold the load close to the body. If possible, ask for assistance with the lift.	.	
PPE	Wear gloves.		

Additional Notes: This work is not permanent. The access panel will only be removed long enough to retrieve the information required to conduct the hazard study.

Appendix D Data Collection

Appendix D.1 Cable Schedule

Cable ID	Service	Cable Type	Cable Length (m)	From	To
	22 KV to 22kV/415V Transformer				
TK4-P1	P6507 EDC K4 Supply Transformer Feeder	3x 120 mm^2 1C Al XLPE 22 kV	≈ 385	P6512 22 kV Supply Fuse/Switch (P6500 - Sub K)	P6507 - 22 kV to 415V TX
	22kV/415V Transformer to EDC K4 MCC				
K4-P1	P6512 - Motor Control Centre Feeder	4x 500 mm^2 1C / Phase + 2x 500 mm^2 2C / Neutral Cu PVC/PVC	≈ 20	P6507 22kV/415V 1.5MVATransformer	P6512 MCC ACB
	Power supplied from EDC K4 MCC				
F6123-P1	F6123 Boiler Control Panel - 15 kW G6124 Burner Fan Motor, 15 kW G6123A Boiler Feed Pump No.1, G6123A Boiler Feed Pump No.2	50 mm^2 4C+E Cu XLPE/PVC	90	EDC K4 - P6512 Tier Q Module 1	P6644 - F6123 Panel
K4EDB1-P1	P6557 415 VAC Electrical Distribution Board - EDC K4	70 mm^2 4C+E Cu PVC/PVC	≈ 20	EDC K4 - P6512 Tier G Module 1	P6557
K4EDB2-P1	P6594 415 VAC Electrical Distribution Board - EDC K4	? mm^2 4C+E Cu PVC/PVC	≈ 20	EDC K4 - P6512 Tier P Module 5	P6594

Cable ID	Service	Cable Type	Cable Length (m)	From	To
K4IDB1-P1	P6556 110 VAC Instrument Distribution Board Feeder 1 - EDC K4	70 mm^2 4C+E Cu PVC/PVC	≈ 20	EDC K4 - P6512 Tier G Module 3	P6556 - 110V TX
G601A-P1	185 kW HP Cooling Water Pump	240 mm^2 3C+E Cu XLPE/PVC	75	EDC K4 - P6512 Tier B	G601A
G601B-P1	185 kW HP Cooling Water Pump	240 mm^2 3C+E Cu XLPE/PVC	75	EDC K4 - P6512 Tier C	G601B
G602A-P1	132 kW LP Cooling Water Circ. Pump	185 mm^2 3C+E Cu XLPE/PVC	87	EDC K4 - P6512 Tier J	G602A
G602B-P1	132 kW LP Cooling Water Circ. Pump	185 mm^2 3C+E Cu XLPE/PVC	87	EDC K4 - P6512 Tier K	G602B
G602C-P1	132 kW LP Cooling Water Circ. Pump	185 mm^2 3C+E Cu XLPE/PVC	93	EDC K4 - P6512 Tier L	G602C
G603A-P1A	37.5 kW Cooling Tower Fan No1 (High Speed)	50 mm^2 3C+E Cu XLPE/PVC	86	EDC K4 - P6512 Tier D Module 4	G603A
G603A-P1B	9 kW Cooling Tower Fan No1 (Low Speed)	50 mm^2 3C+E Cu XLPE/PVC	87	EDC K4 - P6512 Tier D Module 4	G603A
G603B-P1A	37.5 kW Cooling Tower Fan No2 (High Speed)	50 mm^2 3C+E Cu XLPE/PVC	97	EDC K4 - P6512 Tier E Module 4	G603B
G603B-P1B	9 kW Cooling Tower Fan No2 (Low Speed)	50 mm^2 3C+E Cu XLPE/PVC	97	EDC K4 - P6512 Tier E Module 4	G603B
G603C-P1A	37.5 kW Cooling Tower Fan No3 (High Speed)	50 mm^2 3C+E Cu XLPE/PVC	107	EDC K4 - P6512 Tier F Module 4	G603C
G603C-P1B	9 kW Cooling Tower Fan No3 (Low Speed)	50 mm^2 3C+E Cu XLPE/PVC	106	EDC K4 - P6512 Tier F Module 4	G603C
G657-P1	7.5 kW CO_2 Aerator Blower	10 mm^2 3C+E Cu PVC/PVC	67	EDC K4 - P6512 Tier N Module 6	G657

Cable ID	Service	Cable Type	Cable Length (m)	From	To
G659A-P1	22 kW Cation Exchangers Feed Pump 1	25 mm^2 3C+E Cu XLPE/PVC	65	EDC K4 - P6512 Tier O Module 1	G659A
G659B-P1	22 kW Cation Exchangers Feed Pump 2	25 mm^2 3C+E Cu XLPE/PVC	61	EDC K4 - P6512 Tier O Module 2	G659B
G662A-P1	18.5 kW Intermediate Feed Pump 1	16 mm^2 3C+E Cu XLPE/PVC	78	EDC K4 - P6512 Tier O Module 3	G662A
G662B-P1	18.5 kW Intermediate Feed Pump 2	16 mm^2 3C+E Cu XLPE/PVC	78	EDC K4 - P6512 Tier O Module 4	G662B
G664A-P1	15 kW Soft Water Unit Feed Pump 1	35 mm^2 3C+E Cu XLPE/PVC	100	EDC K4 - P6512 Tier H Module 2	G664A
G664B-P1	15 kW Soft Water Unit Feed Pump 2	35 mm^2 3C+E Cu XLPE/PVC	101	EDC K4 - P6512 Tier H Module 3	G664B
G666-P1	11 kW Demin Water Dilution Pump	10 mm^2 3C+E Cu PVC/PVC	49	EDC K4 - P6512 Tier F Module 1	G666
G667A-P1	4 kW Demin Water De-aerator Feed Pump	4 mm^2 3C+E Cu PVC/PVC	47	EDC K4 - P6512 Tier E Module 1	G667A
G667B-P1	4 kW Demin Water De-aerator Feed Pump	4 mm^2 3C+E Cu PVC/PVC	48	EDC K4 - P6512 Tier E Module 2	G667B
G668-P1	7.5 kW Regen. Feed Pump	10 mm^2 3C+E Cu PVC/PVC	62	EDC K4 - P6512 Tier N Module 4	G668
G669-P1	0.75 kW HCl Feed Pump	2.5 mm^2 3C+E Cu PVC/PVC	91	EDC K4 - P6512 Tier P Module 2	G669
G675-P1	1.5 kW Boiler Blowdown Sump Pump	10 mm^2 3C+E Cu PVC/PVC	97	EDC K4 - P6512 Tier N Module 5	G675
G677-P1	0.75 kW Caustic Feed Pump	2.5 mm^2 3C+E Cu PVC/PVC	94	EDC K4 - P6512 Tier P Module 1	G677
G680A-P1	4 kW Mixed Bed Feed Pump 1	4 mm^2 3C+E Cu PVC/PVC	71	EDC K4 - P6512 Tier F Module 2	G680A
G680B-P1	4 kW Mixed Bed Feed Pump 2	4 mm^2 3C+E Cu PVC/PVC	70	EDC K4 - P6512 Tier F Module 3	G680B

Cable ID	Service	Cable Type	Cable Length (m)	From	To
G681-P1	37 kW Soft Water Flue Pond Filling	70 mm^2 3C+E Cu XLPE/PVC	102	EDC K4 - P6512 Tier H Module 1	G681
G695-P1	18.5 kW Plant Maintenance Air Compressor	25 mm^2 3C+E Cu XLPE/PVC	98	EDC K4 - P6512 Tier D Module 3	G695
G6796-P1	37 kW Secondary Water Treatment Sump Pump VSD	25 mm^2 3C+E Cu PVC/PVC	10	EDC K4 - P6512 Tier N Module 2	LY6037 VSD
G6796-P2	37 kW Secondary Water Treatment Sump Pump VSD	25 mm^2 3C+E VSD cable Cu PVC/SCN/PVC	94	LY6037 VSD	G6796
G6827-P1	2.2 kW Diesel Fuel Circulation Pump	2.5 mm^2 3C+E Cu PVC/PVC	75	EDC K4 - P6512 Tier N Module 1	G6827
G6830-P1	7.5 kW Diesel Fuel Unloading Pump	6 mm^2 3C+E Cu PVC/PVC	75	EDC K4 - P6512 Tier N Module 3	G6830
G6892-P1	0.42 kW Caustic Dosing Pump	2.5 mm^2 2C+E Cu PVC/PVC	92	EDC K4 - P6512 Tier P Module 3	G6892
P6019-P1	Emergency Water Control Panel - 75 kW Electrical Emergency Water Pump	120 mm^2 4C+E Cu XLPE/PVC	92	EDC K4 - P6512 Tier D Module 1	P6019
P6446-P1	Reliability Building Distribution Board	120 mm^2 4C+E Cu PVC/PVC	200	EDC K4 - P6512 Tier G Module 4	P6446
P6512-G2-P1	3 Phase Welding Outlet Junction Box 1	50 mm^2 3C+E Cu XLPE/PVC	56	EDC K4 - P6512 Tier G Module 2	P6512 - JB1
P6512-G2-P2	3 Phase Welding Outlet 1	16 mm^2 3C+E Cu XLPE/PVC	50	P6512 - JB1	P6512 - Welding Outlet 1
P6512-G2-P3	3 Phase Welding Outlet Junction Box 2	35 mm^2 3C+E Cu XLPE/PVC	28	P6512 - JB1	P6512 - JB2
P6512-G2-P4	3 Phase Welding Outlet Junction Box 3	50 mm^2 3C+E Cu XLPE/PVC	86	EDC K4 - P6512 Tier G Module 2	P6512 - JB3
P6512-G2-P5	3 Phase Welding Outlet 2	16 mm^2 3C+E Cu XLPE/PVC	50	P6512 - JB2	P6512 - Welding Outlet 2

Cable ID	Service	Cable Type	Cable Length (m)	From	To
P6512-G2-P6	3 Phase Welding Outlet 3	16 mm^2 3C+E Cu XLPE/PVC	50	P6512 - JB3	P6512 - Welding Outlet 3
P6612-P1	F690 Boiler Control Panel - 22kW G691 Blower, 15 kW G690A Feed Pump A, G690B Feed Pump B	35 mm^2 4C+E Cu XLPE/PVC	70	EDC K4 - P6512 Tier E Module 3	P6612 - F690 Panel

Appendix D.2 Cable Protection Data

Cable ID	Service	Protection Type	Part No	Maximum AC Voltage	Rating (A)
	22 KV to 22kV/415V Transformer				
TK4-P1	P6507 EDC K4 Supply Transformer Feeder	Fuse		22kV	63
	22kV/415V Transformer to EDC K4 MCC				
K4-P1	P6512 – Motor Control Centre Feeder	Fuse (Upstream of Primary of Transformer)		22kV	63
	Power supplied from EDC K4 MCC				
F6123-P1	F6123 Boiler Control Panel - 15 kW G6124 Burner Fan Motor, 15 kW G6123A Boiler Feed Pump No.1, G6123A Boiler Feed Pump No.2	Fuse - BS88	TCP100	660	100
K4EDB1-P1	P6557 415 VAC Electrical Distribution Board - EDC K4	Fuse - BS88	TIS63	660	63
K4EDB2-P1	P6594 415 VAC Electrical Distribution Board - EDC K4	Fuse - BS88	TIS63	660	63
K4IDB1-P1	P6556 110 VAC Instrument Distribution Board Feeder 1 – EDC K4	Fuse - BS88	TIS63	660	63
G601A-P1	185 kW HP Cooling Water Pump	Fuse - BS88	TMF355	660	335
G601B-P1	185 kW HP Cooling Water Pump	Fuse - BS88	TMF355	660	335
G602A-P1	132 kW LP Cooling Water Circ. Pump	Fuse - BS88	TKF250	660	250

Cable ID	Service	Protection Type	Part No	Maximum AC Voltage	Rating (A)
G602B-P1	132 kW LP Cooling Water Circ. Pump	Fuse - BS88	TKF250	660	250
G602C-P1	132 kW LP Cooling Water Circ. Pump	Fuse - BS88	TKF250	660	250
G603A-P1A	37.5 kW Cooling Tower Fan No1 (High Speed)	Fuse - BS88	TCP100M160	660	100
G603A-P1B	9 kW Cooling Tower Fan No1 (Low Speed)	Fuse - BS88	TIS32M40	660	32
G603B-P1A	37.5 kW Cooling Tower Fan No2 (High Speed)	Fuse - BS88	TCP100M160	660	100
G603B-P1B	9 kW Cooling Tower Fan No2 (Low Speed)	Fuse - BS88	TIS32M40	660	32
G603C-P1A	37.5 kW Cooling Tower Fan No3 (High Speed)	Fuse - BS88	TCP100M160	660	100
G603C-P1B	9 kW Cooling Tower Fan No3 (Low Speed)	Fuse - BS88	TIS32M40	660	32
G657-P1	7.5 kW CO_2 Aerator Blower	Fuse - BS88	TIA32M40	660	32
G659A-P1	22 kW Cation Exchangers Feed Pump 1	Fuse - BS88	TIS63M80	660	63
G659B-P1	22 kW Cation Exchangers Feed Pump 2	Fuse - BS88	TIS63M80	660	63
G662A-P1	18.5 kW Intermediate Feed Pump 1	Fuse - BS88	TIS63M80	660	63
G662B-P1	18.5 kW Intermediate Feed Pump 2	Fuse - BS88	TIS63M80	660	63
G664A-P1	15 kW Soft Water Unit Feed Pump 1	Fuse - BS88	TIA32M63	660	32
G664B-P1	15 kW Soft Water Unit Feed Pump 2	Fuse - BS88	TIA32M63	660	32
G666-P1	11 kW Demin Water Dilution Pump	Fuse - BS88	TIA32M50	660	32

Cable ID	Service	Protection Type	Part No	Maximum AC Voltage	Rating (A)
G667A-P1	4 kW Demin Water De-aerator Feed Pump	Fuse - BS88	NIT20	550	20
G667B-P1	4 kW Demin Water De-aerator Feed Pump	Fuse - BS88	NIT20	550	20
G668-P1	7.5 kW Regen. Feed Pump	Fuse - BS88	TIA32M40	660	32
G669-P1	0.75 kW HCl Feed Pump	Fuse - BS88	NIT10	550	10
G675-P1	1.5 kW Boiler Blowdown Sump Pump	Fuse - BS88	NIT16	550	16
G677-P1	0.75 kW Caustic Feed Pump	Fuse - BS88	NIT10	550	10
G680A-P1	4 kW Mixed Bed Feed Pump 1	Fuse - BS88	NIT20	550	20
G680B-P1	4 kW Mixed Bed Feed Pump 2	Fuse - BS88	NIT20	550	20
G681-P1	37 kW Soft Water Flue Pond Filling	Fuse - BS88	TCP100M160	660	100
G695-P1	18.5 kW Plant Maintenance Air Compressor	Fuse - BS88	TIS63M80	660	63
G6796-P1	37 kW Secondary Water Treatment Sump Pump VSD	Fuse - BS88	TF125	660	125
G6796-P2	37 kW Secondary Water Treatment Sump Pump VSD	Fuse - BS88 (Upstream of VSD)	TF125	660	125
G6827-P1	2.2 kW Diesel Fuel Circulation Pump	Fuse - BS88	NIT16	550	16
G6830-P1	7.5 kW Diesel Fuel Unloading Pump	Fuse - BS88	TIA32M40	660	32
G6892-P1	0.42 kW Caustic Dosing Pump	Fuse - BS88	NIT16	550	16
P6019-P1	Emergency Water Control Panel - 75 kW Electrical Emergency Water Pump	Fuse - BS88	TF160	660	160

Cable ID	Service	Protection Type	Part No	Maximum AC Voltage	Rating (A)
P6446-P1	Reliability Building Distribution Board	Fuse - BS88	TKF250	660	250
P6512-G2-P1	3 Phase Welding Outlet Junction Box 1	Fuse - BS88	TCP100	660	100
P6512-G2-P2	3 Phase Welding Outlet 1	Fuse - BS88	TCP100	660	100
P6512-G2-P3	3 Phase Welding Outlet Junction Box 2	Fuse - BS88	TCP100	660	100
P6512-G2-P4	3 Phase Welding Outlet Junction Box 3	Fuse - BS88	TCP100	660	100
P6512-G2-P5	3 Phase Welding Outlet 2	Fuse - BS88	TCP100	660	100
P6512-G2-P6	3 Phase Welding Outlet 3	Fuse - BS88	TCP100	660	100
P6612-P1	F690 Boiler Control Panel - 22kW G691 Blower, 15 kW G690A Feed Pump A, G690B Feed Pump B	Fuse - BS88	TF125	660	125

Appendix D.3 P6512 - EDC K4 Motor Control Centre Air Circuit Breaker Data

Micrologic 6.0 P Control Unit

Setting Description	Parameter Identifier	Parameter Description	Setting / Display
Adjustable Dial Settings	Ir	Long-time current setting	0.8 x In = 2000 A
	tr	Long-time tripping delay	2 s (@6Ir)
	Isd	Short-time pickup	3 x Ir = 7500 A
	tsd	Short-time tripping delay	0.1 s on (I^2t)
	Ii	Instantaneous pickup	8 x In = 20000 A
	Ig	Ground-fault pickup	J
	tg	Ground-fault tripping delay	0.3 s on (I^2t)
Current Protection Settings	I (A)	Fine settings of the long-time I^2t, short-time and instantaneous protection functions	2000 A @ 2.0 s
			6000 A @ 0.1 s
			20 kA
	Idmtl (A)	Fine settings of the long-time Idmtl, short-time and instantaneous protection functions	N/A
	I⏚ (A)	Fine settings of the ground-fault protection functions	1200 A / 0.3 s
	Ineutral (A)	Selection of the type of neutral sensor and type of neutral protection	Neutral CT
			Internal
			Protection OFF
	I⏚ Alarm	Setting of the I⏚ Alarm	OFF
			Pick up 400 A / 10.0 s
			Drop out 400 A / 1.0 s

Setting Description	Parameter Identifier	Parameter Description	Setting / Display
Current Protection Settings	I_{unbal} (%)	Setting of the current-unbalance protection I unbal.	OFF
			Pick up 60 % / 40.0 s
			Drop out 60 % / 10.0 s
	$\bar{I}_1$ max (A)	Setting of the maximum-current protection $\bar{I}_1$ max.	OFF
			Pick up 500 A / 1500 s
			Drop out 500 A / 15 s
	$\bar{I}_2$ max (A)	Setting of the maximum-current protection $\bar{I}_2$ max.	OFF
			Pick up 500 A / 1500 s
			Drop out 500 A / 15 s
	$\bar{I}_3$ max (A)	Setting of the maximum-current protection $\bar{I}_3$ max.	OFF
			Pick up 500 A / 1500 s
			Drop out 500 A / 15 s
	$\bar{I}_N$ max (A)	Setting of the maximum-current protection $\bar{I}_N$ max.	OFF
			Pick up 500 A / 1500 s
			Drop out 500 A / 15 s

Setting Description	Parameter Identifier	Parameter Description	Setting / Display
Voltage Protection Settings	U_{min} (V)	Setting of the minimum-voltage protection U min.	OFF
			Pick up 100 V / 10.00 s
			Drop out 100 V / 1.20 s
	U_{max} (V)	Setting of the maximum-voltage protection U max.	OFF
			Pick up 725 V / 10.00 s
			Drop out 725 V / 1.20 s
	U_{unbal} (%)	Setting of the voltage-unbalance protection U unbal.	OFF
			Pick up 30 % / 40.0 s
			Drop out 30 % / 10.0 s
Other Protection Settings	rP_{max} (W)	Setting of the reverse-power protection rP max.	OFF
			Pick up 500 kW / 20.00 s
			Drop out 500 kW / 1.0 s
	F_{min} (Hz)	Setting of the minimum-frequency protection F min.	OFF
			Pick up 45.0 Hz / 10.00 s
			Drop out 45.0 Hz / 1.20 s

Setting Description	Parameter Identifier	Parameter Description	Setting / Display
	F_{max} (Hz)	Setting of the maximum-frequency protection F min.	OFF
			Pick up 65.0 Hz / 10.00 s
			Drop out 65.0 Hz / 1.20 s
	Phase rotation	Setting of the Phase-rotation protection	OFF
			ΔΦ: A,C,B
Load shedding depending on current	Load shedding I	Access to load shedding and reconnection depending on current	OFF
			100 % Ir / 80 % tr
			100 % Ir / 10 s
Load shedding depending on power	Load shedding P	Access to load shedding and reconnection depending on power	OFF
			10.00 MW / 3600 s
			10.00 MW / 10 s

Note: In = 2500 A

Appendix D.4 P6507 EDC K4 – 1.5 MVA 22 kV/415 V Transformer (TK4) Nameplate Data

Description	Data
Manufacturer	Westralian Transformers PTY Ltd
Rating (kVA)	1500
Phases	3
Frequency (Hz)	50
Amps – H.V.	39.4
Amps – L.V.	2000
Vector Group	Dyn 11
Impedance (%)	6.1
Cooling	ONAN
Insulation Class	A
Insulation Level	150 / 50
Winding Temperature (°C)	65
Oil Temperature (°C)	60
Oil Volume (litres)	1370
Mass Untanked (kg)	2434
Mass Total (kg)	5240
Test Pressure	0 / 150

Appendix D.5 P6507 EDC K4 – 1.5 MVA 22 kV/415 V Transformer (TK4) Tap Setting Data

Tap Switch No.	H.V. Volts	L.V. Volts
1	23650	433
2	23100	
3	22550	
4	22000	
5	21450	
6.	20950	
7	20350	

Note: Tap is currently set on Tap Switch No 4. Tap-changing only should only be carried out when the transformer is de-energised.

Appendix E Utility Fault Level Request

Appendix E.1 Utility Fault Level Request Form

westernpower

Electricity Networks Corporation ABN 18 540 492 861

Request for information - Western Power Network Assets

Please submit your completed request to: **Western Power, Locked Bag 2520, Perth WA 6001**,
Fax: **9225 2742** or Email: **workingnearelectricity@westernpower.com.au**

This form requests Western Power to provide details of its electricity network assets at a specific location. The information provided in response may assist you to undertake your planned works near electricity safely. This information should not be used in isolation and we recommend that you refer to the Occupational Safety and Health Act 1984 and Occupational Safety and Health Regulations 1996.

Help us process your request quickly by attaching **an accurate site plan**, of your proposed works. This will assist us to locate and verify the voltages for works in the vicinity. Please also attach any site plans/photos identifying the area where you intend to work, recommended file types are PDF, Word, Excel, TIFF or JPEG.

If you are a business, please complete the following two fields.

Company or business name	Cristal Pigment Australia Limited
ABN	50008683627

Contact person

Title (e.g. Mr, Mrs, Ms)	Mr	First name	Paul
Surname	Dugdale		
Email	paul.dugdale@cristal.com		
Contact number(s)	08 9780 8338 / 08 9780 8833	Fax	08 9780 8355

Postal address (if email address is not supplied)

PO Box		Lot number		Street number	
Street					
Suburb/Town				Postcode	

Site address

☐ As above *(please tick)*

PO Box		Lot number	1
Street	Marriott Road		
Suburb/town	Kemerton Industrial Park, Wellesley	Postcode	6233
Nearest intersection(s)	Devlin & Marriott Road		
GPS coordinates *(if known)*			

Description of work to be carried out *(for example, installing scaffolding)*

We are conducting an Arc Flash assessment of electrical distribution centres at our Kemerton site. This will involve performing a short circuit study, a protection co-ordination study, before finally carrying out the arc flash study. To successfully complete these studies we require the short circuit data for the 22kV supplies to our plant.

Could you please supply this information? I have attached a spreadsheet to assist in the passage of the information required.

■ Please mark to show acceptance of submission of this form to Western Power *(please tick)*

Requestor name	Paul Dugdale	Date	21 / 07 / 2014

Working near electricity - Request for information - Western Power Network Assets 1

Appendix E.2 Utility Data Spreadsheet

Utility Data Required for Short-Circuit Study

Utility Impedance (excluding client impedance) as seen from PCC, or...

		Existing		Future		
		Min	Max	Min	Max	
per unit on 100MVA base	r1					
	x1					
	r2					
	x2					
	ro					
	xo					

Utility Contribution to 3P and PE Short-Circuit at PCC

		Existing		Future		Existing		Future	
		Min	Max	Min	Max	X/R 3P	X/R PE	X/R 3P	X/R PE
Amps	3P								
	PE								
Voltage Factor (c) to AS3851	Yes / No								

3P 3 phase initial symmetrical short-circuit current
PE Single phase to earth initial symmetrical short-circuit current

X/R 3P X1 / R1
X/R PE (Xo + X1 + X2) / (Ro + R1 + R2)

PCC Point of Common Coupling between Utility and Consumer

The preferred data format is Utility Impedance on 100MVA base (excluding client impedance) as seen from the

Utility Data Required for Loadflow Study

Utility Voltage at PCC

		Existing		Future	
		Min	Max	Min	Max
per unit Voltage					

Appendix F Protective Device Modelling

This appendix contains the time-current characteristic curves for the protection devices that were modelled in the PTW program.

Appendix F.1 Fuse TCC

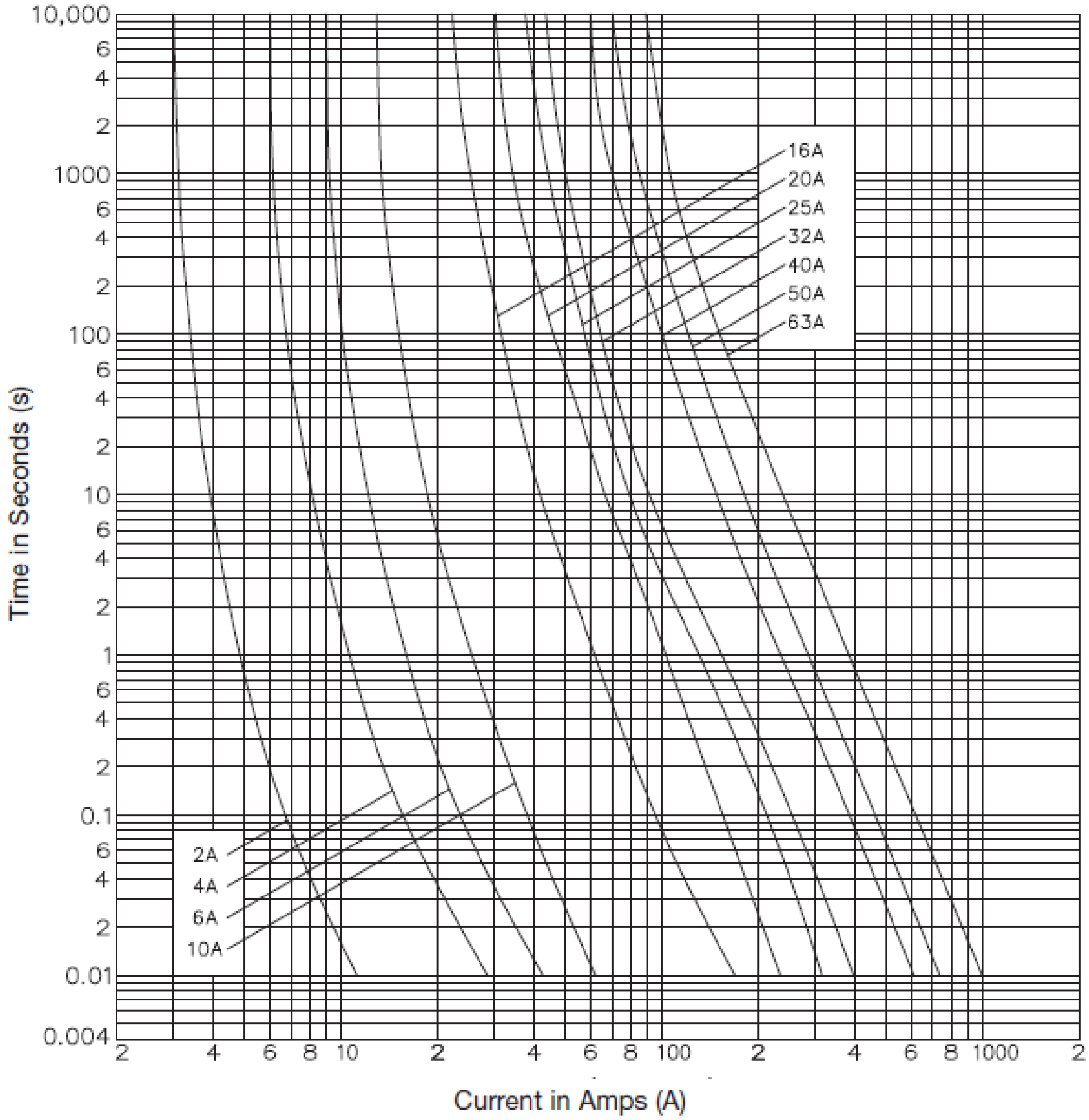


Figure F-1: Time-current characteristics for NIT fuses – 2 to 20 A (*Cooper Bussmann* 2014)

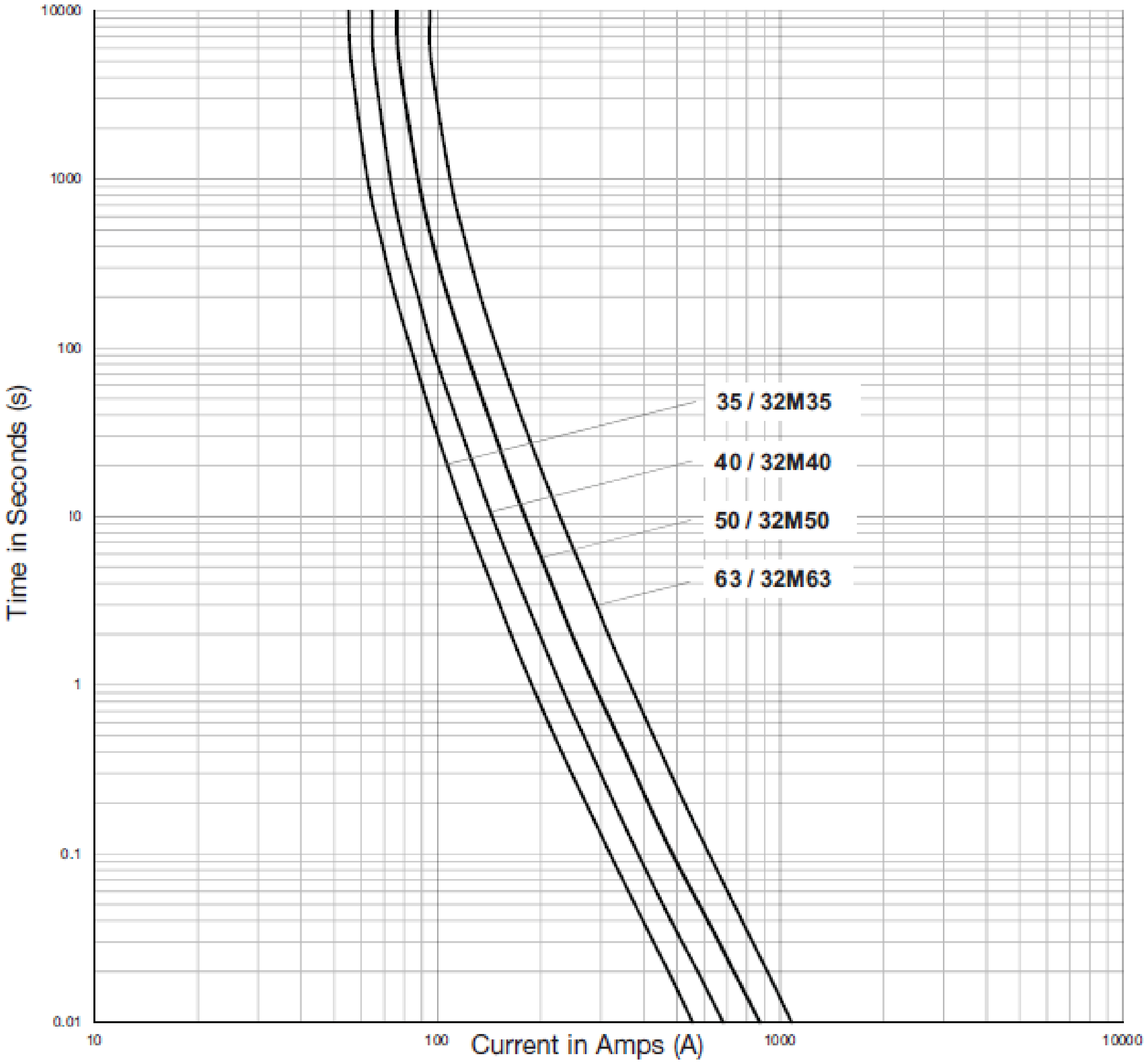


Figure F-2: Time-current characteristics for TIA32M, TIS35 to TIS63, and TCP40 toTCP63 (*Cooper Bussmann* 2014)

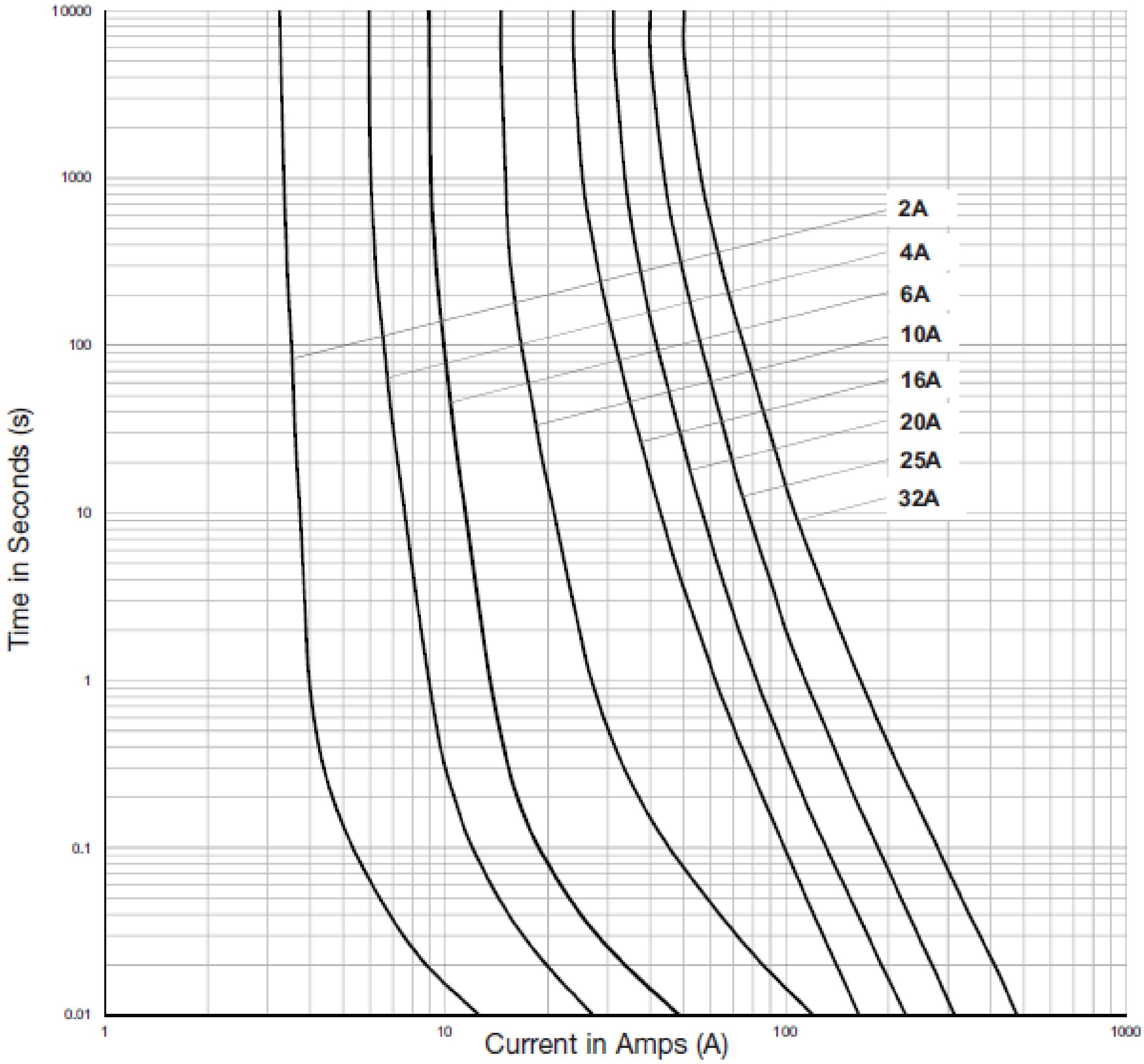


Figure F-3: Time-current characteristics for TIA, and TCP32 (*Cooper Bussmann* 2014)

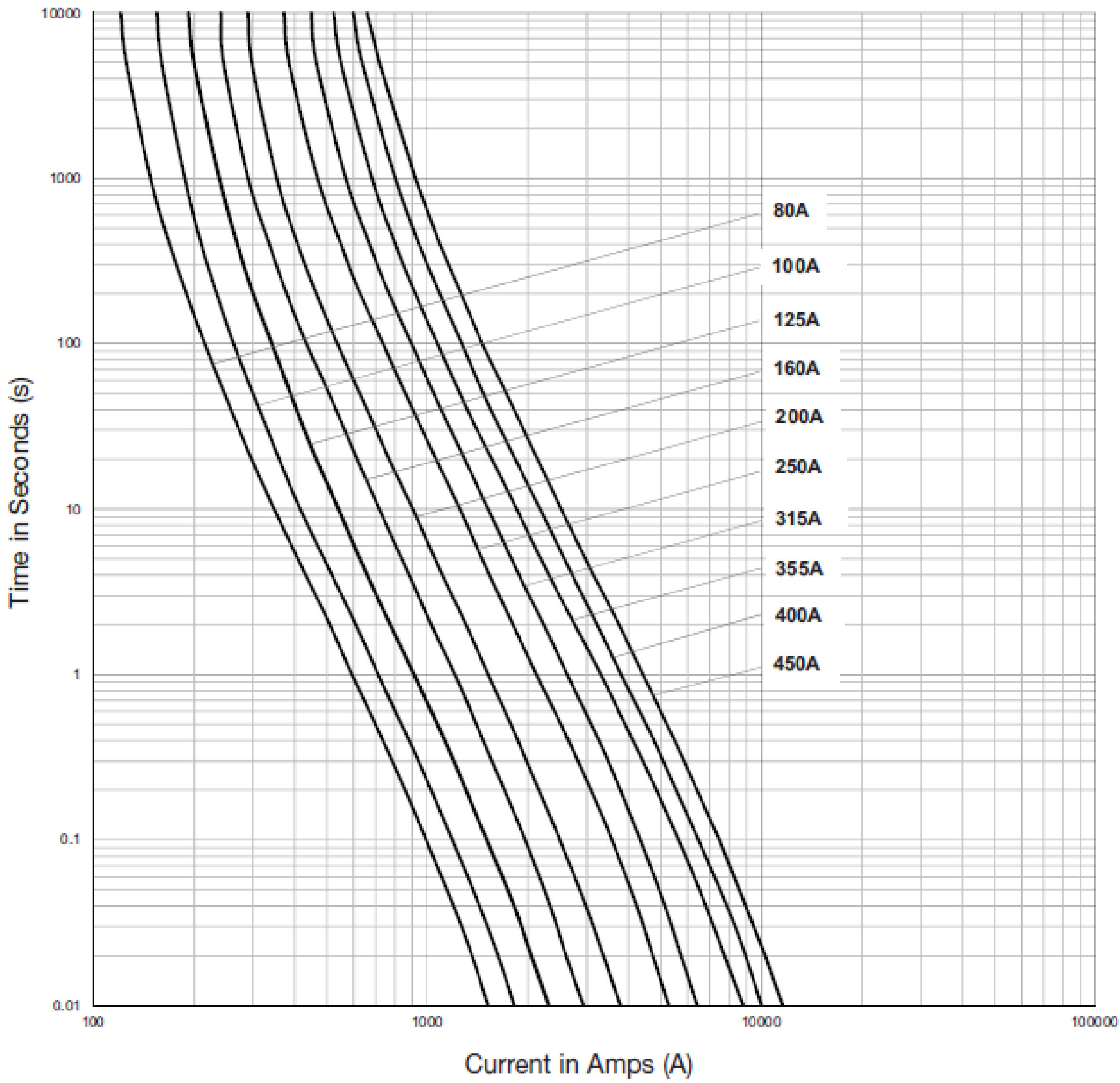


Figure F-4: Time-current characteristics for TCP80 to TCP100, TFP125 to TFP200, TKF250 to TKF315, TMF355 to TMF400, and TTM450 (*Cooper Bussmann* 2014)

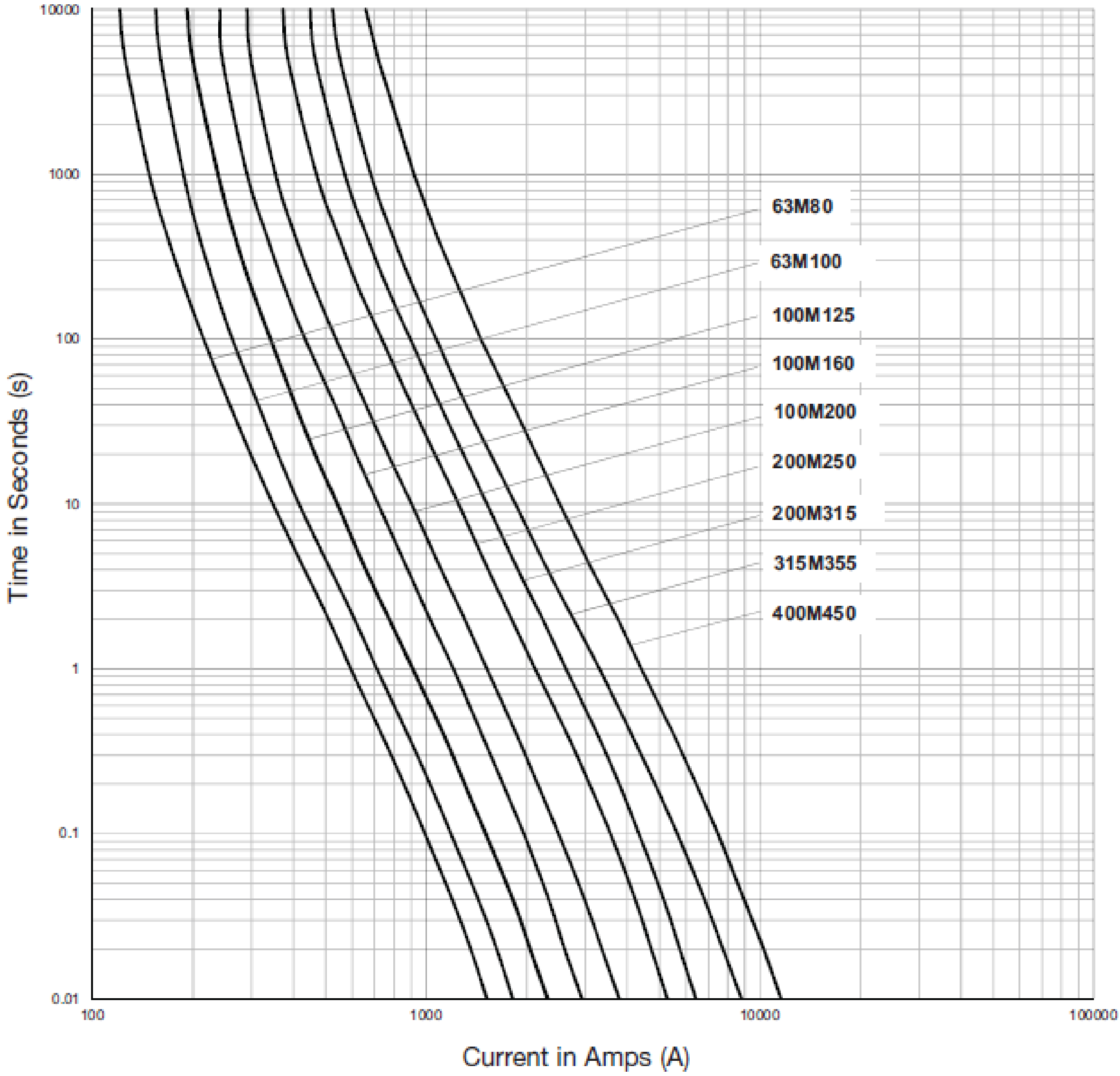


Figure F-5: Time-current characteristics for TIS63M, TCP100M, and TFP200M (*Cooper Bussmann* 2014)

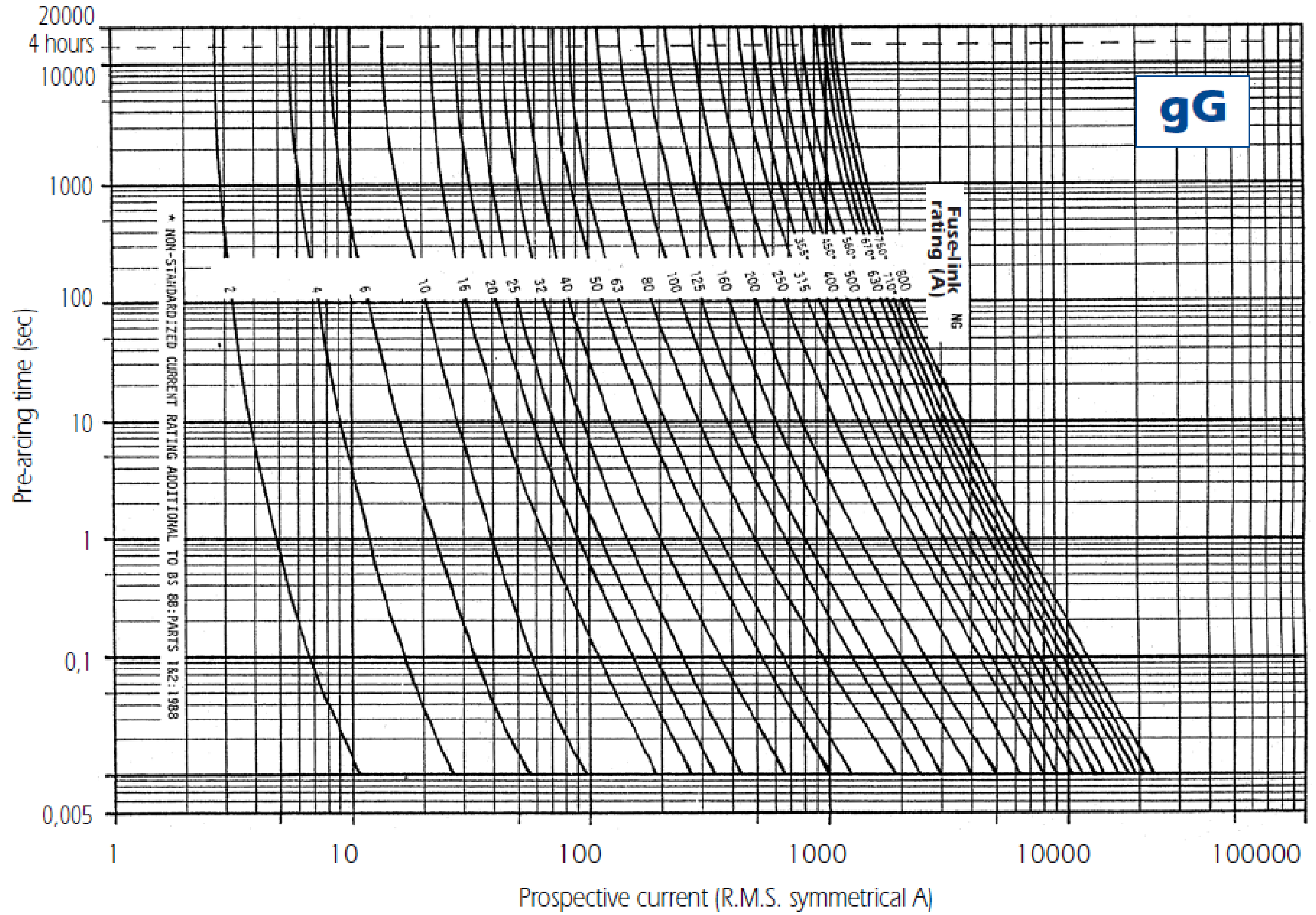


Figure F-6: Time-current characteristics for BS88 Fuse Links – type gG (Ferraz Shawmut 2014)

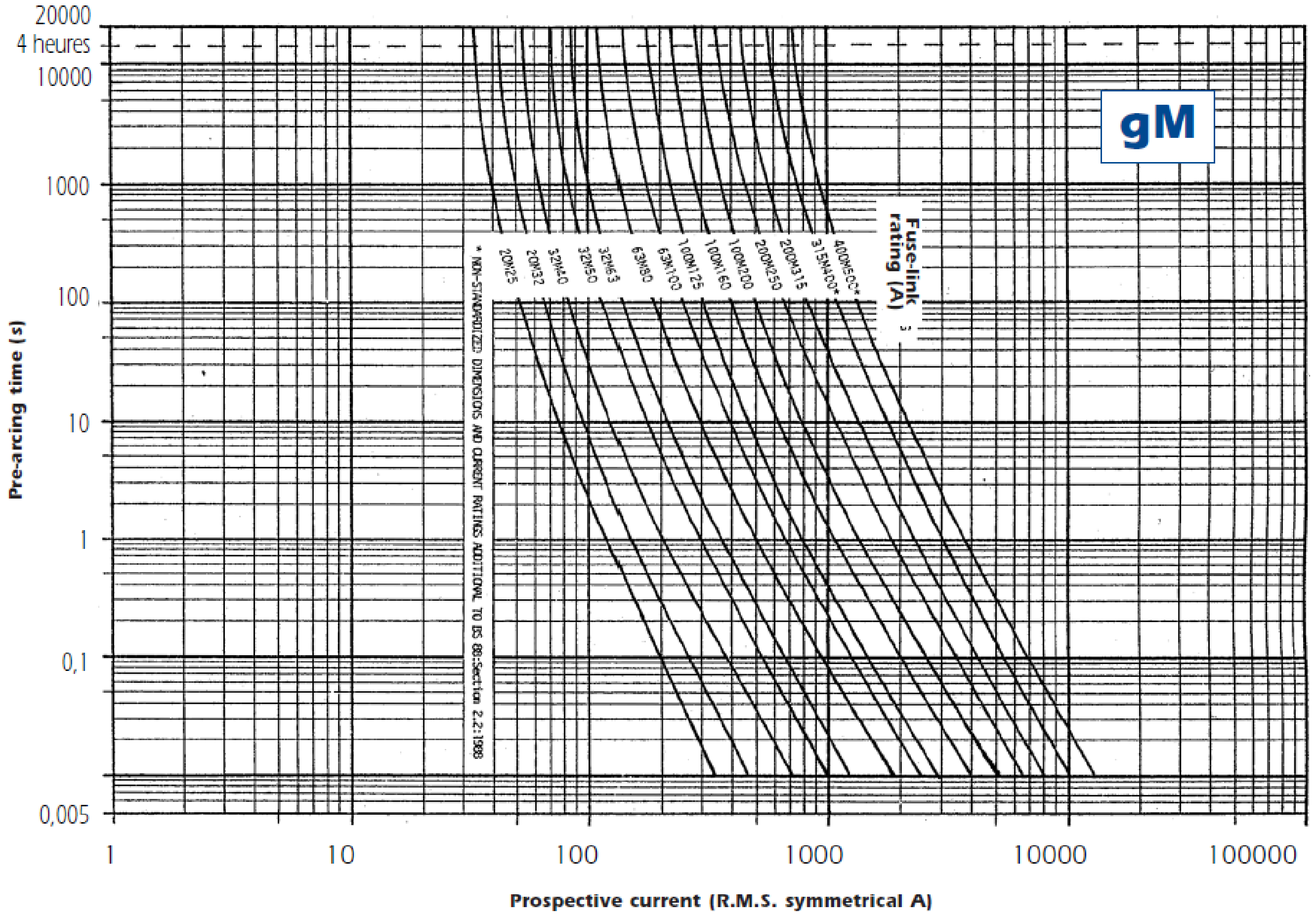


Figure F-7: Time-current characteristics for BS88 Fuse Links – type gM (Ferraz Shawmut 2014)

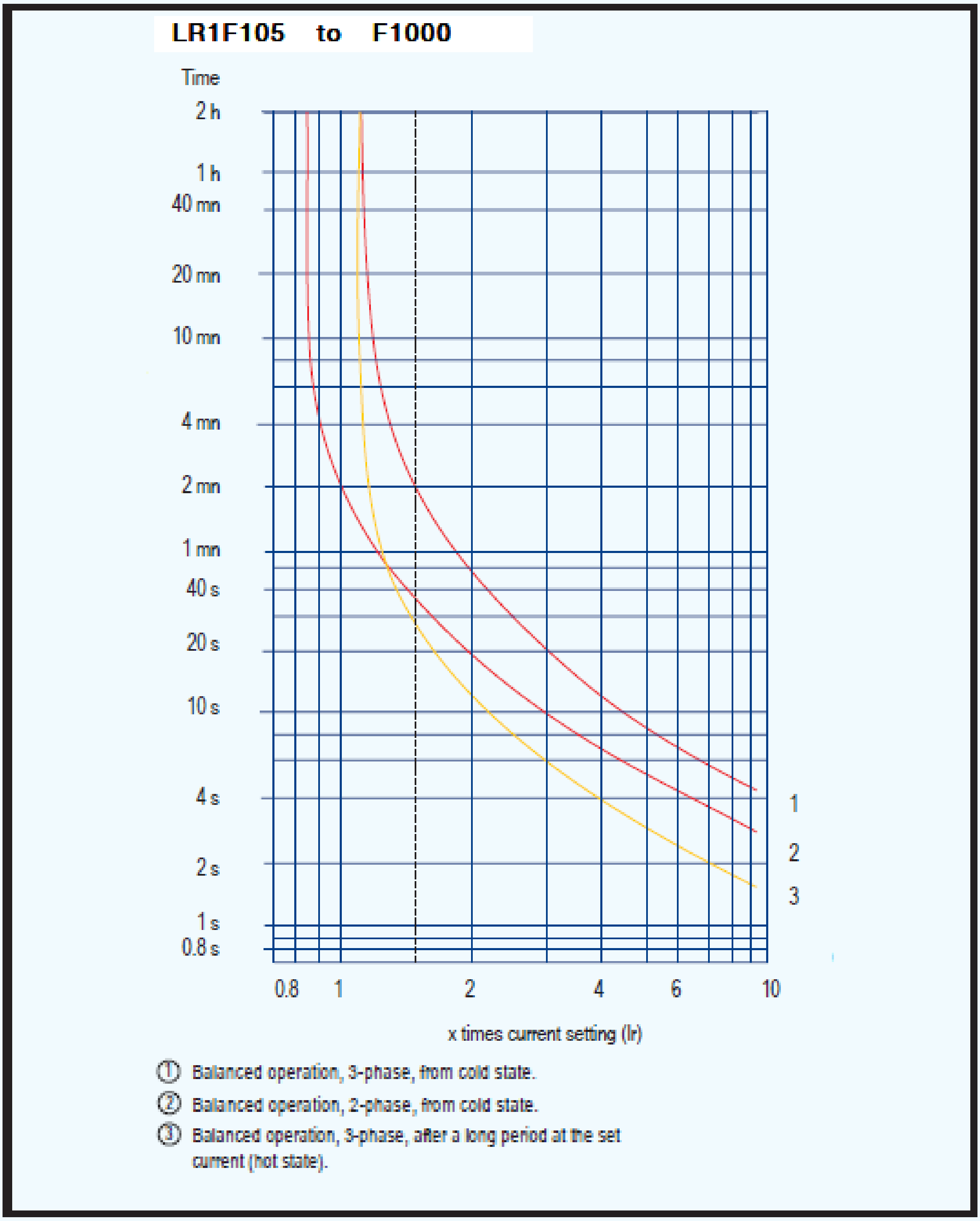
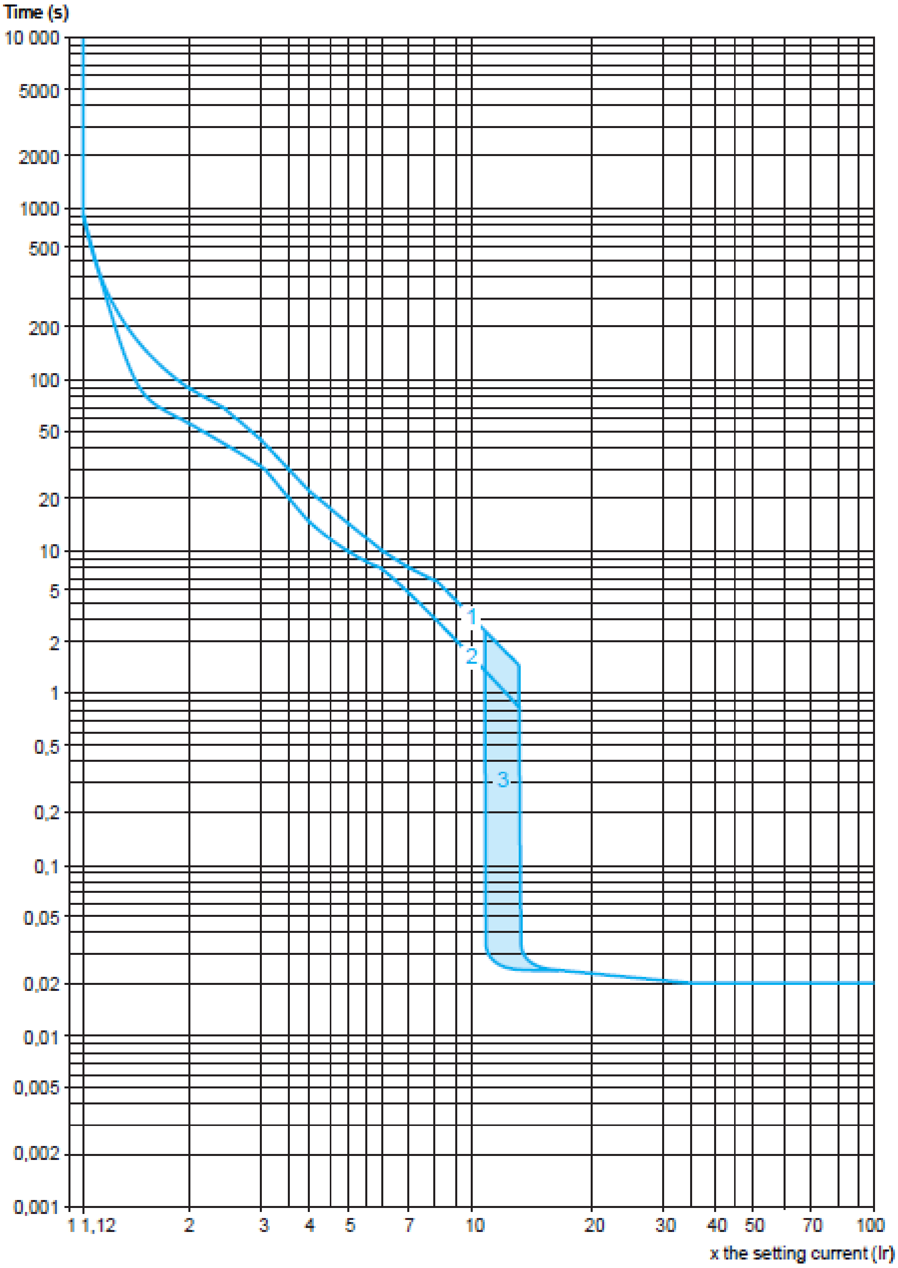


Figure F-8: Time-current characteristics for Telemecanique LR1F105 to F1000 (*C&S Electric Ltd* 2014)

Thermal-magnetic tripping curves for GV7 R

Average operating times at 20 °C related to multiples of the setting current



1 Cold state curve
2 Cold state curve
3 12…14 Ir
In the event of total phase failure, tripping occurs after 4 s ± 20 %

Figure F-9: Time-current characteristics for Telemecanique GV7 R Thermal Magnetic Motor Circuit Breaker (*Schneider Electric* 2014)

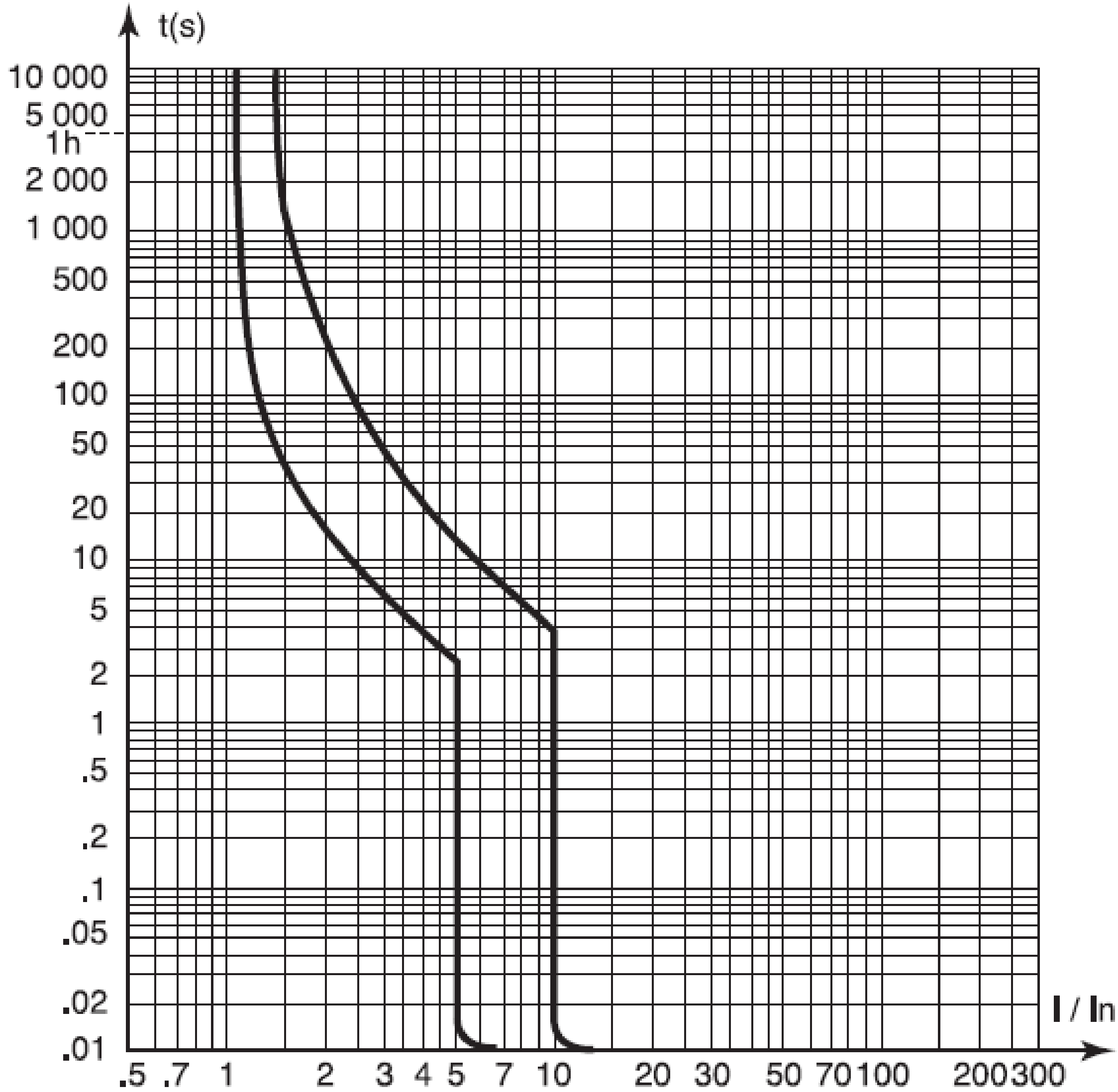


Figure F-10: Time-current characteristics for Merlin Gerin Multi 9 – C60 (C curve) Circuit Breaker (*Schneider Electric* 2014)

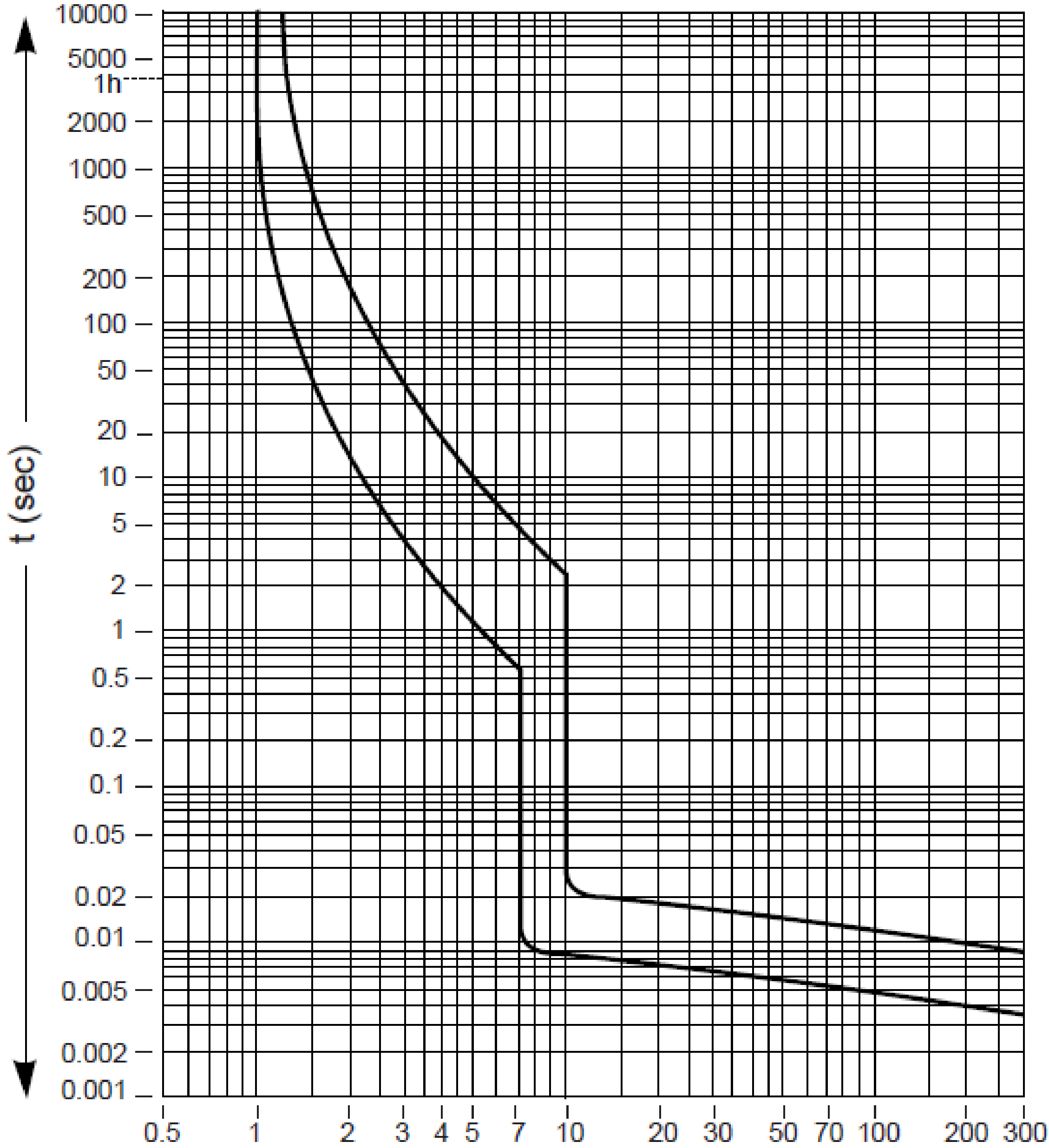
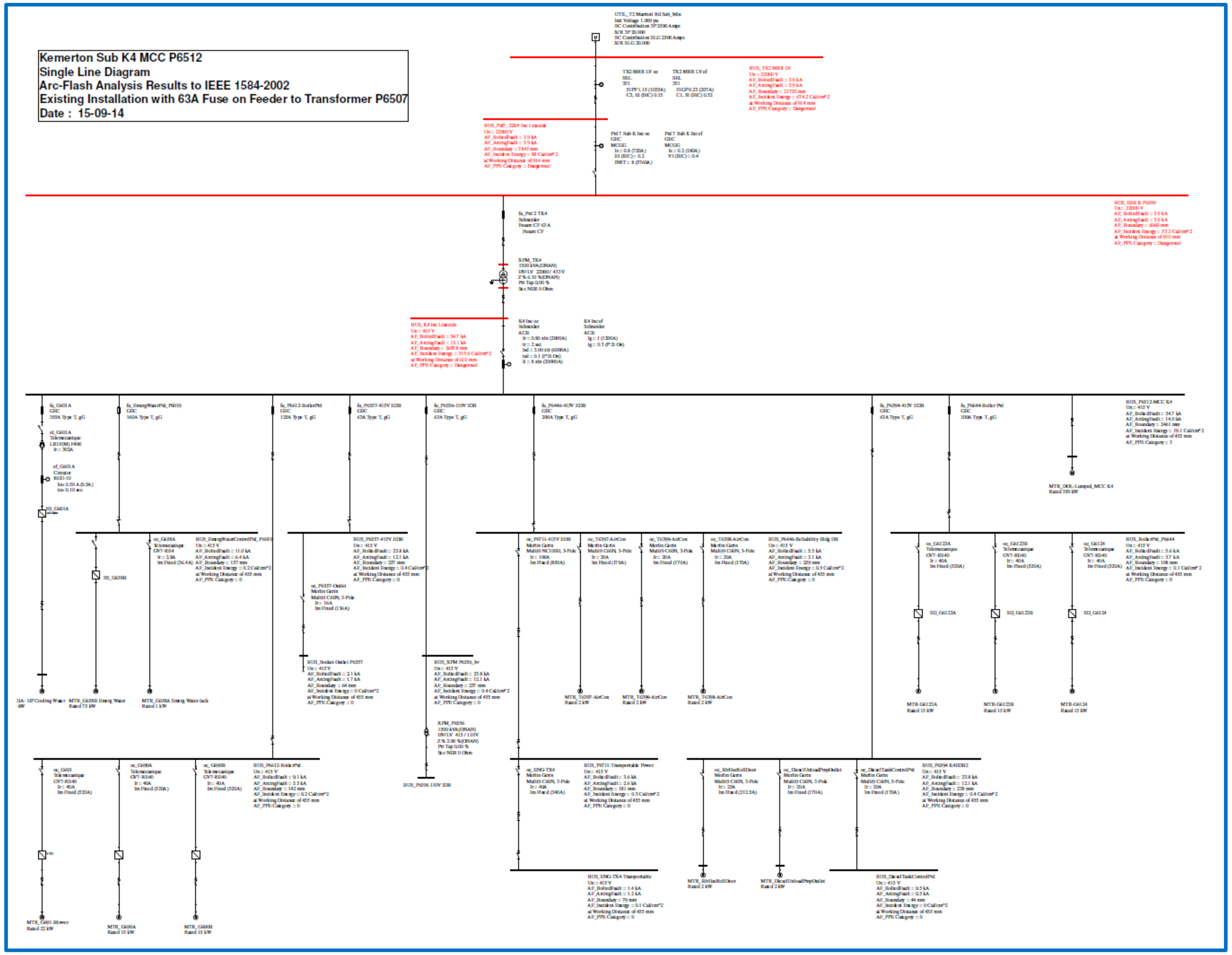
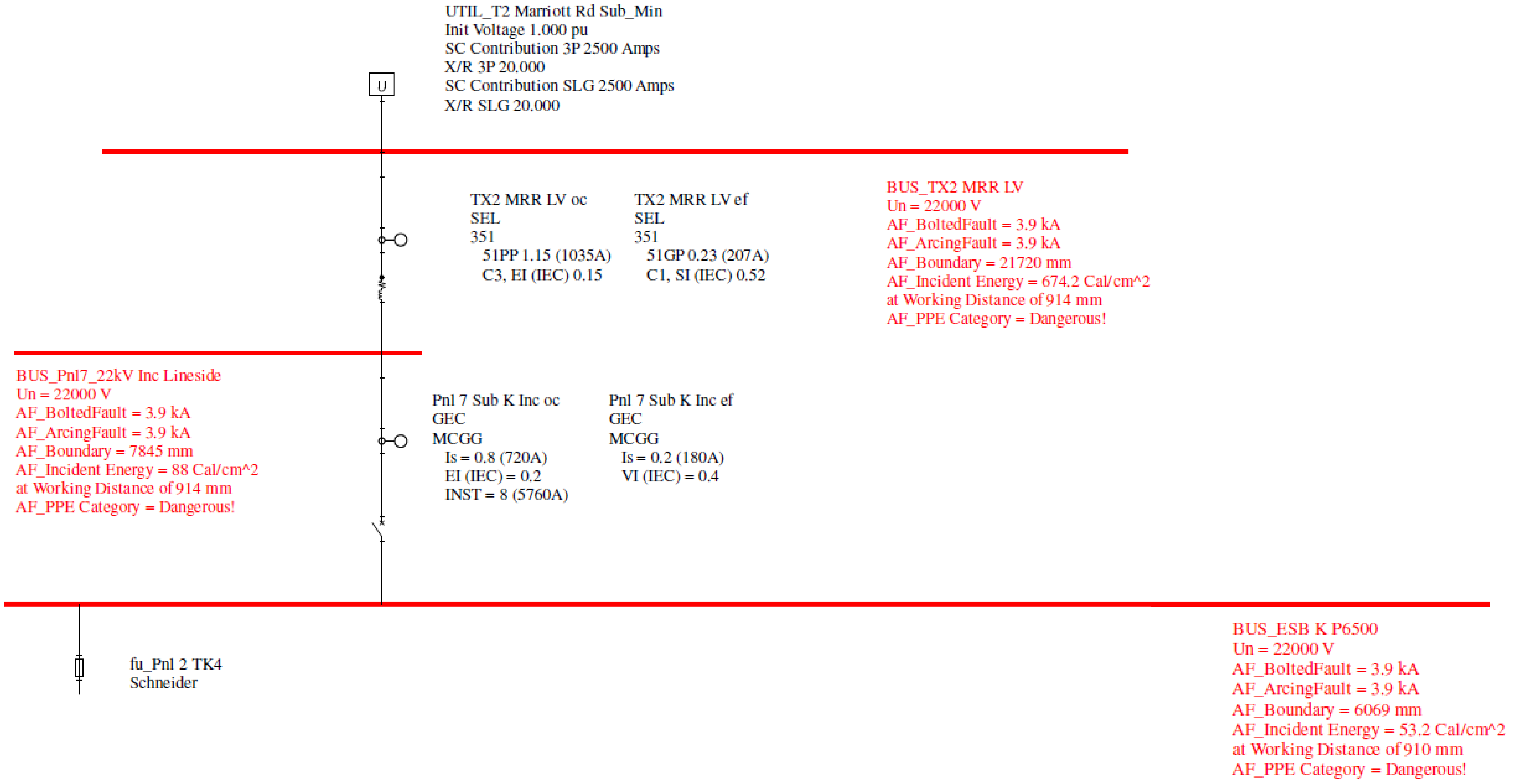


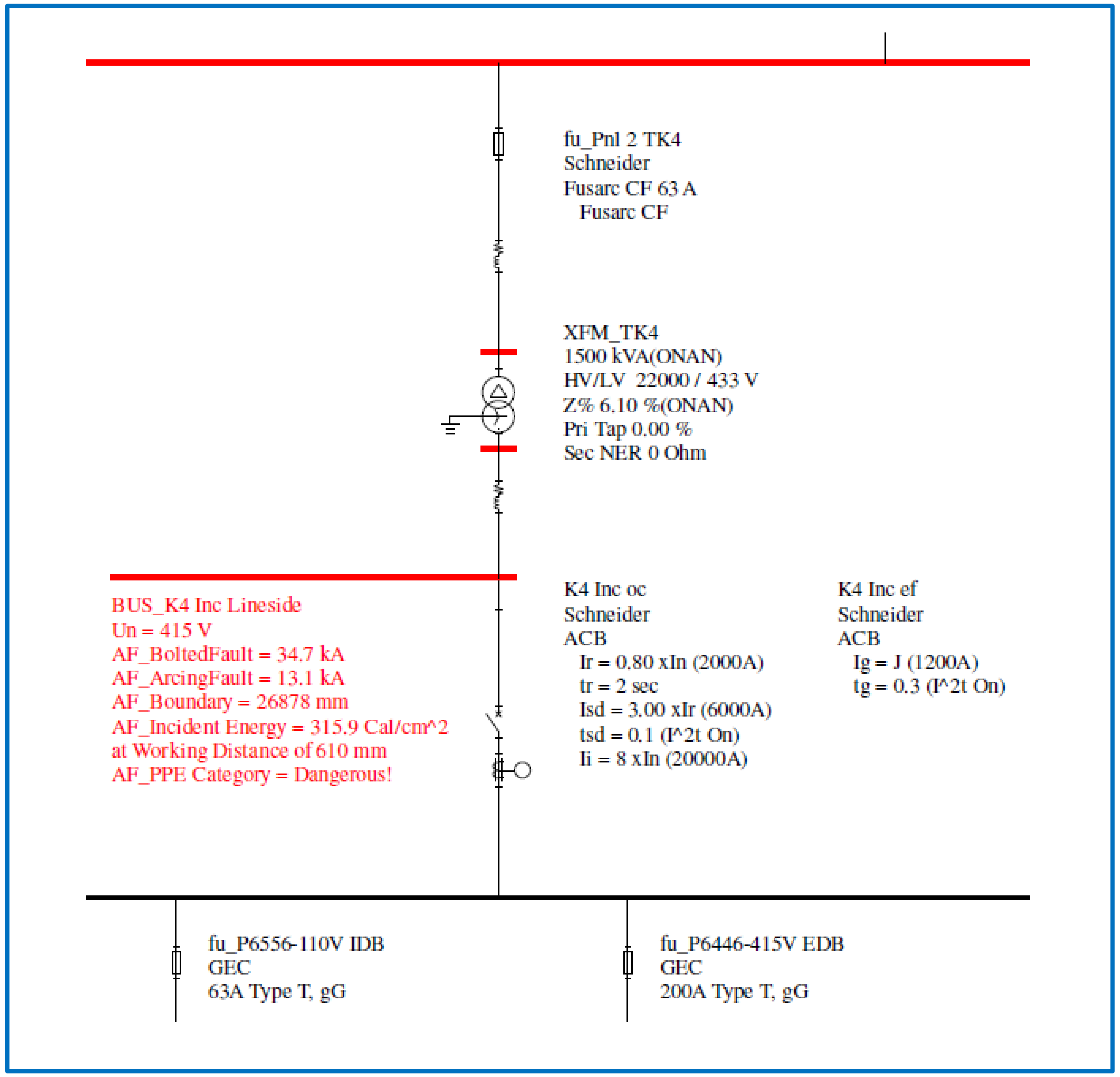
Figure F-11: Time-current characteristics for Merlin Gerin Multi 9 – NC100H (C curve) Circuit Breaker (*Square D* 1998)

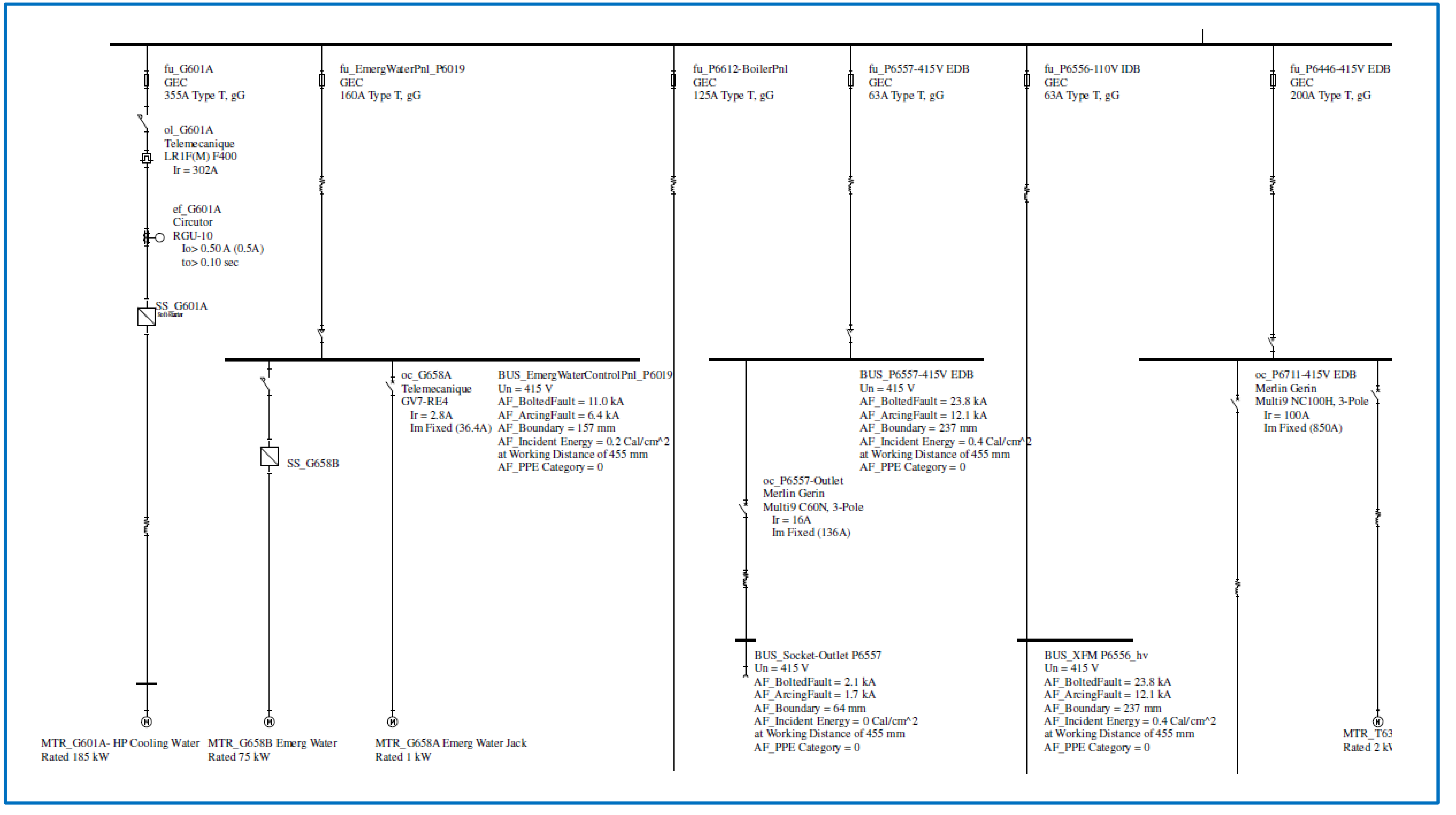
Appendix G Arc Flash Results and PTW Models

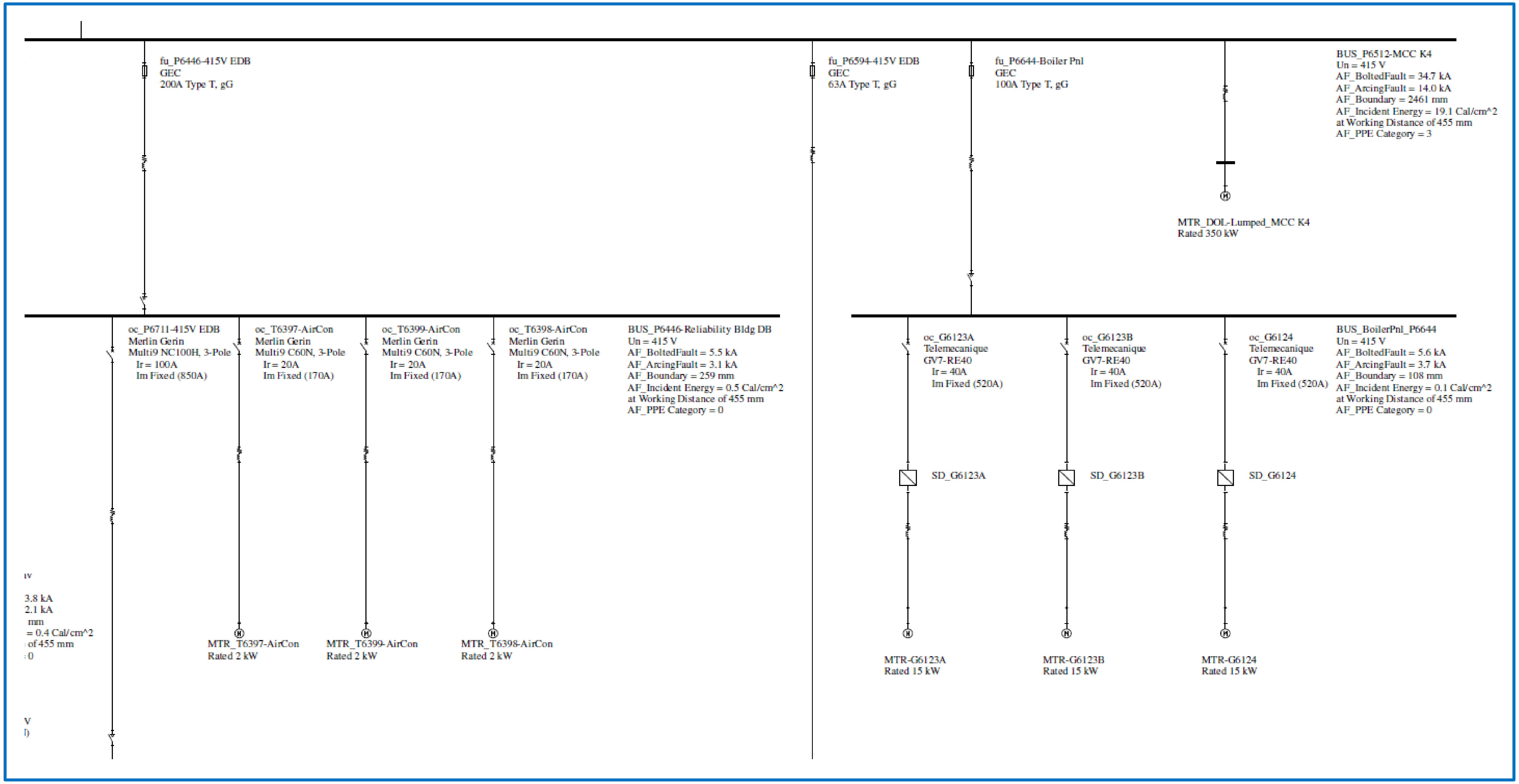


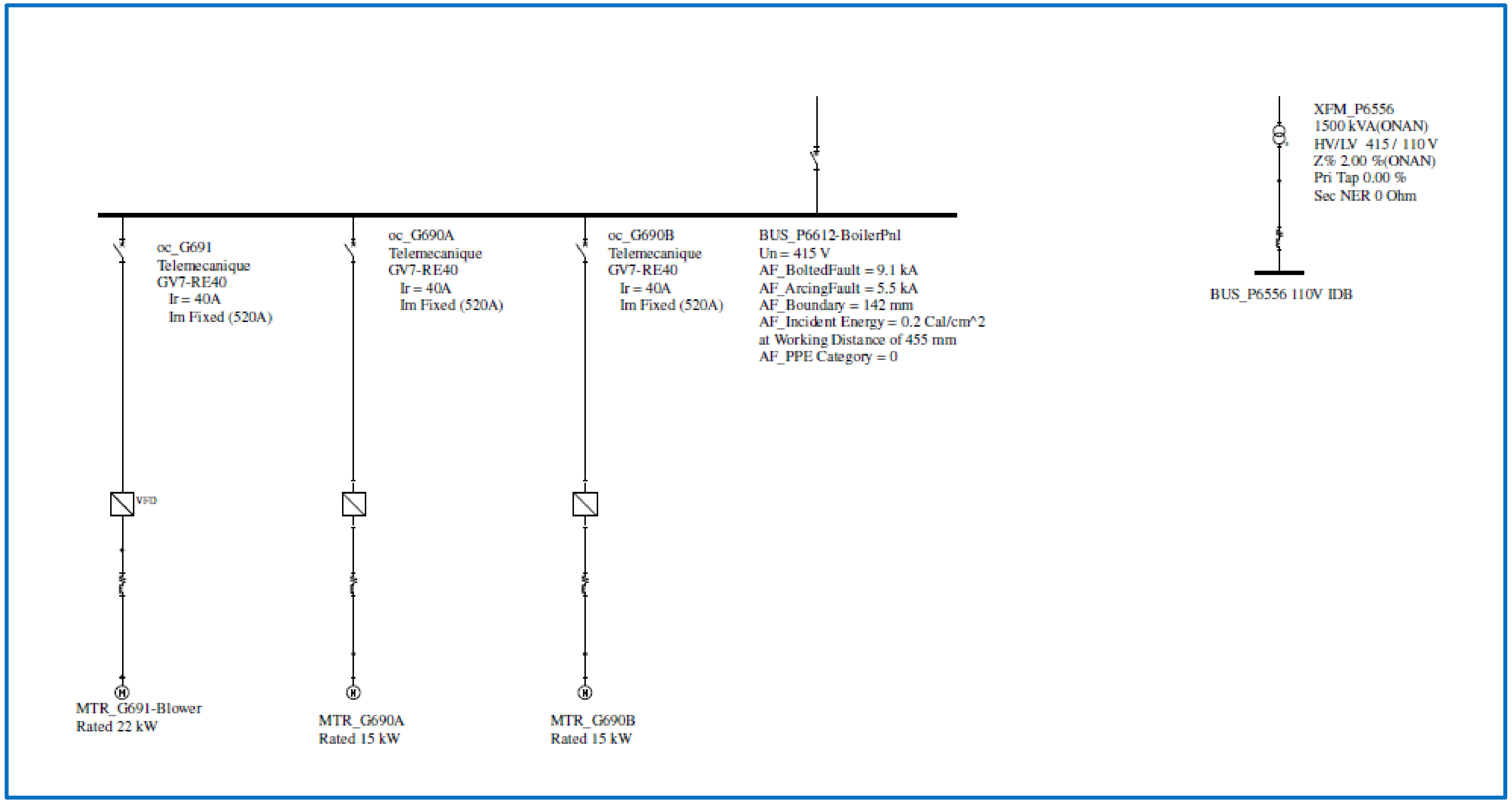
Kemerton Sub K4 MCC P6512
Single Line Diagram
Arc-Flash Analysis Results to IEEE 1584-2002
Existing Installation with 63A Fuse on Feeder to Transformer P6507
Date : 15-09-14




fu_Pnl 2 TK4
Schneider
Fusarc CF 63 A
Fusarc CF
XFM_TK4
1500 kVA(ONAN)
HV/LV 22000 / 433 V
Z% 6.10 %(ONAN)
Pri Tap 0.00 %
Sec NER 0 Ohm
BUS_K4 Inc Lineside
Un = 415 V
AF_BoltedFault = 34.7 kA
AF_ArcingFault = 13.1 kA
AF_Boundary = 26878 mm
AF_Incident Energy = 315.9 Cal/cm^2
at Working Distance of 610 mm
AF_PPE Category = Dangerous!
K4 Inc oc
Schneider
ACB
Ir = 0.80 xIn (2000A)
tr = 2 sec
Isd = 3.00 xIr (6000A)
tsd = 0.1 (I^2t On)
Ii = 8 xIn (20000A)
K4 Inc ef
Schneider
ACB
Ig = J (1200A)
tg = 0.3 (I^2t On)
fu_P6556-110V IDB
GEC
63A Type T, gG
fu_P6446-415V EDB
GEC
200A Type T, gG


fu_G601A
GEC
355A Type T, gG
ol_G601A
Telemecanique
LR1F(M) F400
Ir = 302A
ef_G601A
Circutor
RGU-10
Io> 0.50A (0.5A)
to> 0.10 sec
SS_G601A
fu_EmergWaterPnl_P6019
GEC
160A Type T, gG
SS_G658B
oc_G658A
Telemecanique
GV7-RE4
Ir = 2.8A
Im Fixed (36.4A)
BUS_EmergWaterControlPnl_P6019
Un = 415 V
AF_BoltedFault = 11.0 kA
AF_ArcingFault = 6.4 kA
AF_Boundary = 157 mm
AF_Incident Energy = 0.2 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
MTR_G601A- HP Cooling Water
Rated 185 kW
MTR_G658B Emerg Water
Rated 75 kW
MTR_G658A Emerg Water Jack
Rated 1 kW
fu_P6612-BoilerPnl
GEC
125A Type T, gG
fu_P6557-415V EDB
GEC
63A Type T, gG
fu_P6556-110V IDB
GEC
63A Type T, gG
fu_P6446-415V EDB
GEC
200A Type T, gG
BUS_P6557-415V EDB
Un = 415 V
AF_BoltedFault = 23.8 kA
AF_ArcingFault = 12.1 kA
AF_Boundary = 237 mm
AF_Incident Energy = 0.4 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
oc_P6557-Outlet
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 16A
Im Fixed (136A)
BUS_Socket-Outlet P6557
Un = 415 V
AF_BoltedFault = 2.1 kA
AF_ArcingFault = 1.7 kA
AF_Boundary = 64 mm
AF_Incident Energy = 0 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
BUS_XFM P6556_hv
Un = 415 V
AF_BoltedFault = 23.8 kA
AF_ArcingFault = 12.1 kA
AF_Boundary = 237 mm
AF_Incident Energy = 0.4 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
oc_P6711-415V EDB
Merlin Gerin
Multi9 NC100H, 3-Pole
Ir = 100A
Im Fixed (850A)
MTR_T63
Rated 2 kV


fu_P6446-415V EDB
GEC
200A Type T, gG
fu_P6594-415V EDB
GEC
63A Type T, gG
fu_P6644-Boiler Pnl
GEC
100A Type T, gG
BUS_P6512-MCC K4
Un = 415 V
AF_BoltedFault = 34.7 kA
AF_ArcingFault = 14.0 kA
AF_Boundary = 2461 mm
AF_Incident Energy = 19.1 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 3
MTR_DOL-Lumped_MCC K4
Rated 350 kW
oc_P6711-415V EDB
Merlin Gerin
Multi9 NC100H, 3-Pole
Ir = 100A
Im Fixed (850A)
oc_T6397-AirCon
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
oc_T6399-AirCon
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
oc_T6398-AirCon
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
BUS_P6446-Reliability Bldg DB
Un = 415 V
AF_BoltedFault = 5.5 kA
AF_ArcingFault = 3.1 kA
AF_Boundary = 259 mm
AF_Incident Energy = 0.5 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
oc_G6123A
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
oc_G6123B
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
oc_G6124
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
BUS_BoilerPnl_P6644
Un = 415 V
AF_BoltedFault = 5.6 kA
AF_ArcingFault = 3.7 kA
AF_Boundary = 108 mm
AF_Incident Energy = 0.1 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
SD_G6123A
SD_G6123B
SD_G6124
3.8 kA
2.1 kA
mm
= 0.4 Cal/cm^2
of 455 mm
0
MTR_T6397-AirCon
Rated 2 kW
MTR_T6399-AirCon
Rated 2 kW
MTR_T6398-AirCon
Rated 2 kW
MTR-G6123A
Rated 15 kW
MTR-G6123B
Rated 15 kW
MTR-G6124
Rated 15 kW


XFM_P6556
1500 kVA(ONAN)
HV/LV 415 / 110 V
Z% 2.00 %(ONAN)
Pri Tap 0.00 %
Sec NER 0 Ohm
BUS_P6556 110V IDB
oc_G691
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
oc_G690A
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
oc_G690B
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
BUS_P6612-BoilerPnl
Un = 415 V
AF_BoltedFault = 9.1 kA
AF_ArcingFault = 5.5 kA
AF_Boundary = 142 mm
AF_Incident Energy = 0.2 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
VFD
MTR_G691-Blower
Rated 22 kW
MTR_G690A
Rated 15 kW
MTR_G690B
Rated 15 kW

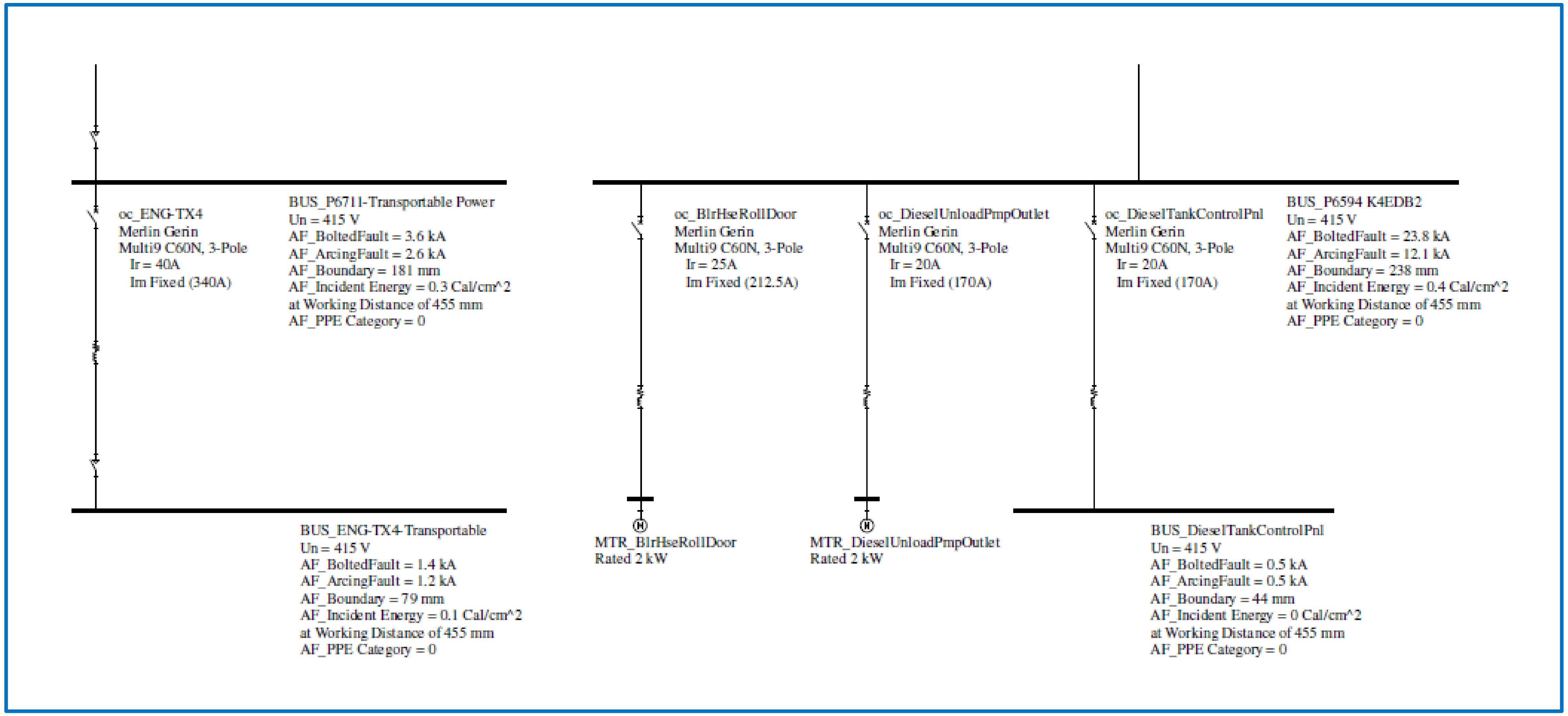

oc_ENG-TX4
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 40A
Im Fixed (340A)
BUS_P6711-Transportable Power
Un = 415 V
AF_BoltedFault = 3.6 kA
AF_ArcingFault = 2.6 kA
AF_Boundary = 181 mm
AF_Incident Energy = 0.3 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
oc_BlrHseRollDoor
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 25A
Im Fixed (212.5A)
oc_DieselUnloadPmpOutlet
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
oc_DieselTankControlPnl
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
BUS_P6594 K4EDB2
Un = 415 V
AF_BoltedFault = 23.8 kA
AF_ArcingFault = 12.1 kA
AF_Boundary = 238 mm
AF_Incident Energy = 0.4 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
BUS_ENG-TX4-Transportable
Un = 415 V
AF_BoltedFault = 1.4 kA
AF_ArcingFault = 1.2 kA
AF_Boundary = 79 mm
AF_Incident Energy = 0.1 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
MTR_BlrHseRollDoor
Rated 2 kW
MTR_DieselUnloadPmpOutlet
Rated 2 kW
BUS_DieselTankControlPnl
Un = 415 V
AF_BoltedFault = 0.5 kA
AF_ArcingFault = 0.5 kA
AF_Boundary = 44 mm
AF_Incident Energy = 0 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0

Table G-1: Arc Flash Results for the existing network (minimum utility fault level scenario)

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_BoilerPnl_P6644	fu_P6644-Boiler Pnl	0.415	5.57	3.68	5.21	3.44	0.01	0.000	Yes	PNL	25	108	455	0.11	Category 0
BUS_BoilerPnl_P6644	oc_G6123A	0.415	5.57	3.68	0.19	0.13	0.06	0.000	Yes	PNL	25	148	455	0.19	Category 0
BUS_BoilerPnl_P6644	oc_G6123B	0.415	5.57	3.68	0.19	0.13	0.06	0.000	Yes	PNL	25	148	455	0.19	Category 0
BUS_BoilerPnl_P6644	oc_G6124	0.415	5.57	3.68	0.19	0.13	0.06	0.000	Yes	PNL	25	148	455	0.19	Category 0
BUS_DieselTankControlPnl	oc_DieselTankControlPnl	0.415	0.55	0.55	0.55	0.55	0.02	0.000	Yes	PNL	25	44	455	0.01	Category 0 (*N11)
BUS_EmergWaterControlPnl_P6019	fu_EmergWaterPnl_P6019	0.415	11.02	6.44	10.45	6.10	0.01	0.000	Yes	PNL	25	157	455	0.21	Category 0
BUS_EmergWaterControlPnl_P6019	oc_G658A	0.415	11.02	6.44	0.02	0.01	0.06	0.000	Yes	PNL	25	201	455	0.31	Category 0
BUS_ENG-TX4-Transportable	oc_ENG-TX4	0.415	1.40	1.19	1.40	1.19	0.02	0.000	Yes	PNL	25	79	455	0.07	Category 0
BUS_ESB K P6500	fu_Pnl 2 TK4	22.00	3.94	3.94	0.12	0.12	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 1 Lime Fu	22.00	3.94	3.94	0.03	0.03	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 12 TK2A_fu	22.00	3.94	3.94	0.11	0.11	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 13 TK3A_fu	22.00	3.94	3.94	0.12	0.12	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 3 TK1A_fu	22.00	3.94	3.94	0.17	0.17	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 4 TK3B_fu	22.00	3.94	3.94	0.12	0.12	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 5 TK2B_fu	22.00	3.94	3.94	0.17	0.17	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 8 CIG/BOC oc	22.00	3.94	3.94	0.62	0.62	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 7 Sub K Inc oc	22.00	3.94	3.94	2.50	2.50	1.451	0.080	Yes	SWG	152	6069	910	53	Dangerous! (*N11)
BUS_K4 Inc Lineside	K4 Inc oc	0.415	34.71	13.08	7.75	3.43	0.06	0.000	Yes	SWG	32	869	610	2.0	Category 1
BUS_K4 Inc Lineside	fu_Pnl 2 TK4	0.415	34.71	13.08	28.17	10.61	14.77	0.000	Yes	SWG	32	26878	610	316	Dangerous! (*N3)

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_P6446-Reliability Bldg DB	fu_P6446-415V EDB	0.415	5.50	3.10	5.45	3.07	0.05	0.000	Yes	PNL	25	259	455	0.47	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6397-AirCon	0.415	5.50	3.10	0.03	0.02	0.06	0.000	Yes	PNL	25	259	455	0.47	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6398-AirCon	0.415	5.50	3.10	0.03	0.02	0.06	0.000	Yes	PNL	25	259	455	0.47	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6399-AirCon	0.415	5.50	3.10	0.03	0.02	0.06	0.000	Yes	PNL	25	259	455	0.47	Category 0 (*N3)
BUS_P6512-MCC K4	fu_EmergWaterPnl_P6019	0.415	34.71	13.98	0.81	0.38	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	fu_P6446-415V EDB	0.415	34.71	13.98	0.09	0.04	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	fu_P6594-415V EDB	0.415	34.71	13.98	0.06	0.03	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	fu_P6612-BoilerPnl	0.415	34.71	13.98	0.38	0.18	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	fu_P6644-Boiler Pnl	0.415	34.71	13.98	0.54	0.26	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	ol_G601A	0.415	34.71	13.98	2.14	1.02	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	K4 Inc oc	0.415	34.71	13.98	27.00	10.88	0.507	0.000	Yes	PNL	25	2461	455	19	Category 3 (*N3)
BUS_P6557-415V EDB	fu_P6557-415V EDB	0.415	23.82	12.09	23.82	12.09	0.01	0.000	Yes	PNL	25	237	455	0.41	Category 0
BUS_P6594 K4EDB2	fu_P6594-415V EDB	0.415	23.85	12.10	23.79	12.07	0.01	0.000	Yes	PNL	25	237	455	0.41	Category 0
BUS_P6594 K4EDB2	oc_BlrHseRollDoor	0.415	23.85	12.10	0.03	0.02	0.06	0.000	Yes	PNL	25	240	455	0.42	Category 0
BUS_P6594 K4EDB2	oc_DieselUnloadPmpOutlet	0.415	23.85	12.10	0.03	0.02	0.06	0.000	Yes	PNL	25	240	455	0.42	Category 0
BUS_P6612-BoilerPnl	fu_P6612-BoilerPnl	0.415	9.14	5.52	8.86	5.36	0.01	0.000	Yes	PNL	25	142	455	0.18	Category 0
BUS_P6612-BoilerPnl	oc_G690A	0.415	9.14	5.52	0.19	0.12	0.06	0.000	Yes	PNL	25	165	455	0.23	Category 0
BUS_P6612-BoilerPnl	oc_G690B	0.415	9.14	5.52	0.19	0.12	0.06	0.000	Yes	PNL	25	165	455	0.23	Category 0
BUS_P6612-BoilerPnl	oc_G691	0.415	9.14	5.52	0.00	0.00	0.06	0.000	Yes	PNL	25	165	455	0.23	Category 0

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_P6711-Transportable Power	oc_P6711-415V EDB	0.415	3.60	2.58	3.60	2.58	0.034	0.000	Yes	PNL	25	181	455	0.26	Category 0
BUS_Socket-Outlet P6557	fu_P6557-415V EDB (oc_P6557-Outlet)	0.415	2.10	1.66	2.10	1.66	0.01	0.000	Yes	PNL	25	64	455	0.05	Category 0 (*N5)
BUS_XFM P6556_hv	fu_P6556-110V IDB	0.415	23.82	12.09	23.82	12.09	0.01	0.000	Yes	PNL	25	237	455	0.41	Category 0

Table G-2: Arc Flash Risk category matrix summary for the results for the existing network (minimum utility fault level scenario)

Hazardous Risk Category	Incident Energy Value (cal/cm^2)	Hazardous Risk Category Description	Number in each Category	Notes (*N)
Category 0: Non-melting, Flammable Materials with Weight >= 4.5 oz/sq yd	0.0 - 1.2 cal/cm^2	Category 0: Non-melting, Flammable Materials with Weight >= 4.5 oz/sq yd, Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Safety glasses, Non-melting or untreated natural fiber (cotton/wool/rayon/silk > 4.5 oz/sq yd), shirt (long-sleeve), pants (long)., > 50V voltage rated tools + Class 0 (minimum) gloves, Dielectric shoes or insulating mat (step and touch potential).	#Category 0 = 11	(*N11) - Out of IEEE 1584 Range, Lee Equation Used. Applicable for Open Air only. Existing Equipment type is not Open Air!
Category 1: Arc-rated FR Shirt & Pants	1.2 - 4.0 cal/cm^2	Category 1: Arc-rated FR Shirt & Pants, Hardhat + Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield., 4 cal/sq cm, FR shirt (long-sleeve) plus FR pants (long), or FR coverall, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash) as needed., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 1 = 0	(*N3) - Arcing Current Low Tolerances Used
Category 2: Arc-rated FR Shirt & Pants	4.0 - 8.0 cal/cm^2	Category 2: Arc-rated FR Shirt & Pants, Hardhat + Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 8 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 2 = 0	(*N5) - Miscoordinated, Upstream Device Tripped
Category 3: Arc-rated FR Shirt & Pants & Arc Flash Suit	8.0 - 25.0 cal/cm^2	Category 3: Arc-rated FR Shirt & Pants & Arc Flash Suit, Hardhat + FR hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 25 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 3 = 1	For additional information refer to NFPA 70 E, Standard for Electrical Safety in the Workplace.
Category 4: Arc-rated FR Shirt & Pants & Arc Flash Suit	25.0 - 40.0 cal/cm^2	Category 4: Arc-rated FR Shirt & Pants & Arc Flash Suit, Hardhat + FR hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 40 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 4 = 0	Device with 90% Cleared Fault Threshold
Category Dangerous!: No FR Category Found	40.0 - 999.0 cal/cm^2	Category Dangerous!: No FR Category Found, Do not work on live!, No FR Category Found, Arc Flash Incident Energy Exceeds the Rating of Category 4 PPE., No FR Category Found	#Danger = 2	NFPA 70E 2012 Annex D.7 - IEEE 1584 Bus Report (- 90% Cleared Fault Threshold, include Ind. Motors for 3.0 Cycles), miscoordination checked

Table G-3: Arc Flash Results for the existing network (maximum utility fault level scenario)

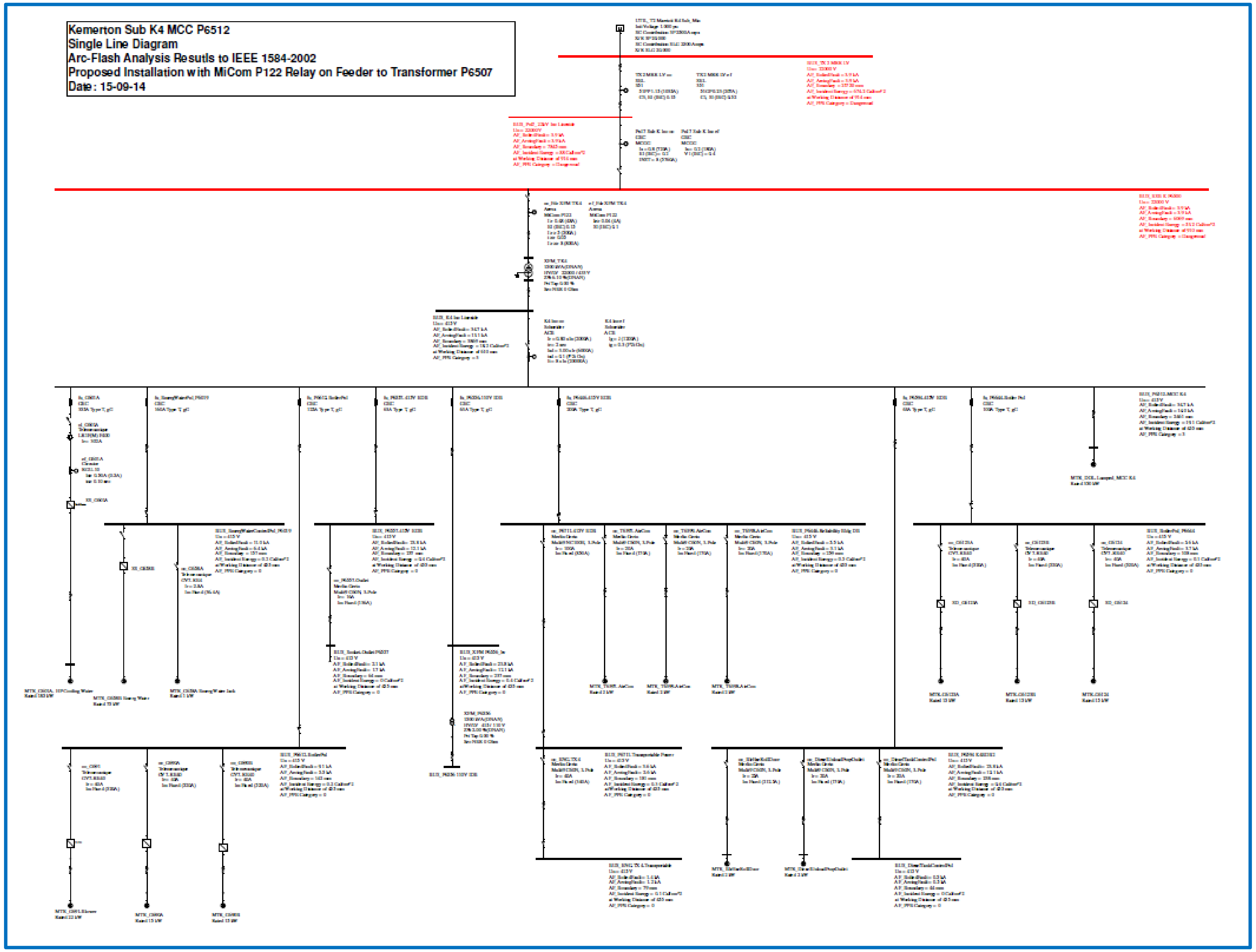
Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_BoilerPnl_P6644	fu_P6644-Boiler Pnl	0.415	5.45	3.62	5.10	3.39	0.01	0.000	Yes	PNL	25	107	455	0.11	Category 0
BUS_BoilerPnl_P6644	oc_G6123A	0.415	5.45	3.62	0.19	0.12	0.06	0.000	Yes	PNL	25	146	455	0.19	Category 0
BUS_BoilerPnl_P6644	oc_G6123B	0.415	5.45	3.62	0.19	0.12	0.06	0.000	Yes	PNL	25	146	455	0.19	Category 0
BUS_BoilerPnl_P6644	oc_G6124	0.415	5.45	3.62	0.19	0.12	0.06	0.000	Yes	PNL	25	146	455	0.19	Category 0
BUS_DieselTankControlPnl	oc_DieselTankControlPnl	0.415	0.54	0.54	0.54	0.54	0.02	0.000	Yes	PNL	25	44	455	0.01	Category 0 (*N11)
BUS_EmergWaterControlPnl_P6019	fu_EmergWaterPnl_P6019	0.415	10.85	6.35	10.29	6.03	0.01	0.000	Yes	PNL	25	155	455	0.20	Category 0
BUS_EmergWaterControlPnl_P6019	oc_G658A	0.415	10.85	6.35	0.02	0.01	0.06	0.000	Yes	PNL	25	199	455	0.31	Category 0
BUS_ENG-TX4-Transportable	oc_ENG-TX4	0.415	1.37	1.17	1.37	1.17	0.02	0.000	Yes	PNL	25	78	455	0.07	Category 0
BUS_ESB K P6500	fu_Pnl 2 TK4	22.00	5.81	5.81	0.12	0.12	0.06	0.000	Yes	SWG	152	1812	910	4.7	Category 2 (*N11)
BUS_ESB K P6500	Pnl 1 Lime Fu	22.00	5.81	5.81	0.03	0.03	0.06	0.000	Yes	SWG	152	1812	910	4.7	Category 2 (*N11)
BUS_ESB K P6500	Pnl 12 TK2A_fu	22.00	5.81	5.81	0.11	0.11	0.06	0.000	Yes	SWG	152	1812	910	4.7	Category 2 (*N11)
BUS_ESB K P6500	Pnl 13 TK3A_fu	22.00	5.81	5.81	0.12	0.12	0.06	0.000	Yes	SWG	152	1812	910	4.7	Category 2 (*N11)
BUS_ESB K P6500	Pnl 3 TK1A_fu	22.00	5.81	5.81	0.17	0.17	0.06	0.000	Yes	SWG	152	1812	910	4.7	Category 2 (*N11)
BUS_ESB K P6500	Pnl 4 TK3B_fu	22.00	5.81	5.81	0.12	0.12	0.06	0.000	Yes	SWG	152	1812	910	4.7	Category 2 (*N11)
BUS_ESB K P6500	Pnl 5 TK2B_fu	22.00	5.81	5.81	0.17	0.17	0.06	0.000	Yes	SWG	152	1812	910	4.7	Category 2 (*N11)
BUS_ESB K P6500	Pnl 8 CIG/BOC oc	22.00	5.81	5.81	0.63	0.63	0.06	0.000	Yes	SWG	152	1812	910	4.7	Category 2 (*N11)
BUS_ESB K P6500	Pnl 7 Sub K Inc oc	22.00	5.81	5.81	4.34	4.34	0.452	0.080	Yes	SWG	152	4754	910	33	Category 4 (*N11)
BUS_K4 Inc Lineside	K4 Inc oc	0.415	35.14	13.21	7.57	3.35	0.06	0.000	Yes	SWG	32	875	610	2.0	Category 1
BUS_K4 Inc Lineside	fu_Pnl 2 TK4	0.415	35.14	13.21	28.80	10.82	11.921	0.000	Yes	SWG	32	24099	610	269	Dangerous! (*N3)

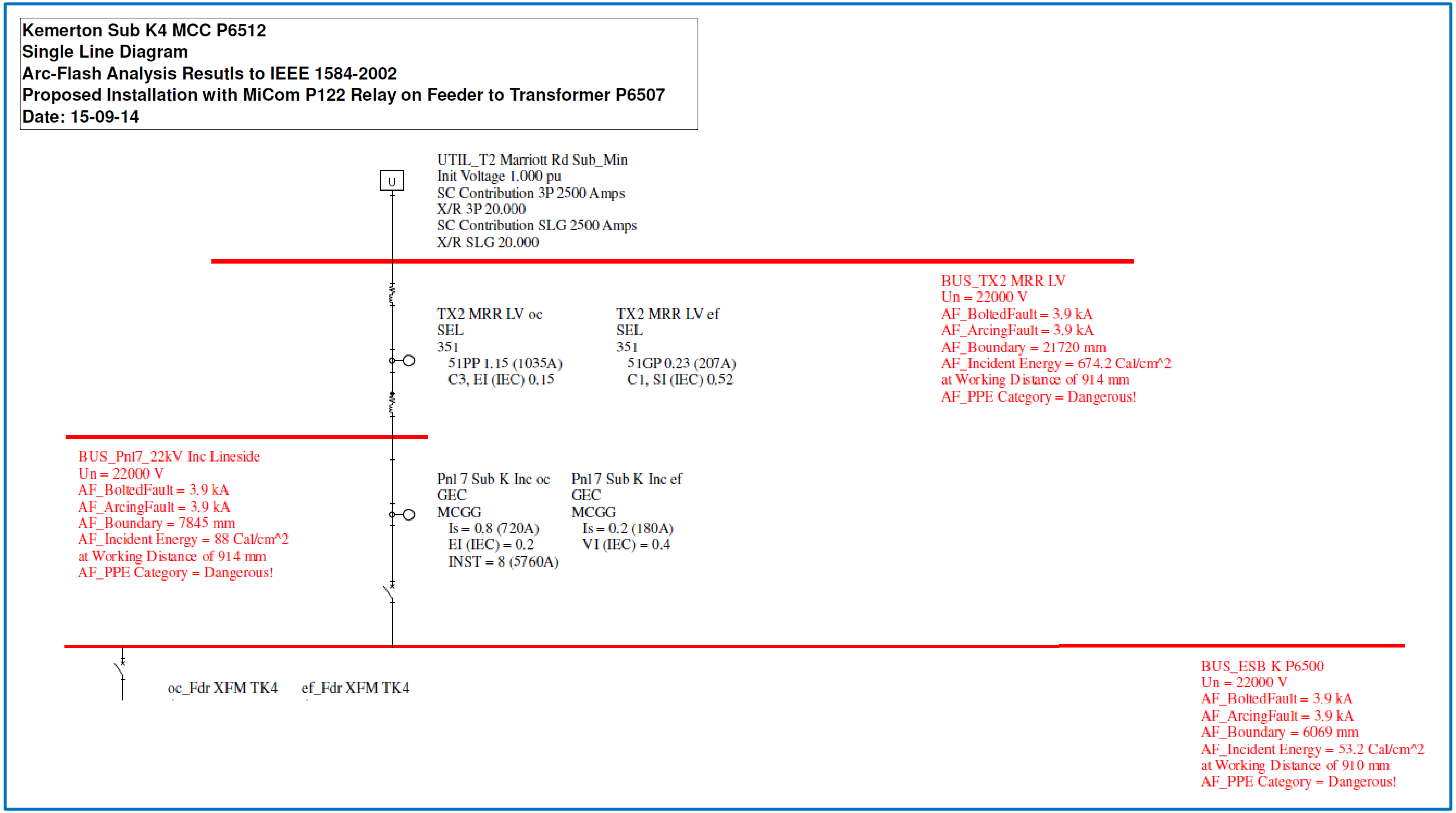
Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_P6446-Reliability Bldg DB	fu_P6446-415V EDB	0.415	5.40	3.05	5.34	3.02	0.053	0.000	Yes	PNL	25	265	455	0.49	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6397-AirCon	0.415	5.40	3.05	0.03	0.02	0.06	0.000	Yes	PNL	25	265	455	0.49	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6398-AirCon	0.415	5.40	3.05	0.03	0.02	0.06	0.000	Yes	PNL	25	265	455	0.49	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6399-AirCon	0.415	5.40	3.05	0.03	0.02	0.06	0.000	Yes	PNL	25	265	455	0.49	Category 0 (*N3)
BUS_P6512-MCC K4	fu_EmergWaterPnl_P6019	0.415	35.14	14.13	0.79	0.37	0.06	0.000	Yes	PNL	25	872	455	3.5	Category 1
BUS_P6512-MCC K4	fu_P6446-415V EDB	0.415	35.14	14.13	0.09	0.04	0.06	0.000	Yes	PNL	25	872	455	3.5	Category 1
BUS_P6512-MCC K4	fu_P6594-415V EDB	0.415	35.14	14.13	0.06	0.03	0.06	0.000	Yes	PNL	25	872	455	3.5	Category 1
BUS_P6512-MCC K4	fu_P6612-BoilerPnl	0.415	35.14	14.13	0.37	0.17	0.06	0.000	Yes	PNL	25	872	455	3.5	Category 1
BUS_P6512-MCC K4	fu_P6644-Boiler Pnl	0.415	35.14	14.13	0.53	0.25	0.06	0.000	Yes	PNL	25	872	455	3.5	Category 1
BUS_P6512-MCC K4	ol_G601A	0.415	35.14	14.13	2.10	0.99	0.06	0.000	Yes	PNL	25	872	455	3.5	Category 1
BUS_P6512-MCC K4	K4 Inc oc	0.415	35.14	14.13	27.61	11.10	0.487	0.000	Yes	PNL	25	2476	455	19	Category 3 (*N3)
BUS_P6557-415V EDB	fu_P6557-415V EDB	0.415	23.77	12.07	23.77	12.07	0.01	0.000	Yes	PNL	25	237	455	0.41	Category 0
BUS_P6594 K4EDB2	fu_P6594-415V EDB	0.415	23.80	12.08	23.75	12.06	0.01	0.000	Yes	PNL	25	237	455	0.41	Category 0
BUS_P6594 K4EDB2	oc_BlrHseRollDoor	0.415	23.80	12.08	0.03	0.02	0.06	0.000	Yes	PNL	25	240	455	0.42	Category 0
BUS_P6594 K4EDB2	oc_DieselUnloadPmpOutlet	0.415	23.80	12.08	0.03	0.02	0.06	0.000	Yes	PNL	25	240	455	0.42	Category 0
BUS_P6612-BoilerPnl	fu_P6612-BoilerPnl	0.415	8.98	5.44	8.71	5.28	0.01	0.000	Yes	PNL	25	140	455	0.17	Category 0
BUS_P6612-BoilerPnl	oc_G690A	0.415	8.98	5.44	0.19	0.11	0.06	0.000	Yes	PNL	25	163	455	0.22	Category 0
BUS_P6612-BoilerPnl	oc_G690B	0.415	8.98	5.44	0.19	0.11	0.06	0.000	Yes	PNL	25	163	455	0.22	Category 0

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_P6711-Transportable Power	oc_P6711-415V EDB	0.415	3.53	2.53	3.53	2.53	0.034	0.000	Yes	PNL	25	179	455	0.26	Category 0
BUS_Socket-Outlet P6557	fu_P6557-415V EDB (oc_P6557-Outlet)	0.415	2.06	1.63	2.06	1.63	0.01	0.000	Yes	PNL	25	63	455	0.05	Category 0 (*N5)
BUS_XFM P6556_hv	fu_P6556-110V IDB	0.415	23.77	12.07	23.77	12.07	0.01	0.000	Yes	PNL	25	237	455	0.41	Category 0

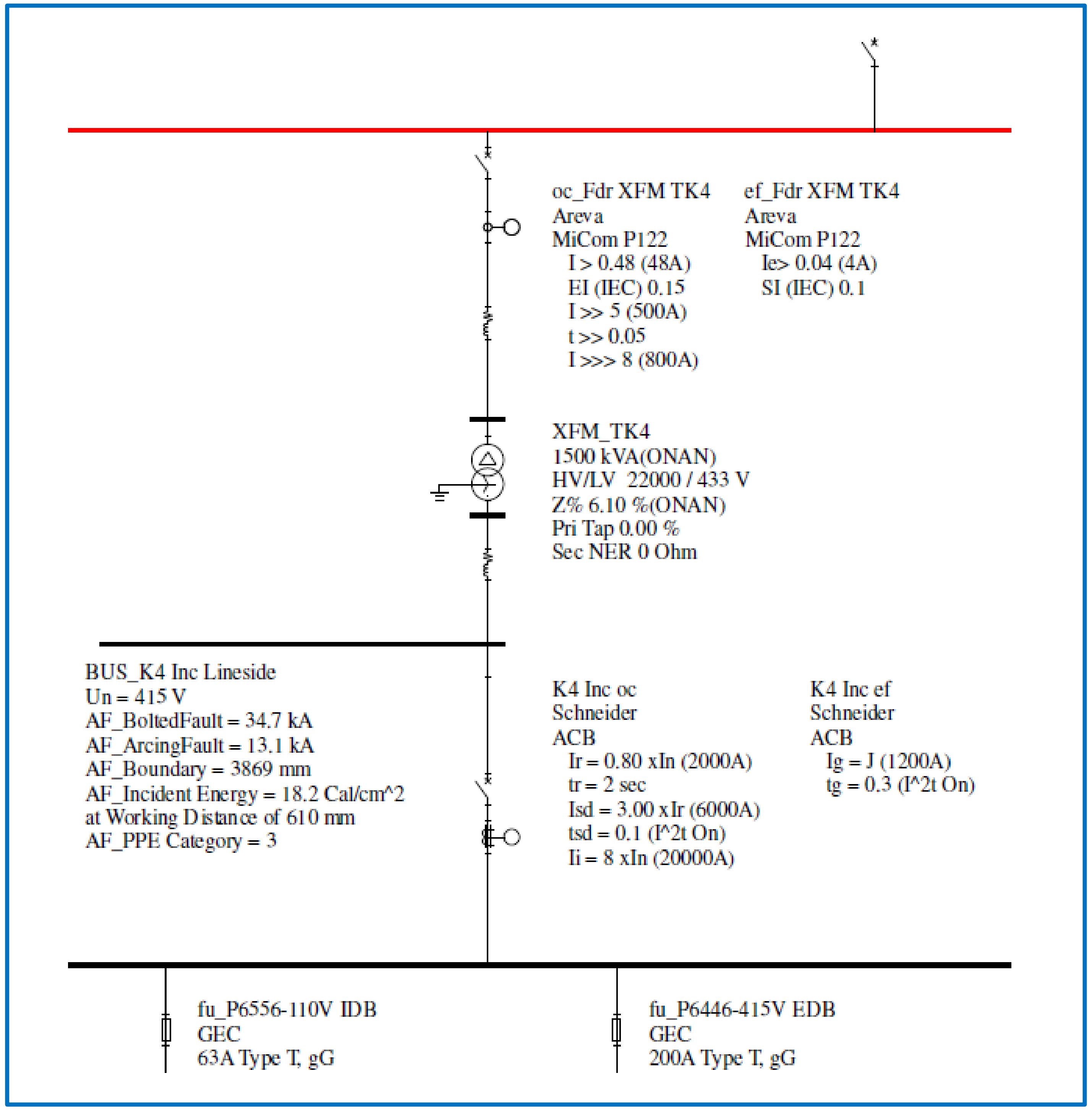
Table G-4: Arc Flash Risk category matrix summary for the results for the existing network (maximum utility fault level scenario)

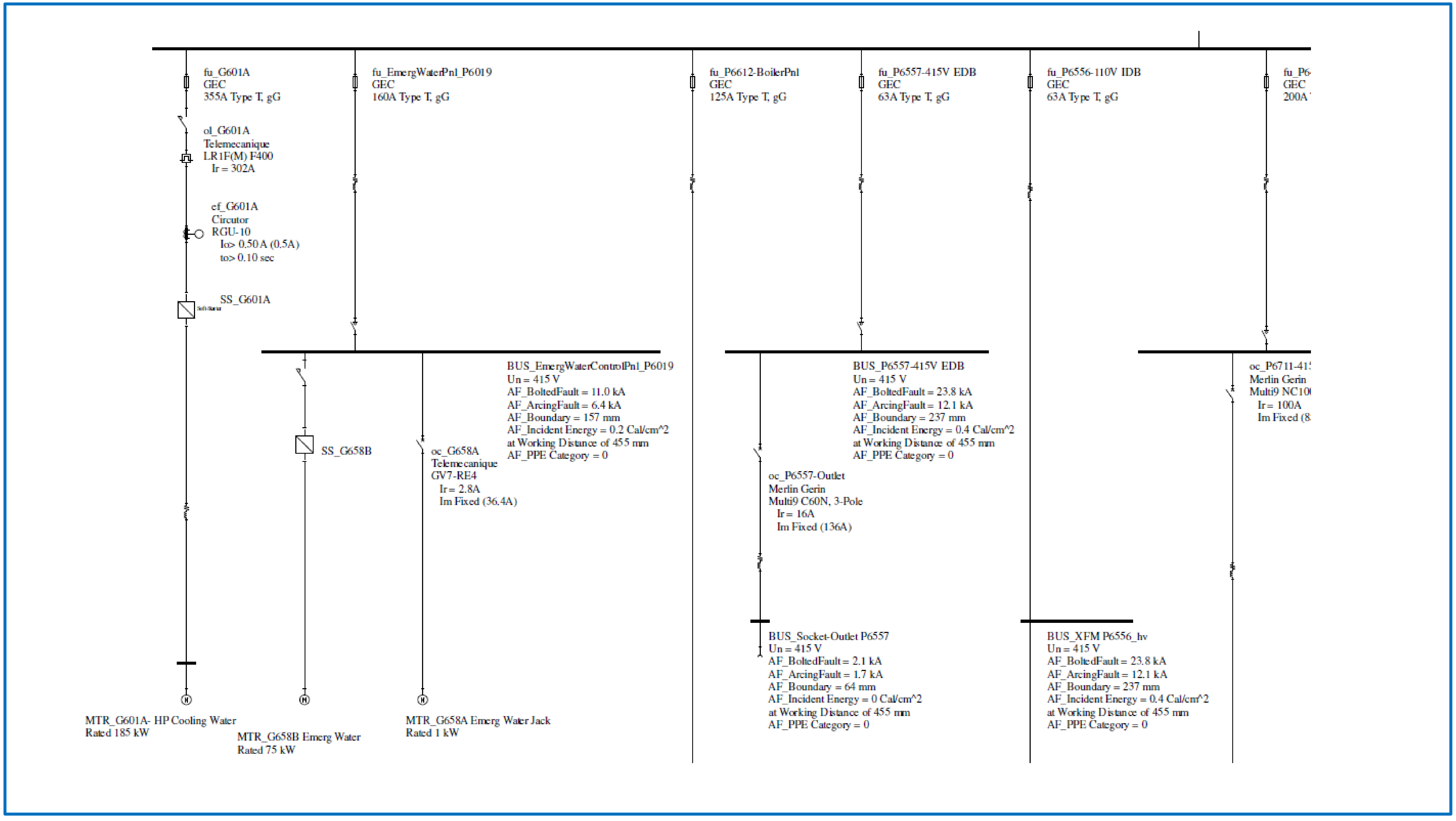
Hazardous Risk Category	Incident Energy Value (cal/cm^2)	Hazardous Risk Category Description	Number in each Category	Notes (*N)
Category 0: Non-melting, Flammable Materials with Weight >= 4.5 oz/sq yd	0.0 - 1.2 cal/cm^2	Category 0: Non-melting, Flammable Materials with Weight >= 4.5 oz/sq yd, Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Safety glasses, Non-melting or untreated natural fiber (cotton/wool/rayon/silk > 4.5 oz/sq yd), shirt (long-sleeve), pants (long)., > 50V voltage rated tools + Class 0 (minimum) gloves, Dielectric shoes or insulating mat (step and touch potential).	#Category 0 = 11	(*N11) - Out of IEEE 1584 Range, Lee Equation Used. Applicable for Open Air only. Existing Equipment type is not Open Air!
Category 1: Arc-rated FR Shirt & Pants	1.2 - 4.0 cal/cm^2	Category 1: Arc-rated FR Shirt & Pants, Hardhat + Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield., 4 cal/sq cm, FR shirt (long-sleeve) plus FR pants (long), or FR coverall, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash) as needed., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 1 = 0	(*N3) - Arcing Current Low Tolerances Used
Category 2: Arc-rated FR Shirt & Pants	4.0 - 8.0 cal/cm^2	Category 2: Arc-rated FR Shirt & Pants, Hardhat + Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 8 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 2 = 0	(*N5) - Miscoordinated, Upstream Device Tripped
Category 3: Arc-rated FR Shirt & Pants & Arc Flash Suit	8.0 - 25.0 cal/cm^2	Category 3: Arc-rated FR Shirt & Pants & Arc Flash Suit, Hardhat + FR hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 25 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 3 = 1	For additional information refer to NFPA 70 E, Standard for Electrical Safety in the Workplace.
Category 4: Arc-rated FR Shirt & Pants & Arc Flash Suit	25.0 - 40.0 cal/cm^2	Category 4: Arc-rated FR Shirt & Pants & Arc Flash Suit, Hardhat + FR hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 40 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 4 = 1	Device with 90% Cleared Fault Threshold
Category Dangerous!: No FR Category Found	40.0 - 999.0 cal/cm^2	Category Dangerous!: No FR Category Found, Do not work on live!, No FR Category Found, Arc Flash Incident Energy Exceeds the Rating of Category 4 PPE., No FR Category Found	#Danger = 1	NFPA 70E 2012 Annex D.7 - IEEE 1584 Bus Report (- 90% Cleared Fault Threshold, include Ind. Motors for 3.0 Cycles), miscoordination checked

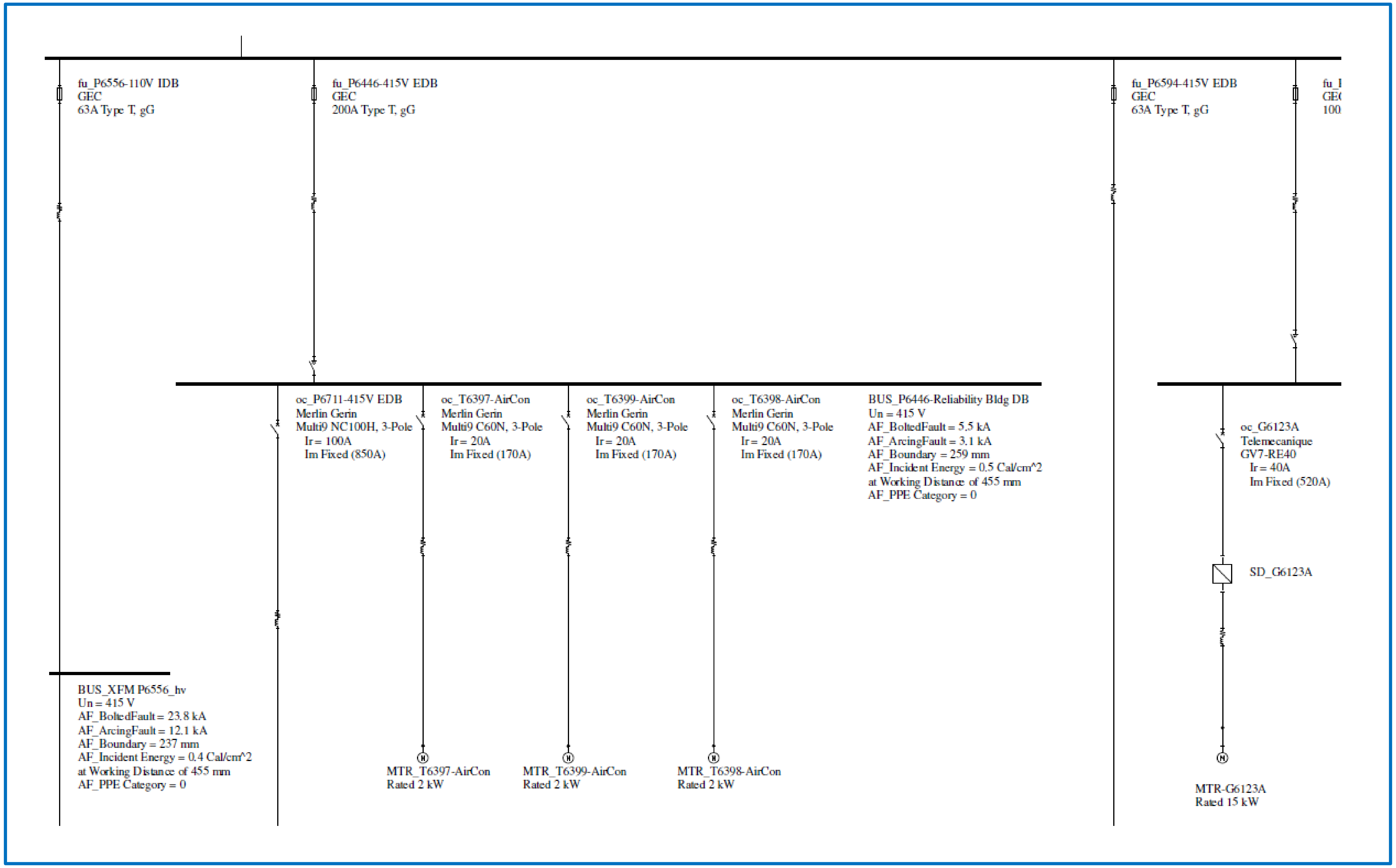

Kemerton Sub K4 MCC P6512
Single Line Diagram
Arc-Flash Analysis Resutls to IEEE 1584-2002
Proposed Installation with MiCom P122 Relay on Feeder to Transformer P6507
Date: 15-09-14

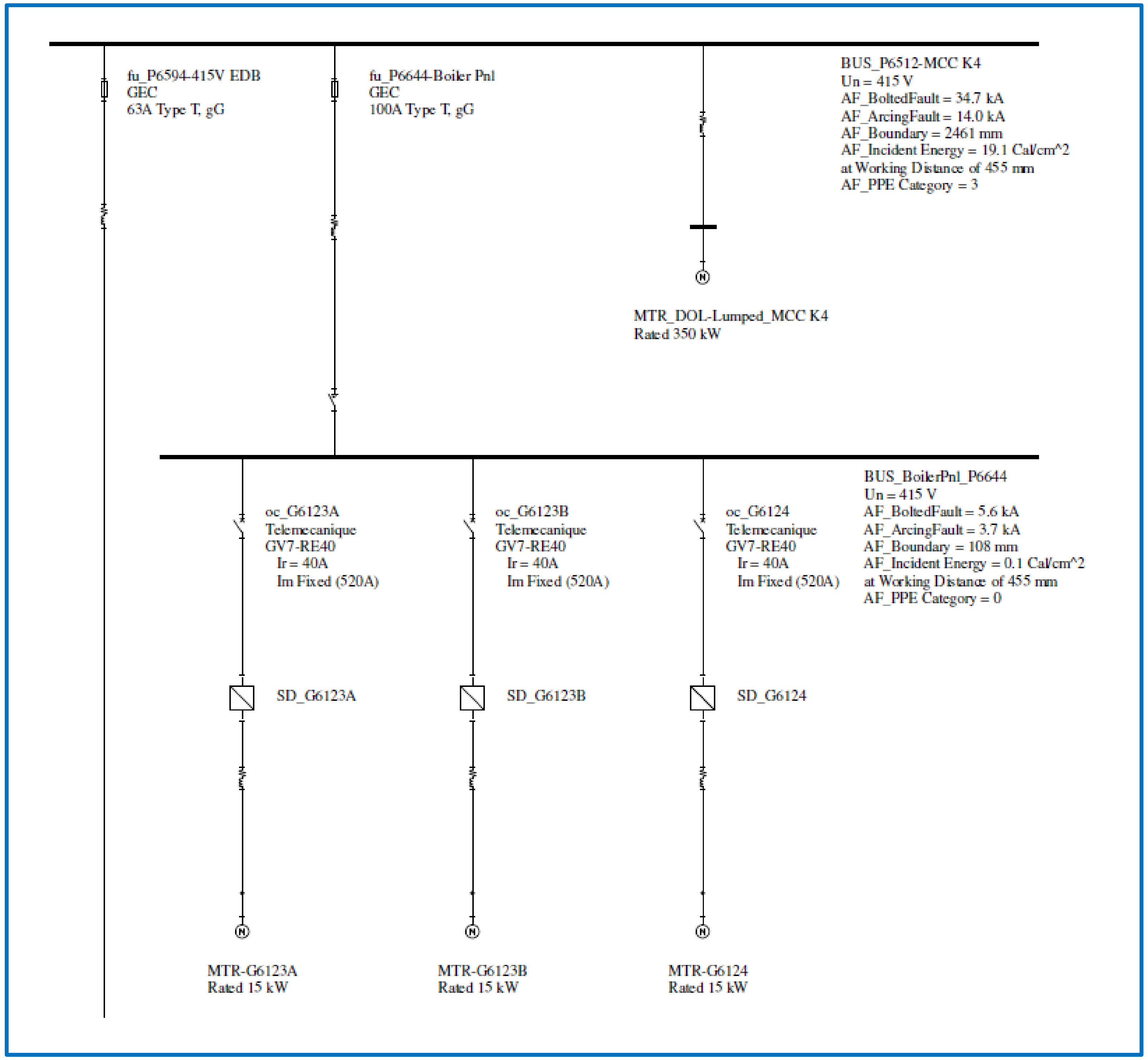


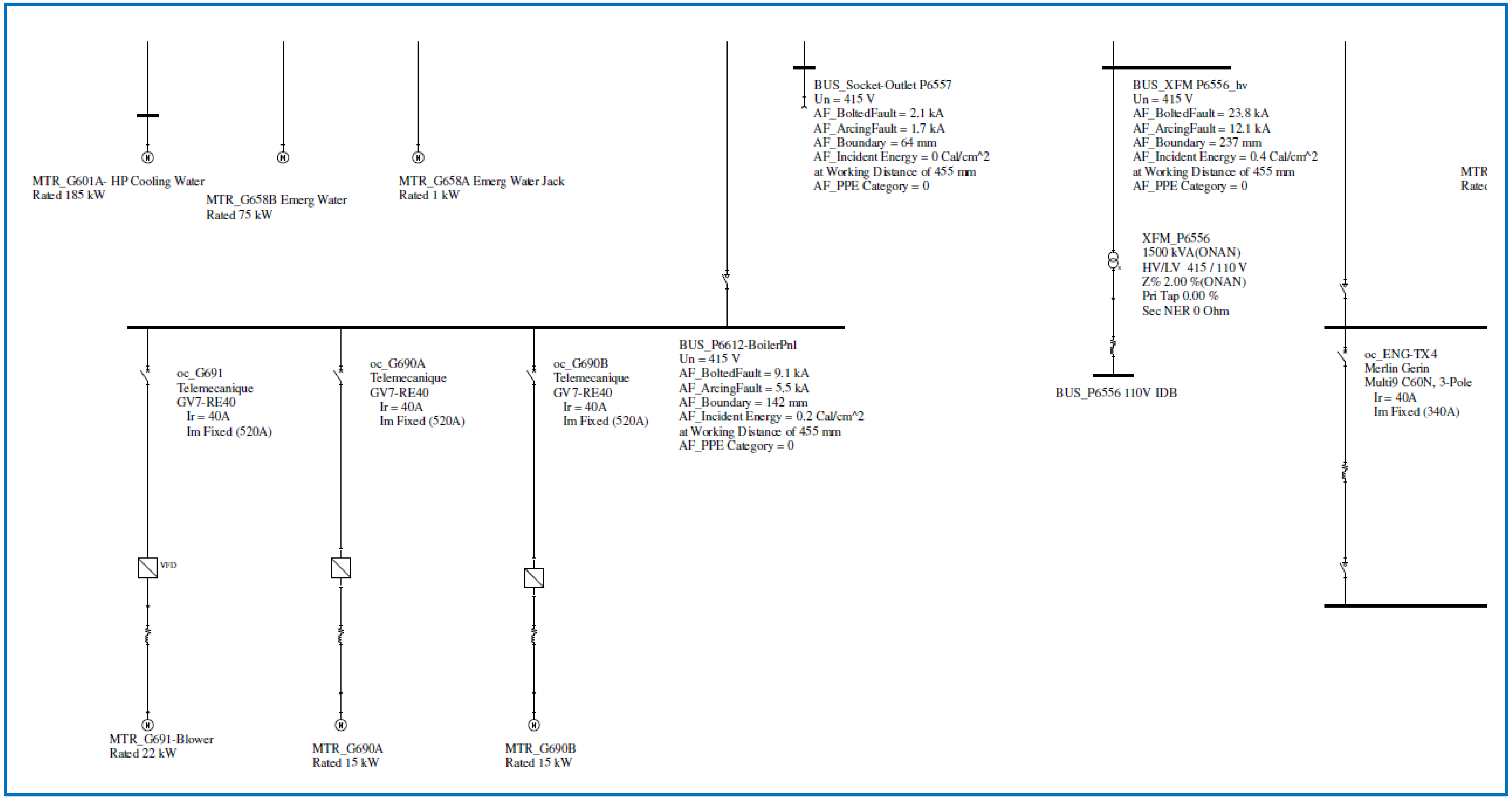
Kemerton Sub K4 MCC P6512
Single Line Diagram
Arc-Flash Analysis Resutls to IEEE 1584-2002
Proposed Installation with MiCom P122 Relay on Feeder to Transformer P6507
Date: 15-09-14
UTIL_T2 Marriott Rd Sub_Min
Init Voltage 1.000 pu
SC Contribution 3P 2500 Amps
X/R 3P 20.000
SC Contribution SLG 2500 Amps
X/R SLG 20.000
BUS_TX2 MRR LV
Un = 22000 V
AF_BoltedFault = 3.9 kA
AF_ArcingFault = 3.9 kA
AF_Boundary = 21720 mm
AF_Incident Energy = 674.2 Cal/cm^2
at Working Distance of 914 mm
AF_PPE Category = Dangerous!
TX2 MRR LV oc
SEL
351
51PP 1.15 (1035A)
C3, EI (IEC) 0.15
TX2 MRR LV ef
SEL
351
51GP 0.23 (207A)
C1, SI (IEC) 0.52
BUS_Pnl7_22kV Inc Lineside
Un = 22000 V
AF_BoltedFault = 3.9 kA
AF_ArcingFault = 3.9 kA
AF_Boundary = 7845 mm
AF_Incident Energy = 88 Cal/cm^2
at Working Distance of 914 mm
AF_PPE Category = Dangerous!
Pnl 7 Sub K Inc oc
GEC
MCGG
Is = 0.8 (720A)
EI (IEC) = 0.2
INST = 8 (5760A)
Pnl 7 Sub K Inc ef
GEC
MCGG
Is = 0.2 (180A)
VI (IEC) = 0.4
oc_Fdr XFM TK4
ef_Fdr XFM TK4
BUS_ESB K P6500
Un = 22000 V
AF_BoltedFault = 3.9 kA
AF_ArcingFault = 3.9 kA
AF_Boundary = 6069 mm
AF_Incident Energy = 53.2 Cal/cm^2
at Working Distance of 910 mm
AF_PPE Category = Dangerous!


oc_Fdr XFM TK4
Areva
MiCom P122
I > 0.48 (48A)
EI (IEC) 0.15
I >> 5 (500A)
t >> 0.05
I >>> 8 (800A)
ef_Fdr XFM TK4
Areva
MiCom P122
Ie> 0.04 (4A)
SI (IEC) 0.1
XFM_TK4
1500 kVA(ONAN)
HV/LV 22000 / 433 V
Z% 6.10 %(ONAN)
Pri Tap 0.00 %
Sec NER 0 Ohm
BUS_K4 Inc Lineside
Un = 415 V
AF_BoltedFault = 34.7 kA
AF_ArcingFault = 13.1 kA
AF_Boundary = 3869 mm
AF_Incident Energy = 18.2 Cal/cm^2
at Working Distance of 610 mm
AF_PPE Category = 3
K4 Inc oc
Schneider
ACB
Ir = 0.80 xIn (2000A)
tr = 2 sec
Isd = 3.00 x Ir (6000A)
tsd = 0.1 (I^2t On)
Ii = 8 xIn (20000A)
K4 Inc ef
Schneider
ACB
Ig = J (1200A)
tg = 0.3 (I^2t On)
fu_P6556-110V IDB
GEC
63A Type T, gG
fu_P6446-415V EDB
GEC
200A Type T, gG


fu_G601A
GEC
355A Type T, gG
ol_G601A
Telemecanique
LR1F(M) F400
Ir = 302A
ef_G601A
Circutor
RGU-10
Io> 0.50A (0.5A)
to> 0.10 sec
SS_G601A
fu_EmergWaterPnl_P6019
GEC
160A Type T, gG
fu_P6612-BoilerPnl
GEC
125A Type T, gG
fu_P6557-415V EDB
GEC
63A Type T, gG
fu_P6556-110V IDB
GEC
63A Type T, gG
BUS_EmergWaterControlPnl_P6019
Un = 415 V
AF_BoltedFault = 11.0 kA
AF_ArcingFault = 6.4 kA
AF_Boundary = 157 mm
AF_Incident Energy = 0.2 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
SS_G658B
oc_G658A
Telemecanique
GV7-RE4
Ir = 2.8A
Im Fixed (36.4A)
BUS_P6557-415V EDB
Un = 415 V
AF_BoltedFault = 23.8 kA
AF_ArcingFault = 12.1 kA
AF_Boundary = 237 mm
AF_Incident Energy = 0.4 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
oc_P6557-Outlet
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 16A
Im Fixed (136A)
Merlin Gerin
Ir = 100A
BUS_Socket-Outlet P6557
Un = 415 V
AF_BoltedFault = 2.1 kA
AF_ArcingFault = 1.7 kA
AF_Boundary = 64 mm
AF_Incident Energy = 0 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
BUS_XFM P6556_hv
Un = 415 V
AF_BoltedFault = 23.8 kA
AF_ArcingFault = 12.1 kA
AF_Boundary = 237 mm
AF_Incident Energy = 0.4 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
MTR_G601A- HP Cooling Water
Rated 185 kW
MTR_G658B Emerg Water
Rated 75 kW
MTR_G658A Emerg Water Jack
Rated 1 kW


fu_P6556-110V IDB
GEC
63A Type T, gG
fu_P6446-415V EDB
GEC
200A Type T, gG
fu_P6594-415V EDB
GEC
63A Type T, gG
oc_P6711-415V EDB
Merlin Gerin
Multi9 NC100H, 3-Pole
Ir = 100A
Im Fixed (850A)
oc_T6397-AirCon
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
oc_T6399-AirCon
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
oc_T6398-AirCon
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
BUS_P6446-Reliability Bldg DB
Un = 415 V
AF_BoltedFault = 5.5 kA
AF_ArcingFault = 3.1 kA
AF_Boundary = 259 mm
AF_Incident Energy = 0.5 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
oc_G6123A
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
SD_G6123A
BUS_XFM P6556_hv
Un = 415 V
AF_BoltedFault = 23.8 kA
AF_ArcingFault = 12.1 kA
AF_Boundary = 237 mm
AF_Incident Energy = 0.4 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
MTR_T6397-AirCon
Rated 2 kW
MTR_T6399-AirCon
Rated 2 kW
MTR_T6398-AirCon
Rated 2 kW
MTR-G6123A
Rated 15 kW


fu_P6594-415V EDB
GEC
63A Type T, gG
fu_P6644-Boiler Pnl
GEC
100A Type T, gG
BUS_P6512-MCC K4
Un = 415 V
AF_BoltedFault = 34.7 kA
AF_ArcingFault = 14.0 kA
AF_Boundary = 2461 mm
AF_Incident Energy = 19.1 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 3
MTR_DOL-Lumped_MCC K4
Rated 350 kW
BUS_BoilerPnl_P6644
Un = 415 V
AF_BoltedFault = 5.6 kA
AF_ArcingFault = 3.7 kA
AF_Boundary = 108 mm
AF_Incident Energy = 0.1 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
oc_G6123A
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
oc_G6123B
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
oc_G6124
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
SD_G6123A
SD_G6123B
SD_G6124
MTR-G6123A
Rated 15 kW
MTR-G6123B
Rated 15 kW
MTR-G6124
Rated 15 kW


BUS_Socket-Outlet P6557
Un = 415 V
AF_BoltedFault = 2.1 kA
AF_ArcingFault = 1.7 kA
AF_Boundary = 64 mm
AF_Incident Energy = 0 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
BUS_XFM P6556_hv
Un = 415 V
AF_BoltedFault = 23.8 kA
AF_ArcingFault = 12.1 kA
AF_Boundary = 237 mm
AF_Incident Energy = 0.4 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
MTR_G601A- HP Cooling Water
Rated 185 kW
MTR_G658B Emerg Water
Rated 75 kW
MTR_G658A Emerg Water Jack
Rated 1 kW
MTR
Ratec
XFM_P6556
1500 kVA(ONAN)
HV/LV 415 / 110 V
Z% 2.00 %(ONAN)
Pri Tap 0.00 %
Sec NER 0 Ohm
BUS_P6612-BoilerPnl
Un = 415 V
AF_BoltedFault = 9.1 kA
AF_ArcingFault = 5.5 kA
AF_Boundary = 142 mm
AF_Incident Energy = 0.2 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
oc_G691
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
oc_G690A
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
oc_G690B
Telemecanique
GV7-RE40
Ir = 40A
Im Fixed (520A)
BUS_P6556 110V IDB
oc_ENG-TX4
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 40A
Im Fixed (340A)
VFD
MTR_G691-Blower
Rated 22 kW
MTR_G690A
Rated 15 kW
MTR_G690B
Rated 15 kW

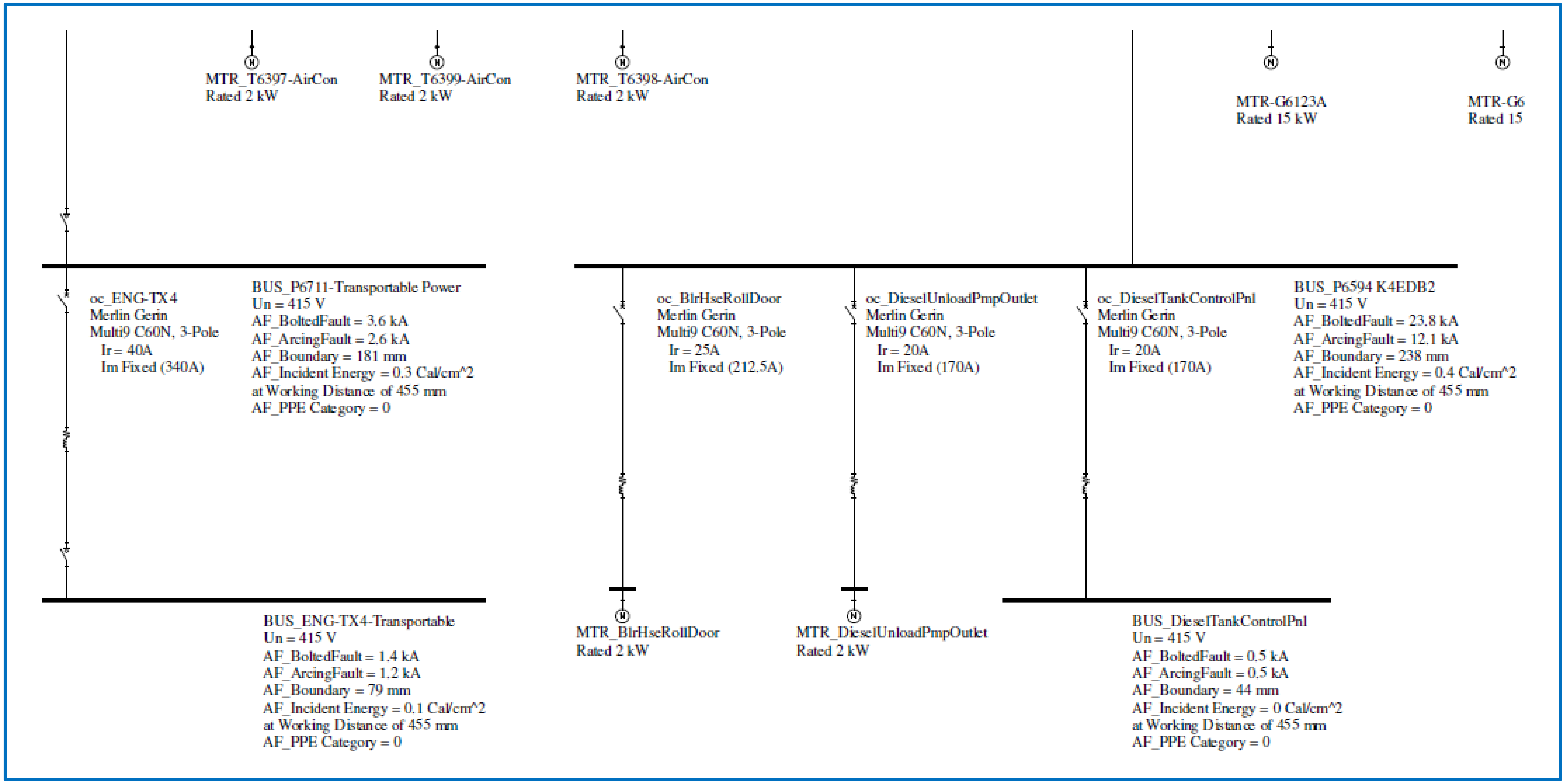

MTR_T6397-AirCon
Rated 2 kW
MTR_T6399-AirCon
Rated 2 kW
MTR_T6398-AirCon
Rated 2 kW
MTR-G6123A
Rated 15 kW
MTR-G6
Rated 15
oc_ENG-TX4
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 40A
Im Fixed (340A)
BUS_P6711-Transportable Power
Un = 415 V
AF_BoltedFault = 3.6 kA
AF_ArcingFault = 2.6 kA
AF_Boundary = 181 mm
AF_Incident Energy = 0.3 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
oc_BlrHseRollDoor
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 25A
Im Fixed (212.5A)
oc_DieselUnloadPmpOutlet
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
oc_DieselTankControlPnl
Merlin Gerin
Multi9 C60N, 3-Pole
Ir = 20A
Im Fixed (170A)
BUS_P6594 K4EDB2
Un = 415 V
AF_BoltedFault = 23.8 kA
AF_ArcingFault = 12.1 kA
AF_Boundary = 238 mm
AF_Incident Energy = 0.4 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
BUS_ENG-TX4-Transportable
Un = 415 V
AF_BoltedFault = 1.4 kA
AF_ArcingFault = 1.2 kA
AF_Boundary = 79 mm
AF_Incident Energy = 0.1 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0
MTR_BlrHseRollDoor
Rated 2 kW
MTR_DieselUnloadPmpOutlet
Rated 2 kW
BUS_DieselTankControlPnl
Un = 415 V
AF_BoltedFault = 0.5 kA
AF_ArcingFault = 0.5 kA
AF_Boundary = 44 mm
AF_Incident Energy = 0 Cal/cm^2
at Working Distance of 455 mm
AF_PPE Category = 0

Table G-5: Arc Flash Results for the proposed network (minimum utility fault level scenario)

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_BoilerPnl_P6644	fu_P6644-Boiler Pnl	0.415	5.57	3.68	5.21	3.44	0.01	0.000	Yes	PNL	25	108	455	0.11	Category 0
BUS_BoilerPnl_P6644	oc_G6123A	0.415	5.57	3.68	0.19	0.13	0.06	0.000	Yes	PNL	25	148	455	0.19	Category 0
BUS_BoilerPnl_P6644	oc_G6123B	0.415	5.57	3.68	0.19	0.13	0.06	0.000	Yes	PNL	25	148	455	0.19	Category 0
BUS_BoilerPnl_P6644	oc_G6124	0.415	5.57	3.68	0.19	0.13	0.06	0.000	Yes	PNL	25	148	455	0.19	Category 0
BUS_DieselTankControlPnl	oc_DieselTankControlPnl	0.415	0.55	0.55	0.55	0.55	0.02	0.000	Yes	PNL	25	44	455	0.01	Category 0 (*N11)
BUS_EmergWaterControlPnl_P6019	fu_EmergWaterPnl_P6019	0.415	11.02	6.44	10.45	6.10	0.01	0.000	Yes	PNL	25	157	455	0.21	Category 0
BUS_EmergWaterControlPnl_P6019	oc_G658A	0.415	11.02	6.44	0.02	0.01	0.06	0.000	Yes	PNL	25	201	455	0.31	Category 0
BUS_ENG-TX4-Transportable	oc_ENG-TX4	0.415	1.40	1.19	1.40	1.19	0.02	0.000	Yes	PNL	25	79	455	0.07	Category 0
BUS_ESB K P6500	oc_Fdr XFM TK4	22.00	3.94	3.94	0.12	0.12	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 1 Lime Fu	22.00	3.94	3.94	0.03	0.03	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 12 TK2A_fu	22.00	3.94	3.94	0.11	0.11	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 13 TK3A_fu	22.00	3.94	3.94	0.12	0.12	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 3 TK1A_fu	22.00	3.94	3.94	0.17	0.17	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 4 TK3B_fu	22.00	3.94	3.94	0.12	0.12	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 5 TK2B_fu	22.00	3.94	3.94	0.17	0.17	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 8 CIG/BOC oc	22.00	3.94	3.94	0.62	0.62	0.06	0.000	Yes	SWG	152	1492	910	3.2	Category 1 (*N11)
BUS_ESB K P6500	Pnl 7 Sub K Inc oc	22.00	3.94	3.94	2.50	2.50	1.451	0.080	Yes	SWG	152	6069	910	53	Dangerous! (*N11)
BUS_K4 Inc Lineside	K4 Inc oc	0.415	34.71	13.08	7.75	3.43	0.06	0.000	Yes	SWG	32	869	610	2.0	Category 1
BUS_K4 Inc Lineside	oc_Fdr XFM TK4	0.415	34.71	13.08	28.17	10.61	0.732	0.100	Yes	SWG	32	3869	610	18	Category 3 (*N3)

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_P6446-Reliability Bldg DB	fu_P6446-415V EDB	0.415	5.50	3.10	5.45	3.07	0.05	0.000	Yes	PNL	25	259	455	0.47	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6397-AirCon	0.415	5.50	3.10	0.03	0.02	0.06	0.000	Yes	PNL	25	259	455	0.47	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6398-AirCon	0.415	5.50	3.10	0.03	0.02	0.06	0.000	Yes	PNL	25	259	455	0.47	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6399-AirCon	0.415	5.50	3.10	0.03	0.02	0.06	0.000	Yes	PNL	25	259	455	0.47	Category 0 (*N3)
BUS_P6512-MCC K4	fu_EmergWaterPnl_P6019	0.415	34.71	13.98	0.81	0.38	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	fu_P6446-415V EDB	0.415	34.71	13.98	0.09	0.04	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	fu_P6594-415V EDB	0.415	34.71	13.98	0.06	0.03	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	fu_P6612-BoilerPnl	0.415	34.71	13.98	0.38	0.18	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	fu_P6644-Boiler Pnl	0.415	34.71	13.98	0.54	0.26	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	ol_G601A	0.415	34.71	13.98	2.14	1.02	0.06	0.000	Yes	PNL	25	866	455	3.4	Category 1
BUS_P6512-MCC K4	K4 Inc oc	0.415	34.71	13.98	27.00	10.88	0.507	0.000	Yes	PNL	25	2461	455	19	Category 3 (*N3)
BUS_P6557-415V EDB	fu_P6557-415V EDB	0.415	23.82	12.09	23.82	12.09	0.01	0.000	Yes	PNL	25	237	455	0.41	Category 0
BUS_P6594 K4EDB2	fu_P6594-415V EDB	0.415	23.85	12.10	23.79	12.07	0.01	0.000	Yes	PNL	25	237	455	0.41	Category 0
BUS_P6594 K4EDB2	oc_BlrHseRollDoor	0.415	23.85	12.10	0.03	0.02	0.06	0.000	Yes	PNL	25	240	455	0.42	Category 0
BUS_P6594 K4EDB2	oc_DieselUnloadPmpOutlet	0.415	23.85	12.10	0.03	0.02	0.06	0.000	Yes	PNL	25	240	455	0.42	Category 0
BUS_P6612-BoilerPnl	fu_P6612-BoilerPnl	0.415	9.14	5.52	8.86	5.36	0.01	0.000	Yes	PNL	25	142	455	0.18	Category 0
BUS_P6612-BoilerPnl	oc_G690A	0.415	9.14	5.52	0.19	0.12	0.06	0.000	Yes	PNL	25	165	455	0.23	Category 0
BUS_P6612-BoilerPnl	oc_G690B	0.415	9.14	5.52	0.19	0.12	0.06	0.000	Yes	PNL	25	165	455	0.23	Category 0
BUS_P6612-BoilerPnl	oc_G691	0.415	9.14	5.52	0.00	0.00	0.06	0.000	Yes	PNL	25	165	455	0.23	Category 0

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_P6711-Transportable Power	oc_P6711-415V EDB	0.415	3.60	2.58	3.60	2.58	0.034	0.000	Yes	PNL	25	181	455	0.26	Category 0
BUS_Socket-Outlet P6557	fu_P6557-415V EDB (oc_P6557-Outlet)	0.415	2.10	1.66	2.10	1.66	0.01	0.000	Yes	PNL	25	64	455	0.05	Category 0 (*N5)
BUS_XFM P6556_hv	fu_P6556-110V IDB	0.415	23.82	12.09	23.82	12.09	0.01	0.000	Yes	PNL	25	237	455	0.41	Category 0

Table G-6: Arc Flash Risk category matrix summary for the results for the proposed network (minimum utility fault level scenario)

Hazardous Risk Category	Incident Energy Value (cal/cm^2)	Hazardous Risk Category Description	Number in each Category	Notes (*N)
Category 0: Non-melting, Flammable Materials with Weight >= 4.5 oz/sq yd	0.0 - 1.2 cal/cm^2	Category 0: Non-melting, Flammable Materials with Weight >= 4.5 oz/sq yd, Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Safety glasses, Non-melting or untreated natural fiber (cotton/wool/rayon/silk > 4.5 oz/sq yd), shirt (long-sleeve), pants (long)., > 50V voltage rated tools + Class 0 (minimum) gloves, Dielectric shoes or insulating mat (step and touch potential).	#Category 0 = 11	(*N11) - Out of IEEE 1584 Range, Lee Equation Used. Applicable for Open Air only. Existing Equipment type is not Open Air!
Category 1: Arc-rated FR Shirt & Pants	1.2 - 4.0 cal/cm^2	Category 1: Arc-rated FR Shirt & Pants, Hardhat + Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield., 4 cal/sq cm, FR shirt (long-sleeve) plus FR pants (long), or FR coverall, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash) as needed., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 1 = 0	(*N3) - Arcing Current Low Tolerances Used
Category 2: Arc-rated FR Shirt & Pants	4.0 - 8.0 cal/cm^2	Category 2: Arc-rated FR Shirt & Pants, Hardhat + Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 8 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 2 = 0	(*N5) - Miscoordinated, Upstream Device Tripped
Category 3: Arc-rated FR Shirt & Pants & Arc Flash Suit	8.0 - 25.0 cal/cm^2	Category 3: Arc-rated FR Shirt & Pants & Arc Flash Suit, Hardhat + FR hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 25 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 3 = 2	For additional information refer to NFPA 70 E, Standard for Electrical Safety in the Workplace.
Category 4: Arc-rated FR Shirt & Pants & Arc Flash Suit	25.0 - 40.0 cal/cm^2	Category 4: Arc-rated FR Shirt & Pants & Arc Flash Suit, Hardhat + FR hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 40 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 4 = 0	Device with 90% Cleared Fault Threshold
Category Dangerous!: No FR Category Found	40.0 - 999.0 cal/cm^2	Category Dangerous!: No FR Category Found, Do not work on live!, No FR Category Found, Arc Flash Incident Energy Exceeds the Rating of Category 4 PPE., No FR Category Found	#Danger = 1	NFPA 70E 2012 Annex D.7 - IEEE 1584 Bus Report (- 90% Cleared Fault Threshold, include Ind. Motors for 3.0 Cycles), miscoordination checked

Table G-7: Arc Flash Results for the proposed network (maximum utility fault level scenario)

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_BoilerPnl_P6644	fu_P6644-Boiler Pnl	0.415	5.58	3.69	5.22	3.45	0.01	0.000	Yes	PNL	25	109	455	0.11	Category 0
BUS_BoilerPnl_P6644	oc_G6123A	0.415	5.58	3.69	0.19	0.13	0.06	0.000	Yes	PNL	25	148	455	0.19	Category 0
BUS_BoilerPnl_P6644	oc_G6123B	0.415	5.58	3.69	0.19	0.13	0.06	0.000	Yes	PNL	25	148	455	0.19	Category 0
BUS_BoilerPnl_P6644	oc_G6124	0.415	5.58	3.69	0.19	0.13	0.06	0.000	Yes	PNL	25	148	455	0.19	Category 0
BUS_DieselTankControlPnl	oc_DieselTankControlPnl	0.415	0.55	0.55	0.55	0.55	0.02	0.000	Yes	PNL	25	44	455	0.01	Category 0 (*N11)
BUS_EmergWaterControlPnl_P6019	fu_EmergWaterPnl_P6019	0.415	11.09	6.47	10.53	6.14	0.01	0.000	Yes	PNL	25	157	455	0.21	Category 0
BUS_EmergWaterControlPnl_P6019	oc_G658A	0.415	11.09	6.47	0.02	0.01	0.06	0.000	Yes	PNL	25	202	455	0.32	Category 0
BUS_ENG-TX4-Transportable	oc_ENG-TX4	0.415	1.40	1.19	1.40	1.19	0.02	0.000	Yes	PNL	25	79	455	0.07	Category 0
BUS_ESB K P6500	oc_Fdr XFM TK4	22.00	5.70	5.70	0.12	0.12	0.06	0.000	Yes	SWG	152	1794	910	4.6	Category 2 (*N11)
BUS_ESB K P6500	Pnl 1 Lime Fu	22.00	5.70	5.70	0.03	0.03	0.06	0.000	Yes	SWG	152	1794	910	4.6	Category 2 (*N11)
BUS_ESB K P6500	Pnl 12 TK2A_fu	22.00	5.70	5.70	0.11	0.11	0.06	0.000	Yes	SWG	152	1794	910	4.6	Category 2 (*N11)
BUS_ESB K P6500	Pnl 13 TK3A_fu	22.00	5.70	5.70	0.12	0.12	0.06	0.000	Yes	SWG	152	1794	910	4.6	Category 2 (*N11)
BUS_ESB K P6500	Pnl 3 TK1A_fu	22.00	5.70	5.70	0.17	0.17	0.06	0.000	Yes	SWG	152	1794	910	4.6	Category 2 (*N11)
BUS_ESB K P6500	Pnl 4 TK3B_fu	22.00	5.70	5.70	0.12	0.12	0.06	0.000	Yes	SWG	152	1794	910	4.6	Category 2 (*N11)
BUS_ESB K P6500	Pnl 5 TK2B_fu	22.00	5.70	5.70	0.17	0.17	0.06	0.000	Yes	SWG	152	1794	910	4.6	Category 2 (*N11)
BUS_ESB K P6500	Pnl 8 CIG/BOC oc	22.00	5.70	5.70	0.62	0.62	0.06	0.000	Yes	SWG	152	1794	910	4.6	Category 2 (*N11)
BUS_ESB K P6500	Pnl 7 Sub K Inc oc	22.00	5.70	5.70	4.26	4.26	0.471	0.080	Yes	SWG	152	4787	910	33	Category 4 (*N11)
BUS_K4 Inc Lineside	K4 Inc oc	0.415	35.95	13.45	7.75	3.41	0.06	0.000	Yes	SWG	32	887	610	2.1	Category 1
BUS_K4 Inc Lineside	oc_Fdr XFM TK4	0.415	35.95	13.45	29.46	11.02	0.676	0.100	Yes	SWG	32	3871	610	18	Category 3 (*N3)

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_P6446-Reliability Bldg DB	fu_P6446-415V EDB	0.415	5.52	3.11	5.47	3.08	0.05	0.000	Yes	PNL	25	258	455	0.47	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6397-AirCon	0.415	5.52	3.11	0.03	0.02	0.06	0.000	Yes	PNL	25	258	455	0.47	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6398-AirCon	0.415	5.52	3.11	0.03	0.02	0.06	0.000	Yes	PNL	25	258	455	0.47	Category 0 (*N3)
BUS_P6446-Reliability Bldg DB	oc_T6399-AirCon	0.415	5.52	3.11	0.03	0.02	0.06	0.000	Yes	PNL	25	258	455	0.47	Category 0 (*N3)
BUS_P6512-MCC K4	fu_EmergWaterPnl_P6019	0.415	35.95	14.39	0.81	0.38	0.06	0.000	Yes	PNL	25	883	455	3.5	Category 1
BUS_P6512-MCC K4	fu_P6446-415V EDB	0.415	35.95	14.39	0.09	0.04	0.06	0.000	Yes	PNL	25	883	455	3.5	Category 1
BUS_P6512-MCC K4	fu_P6594-415V EDB	0.415	35.95	14.39	0.06	0.03	0.06	0.000	Yes	PNL	25	883	455	3.5	Category 1
BUS_P6512-MCC K4	fu_P6612-BoilerPnl	0.415	35.95	14.39	0.38	0.18	0.06	0.000	Yes	PNL	25	883	455	3.5	Category 1
BUS_P6512-MCC K4	fu_P6644-Boiler Pnl	0.415	35.95	14.39	0.54	0.26	0.06	0.000	Yes	PNL	25	883	455	3.5	Category 1
BUS_P6512-MCC K4	ol_G601A	0.415	35.95	14.39	2.14	1.01	0.06	0.000	Yes	PNL	25	883	455	3.5	Category 1
BUS_P6512-MCC K4	K4 Inc oc	0.415	35.95	14.39	28.24	11.30	0.47	0.000	Yes	PNL	25	2452	455	19	Category 3 (*N3)
BUS_P6557-415V EDB	fu_P6557-415V EDB	0.415	24.32	12.30	24.32	12.30	0.01	0.000	Yes	PNL	25	240	455	0.42	Category 0
BUS_P6594 K4EDB2	fu_P6594-415V EDB	0.415	24.35	12.31	24.29	12.28	0.01	0.000	Yes	PNL	25	240	455	0.42	Category 0
BUS_P6594 K4EDB2	oc_BlrHseRollDoor	0.415	24.35	12.31	0.03	0.02	0.06	0.000	Yes	PNL	25	243	455	0.43	Category 0
BUS_P6594 K4EDB2	oc_DieselUnloadPmpOutlet	0.415	24.35	12.31	0.03	0.02	0.06	0.000	Yes	PNL	25	243	455	0.43	Category 0
BUS_P6612-BoilerPnl	fu_P6612-BoilerPnl	0.415	9.18	5.54	8.91	5.38	0.01	0.000	Yes	PNL	25	142	455	0.18	Category 0
BUS_P6612-BoilerPnl	oc_G690A	0.415	9.18	5.54	0.19	0.12	0.06	0.000	Yes	PNL	25	165	455	0.23	Category 0
BUS_P6612-BoilerPnl	oc_G690B	0.415	9.18	5.54	0.19	0.12	0.06	0.000	Yes	PNL	25	165	455	0.23	Category 0
BUS_P6612-BoilerPnl	oc_G691	0.415	9.18	5.54	0.00	0.00	0.06	0.000	Yes	PNL	25	165	455	0.23	Category 0

Bus Name	Protective Device Name	Bus (kV)	Bus Bolted Fault (kA)	Bus Arcing Fault (kA	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	PPE Level / Notes (*N)
BUS_P6711-Transportable Power	oc_P6711-415V EDB	0.415	3.61	2.58	3.61	2.58	0.034	0.000	Yes	PNL	25	181	455	0.26	Category 0
BUS_Socket-Outlet P6557	fu_P6557-415V EDB (oc_P6557-Outlet)	0.415	2.11	1.66	2.11	1.66	0.01	0.000	Yes	PNL	25	64	455	0.05	Category 0 (*N5)
BUS_XFM P6556_hv	fu_P6556-110V IDB	0.415	24.32	12.30	24.32	12.30	0.01	0.000	Yes	PNL	25	240	455	0.42	Category 0

Table G-8: Arc Flash Risk category matrix summary for the results for the proposed network (maximum utility fault level scenario)

Hazardous Risk Category	Incident Energy Value (cal/cm^2)	Hazardous Risk Category Description	Number in each Category	Notes (*N)
Category 0: Non-melting, Flammable Materials with Weight >= 4.5 oz/sq yd	0.0 - 1.2 cal/cm^2	Category 0: Non-melting, Flammable Materials with Weight >= 4.5 oz/sq yd, Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Safety glasses, Non-melting or untreated natural fiber (cotton/wool/rayon/silk > 4.5 oz/sq yd), shirt (long-sleeve), pants (long)., > 50V voltage rated tools + Class 0 (minimum) gloves, Dielectric shoes or insulating mat (step and touch potential).	#Category 0 = 11	(*N11) - Out of IEEE 1584 Range, Lee Equation Used. Applicable for Open Air only. Existing Equipment type is not Open Air!
Category 1: Arc-rated FR Shirt & Pants	1.2 - 4.0 cal/cm^2	Category 1: Arc-rated FR Shirt & Pants, Hardhat + Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield., 4 cal/sq cm, FR shirt (long-sleeve) plus FR pants (long), or FR coverall, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash) as needed., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 1 = 0	(*N3) - Arcing Current Low Tolerances Used
Category 2: Arc-rated FR Shirt & Pants	4.0 - 8.0 cal/cm^2	Category 2: Arc-rated FR Shirt & Pants, Hardhat + Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 8 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 2 = 0	(*N5) - Miscoordinated, Upstream Device Tripped
Category 3: Arc-rated FR Shirt & Pants & Arc Flash Suit	8.0 - 25.0 cal/cm^2	Category 3: Arc-rated FR Shirt & Pants & Arc Flash Suit, Hardhat + FR hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 25 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 3 = 2	For additional information refer to NFPA 70 E, Standard for Electrical Safety in the Workplace.
Category 4: Arc-rated FR Shirt & Pants & Arc Flash Suit	25.0 - 40.0 cal/cm^2	Category 4: Arc-rated FR Shirt & Pants & Arc Flash Suit, Hardhat + FR hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection., 40 cal/sq cm, cotton underwear T-shirt and briefs or shorts, FR shirt (long-sleeve) plus FR pants (long), or FR coverall/coat, rainwear as needed., > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash)., Leather shoes (flash) as needed. Dielectric shoes or insulating mat (step and touch potential).	#Category 4 = 1	Device with 90% Cleared Fault Threshold
Category Dangerous!: No FR Category Found	40.0 - 999.0 cal/cm^2	Category Dangerous!: No FR Category Found, Do not work on live!, No FR Category Found, Arc Flash Incident Energy Exceeds the Rating of Category 4 PPE., No FR Category Found	#Danger = 0	NFPA 70E 2012 Annex D.7 - IEEE 1584 Bus Report (- 90% Cleared Fault Threshold, include Ind. Motors for 3.0 Cycles), miscoordination checked

Table G-9: Summary of Arc Flash Results for all four scenarios

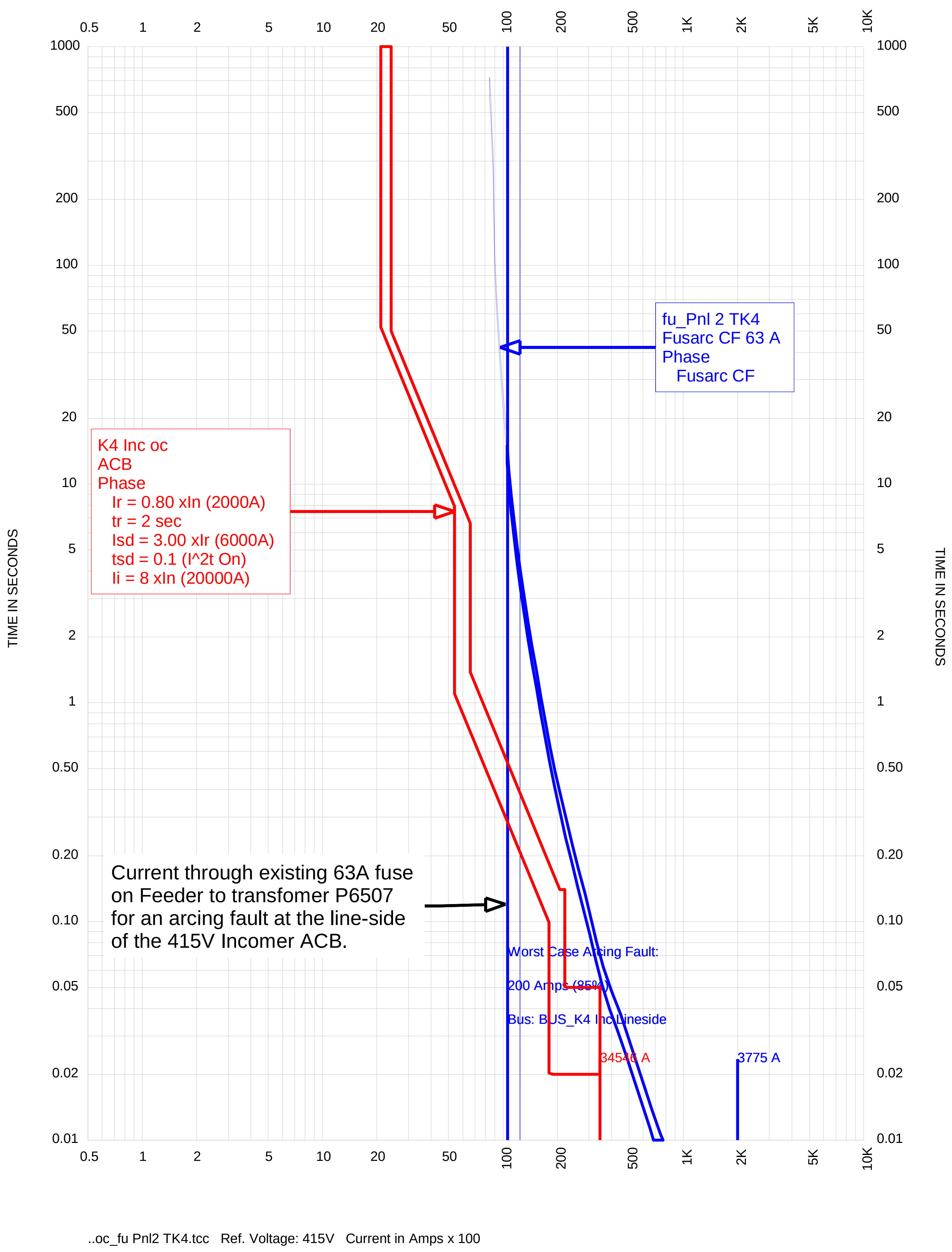
Component	Field	S1_Exist 22kV Fuses_max	S2_Exist 22kV Fuses_min	S3_Proposed CB on XFM TK4_max	S4_Proposed CB on XFM TK4_min	Max
BUS_BoilerPnl_P6644	Un = (V)	415	415	415	415	415
BUS_BoilerPnl_P6644	AF_BoltedFault = (kA)	5.5	5.6	5.6	5.6	5.6
BUS_BoilerPnl_P6644	AF_ArcingFault = (kA)	3.6	3.7	3.7	3.7	3.7
BUS_BoilerPnl_P6644	AF_Boundary = (mm)	107	108	109	108	109
BUS_BoilerPnl_P6644	AF_Incident Energy = (Cal/cm^2)	0.1	0.1	0.1	0.1	0.1
BUS_BoilerPnl_P6644	at Working Distance of (mm)	455	455	455	455	455
BUS_BoilerPnl_P6644	AF_PPE Category =	0	0	0	0	0
BUS_EmergWaterControlPnl_P6019	Un = (V)	415	415	415	415	415
BUS_EmergWaterControlPnl_P6019	AF_BoltedFault = (kA)	10.8	11.0	11.1	11.0	11.1
BUS_EmergWaterControlPnl_P6019	AF_ArcingFault = (kA)	6.4	6.4	6.5	6.4	6.5
BUS_EmergWaterControlPnl_P6019	AF_Boundary = (mm)	155	157	157	157	157
BUS_EmergWaterControlPnl_P6019	AF_Incident Energy = (Cal/cm^2)	0.2	0.2	0.2	0.2	0.2
BUS_EmergWaterControlPnl_P6019	at Working Distance of (mm)	455	455	455	455	455
BUS_EmergWaterControlPnl_P6019	AF_PPE Category =	0	0	0	0	0
BUS_ENG-TX4-Transportable	Un = (V)	415	415	415	415	415
BUS_ENG-TX4-Transportable	AF_BoltedFault = (kA)	1.4	1.4	1.4	1.4	1.4
BUS_ENG-TX4-Transportable	AF_ArcingFault = (kA)	1.2	1.2	1.2	1.2	1.2
BUS_ENG-TX4-Transportable	AF_Boundary = (mm)	78	79	79	79	79
BUS_ENG-TX4-Transportable	AF_Incident Energy = (Cal/cm^2)	0.1	0.1	0.1	0.1	0.1
BUS_ENG-TX4-Transportable	at Working Distance of (mm)	455	455	455	455	455
BUS_ENG-TX4-Transportable	AF_PPE Category =	0	0	0	0	0
BUS_ESB K P6500	Un = (V)	22000	22000	22000	22000	22000
BUS_ESB K P6500	AF_BoltedFault = (kA)	5.8	3.9	5.7	3.9	5.8
BUS_ESB K P6500	AF_ArcingFault = (kA)	5.8	3.9	5.7	3.9	5.8
BUS_ESB K P6500	AF_Boundary = (mm)	4754	6069	4787	6069	6069
BUS_ESB K P6500	AF_Incident Energy = (Cal/cm^2)	32.6	53.2	33.1	53.2	53.2
BUS_ESB K P6500	at Working Distance of (mm)	910	910	910	910	910
BUS_ESB K P6500	AF_PPE Category =	4	Dangerous!	4	Dangerous!	Dangerous!

Component	Field	S1_Exist 22kV Fuses_max	S2_Exist 22kV Fuses_min	S3_Proposed CB on XFM TK4_max	S4_Proposed CB on XFM TK4_min	Max
BUS_K4 Inc Lineside	Un = (V)	415	415	415	415	415
BUS_K4 Inc Lineside	AF_BoltedFault = (kA)	35.1	34.7	36.0	34.7	36.0
BUS_K4 Inc Lineside	AF_ArcingFault = (kA)	13.2	13.1	13.4	13.1	13.4
BUS_K4 Inc Lineside	AF_Boundary = (mm)	24100	26878	3871	3869	26878
BUS_K4 Inc Lineside	AF_Incident Energy = (Cal/cm^2)	269.0	315.9	18.2	18.2	315.9
BUS_K4 Inc Lineside	at Working Distance of (mm)	610	610	610	610	610
BUS_K4 Inc Lineside	AF_PPE Category =	Dangerous!	Dangerous!	3	3	Dangerous!
BUS_P6446-Reliability Bldg DB	Un = (V)	415	415	415	415	415
BUS_P6446-Reliability Bldg DB	AF_BoltedFault = (kA)	5.4	5.5	5.5	5.5	5.5
BUS_P6446-Reliability Bldg DB	AF_ArcingFault = (kA)	3.1	3.1	3.1	3.1	3.1
BUS_P6446-Reliability Bldg DB	AF_Boundary = (mm)	265	259	258	259	265
BUS_P6446-Reliability Bldg DB	AF_Incident Energy = (Cal/cm^2)	0.5	0.5	0.5	0.5	0.5
BUS_P6446-Reliability Bldg DB	at Working Distance of (mm)	455	455	455	455	455
BUS_P6446-Reliability Bldg DB	AF_PPE Category =	0	0	0	0	0
BUS_P6512-MCC K4	Un = (V)	415	415	415	415	415
BUS_P6512-MCC K4	AF_BoltedFault = (kA)	35.1	34.7	36.0	34.7	36.0
BUS_P6512-MCC K4	AF_ArcingFault = (kA)	14.1	14.0	14.4	14.0	14.4
BUS_P6512-MCC K4	AF_Boundary = (mm)	2476	2461	2452	2461	2476
BUS_P6512-MCC K4	AF_Incident Energy = (Cal/cm^2)	19.3	19.1	19.0	19.1	19.3
BUS_P6512-MCC K4	at Working Distance of (mm)	455	455	455	455	455
BUS_P6512-MCC K4	AF_PPE Category =	3	3	3	3	3
BUS_P6557-415V EDB	Un = (V)	415	415	415	415	415
BUS_P6557-415V EDB	AF_BoltedFault = (kA)	23.8	23.8	24.3	23.8	24.3
BUS_P6557-415V EDB	AF_ArcingFault = (kA)	12.1	12.1	12.3	12.1	12.3
BUS_P6557-415V EDB	AF_Boundary = (mm)	237	237	240	237	240
BUS_P6557-415V EDB	AF_Incident Energy = (Cal/cm^2)	0.4	0.4	0.4	0.4	0.4
BUS_P6557-415V EDB	at Working Distance of (mm)	455	455	455	455	455
BUS_P6557-415V EDB	AF_PPE Category =	0	0	0	0	0
BUS_P6594 K4EDB2	Un = (V)	415	415	415	415	415
BUS_P6594 K4EDB2	AF_BoltedFault = (kA)	23.8	23.8	24.3	23.8	24.3
BUS_P6594 K4EDB2	AF_ArcingFault = (kA)	12.1	12.1	12.3	12.1	12.3
BUS_P6594 K4EDB2	AF_Boundary = (mm)	237	238	240	238	240
BUS_P6594 K4EDB2	AF_Incident Energy = (Cal/cm^2)	0.4	0.4	0.4	0.4	0.4
BUS_P6594 K4EDB2	at Working Distance of (mm)	455	455	455	455	455
BUS_P6594 K4EDB2	AF_PPE Category =	0	0	0	0	0

Component	Field	S1_Exist 22kV Fuses_max	S2_Exist 22kV Fuses_min	S3_Proposed CB on XFM TK4_max	S4_Proposed CB on XFM TK4_min	Max
BUS_P6612-BoilerPnl	Un = (V)	415	415	415	415	415
BUS_P6612-BoilerPnl	AF_BoltedFault = (kA)	9.0	9.1	9.2	9.1	9.2
BUS_P6612-BoilerPnl	AF_ArcingFault = (kA)	5.4	5.5	5.5	5.5	5.5
BUS_P6612-BoilerPnl	AF_Boundary = (mm)	140	142	142	142	142
BUS_P6612-BoilerPnl	AF_Incident Energy = (Cal/cm^2)	0.2	0.2	0.2	0.2	0.2
BUS_P6612-BoilerPnl	at Working Distance of (mm)	455	455	455	455	455
BUS_P6612-BoilerPnl	AF_PPE Category =	0	0	0	0	0
BUS_P6711-Transportable Power	Un = (V)	415	415	415	415	415
BUS_P6711-Transportable Power	AF_BoltedFault = (kA)	3.5	3.6	3.6	3.6	3.6
BUS_P6711-Transportable Power	AF_ArcingFault = (kA)	2.5	2.6	2.6	2.6	2.6
BUS_P6711-Transportable Power	AF_Boundary = (mm)	179	181	181	181	181
BUS_P6711-Transportable Power	AF_Incident Energy = (Cal/cm^2)	0.3	0.3	0.3	0.3	0.3
BUS_P6711-Transportable Power	at Working Distance of (mm)	455	455	455	455	455
BUS_P6711-Transportable Power	AF_PPE Category =	0	0	0	0	0
BUS_Socket-Outlet P6557	Un = (V)	415	415	415	415	415
BUS_Socket-Outlet P6557	AF_BoltedFault = (kA)	2.1	2.1	2.1	2.1	2.1
BUS_Socket-Outlet P6557	AF_ArcingFault = (kA)	1.6	1.7	1.7	1.7	1.7
BUS_Socket-Outlet P6557	AF_Boundary = (mm)	63	64	64	64	64
BUS_Socket-Outlet P6557	AF_Incident Energy = (Cal/cm^2)	0.0	0.0	0.0	0.0	0.0
BUS_Socket-Outlet P6557	at Working Distance of (mm)	455	455	455	455	455
BUS_Socket-Outlet P6557	AF_PPE Category =	0	0	0	0	0
BUS_XFM P6556_hv	Un = (V)	415	415	415	415	415
BUS_XFM P6556_hv	AF_BoltedFault = (kA)	23.8	23.8	24.3	23.8	24.3
BUS_XFM P6556_hv	AF_ArcingFault = (kA)	12.1	12.1	12.3	12.1	12.3
BUS_XFM P6556_hv	AF_Boundary = (mm)	237	237	240	237	240
BUS_XFM P6556_hv	AF_Incident Energy = (Cal/cm^2)	0.4	0.4	0.4	0.4	0.4
BUS_XFM P6556_hv	at Working Distance of (mm)	455	455	455	455	455
BUS_XFM P6556_hv	AF_PPE Category =	0	0	0	0	0

Appendix H Time-Current Characteristic (TCC) Curves

Appendix H.1 MCC Feeder Time-Current Characteristic Curves, including tripping duration



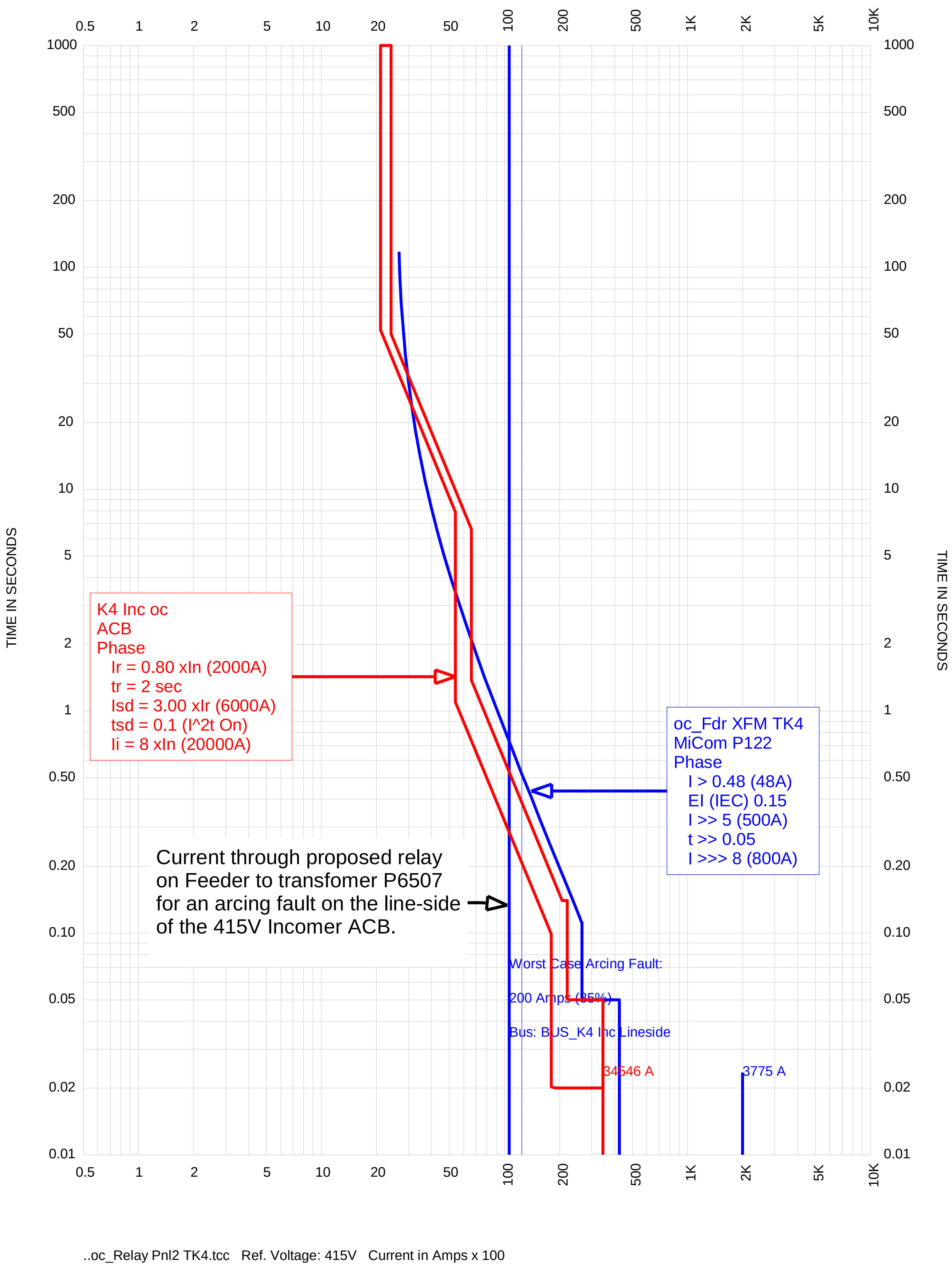
Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Existing installation with 63A fuse on Feeder to transfomer P6507

..oc_fu Pnl2 TK4
6/9/2014

Blue curve - 22kV 63A fuse on Feeder to 1.5 MVA transformer P6507.
Red curve - 415V Incomer ACB to MCC P6512.
Blue solid / dashed vertical lines represent 85 % / 100% of current through the 63A fuse
for an arcing fault on the line-side of the Incomer ACB.

Figure H-1: Existing Sub K4 MCC (P6512) Feeder TCC



Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with relay on Feeder to transformer P6507.

..oc_Relay Pnl2 TK4
14/9/2014

Blue curve - 22kV relay on Feeder to 1.5 MVA transformer P6507.
Red curve - 415V Incomer ACB to MCC P6512.
Blue solid / dashed vertical lines represent 85 % / 100% of current through the 22kV relay
for an arcing fault on the line-side of the Incomer ACB.

Figure H-2: Proposed Sub K4 MCC (P6512) Feeder TCC

Appendix H.2 G601A - Time-Current Characteristic Curves (Protection grading - Largest Drive)

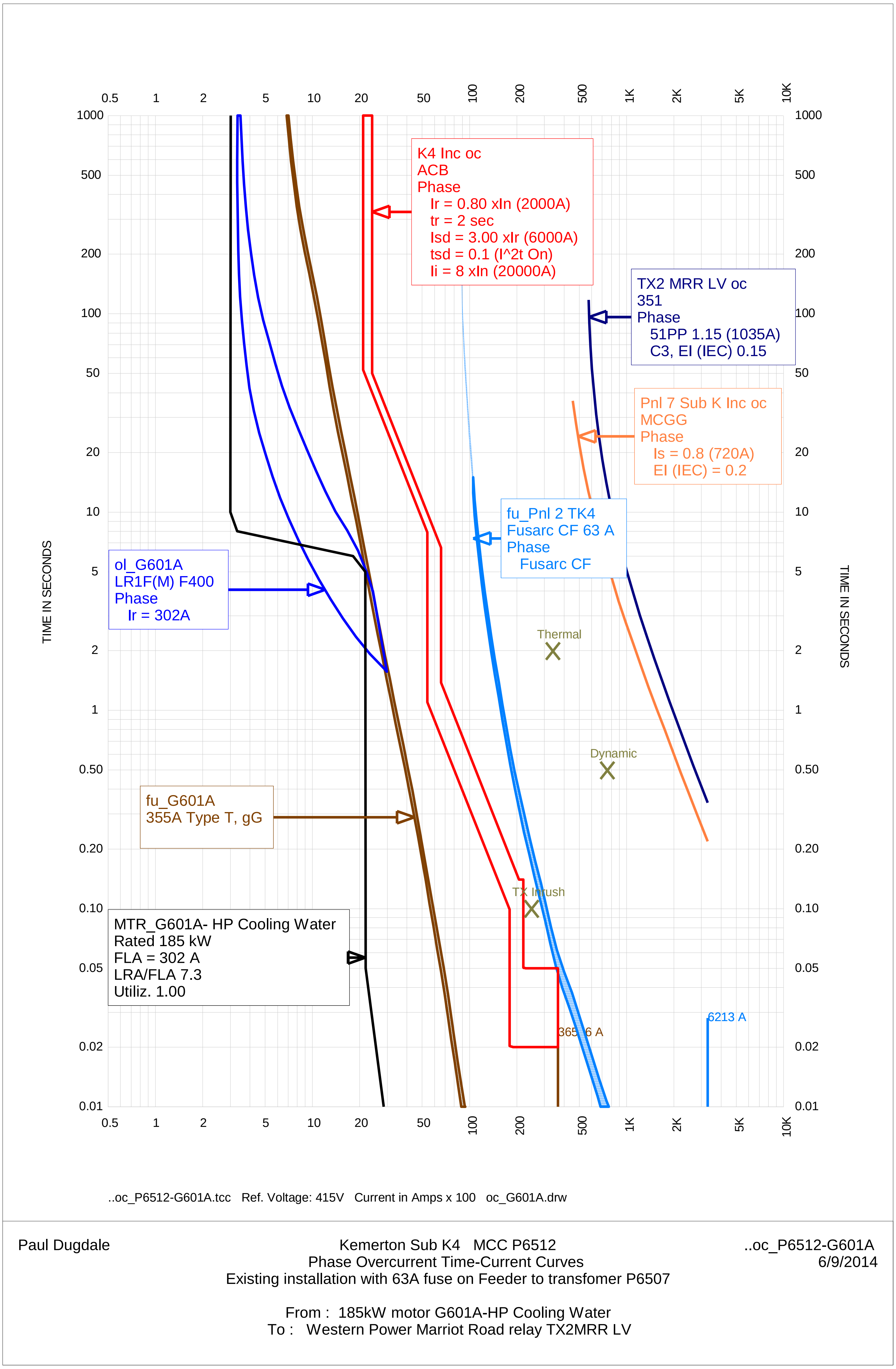
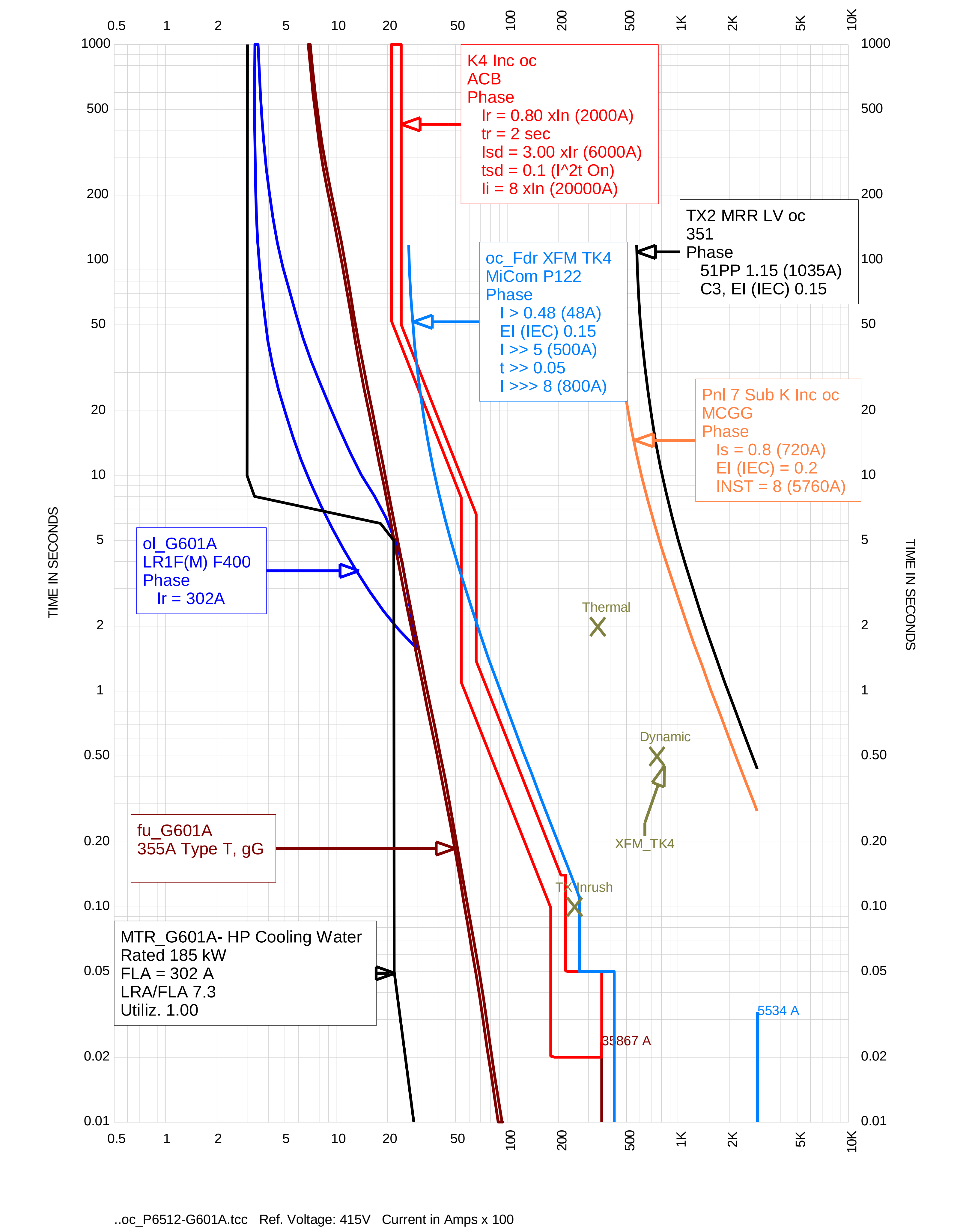


Figure H-3: Grading of existing network to largest drive on Sub K4 MCC (P6512)



Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with relay on Feeder to transfomer P6507

From : 185kW motor G601A-HP Cooling Water
To : Western Power Marriot Road relay TX2MRR LV

..oc_P6512-G601A
6/9/2014

Figure H-4: Grading of proposed network to largest drive on Sub K4 MCC (P6512)

Appendix H.3 MCC Feeder Time-Current Characteristic Curves, including tripping duration and PTW Single Line Diagram

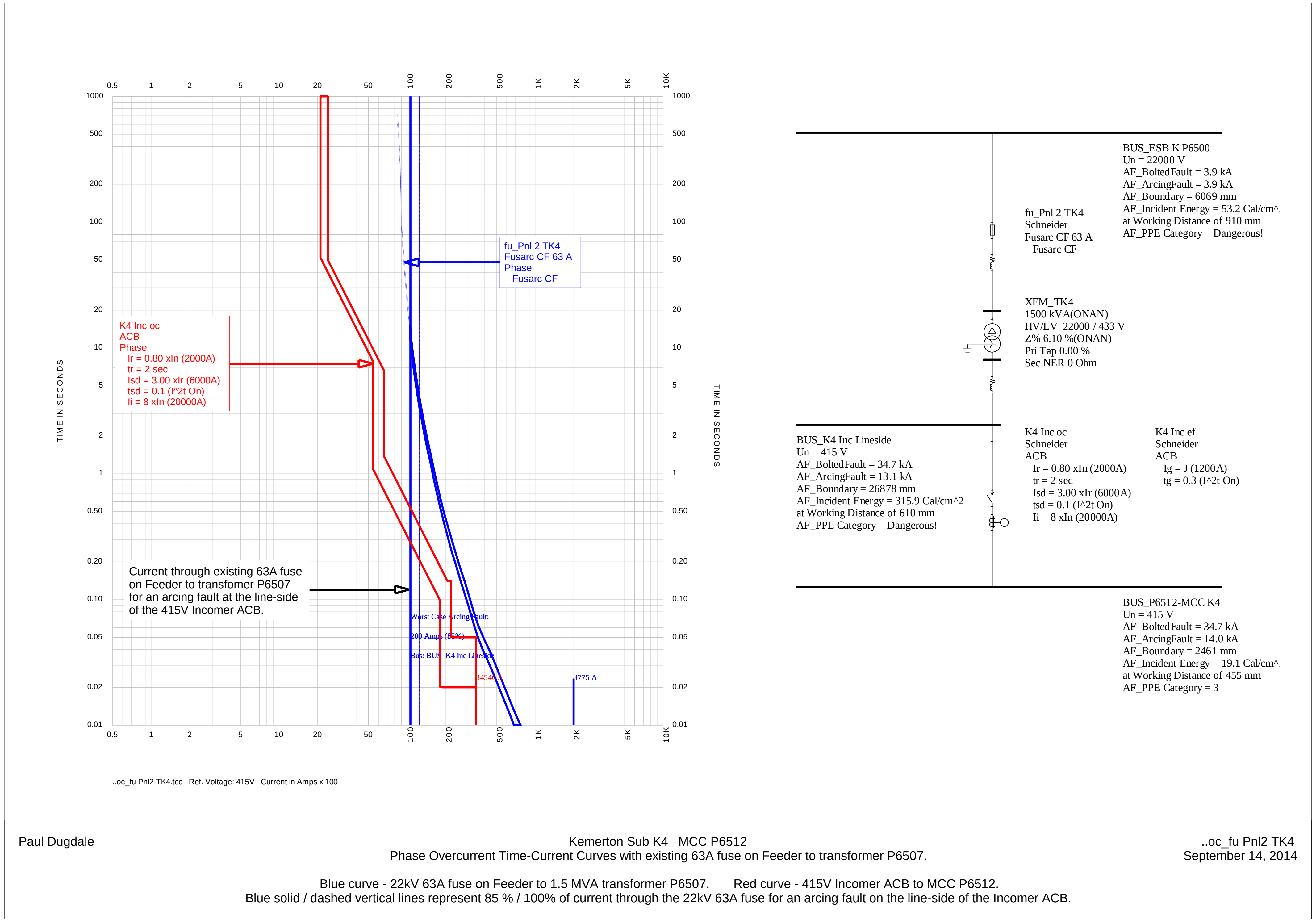
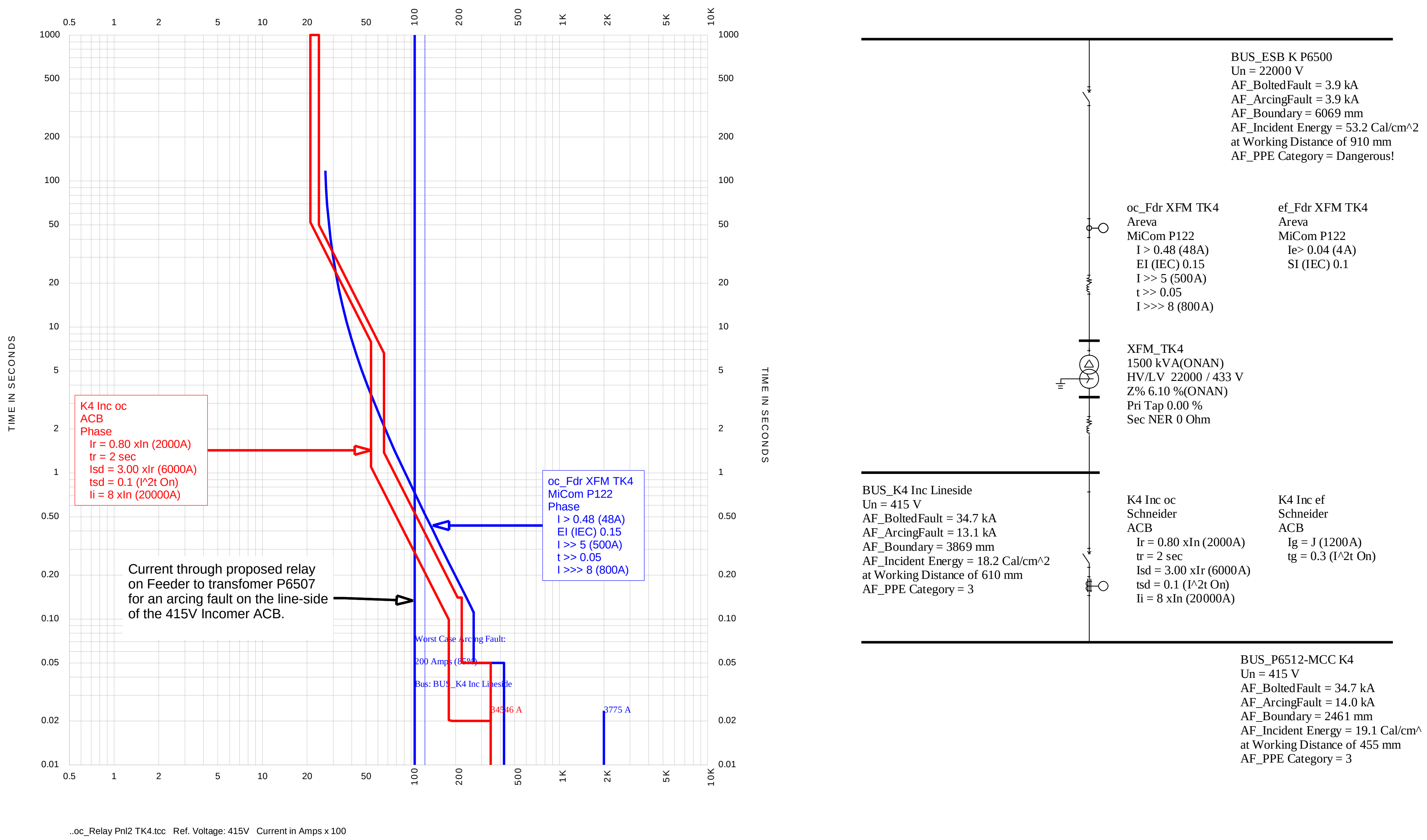


Figure H-5: Existing Sub K4 MCC (P6512) Feeder TCC and SLD



Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves for proposed installation with MiCom P122 relay on Feeder to transformer P6507.

..oc_Relay Pnl2 TK4
September 14, 2014

Blue curve - 22kV MiCom P122 relay on Feeder to 1.5 MVA transformer P6507. Red curve - 415V Incomer ACB to MCC P6512.
Blue solid / dashed vertical lines represent 85 % / 100% of current through the 22kV MiCom P122 relay for an arcing fault on the line-side of the Incomer ACB.

Figure H-6: Proposed Sub K4 MCC (P6512) Feeder TCC and SLD

Appendix H.4 G601A – Time-Current Characteristic Curves (Protection grading – Largest Drive), including PTW Single Line Diagram

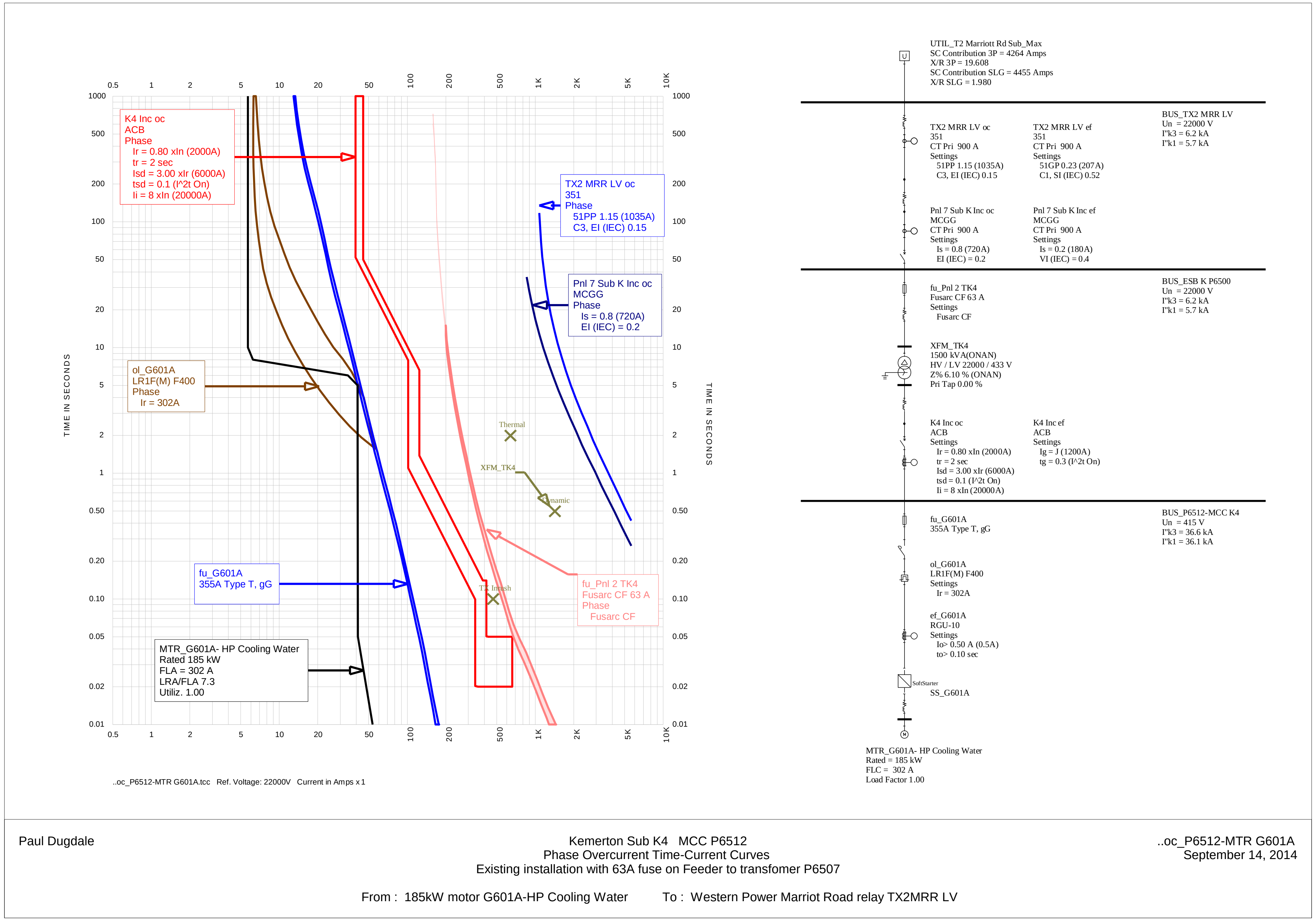
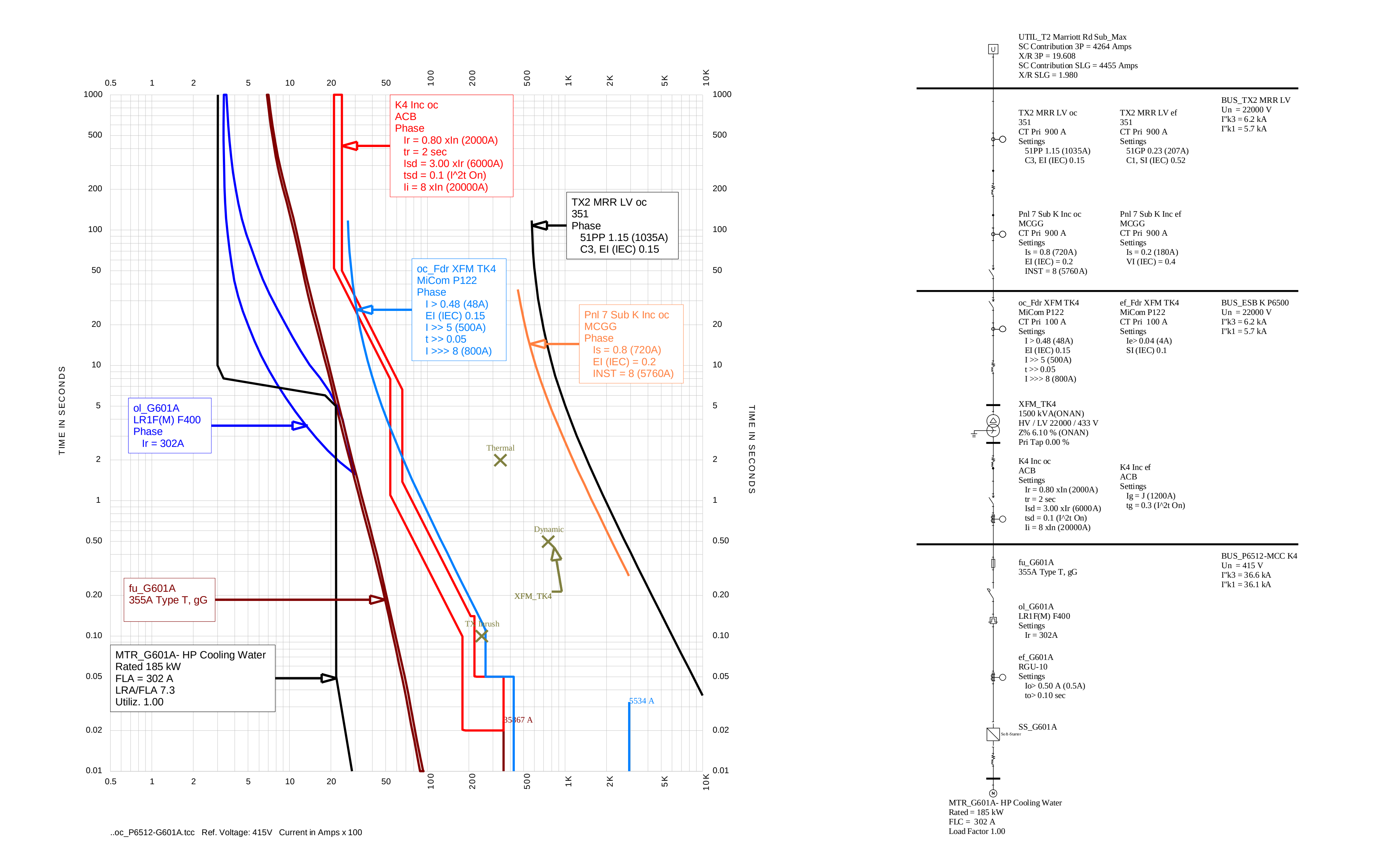


Figure H-7: Grading of existing network to largest drive on Sub K4 MCC (P6512)



Paul Dugdale

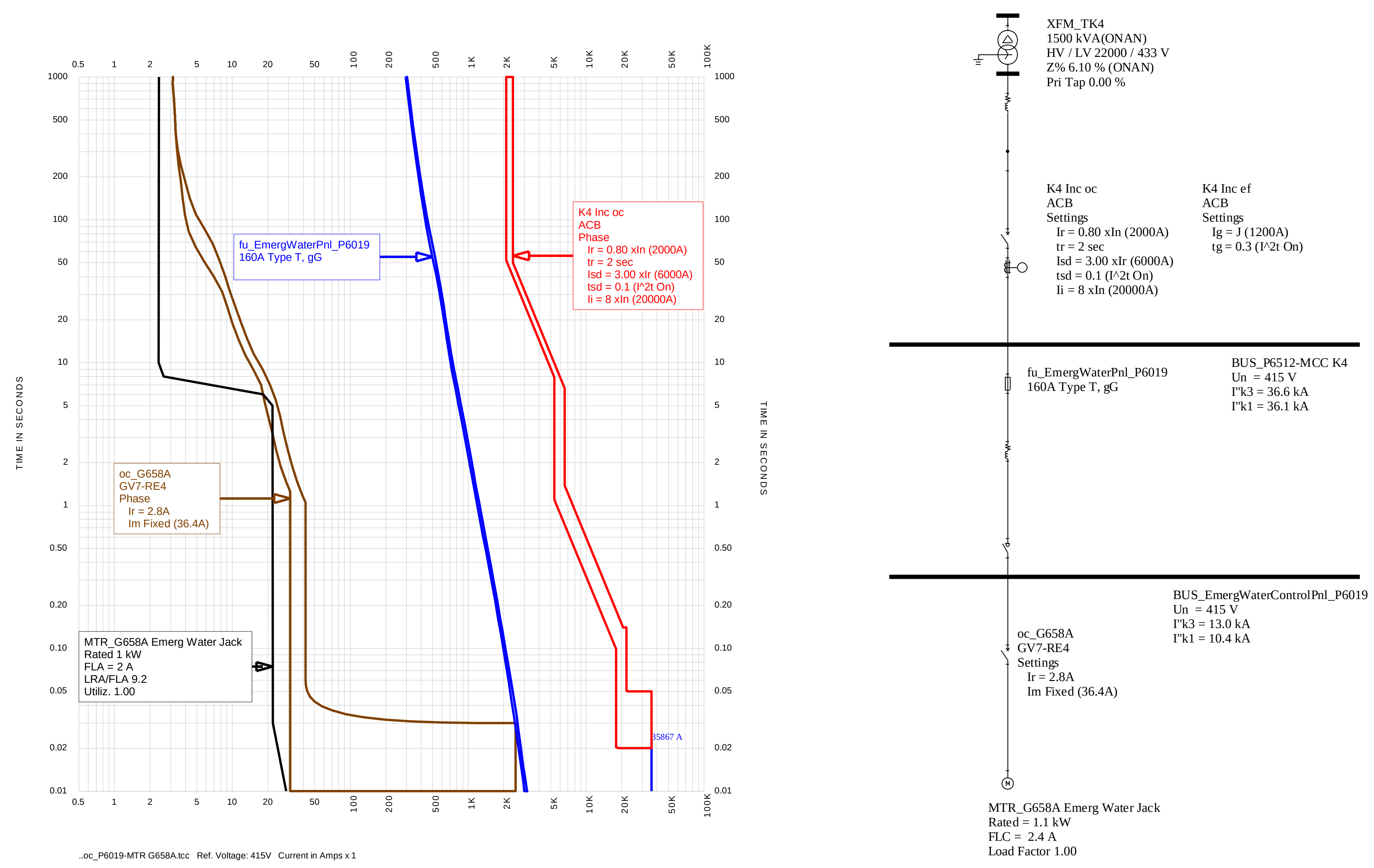
Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with 22kV Micom P122 relay on Feeder to transfomer P6507

..oc_P6512-G601A
September 14, 2014

From : 185kW motor G601A-HP Cooling Water To : Western Power Marriot Road relay TX2MRR LV

Figure H-8: Grading of proposed network to largest drive on Sub K4 MCC (P6512)

Appendix H.5 Sub K4 MCC (P6512) Out-going Feeder Time-Current Characteristic Curves (Protection grading), including PTW Single Line Diagram



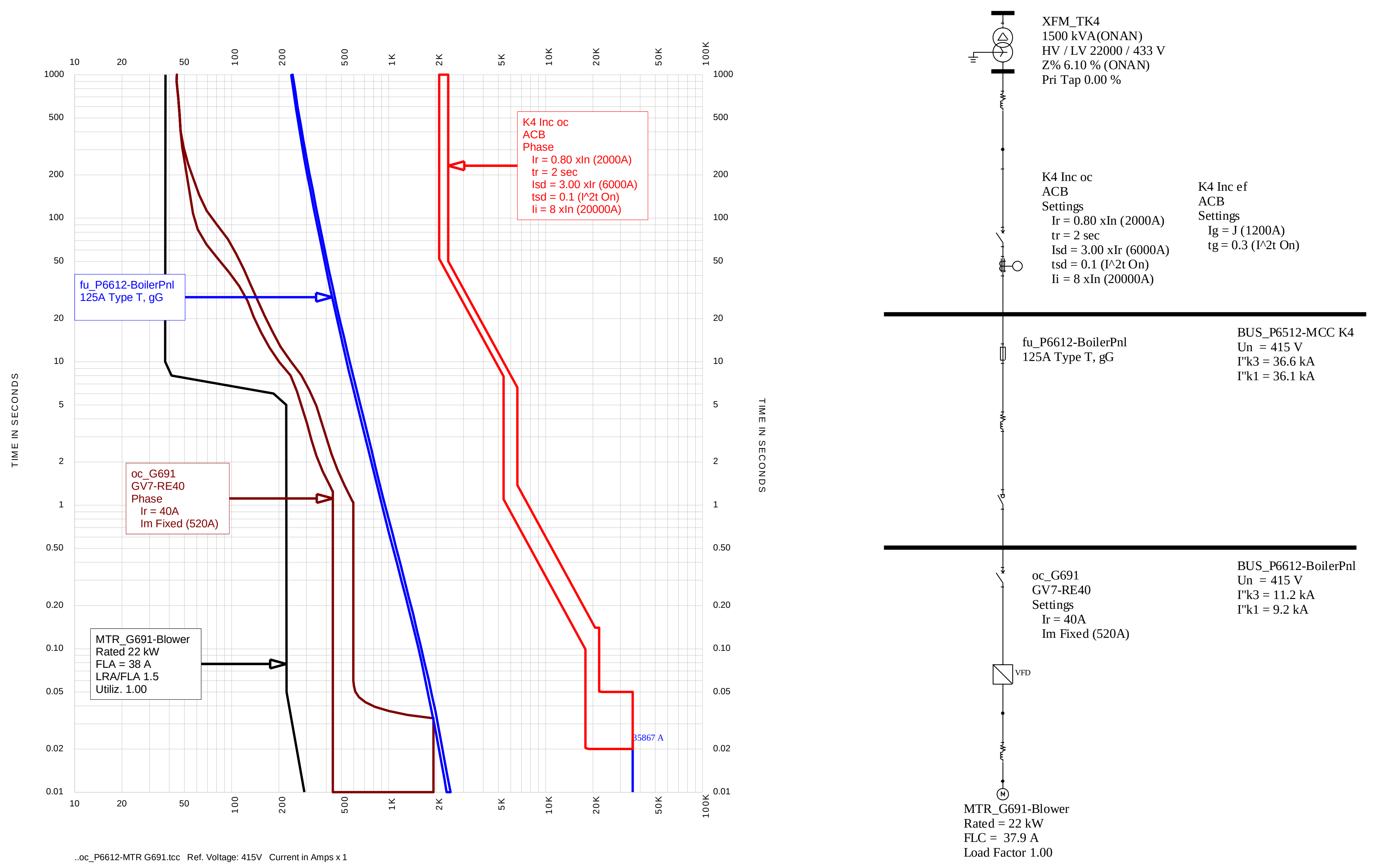
Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with 22kV Micom P122 relay on Feeder to transfomer P6507

..oc_P6019-MTR G658A
October 12, 2014

From : 1.1 kW motor G658A Emerg Water Jack To : 415V ACB on Incomer to MCC K4

Figure H-9: Grading of proposed network from MCC K4 (P6512) to 1.1kW G658A Emergency Jacking Water Pump



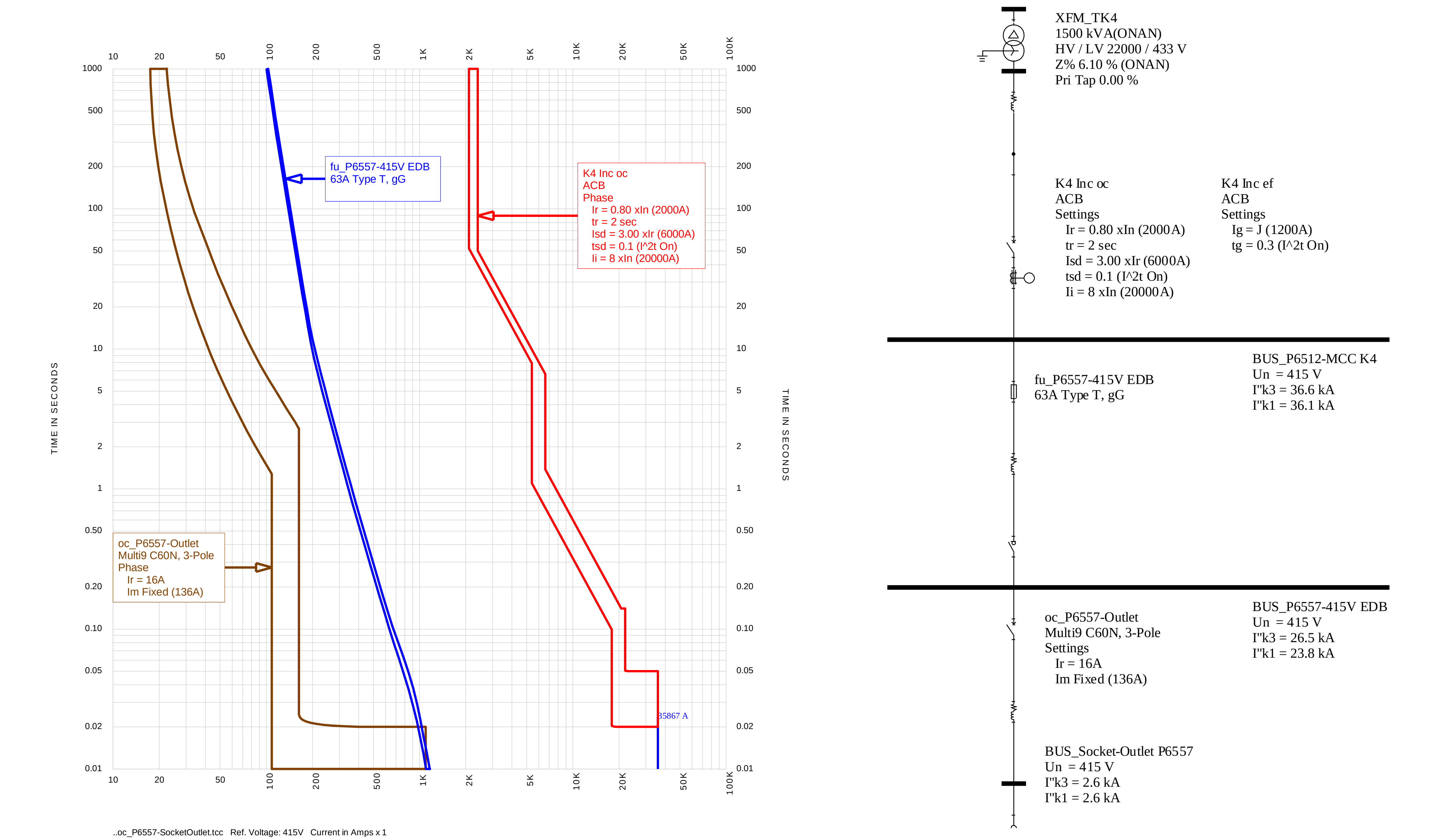
Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with 22kV Micom P122 relay on Feeder to transfomer P6507

From : 22 kW motor G691 Blower To : 415V ACB on Incomer to MCC K4

..oc_P6612-MTR G691
October 12, 2014

Figure H-10: Grading of proposed network from MCC K4 (P6512) to 22kW G691 Blower Motor



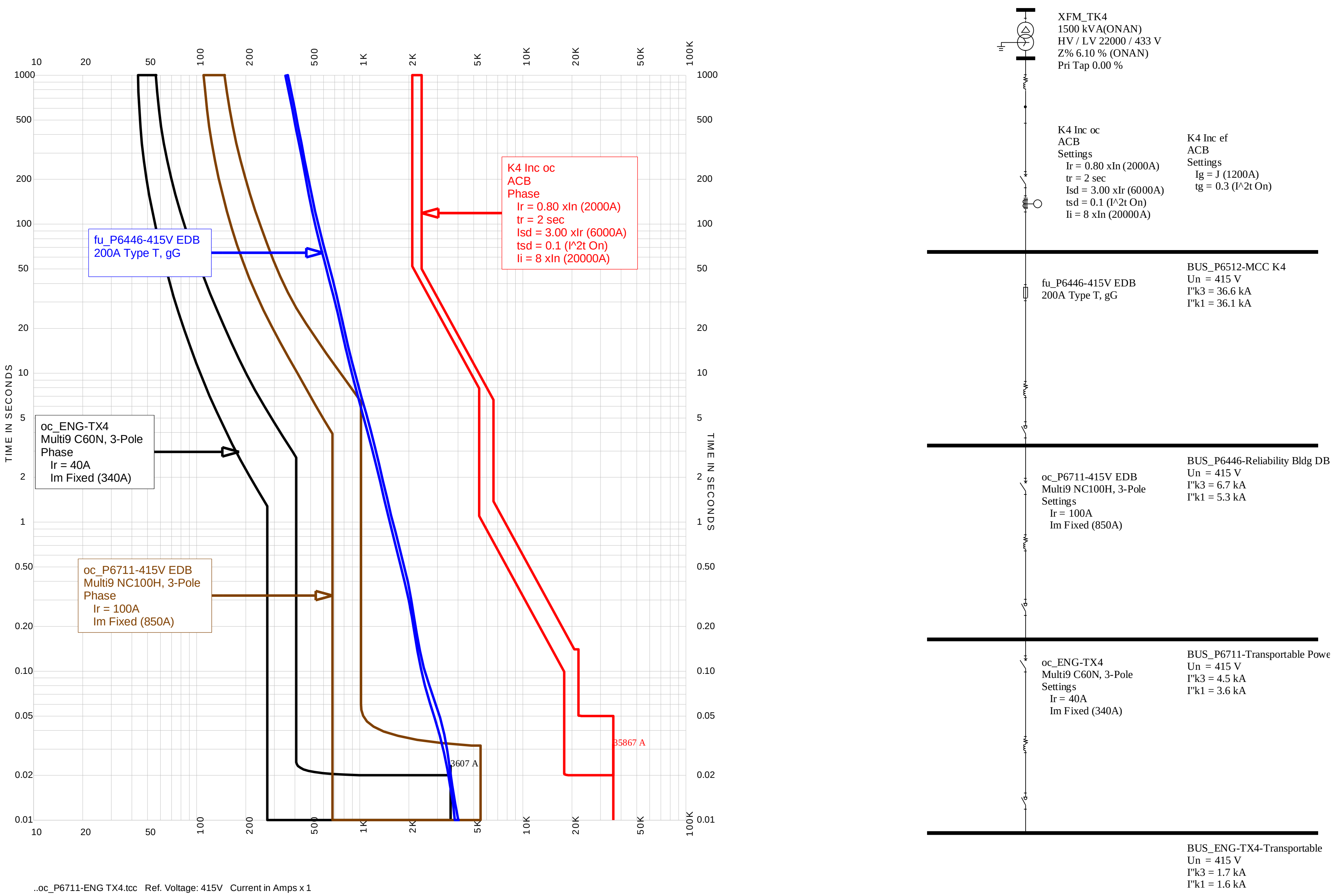
Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with 22kV Micom P122 relay on Feeder to transfomer P6507

From : Socket Outlet P6557 To : 415V ACB on Incomer to MCC K4

..oc_P6557-SocketOutlet
October 12, 2014

Figure H-11: Grading of proposed network from MCC K4 (P6512) to P6557 Socket Outlet



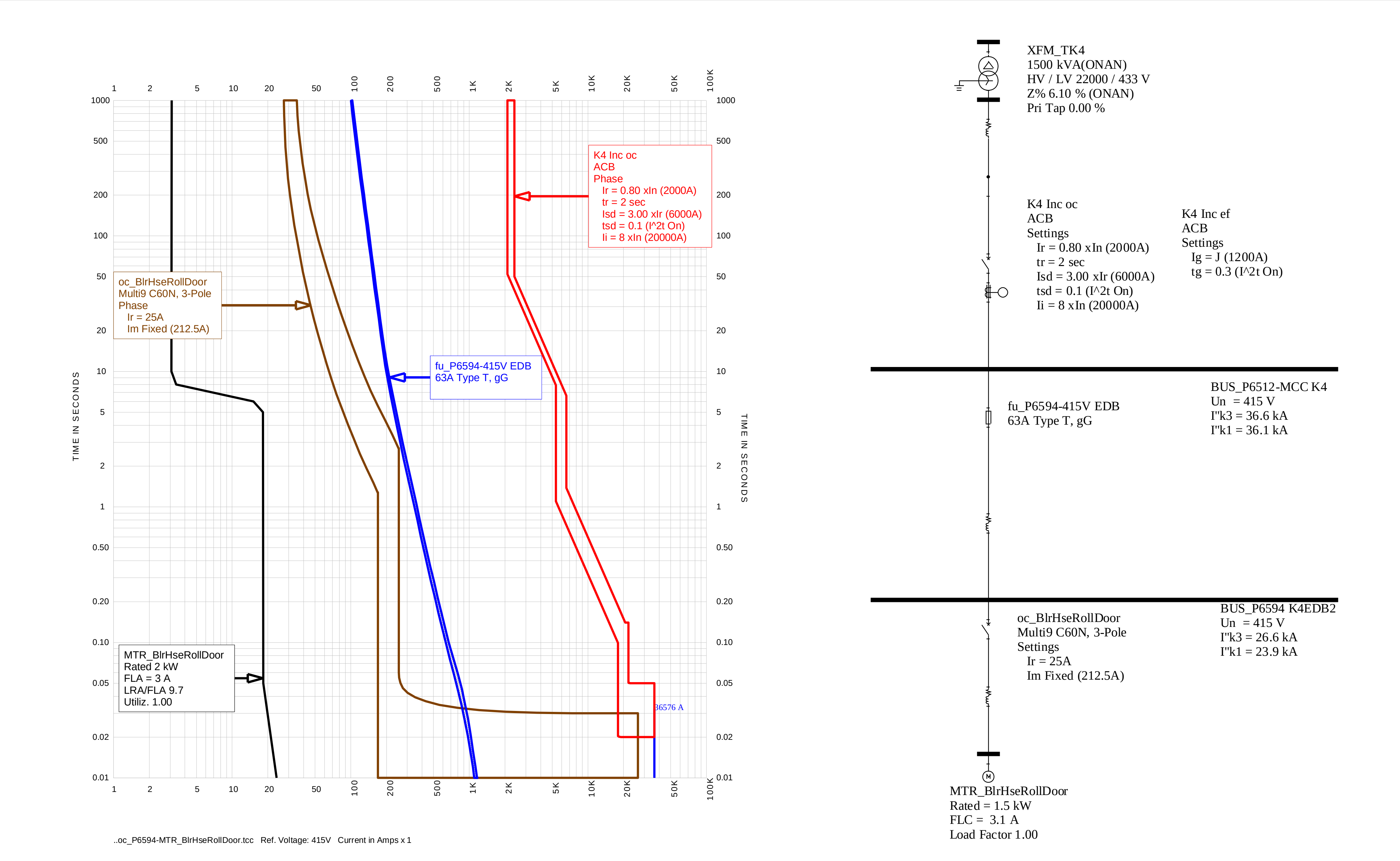
Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with 22kV Micom P122 relay on Feeder to transfomer P6507

..oc_P6711-ENG TX4
October 12, 2014

From : Multi9 C60N, 3-Pole MCCB on Feeder to ENG-TX4 Transportable To : 415V ACB on Incomer to MCC K4

Figure H-12: Grading of proposed network from MCC K4 (P6512) to Feeder to ENG-TX4 Transportable



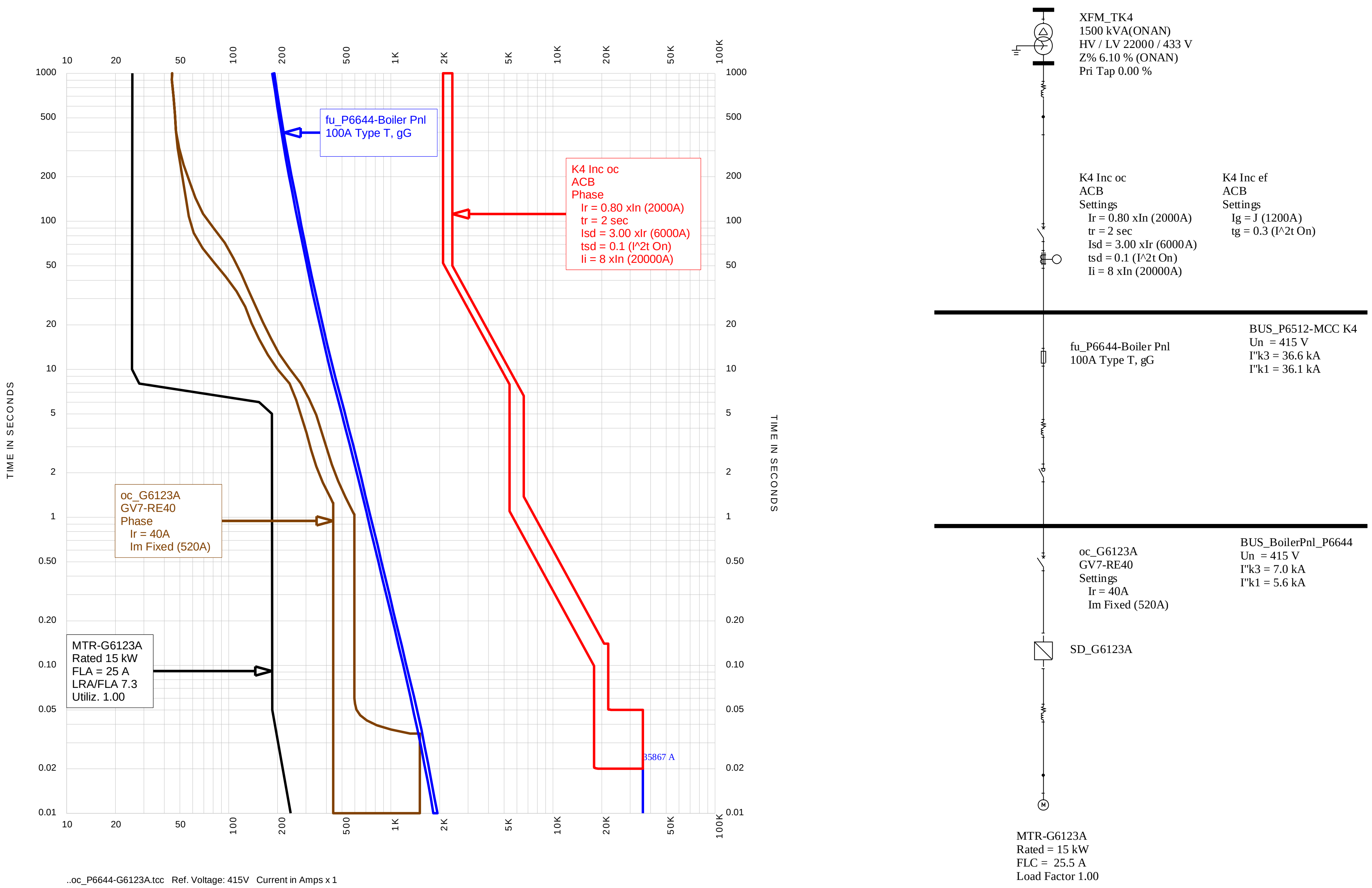
Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with 22kV Micom P122 relay on Feeder to transfomer P6507

..oc_P6594-MTR_BlrHseRollDoor
October 12, 2014

From : Multi9 C60N, 3 pole, Ir = 25A on Feeder to Boilerhouse Roll Door To : 415V ACB on Incomer to MCC K4

Figure H-13: Grading of proposed network from MCC K4 (P6512) to 1.5kW Boiler house Roller Door Motor



Paul Dugdale

Kemerton Sub K4 MCC P6512
Phase Overcurrent Time-Current Curves
Proposed installation with 22kV Micom P122 relay on Feeder to transformer P6507

From : 15 kW motor G6123A To : 415V ACB on Incomer to MCC K4

..oc_P6644-G6123A
October 12, 2014

Figure H-14: Grading of proposed network from MCC K4 (P6512) to 15kW G6123A Boiler Feed Pump

Appendix I Arc Flash Labels

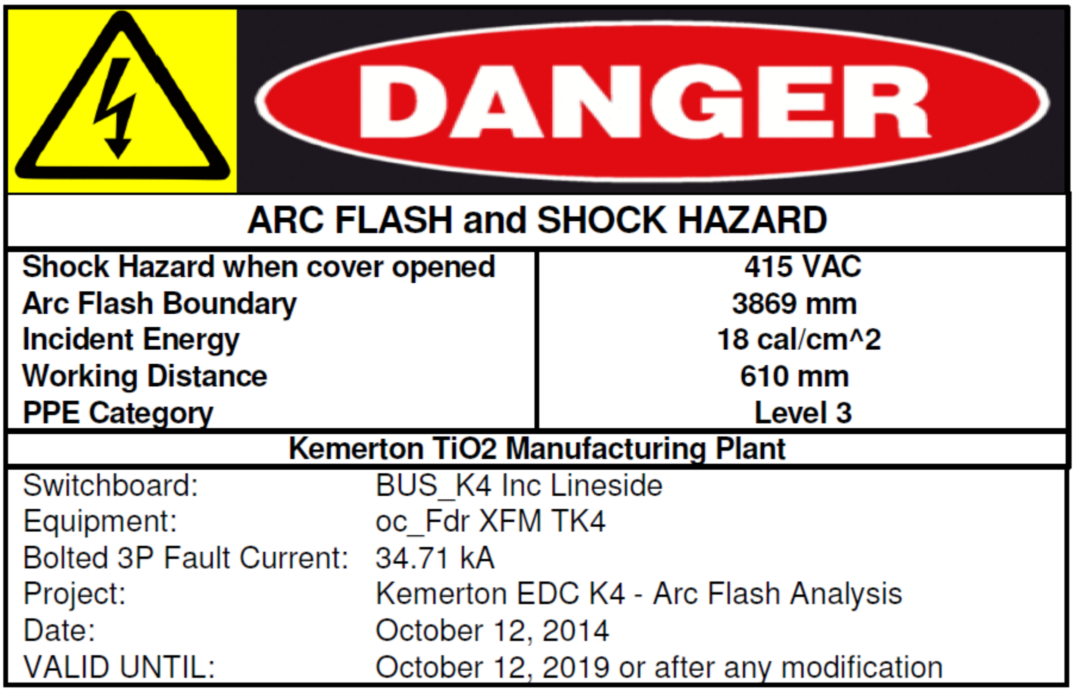


Figure I-1: Arc Flash Label for Incoming Supply Tier of MCC K4 (P6512)

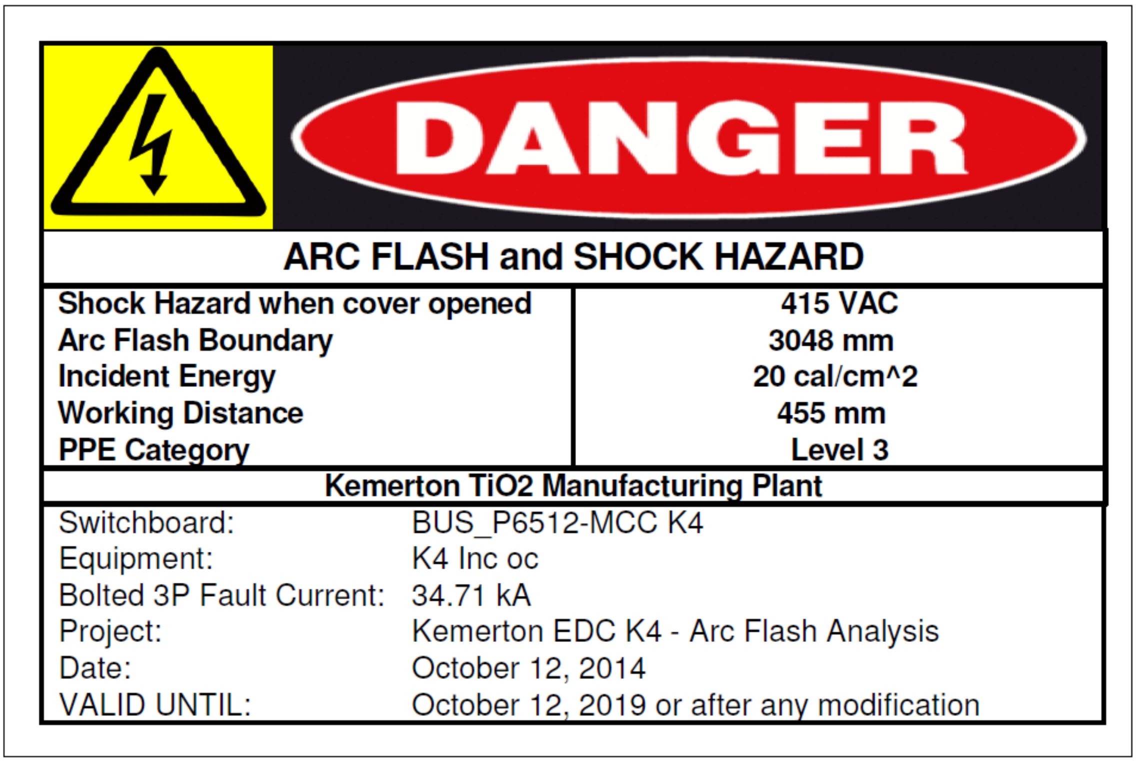


Figure I-2: Arc Flash Label for MCC K4 (P6512)

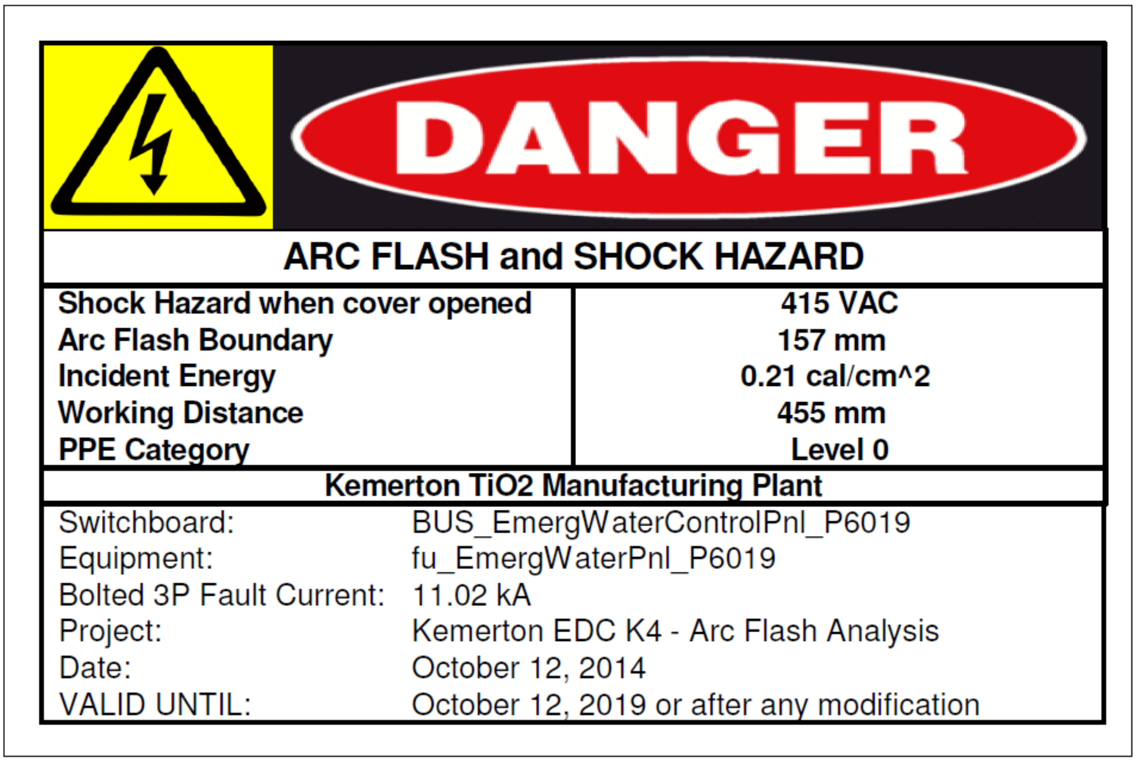


Figure I-3: Arc Flash Label for P6019 Emergency Water Control Panel

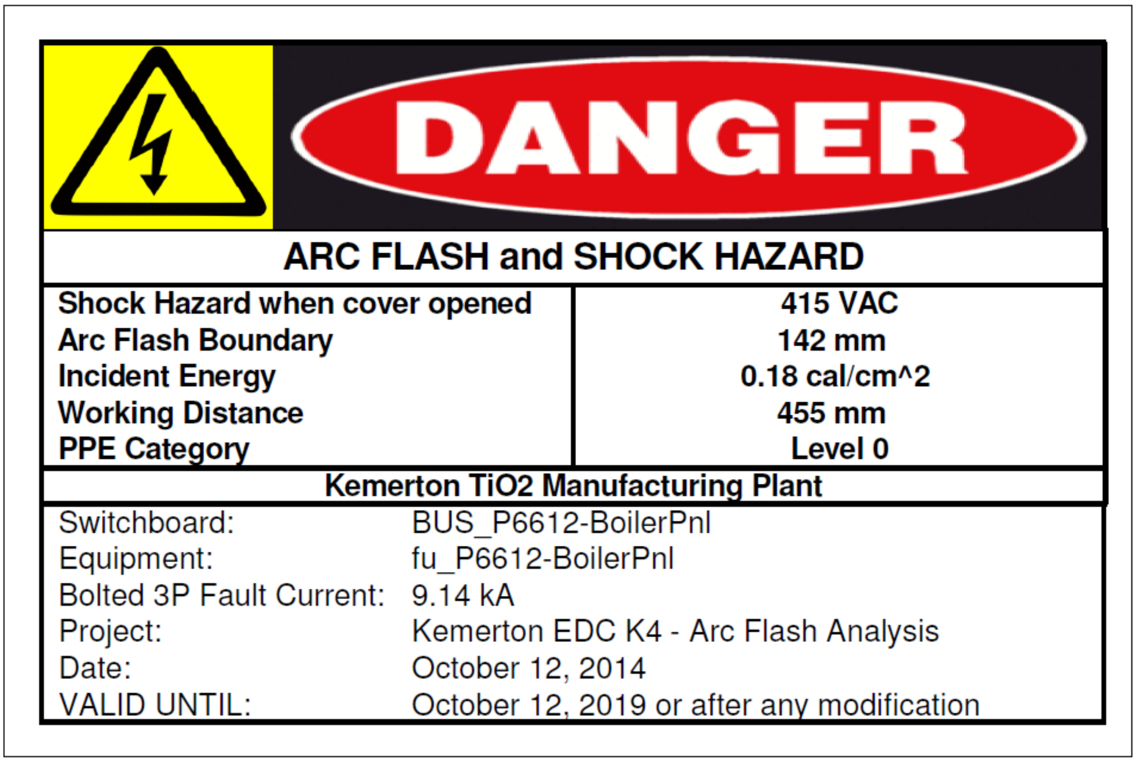


Figure I-4: Arc Flash Label for P6612 Boiler F690 Control Panel

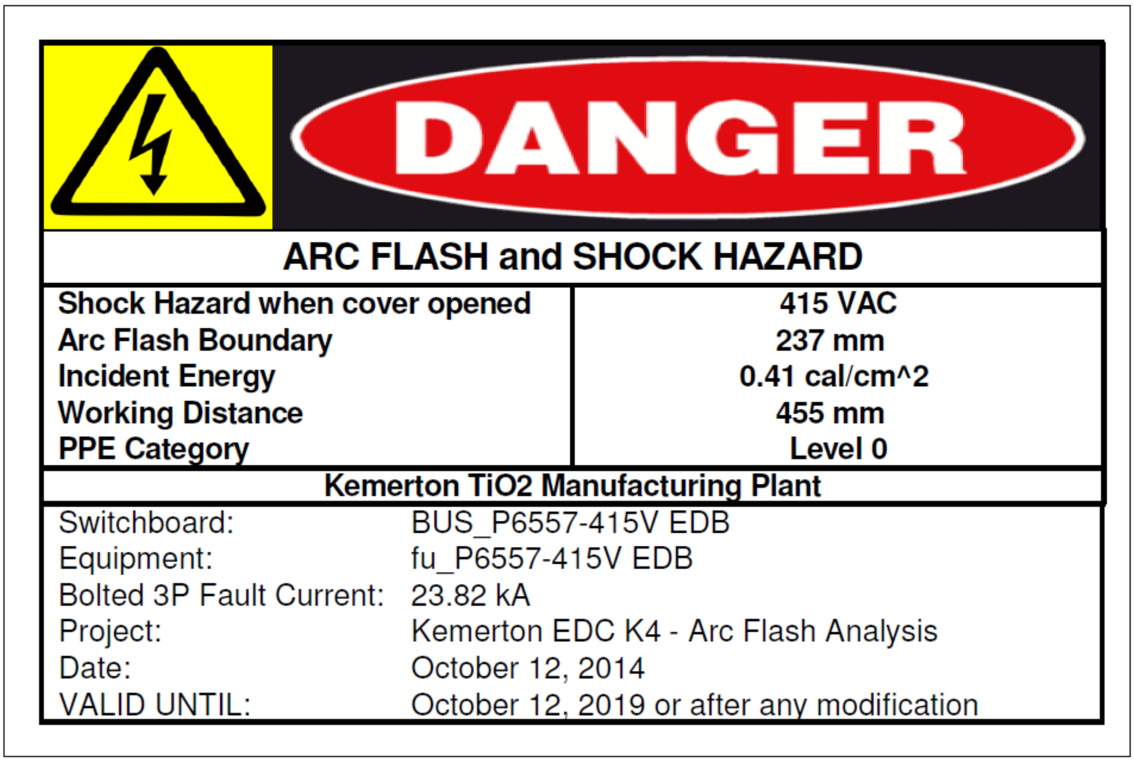


Figure I-5: Arc Flash Label for P6557 415VAC Electrical Distribution Board

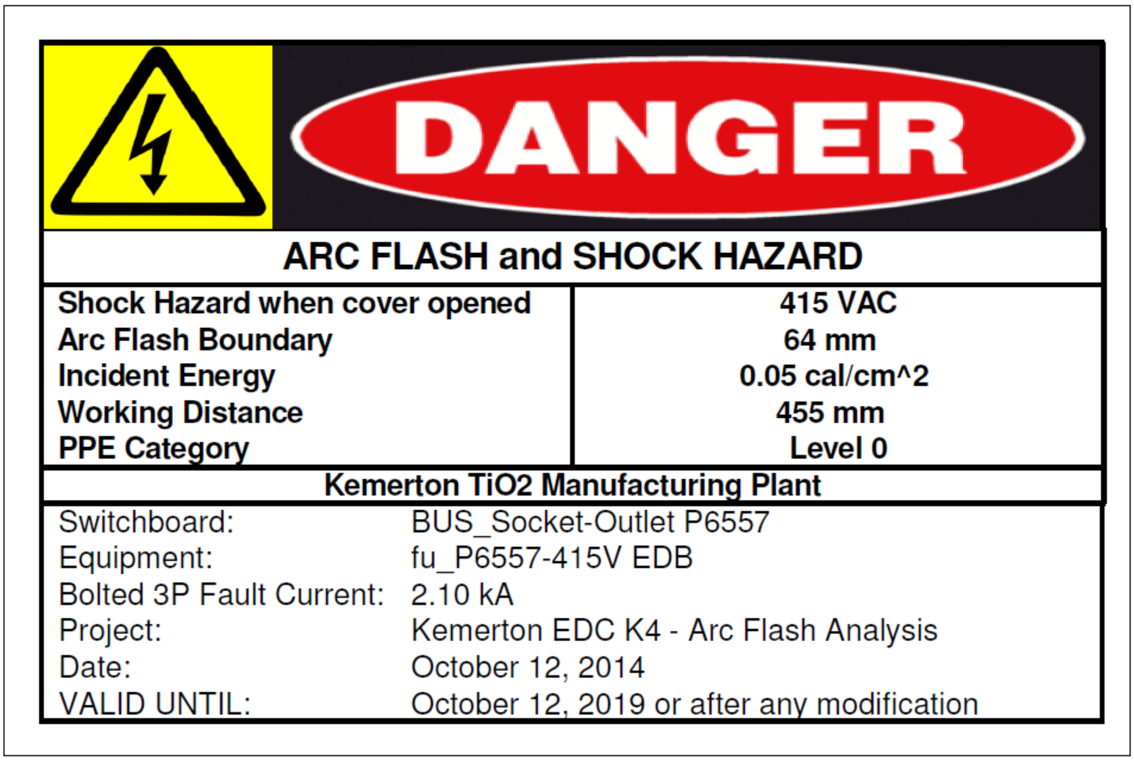


Figure I-6: Arc Flash Label for P6557 Socket Outlet

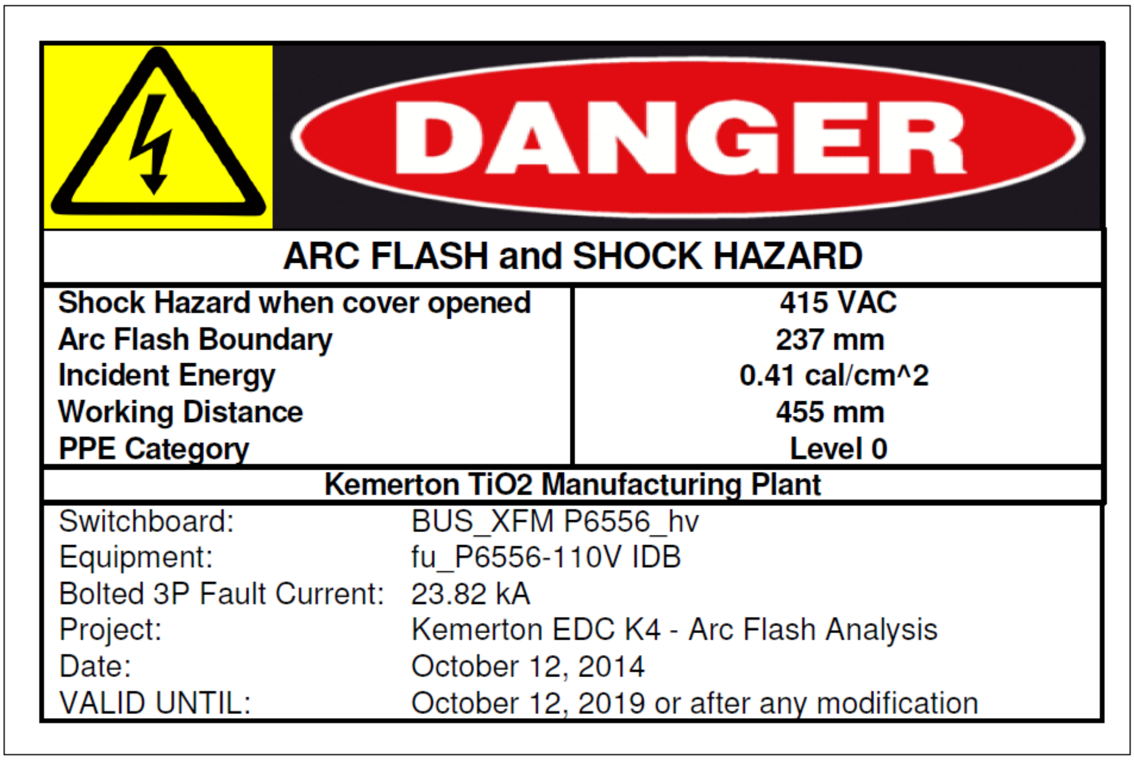


Figure I-7: Arc Flash Label for 415VAC Primary winding terminations of 110VAC Instrumentation Distribution Board Feed Transformer

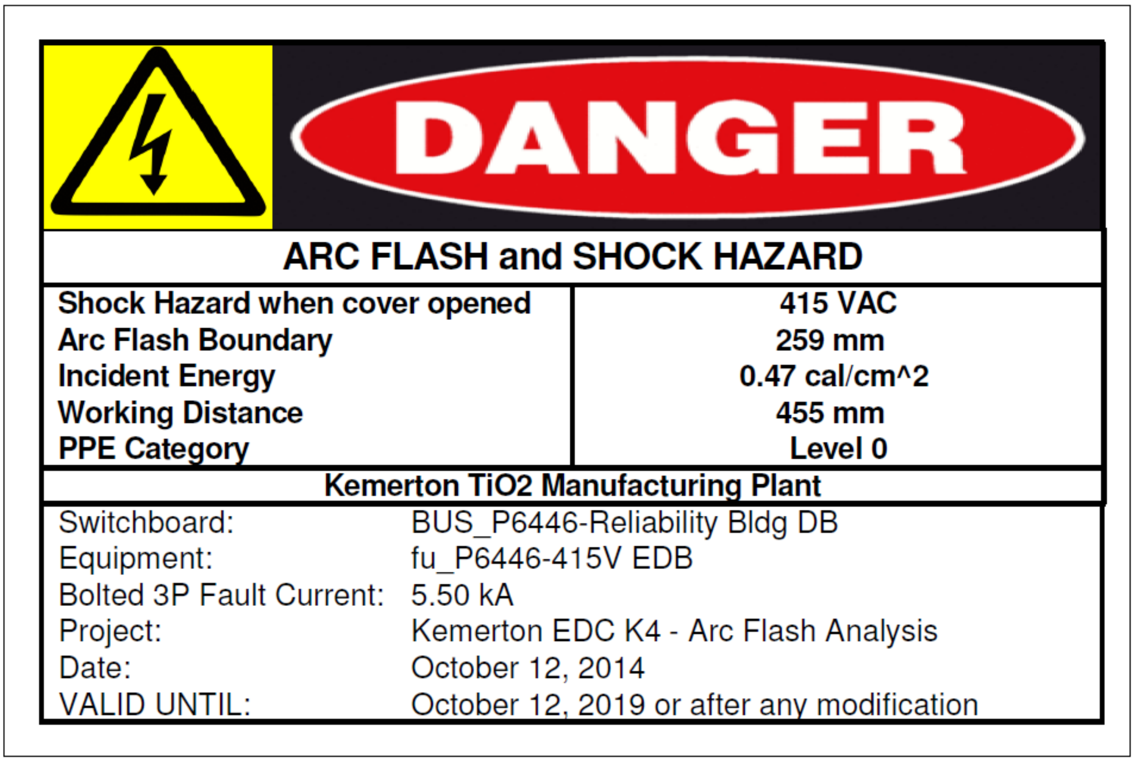


Figure I-8: Arc Flash Label for P6446 415VAC Electrical Distribution Board

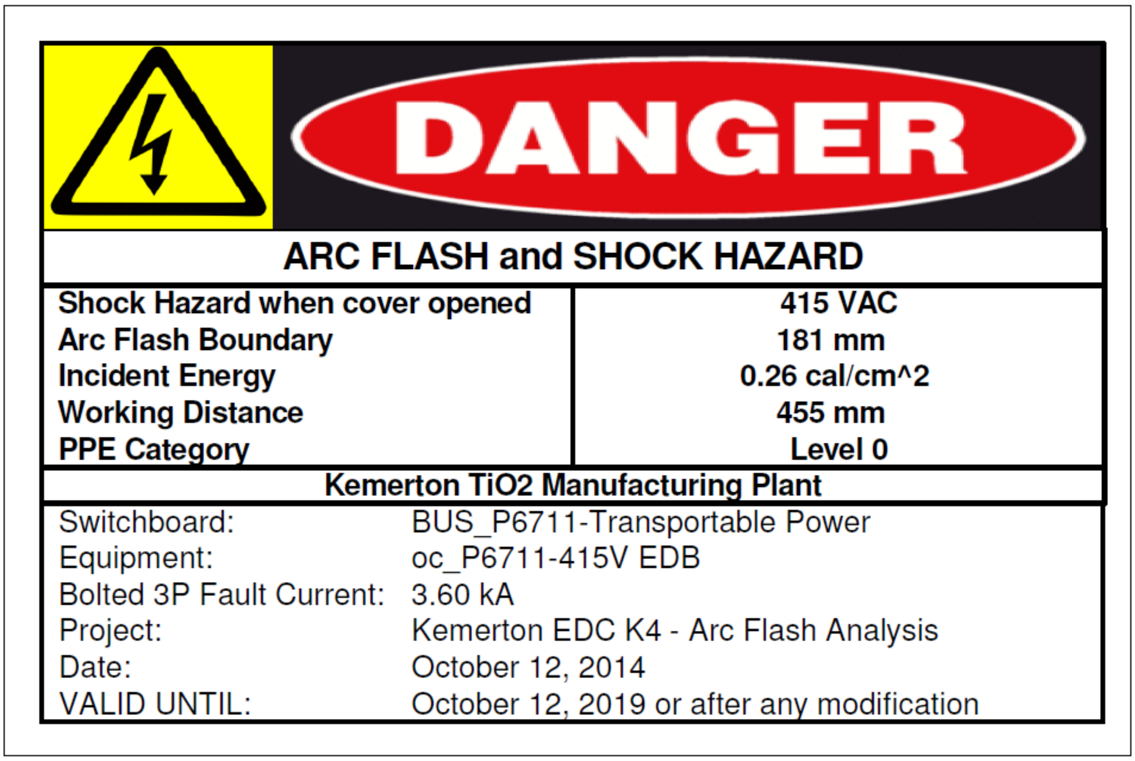


Figure I-9: Arc Flash Label for P6711 415VAC Electrical Distribution Board

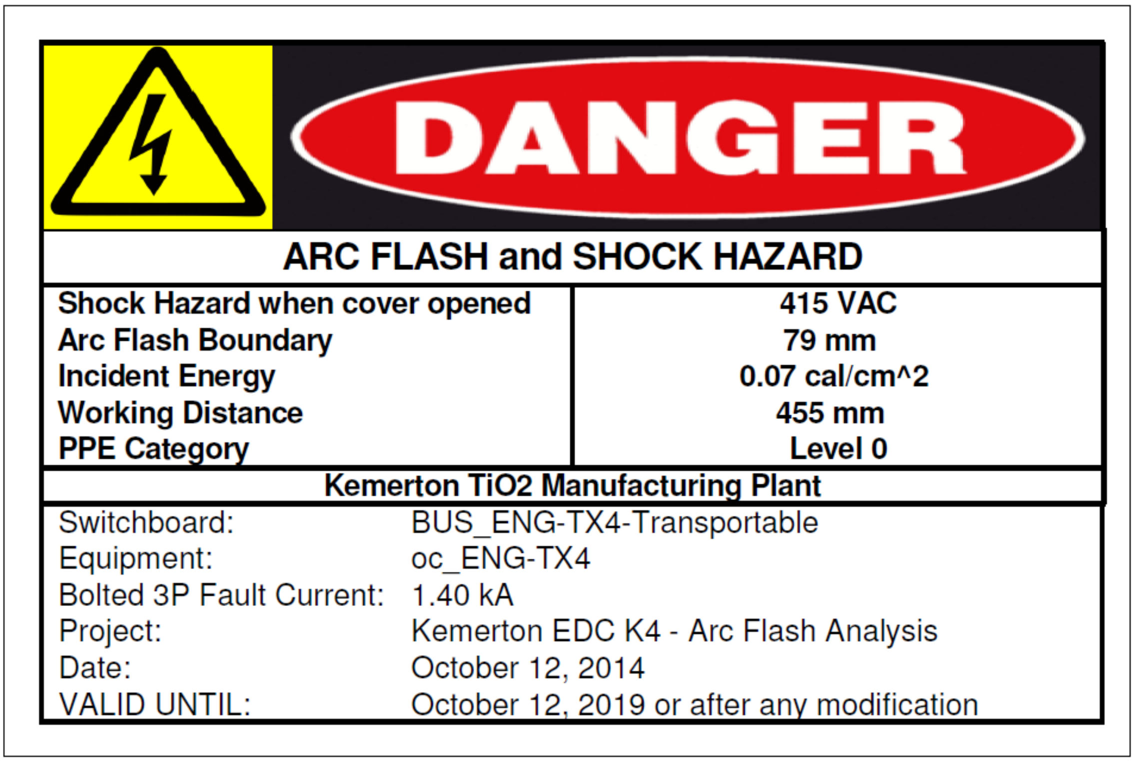


Figure I-10: Arc Flash Label for ENG-TX4 Transportable 415VAC Electrical Distribution Board

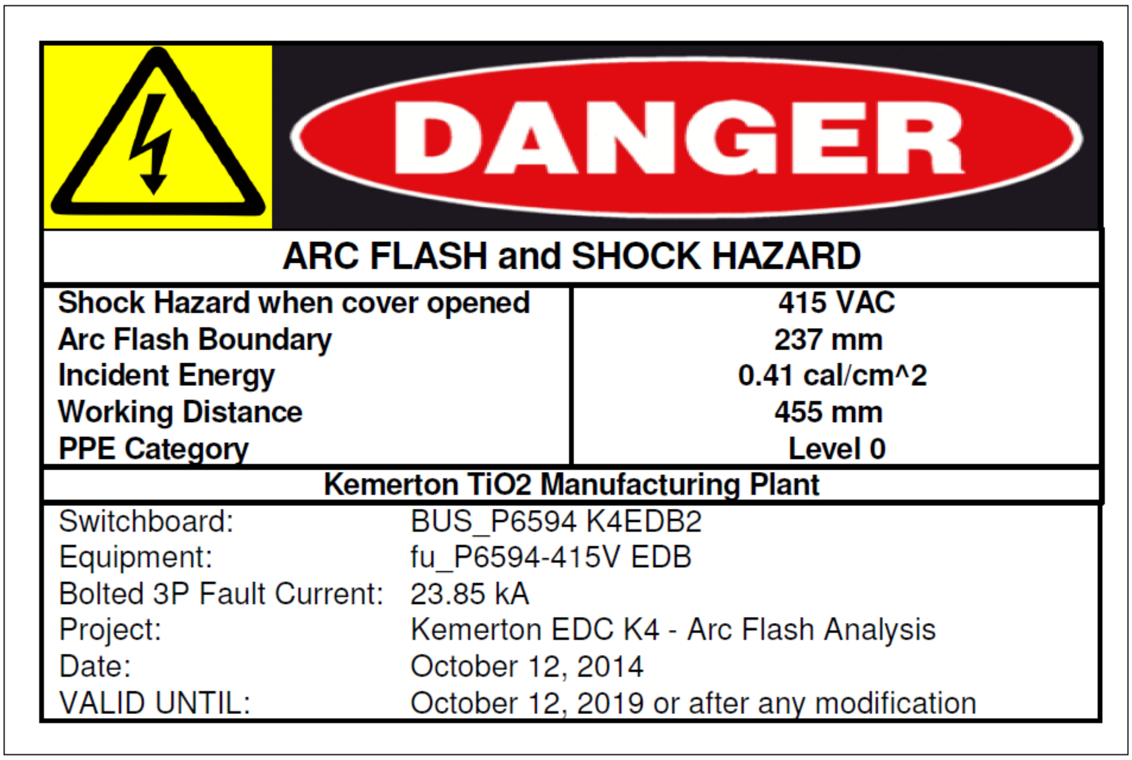


Figure I-11: Arc Flash Label for P6594 415VAC Electrical Distribution Board

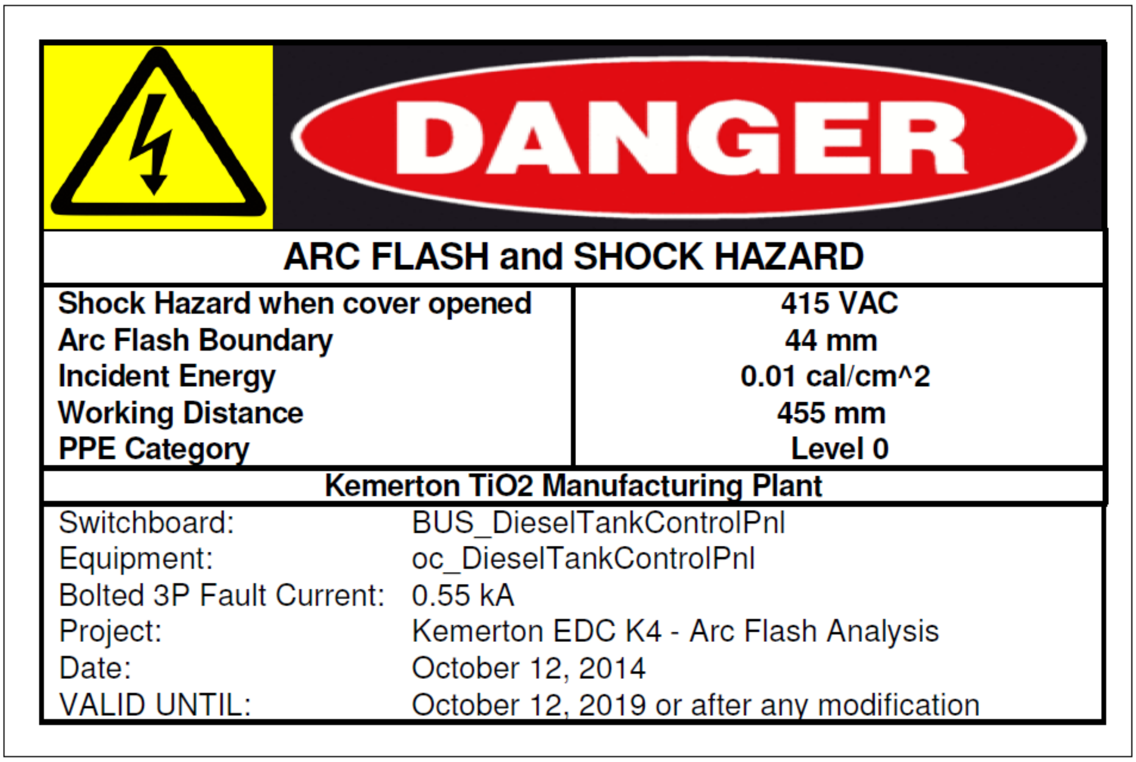


Figure I-12: Arc Flash Label for Diesel Tank Control Panel

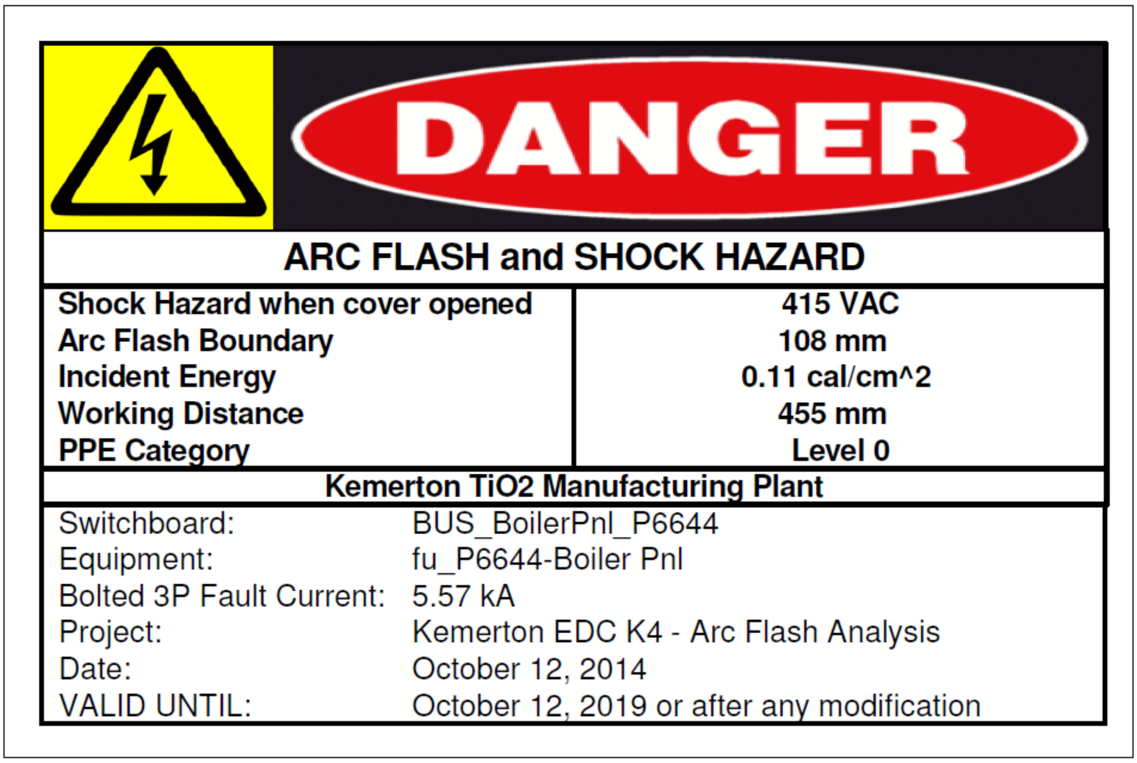


Figure I-13: Arc Flash Label for P6644 Boiler F6123 Control Panel

Appendix J Validation Spreadsheet

Arc Flash Calculator for Arcing Current and Incident Energy - to IEEE 1584 - 2002

Note: Only one contribution to bus arcing fault.

		Un < 1kV	0.85 x Ia	Un =>1kV	Un>15kV Lee Method	
Input data	J / cal =	4.1840				
Nom Voltage	V(kV)	0.415	0.415		0	Nominal Voltage
Fault Current	Ibf(kA)	27	27		0	Bolted three phase short-circuit current
Working Dist	D (mm)	455	455		0	Working distance between arc and worker's chest and face AS 4836 = 500mm for 415V
Fault Clearing Time	t(s)	0.14	0.463		0	Relay tripping time plus breaker clearing time
Bus bar Gap - MCC/Pnl Bus bar Gap - SwGr	G = 25mm G = 32mm	32	32			Distance between conductive parts IEEE 1584 Table 2
Arc in box Arc in open	K = -0.097 K = -0.153	-0.097	-0.097	-0.097		see IEEE 1584 section 5.2 equation 1
	log(Ia)	1.100	1.030	#NUM!		Log (arcing current) IEEE1584 Equi (1) for V < 1kV, Equi (2) for V => 1kV
Arc Current	Ia	**12.594**	x 0.85 = **10.705**	**#NUM!**		Arcing current
Arc in box Arc in open	K1 = -0.555 K1 = -0.792	-0.555	-0.555	-0.555		see IEEE 1584 section 5.3 equation 4
Grounded system Ungrounded system	K2 = -0.113 K2 = 0	-0.113	-0.113	0		see IEEE 1584 section 5.3 equation 4
	log(En)	0.556	0.480	#NUM!		Log (Incident energy normalized for arcing time of 0.2 sec and working distance of 610 mm)
	En	3.602	3.021	#NUM!		Incident energy normalized for arcing time of 0.2 sec and working distance of 610 mm)
Panel/MCC Distance Factor SwGr Distance Factor	x = 1.641 x = 1.473	1.641	1.641	0.973		See table 4 of IEEE 1584
Un =< 1000V Un > 1000V	Cf = 1.5 Cf = 1.0	1.5	1.5	1.0		See equi 6 of IEEE 1584
IEEE - Inc Energy (J/cm2)	IEEE 1584	**25.60**	**71.02**	**#NUM!**		Incident Energy
IEEE - Inc Energy (cal/cm2)	IEEE 1584	**6.12**	**16.97**	**#NUM!**		Incident Energy
Lee Method - (J/cm²)	Lee Method				**#DIV/0!**	Incident Energy
Lee Method - (cal/cm²)	Lee Method				**#DIV/0!**	Incident Energy
Arc Flash Boundary (D_B) 5.0208 Cal/cm^2 1.2000 J/cm^2	mm	**1228**	**2286**	**#NUM!**	**0**	

Figure J-1: PTW Arc Flash Calculation to IEEE 1584 Validation spreadsheet