University of Southern Queensland

Faculty of Health, Engineering and Sciences

Terrestrial Laser Scanning for 3D Zone Substation Modelling and Safety Clearances.

A dissertation submitted by

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in fulfilment of the requirements of

ENG4111/ENG4112 Research Project

towards the degree of

Bachelor of Electrical Engineering (Power)

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Abstract

Essential Energy is a State Owned Corporation (SOC) responsible for construction and maintenance of the electricity network in NSW. An important part of this network are Zone Substations which are primarily used to transform voltage levels and distribute the voltage at a useable level.

Construction and augmentation of Zone Substations requires accurate design drawings to enable upgrade and new installations of plant and equipment. Many of these Substations are ageing assets and do not have accurate design drawings of current equipment layouts.

For these sites the inaccuracies contained in old hand drawn general arrangement drawings does not provide a good basis from which to begin a design.

The purpose of this Dissertation aims to determine whether Terrestrial Laser Scanning technology could be used to scan existing Zone Substation sites for the purpose of 3D modelling and determining if the sites are compliant with current safety clearance standards.

Nevertire Zone Substation is located 100km’s west of the city of Dubbo and this site has been used for the purpose of this document to prove that Terrestrial Laser Scanning equipment can produce accurate 3D models which are able to be used for Zone Substation Design and safety clearance checks.

Nevertire Zone Substation was scanned on site with a high definition laser scanner and a 3D model produced in the form of a point cloud file. This point cloud file was then used to produce a 3D wireframe model which can be used for design purposes.

The point cloud file and wireframe model were checked for accuracy against on site measurements and both models produced extremely accurate results. These results were then compared directly with conventional survey measurements (already completed at Nevertire Zone Substation) to highlight the differing levels of accuracy available in the different data capture techniques.

Using the point cloud file of Nevertire Zone Substation the site was thoroughly analysed to ensure it was compliant with the current Essential Energy and Australian

Standards for electrical safety clearances. The Zone Substation lightning protection coverage was also modelled using the point cloud file and rolling sphere method.

Results and conclusions produced from the analysis clearly show that there are several existing areas within the Nevertire Zone Substation which do not comply with the required clearances specified by Essential Energy.

In addition to the results and conclusions a benefit analysis is provided to highlight the additional value that using this method of data capture has, over using conventional survey techniques.

The intention is that Essential Energy will be provided directly with all of the information and results developed throughout the writing of this document. Allowing further work to proceed will be based on decisions made by Essential Energy management on the value that this method will provide to the organisation.

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Certification of Dissertation

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.

Darrin Edwards

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Acknowledgments

This Dissertation is the final product in what has been the longest endurance test of my 35 years of life. Over the last 5 years that I have spent as a student completing my degree, not only have I been tested academically but tested also in life, and in learning to manage my time in my various roles as an employee, friend, husband and most importantly a father.

I take time now to firstly thank my wife Cheriee and our 4 children, Aidan, Blake, Drew and Chayse, throughout the duration of this degree our family has grown from 3 to 6, I know it hasn't always been easy on our family but the patience and resilience they have shown has been amazing – and yes we finally made it !

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Thanks to my employer Essential Energy who have provided financial assistance to a topic which would have been an unrealistic choice without this support, and to Jason Streatfeild who has given this topic his individual support, even from its early stages as an idea being attempted to fit into the mould of a formal topic.

Lastly I would like to acknowledge Andrew Geary and Peter Couch, the two people who have studied alongside me over the last 5 years and provided not only someone to study with but friendship and support, thanks gents.

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Glossary of Terms

B.I.L – Basic Impulse Level.

B.S.L – Basic Switching Level.

Ground safety clearance – The distance from ground to live equipment.

Horizontal work safety clearance – Horizontal clearance from person to live equipment.

IEC – International Electro technical Commission.

IEEE – Institute of Electrical and Electronics Engineers.

Jack bus – A busbar system used to switch load between outgoing feeders.

LiDAR – Light Detection and Ranging.

L.P.S – Lightning Protection System.

M.C.O.V – Maximum Continuous Operating Voltage.

Point cloud – A file containing millions of dots with x,y and z coordinates displayed in a co-ordinate system.

Scan world – The raw data file produced from a TLS.

Section safety clearance – The distance to live equipment from an isolated section.

S.P.D – Surge Protection Device.

T.L.S – Terrestrial Laser Scanner.

T.O.C – Top of Concrete.

Vertical work safety clearance - Vertical clearance from person to live equipment.

Wire frame model – A 3D CAD model made using shapes and surfaces.

Zone Substation – A part of the electricity network used to change voltage levels for voltage distribution.

1 Introduction

1.1 Business

As an organisation Essential Energy is responsible for the construction, maintenance and reliable transmission and distribution of power around the state of New South Wales and also small portions of Southern Queensland. The majority of the infrastructure within Essential Energy's network is made up of poles and wires.

This includes more than 200,000 kilometres of power lines and 1.4 million poles that make up a network which services more than 800,000 homes and businesses across 95 per cent of NSW.

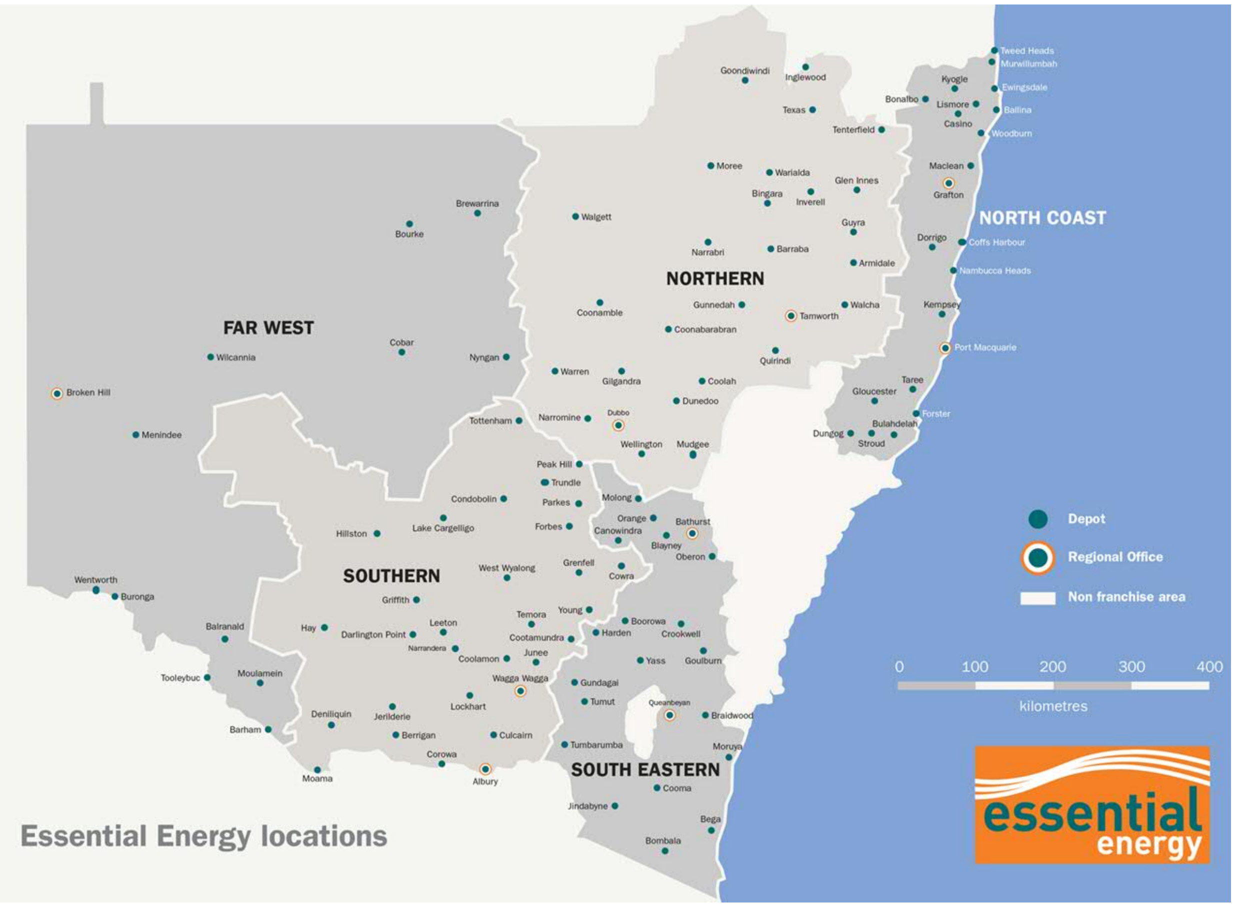


Figure 1: Essential Energy area map.

1.2 Background

Zone Substations have been designed and constructed in New South Wales for many years, even going back to the early to mid-1900.

Many of these sites were constructed by the New South Wales Electricity Commission which many people referred to as ELCOM.

For construction purposes Zone Substations designers were required to provide a comprehensive set of construction drawings which provided all of the detail of the project and would be used by field staff to build the Substation. These drawings were called the construction drawings and were critical drawings which should be produced for every Zone Substation site.

Initially a Zone Substation site would have a set of preliminary drawings produced which included:

- A single line diagram.
- A site locality or site layout.
- General arrangement – Plan view
- Operating diagram.

The construction set of drawings produced would consist of:

- Site layout.
- Earthworks.
- Footing arrangement – Plan view.
- Conduit and trench – Plan view.
- Drainage and utilities – Plan view.
- Earth grid arrangement – Plan view.

The general arrangement drawing is one of the most critical drawings and once completed, it would be used as a template or model to produce the remaining construction drawings.

Production of Zone Substations drawings in today's design process are completed using computer aided drafting software and pre made templates and cells which all help in making the process of producing an accurate drawing much less time consuming, and far easier to keep track of changes.

Producing Zone Substation drawings before computer technology was a much more laborious task and required the use of special drawing tables, scale rulers, pencils and markers and plenty of patience.

This process was one which took considerable time and it was often very difficult to eliminate every error from the drawing before it was issued, this made mark ups to the drawings after the Zone Substation was built a longer process as well.

Due to the age of many of the existing Zone Substations within Essential Energy's footprint, combined with the old drawing practices that were used back in the early to mid-1900's, there are still many sites where the majority of the drawings are still old hand sketched drawings.

Within Essential Energy a large portion of these drawings have been converted to digital images using high definition scanners which enables the drawings to be stored in an electronic database, the drawings are then able to be reproduced as required, however this does not solve the problem of inaccurate data contained within these drawings.

Outstanding accuracy issues become a problem when sites are being refurbished and general arrangement and footing arrangement drawings are required for the position of new equipment, where many of these sites are hundreds of kilometres away from the nearest Substation design office.

This requirement has led to the necessity to have sites surveyed which is a time consuming and expensive process due to the labour involved, and also the intricate structures of a Substation.

Using conventional survey techniques typically only results in obtaining true footing locations and footing reference levels, and the accuracy of the dimensions of these footings is still reliant to a degree on human accuracy.

In all cases the ideal situation is to have a digital image of the entire Zone Substation, which would include not just concrete equipment footings, but everything from steel structures, to buildings, to power transformers and this is what this Dissertation will be concerned with: - obtaining 3D digital models of existing Zone Substation sites for the purpose of design and network development.

The initial cost to obtain a digital image may be greater than the cost of obtaining a conventional site survey, however there are many added benefits that a digital image provides such as:

- Eliminating frequent site visits.
- Reducing desktop design time.
- Providing the as built state of the Substation site.
- Equipment types/models can be confirmed.
- Availability for further design work.
- Accuracy of measurements.

These are only some of the benefits, but if a price could be put on the additional value that they provide, this would surely prove that the initial cost outlay was money well spent.

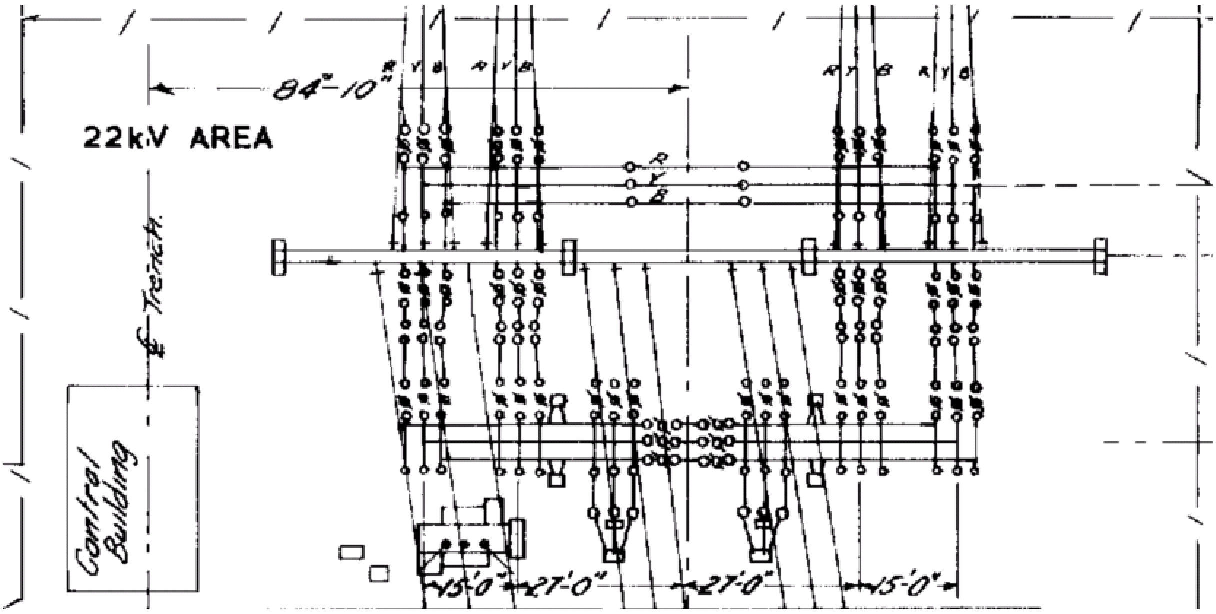


Figure 2: A Section of a hand drawn 22kV Nevertire layout drawing.

1.3 Nevertire Refurbishment Project

Nevertire Zone Substation (Figures 2,3 & 4) is an existing site in the North West Area of New South Wales. The site is a dual high voltage 132-66/22kV Zone Substation which is a former Electricity Commission of NSW Zone Substation.

The Substation configuration has two incoming feeders, the main supply being a ‘T’ connected 132kV feeder which comes from Dubbo 132/66kV Transmission Substation and supplies a 132/22kV, 17/24 MVA Wilson transformer. The secondary (or backup) supply is a 66kV incoming feeder from Nyngan 132kV Zone Substation, which supplies a 66/22kV, 10 MVA English Electric transformer.

The two transformers supply six 22kV circuit breakers comprising of two 22kV transformer circuit breakers and four 22kV feeder circuit breakers. The overall site consists of four radial HV feeders, with the 22kV being an overhead 22kV busbar and jack bus arrangement.

The four 22kV feeders supply the village of Nevertire, the township of Warren and the surrounding rural areas.

During the process of selecting a USQ project for 2014, an Essential Energy design scope was being prepared for major upgrade work to be done at Nevertire Zone Substation.

This was the perfect opportunity to be able to include a real world practical application of 3D Laser Scanning into this Dissertation, as without Essential Energy providing financial assistance this Dissertation would otherwise have not been possible.

A newly formed Network Development group within Essential Energy had already expressed their interest in utilising the use of TLS technology at further sites across the network, if this method is able to provide a reasonable cost benefit to the business.

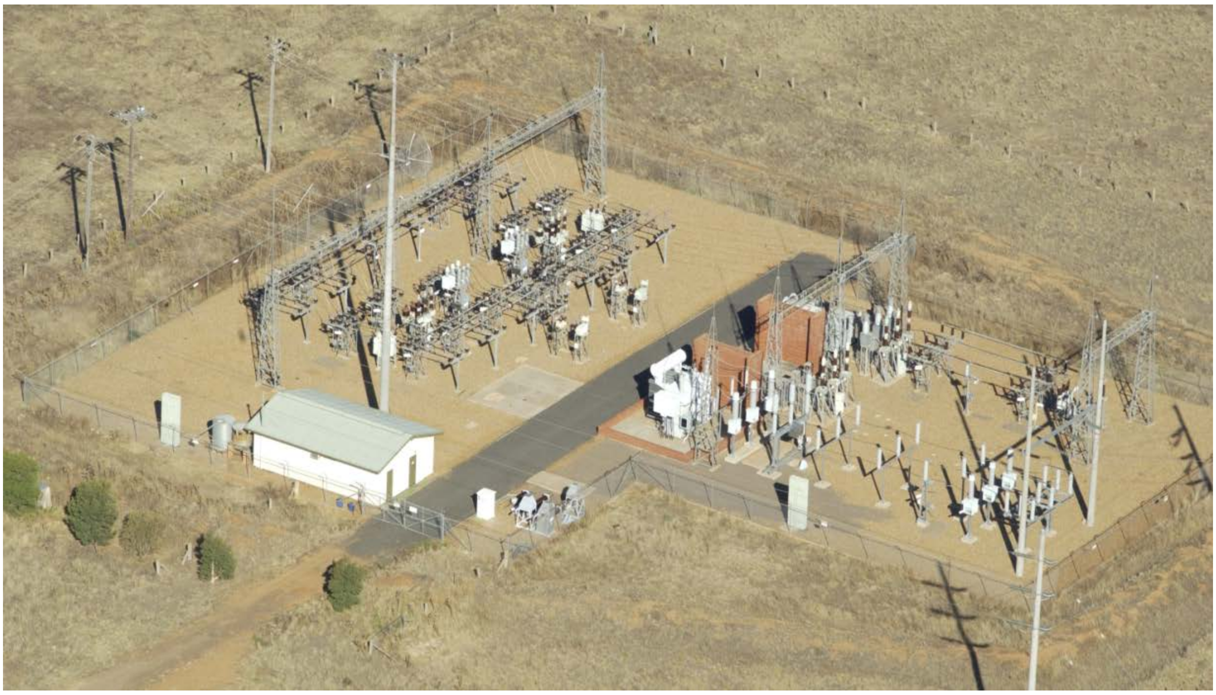


Figure 3: Nevertire Zone Substation site overview.

Nevertire Zone Substation was constructed in the 1960's and is ideal for the purpose of this Dissertation due to the:

- Lack of drawings at site.
- Poor quality of the drawings at site.
- Inaccuracies in drawings.
- Many drawings had not been updated with upgrade works.
- Ageing equipment within the site.
- Design work was required as part of the pending project.

Figure 4: 22kV Substation equipment with suspected poor clearances.

The 22kV side of the Substation is a rigid busbar configuration (Figure 4), in an options report which was written for Nevertire Zone Substation in May 2012 prior to project approval, there were concerns that the clearances between 22kV phases and from phase to ground were not sufficient for the Substation to be compliant with the Australian Standard and Essential Energy standards.

To allow accurate on site measurements to be taken would require switching to isolate sections of the 22kV busbar, this is possible with the use of the jack busbar within the Substation and field bypass switches external to the Substation.

This is not a desirable situation due to the changed protection requirements while the network is not operating in its normal state, and also the availability of field staff to perform switching for the purpose of site analysis and augmentation work.

The Nevertire Zone Substation two existing incoming feeder bays also require refurbishment works, the accurate locations of the existing footings in each of the feeder bays will be required to allow the new equipment positions to be designed without affecting or interfering with existing footings and clearances.

The site also has several redundant footings on this side of the Substation which are not recorded or shown on current site drawings. This detail is required as part of design and to enable drawings to be updated.

There are also many other design requirements within this project which will not be covered by this Dissertation.

2 TLS and LiDAR Technology

2.1 What Is It?

A Terrestrial Laser Scanner (TLS) is a ground based system which uses a laser source emitted from a TLS device, to scan real world items and create a three dimensional geo-referenced point cloud software file. The device used in this Dissertation is a phase based scanner, which uses a continuous (modulated wave) beam emitted from a TLS device.

Figure 5: Operation of a TLS device.

In comparison, LiDAR scanning is generally used as an airborne system which uses a beam of light to reflect off surfaces, a sensor on the device records the reflected light to measure range. This data combined with GPS and additional collected airborne data is then used to produce geo-referenced point cloud files.

2.2 Availability

With the recent advances and cost reductions in ground based LiDAR or TLS survey techniques, it is now becoming a realistic possibility to utilise this technology in areas which have previously relied on other methods of data capture due to price.

The reduction in hardware and software equipment cost, and also the improvements and advances in the handling of the data are some of the key driving factors of this Dissertation. Computer software which can handle the large point cloud files produced by scanning software is now more readily available, with many commonly used CAD packages catering for the use of point cloud files.

2.3 Recent Use

Essential Energy has experimented with the use of aerial LiDAR and aerial TLS for the surveying of small sections of transmission lines and sub transmission lines for projects over the last few years.

The positive use of this technology led to discussions within the organisation on the possibility of utilising these surveying methods to capture larger portions of transmission and distribution network using aerial lidar and using the data gathered to:

- Develop an electronic map of the ageing network.
- Examine lines for defects.
- Keep track of vegetation growth.
- Use in future line upgrades.
- Schedule line maintenance.

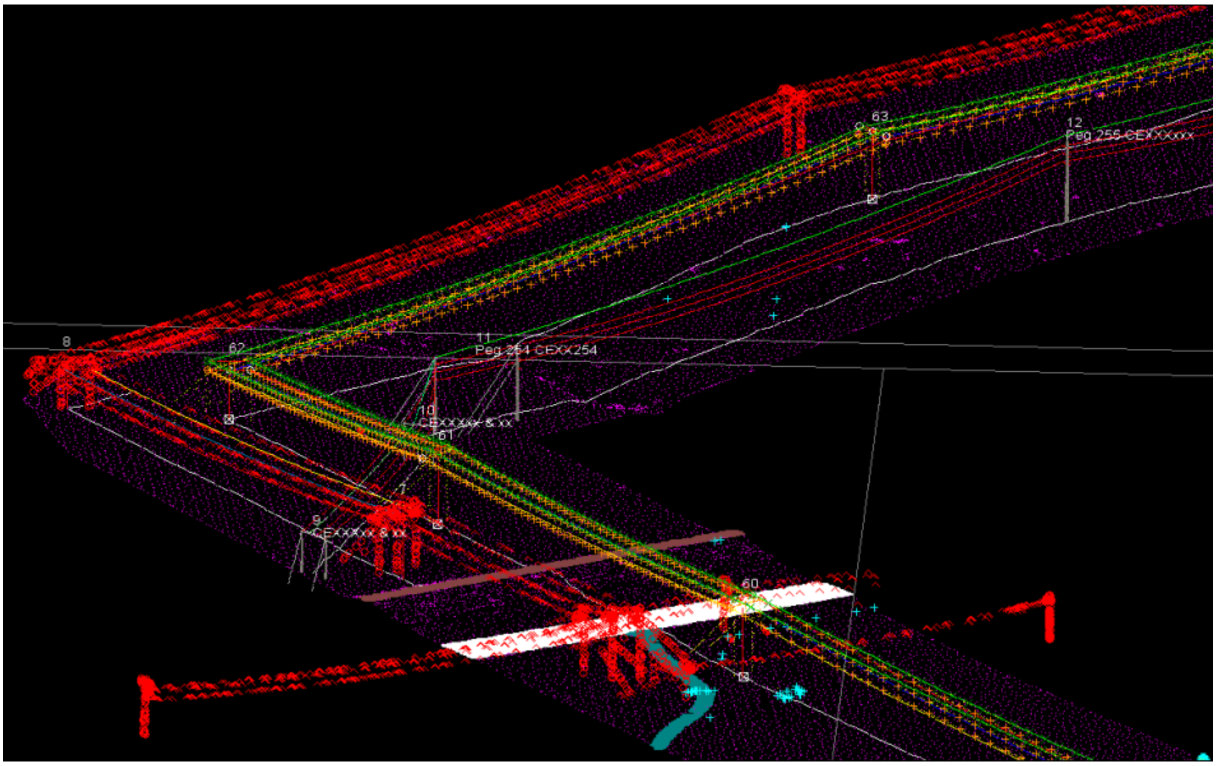


Figure 6: Aerial LiDAR scan of Essential Energy sub transmission line.

In early 2014 a tender was put out and two contracts were awarded for the delivery of the Essential Energy "LiDAR" program across approximately 43,000kms of the rural overhead network in the South East and Southern regions of Essential Energy's network. The work on capturing the identified sections of the network commenced in early April 2014, and is still ongoing.

With this recent contract being awarded for the survey of a large portion of the poles and wires section of the network, it would make sense for Essential Energy to utilise the ground based technology which has been examined in this Dissertation, for the purpose of obtaining 3D scans of more of the older Zone Substations within the network.

Having a contract currently in place to have 43,000kms of line surveyed places much more emphasis on the effectiveness of using laser scanning technology to capture and store 3D imaging of Essential Energy’s electrical assets. It was unknown at the time of starting this Dissertation, that Essential Energy were preparing to go out to tender to have lines surveyed using LiDAR technology.

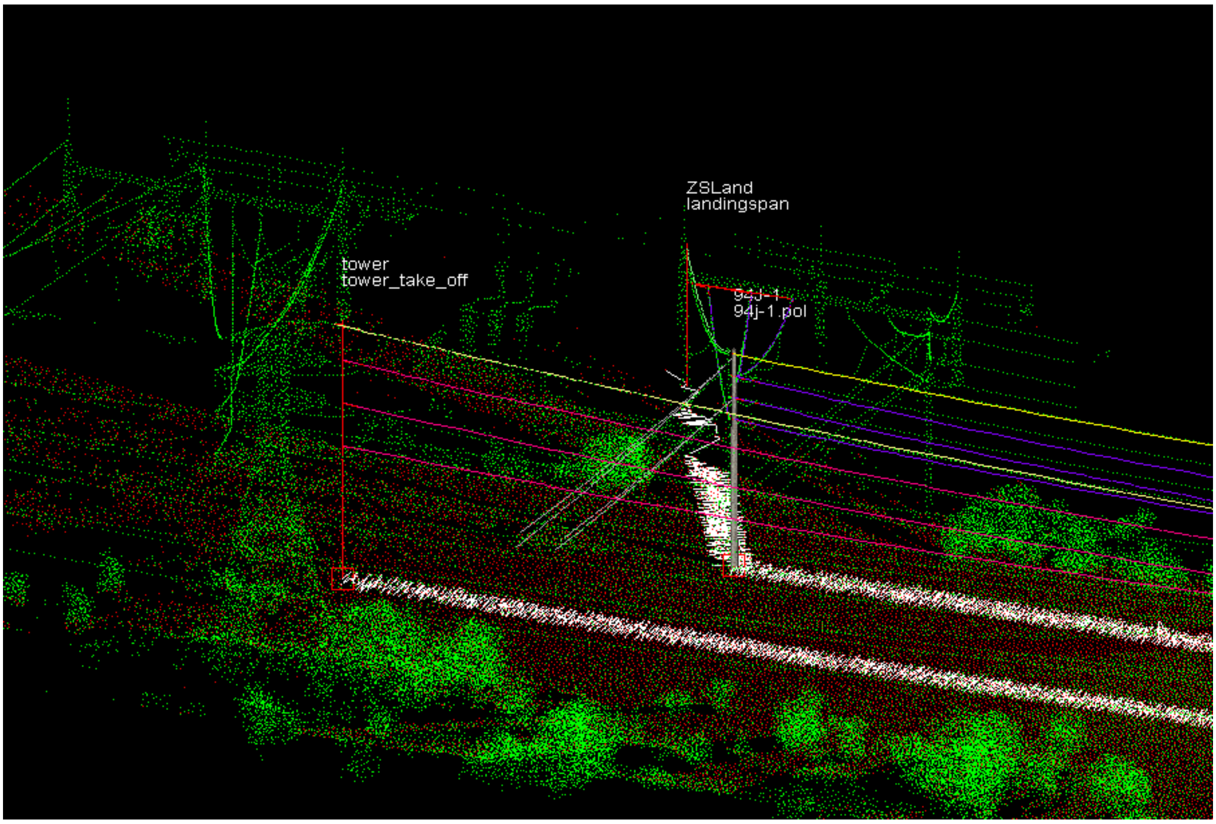


Figure 7: Aerial TLS of Essential Energy Sub transmission line.

The detail of TLS scanning can be seen in figure 7, this data has been manually filtered down to allow it to be displayed on screen without processing issues. Even with the reduced data, the steel Sub Transmission tower is still able to be made out in the left of the image.

At existing Zone Substations sites which were constructed prior to the use of computer aided drafting software and personal computers, this scanning technology could be used to replace the hand drawn Substation general arrangement drawings, with 3D general arrangement drawings which will depict an exact replication of what has been constructed and any modifications that have been done to the original design.

From a Substation design perspective many of the older sites which were constructed around the 1950's, are now beginning to need major augmentation work due to equipment reaching the end of its life span, and the need to update to current technology.

Presentation of the results of this Dissertation will hopefully prove to the organisation the many benefits and allow further work utilising Terrestrial Laser Scanning in existing Zone Substations to proceed.

2.4 Project Aim Using TLS

This Dissertation has several major aims:

- The creation of a 3D model of an existing Zone Substation.
- Analysis of an existing Zone Substation 3D model to check safety clearances.
- Analysis of an existing Zone Substation 3D model to check lightning protection.
- Compare the cost of conventional survey and results against the cost of TLS survey and results.
- Presentation of results of findings to Essential Energy

2.4.1 3D Modelling of Existing Zone Substation

Essential Energy uses the Bentley software Microstation V8i for all Substation related drafting, this software has the capability to produce 3D designs and when updated with service pack 3 is also capable of working with point clouds.

To date Essential Energy has not used the software for 3D modelling of any existing or new Substation sites, therefore producing an accurate and detailed 3D image of an existing Zone Substation is critical to the possibility of further use of this technology beyond the scope of this Dissertation.

2.4.2 Analysis of the 3D Model

A primary goal of this Dissertation was the being able to measure the “as built” distances at an in service Zone Substation, in areas which would not be possible under normal circumstances.

This is mainly due to the requirement of measurements which would be within electrical clearance distances, or touching live parts of equipment. The Substation site being used for the model analysis is Nevertire Zone Substation, this Substation is currently a preliminary design project due to several factors, one of them which is busbar safety clearance distance on the 22kV side of the Substation.

In addition to checking low clearances the existing lightning protection is able to be checked against current standards for compliance and also for coverage of any augmentation or future upgrade work.

Analysis of the 3D model will enable accurate measurements to be taken of all live busbars and equipment without the need for equipment to be switched off and isolated. A determination will then be made on whether the as built clearances are within the required standards or further action is required to be taken.

The 3D model also provides several other design benefits which are beyond the intended scope of this Dissertation, but will help to build a good supporting case to pursue this work further for use as a desktop design tool.

2.4.3 Cost Analysis of Survey Methods

Existing Zone Substation sites such as Nevertire which have limited up to date drawings available will normally have a full site survey done in preparation for preliminary design work to be conducted.

These surveys can often be a full day’s work in the field for a surveyor even with the help of an Essential Energy staff member. The information gathered is normally limited to footing dimensions and footing reference levels (R.L’s).

The cost to Essential Energy for a full Substation the size of Nevertire to be surveyed will often be between $2000 to $3000, once the surveyed information has been processed and presented in a useable format.

The option to have a full site such as Nevertire Zone Substation scanned with a high definition TLS (which will produce a useable 3D image of the entire site) is now much more realistic due to the reductions in cost. A full site survey of a Substation the size of Nevertire can be conducted in half a day and can be done without the help of an Essential Energy staff member, with the end result being a 3D replica of the actual Substation site.

This may be a more expensive option due to equipment and file processing costs, but the benefit to the organisation to have a 3D “as built” general arrangement of an existing Zone Substation, will be proven by this Dissertation to be worth the price.

2.4.4 Presentation to Essential Energy

On completion of this Dissertation and finalisation of University of Southern Queensland subject requirements, the results and findings of this document are to be presented to the Essential Energy Project Development Manager.

The objective on completion of University requirements is to progress further with the use of 3D Zone Substation modelling within Essential Energy at existing sites, verification of new constructions and the use of 3D modelling for Substation design at green field sites. This will be dictated mainly by the financial benefit to the organisation which is to be examined.

3 Literature review

3.1 Introduction

Electrical Substations are a requirement for the effective distribution and transmission of electrical power within cities, between cities and between regional centres, electrical Substations have been utilised for this purpose for many years and are still widely used in electrical networks within Australia.

Substations must be built with the primary function of effective and efficient electrical distribution, but substations must also be designed and constructed to ensure that the equipment within these substations will operate safely and reliably under all circumstances

Electrical Substations have been constructed and have formed part of electricity networks for many years, and there are numerous substations currently in service within NSW which were constructed in the mid 1900’s.

Evidence of this is provided by the many site specific archived drawings of Zone Substations which were originally operated by the Electricity Commission of New South Wales but are now operated by Essential Energy, these drawings are marked with the date that they were issued for construction.

The construction of the electrical infrastructure within Zone Substations cannot be done without adequate designs and standards for construction.

3.2 Standards for Minimum Clearances

There are currently Australian Standards and IEEE standards which are used by electrical transmission and distribution companies within NSW as a guide when developing their own set of standards for the design and construction of electrical Substations. Both of these standard documents use referencing and values which relate closely to many of the existing IEC standards, this provides many similarities between the two documents but each document does however provide a unique approach.

The distance between phases and between phase and ground within electrical Substations are critical measurements which must be designed and constructed accurately to provide the correct safety factor for people working in these Substations (Essential Energy, 2011), and the safe operation of plant and equipment contained within the Substations. Also of high importance is the protection of the Substation plant and equipment from direct lightning strike.

The focus of this literature review is the minimum clearance distances as follows:

- Phase to phase.
- Phase to ground.
- Non flash over.

In addition to these clearances the safety clearance distance from ground for providing adequate lightning protection will be reviewed.

Once the minimum clearance values have been determined, the safety clearances distances are then able to be determined, and there is several safety clearance values which are also of interest to the subject of this Dissertation these values are as follows:

- Ground safety clearance.
- Section safety clearance.
- Horizontal work safety clearance.
- Vertical work safety clearance.

All of these parameters are to be reviewed at the range of system voltages used within Essential Energy Substations to determine if Nevertire Zone Substation is compliant with the current standards required. It should also be noted that Essential

Energy Substations do not exceed 132kV and that voltages above this level will not be included within this review.

3.3 Minimum Clearances

3.3.1 Australian Standard Method

Section 3 of the Australian Standard AS2067-2008 [22], “Substations and high voltage installations exceeding 1kV a.c”, contains the method for determining minimum clearances and safety clearances. The clearance values are presented in two tables and the correct values are able to be taken directly from the tables providing the required information relating to the site is known.

The site specific information required to be able to implement the tables is:

- Nominal Voltage (U_n).
- Highest Voltage (U_m).
- Rated short duration power frequency withstand voltage.
- Rated lightning impulse withstand voltage (B.I.L).
- Rated switching impulse withstand voltage (B.S.L).

Use of this table ensures a consistent approach to determining clearances in Substations within Australia, the Nominal Voltage and Highest Voltage are standard values for the various system voltages used within Australia they can be found in the Australian Standard document AS 60038-2012 Standard Voltages [23]. The rated short duration power withstand voltage can be found in the Australian Standard document IEC 62271.100-2008 High Voltage Switchgear and Controlgear Part 100 [21].

The values which are used in the tables seen in AS 2067-2008 [22] have been taken directly from the Australian Standard for Insulation Co-ordination AS 1824.1-1995 [20], this document also relies heavily on the information which is provided in the IEC standard documents 60-1, 60 and 30.

Safety clearance values can simply be read directly from the table for the corresponding system voltages once the required site specific information is available, these distances have a close relation to the non-flash over distance and ground safety clearance.

The Australian Standard AS 1824.1-2008 [20] is a reproduction of an International standard document which utilises references to further Australian standards, the values used within the Australian Standards are further backed by the IEC standards, these relationships provide the reader with re-assurance and confidence that the information being utilised is correct.

3.3.2 IEEE Method

The IEEE Standard 1427-2006 [12] “Guide for Recommended Electrical Clearances and Insulation Levels in Air-Insulated Electrical Power Substations” provides minimum electrical clearances which are presented in a table similar to the Australian Standard.

Use of this table requires the user to have site specific data relating to:

- Maximum system voltage – phase to phase.
- Basic B.I.L.

The document structure provides the reader with detailed reasoning on criteria relating to proper electrical clearance selection by introducing external factors affecting clearances such as economic and community aspects and also operating history.

The reader is then directed to the major technical issue relating to Substation clearances being insulation co-ordination. The importance of surge arrester and protection margin selection in relation to setting a B.I.L are also discussed, this leads into the reasoning behind standard insulation levels for given system voltages.

The IEEE standard contains a comprehensive and technical approach to establishing a suitable B.I.L for use of the table, and also provides details and background on factors affecting B.I.L, and the history of how standard levels of B.I.L have been developed for given maximum system voltage levels. This document has been written with the intention of being more of a guide then an actual standard and when compared directly with the Australian Standard it does provide more insight into how values are calculated and where they are taken from.

Safety clearances within the IEEE document are not addressed within a table as they are in the Australian Standard, and no exact values are given but instead gives a guide on the need for safety clearances and types of safety clearances that should be included for consideration by the reader.

Much of the general and technical information contained in the IEEE standard for determining minimum clearance values, is reflected throughout the Australian Standard. Both documents focus around two of the higher priority areas for selecting, minimum clearance which are B.I.L and surge arrester selection.

3.3.3 Essential Energy Method

The Essential Energy Standard CEOM7051.24 [3] “Substation Electrical Design Clearances” contains minimum clearances for network system voltage up to 132kV as follows:

- Phase to phase.
- Phase to ground.
- Section safety.
- Horizontal safety.
- Vertical safety.

Due to this document being a dedicated Essential Energy Zone Substation design policy, in addition to the above clearances the policy also includes the following minimum clearances for network system voltages up to 132kV:

- Switchgear bay centres.
- Transformer bay centres.
- Busbar centres.
- Busbar heights.
- Cable boxes and metal-clad switchgear.

These additional clearances are not covered by either the Australian Standard AS2067-2008 [22] or the IEEE standard 1427-2006 [12].

The electrical clearances used within table 1 of CEM7051.24 [3] have been taken directly from table 3.1 of AS2067-2008 [22], Essential Energy makes use of the higher lightning impulse withstand voltage where listed for all voltages up to 132kV, the Substation related clearances such as equipment centres listed in table 2 of CEOM7051.24 [3] are an Essential Energy design standard and are implemented on new designs and on existing substation upgrades where possible.

Implementing the required clearances documented in table 1 of the Essential Energy document does not require calculation of B.I.L limits as a standard value is adopted at all system voltage levels, period contract equipment, design standard documents and drawing templates ensure that the minimum clearance distances listed in table 1 will be adhered to in all cases for new designs and the majority of cases in augmentation work.

3.4 Insulation Co-ordination

3.4.1 Basic Insulation Level

Very closely related to the subject of minimum clearance distances within substations is insulation co-ordination, and for the purposes of calculating or setting a value of minimum clearance at particular voltage levels it becomes necessary to decide upon a required basic insulation level at a base value of voltage (Standards Australia, 1995) [20], before a decision can be made for minimum clearance.

The Basic Insulation Level or B.I.L of plant and equipment is determined by manufacturers and is defined by the IEEE Guide for Recommended Electrical Clearances and Insulation Levels in Air Insulated Electrical Power Substations as: The electrical strength of insulation expressed in terms of the crest value of a standard lightning impulse under standard atmospheric conditions (IEEE, 2007) [12].

All Substation major plant and equipment has a Basic Insulation Level (B.I.L) specified by the manufacturer which will contribute to the B.I.L that is chosen to be used at a particular site. The piece of plant or equipment in the Substation with the lowest B.I.L will ultimately determine what the overall B.I.L for a particular site will be, and it is typical that the equipment within a Substation will be selected at a particular B.I.L.

The actual process of determining the basic insulation level or B.I.L is beyond the scope of this Dissertation and literature review and will not be included, this literature review will therefore use the standard or typical values of B.I.L for the different system voltage levels which will enable the appropriate distances to be selected and applied.

3.4.2 Basic Switching Impulse Level

B.S.L is also a rating applied to plant and equipment after factory testing has been undertaken, the Basic Switching Insulation Level is defined by the IEEE Guide for Recommended Electrical Clearances and Insulation Levels in Air Insulated Electrical Power Substations as: The electrical strength of insulation expressed in terms of the crest value of a standard switching impulse (IEEE, 2007) [12].

The use of B.S.L only becomes relevant for clearances at voltages in excess of 245kV which is beyond the scope of this Dissertation therefore further assessment of B.S.L will not be covered as part of this literature review

3.4.3 Surge Arresters

Surge diverters or surge arresters become a critical area for substations and their equipment in regard to insulation co-ordination and selecting an appropriate B.I.L at a particular site. Due to the placement and selection of surge arresters the busbar or line overvoltage can be kept to within a certain level providing there is a tolerance or protection margin involved, this allows the site B.I.L to be selected in relation to the selected surge arrester specifications.

The use of surge arresters at a Substation can also be used to lower the B.I.L at the site providing the normal operating overvoltage incidents do not exceed the maximum continuous operating voltage (MCOV) of the surge arrester unit (IEEE, 2007) [12]. From a design perspective installation of surge arresters on the incoming feeders is a standard part of any new Substation. There are still however, Substations built prior to standards being introduced which do not have surge arresters installed on all incoming feeders which ensures the best overvoltage protection.

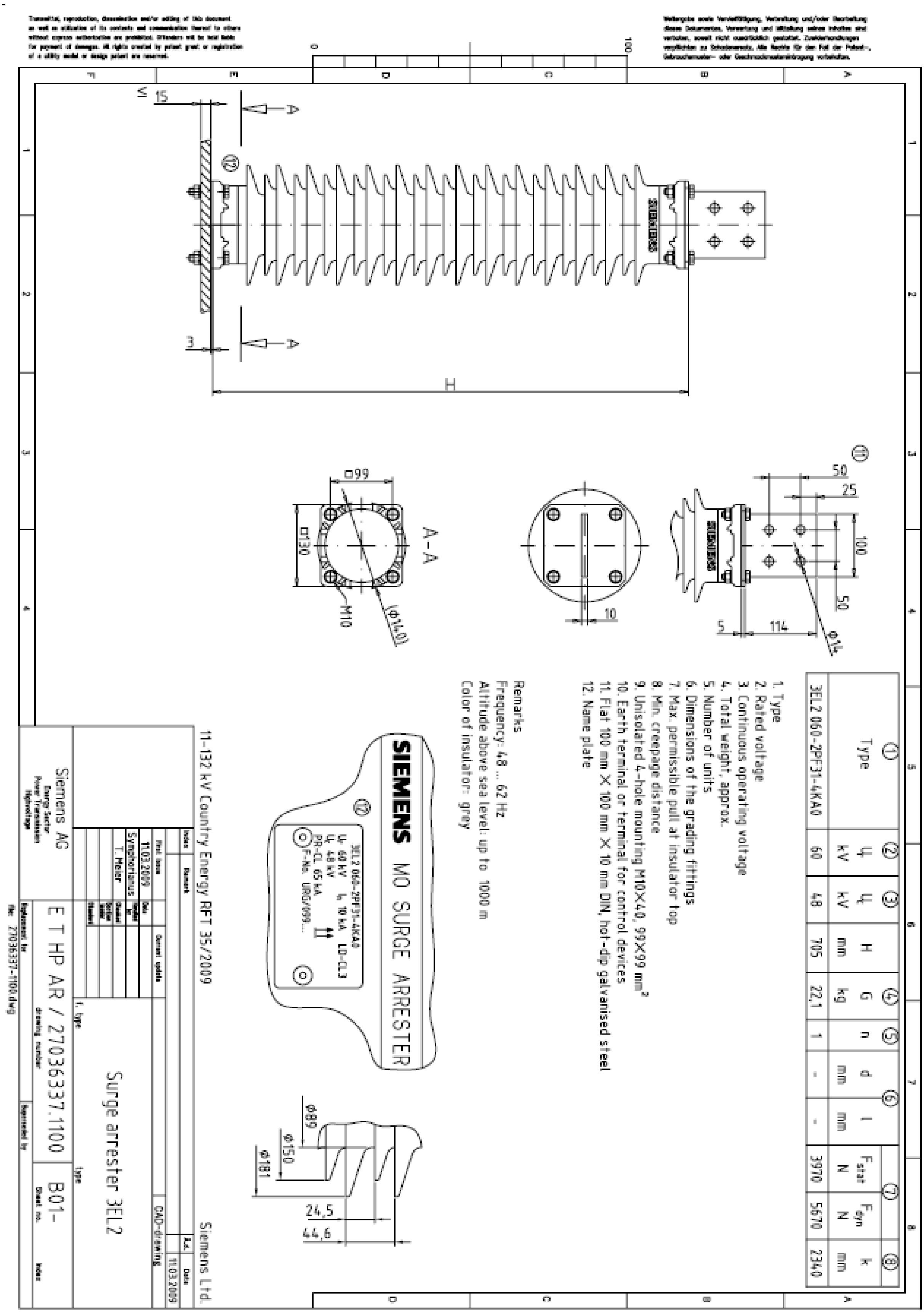


Figure 8: Essential Energy period contract surge arrester.

3.4.4 Spark Gaps

Prior to the introduction of surge arresters to protect against overvoltage surges, Zone Substations employed the use of high voltage spark gaps on incoming feeders and at power transformers. These devices still exist at some older sites and operate by directing the overvoltage surge across an air insulated gap.

Figure 9: Spark gap shown on spare single pole circuit breaker.

From a Substation clearance perspective these devices are consistently removed in old sites and replaced with surge arresters wherever possible as surge arresters provide greater accuracy and flexibility for setting up and calculating required insulation levels.

They also create problems in areas frequented by birds because of the birds coming between the two points of the gap and reducing the distance of the air insulated gap (Standards Australia/New Zealand, 2007) [24].

The Australian Standard IEEE standard and Essential Energy standard documents all still include information in regards to the use of spark gaps as a surge protection device (S.P.D) for high voltage use in Substations.

3.5 Substation Lightning Protection

The initial step in designing lightning protection for Substations is determining the level of risk to which the Substation will be exposed to, this process can be quite involved and time consuming, and this section of the literature review will not include the process but focus on protection methods and how they are implemented from a design perspective.

There are several methods that still exist for designing Substation lightning protection or Substation shielding, three of the main methods still being used by Substation designers either combinations of or individually are:

- Fixed Angles.
- Empirical Curves.
- Rolling sphere method.

The aim of examining literature regarding these methods is to determine if there is a current applicable industry standard amongst literature that re-enforces the ground safety clearance values for lightning design which is currently used by Essential Energy Substation designers.

3.6 Lightning Protection Methods

3.6.1 Essential Energy Standard and Method

Essential Energy currently uses a minimum clearance distance of 7.0m for all system voltages up to 66kV and 8.0m for 132kV (Essential Energy, 2011) [3], when designing lightning protection, these distances are used from the ground measured vertically up and a safety clearance line is drawn. These distances were chosen and included within Essential Energy's Substation Design Guidelines in relation to the heights of the period contract equipment that is used for particular system voltages. For example a height of 7.0m will be higher than all plant and equipment at 66kV and under while still allowing approximately 1 metre tolerance, for non-standard equipment or possible future upgrades.

Using the rolling sphere method with a radius of 30.0m, this clearance line must not be impeded or crossed whilst the rolling sphere is supported by purpose built lightning structures at any point within the Substation fence. This method ensures that all plant and equipment within the Substation is adequately protected to within a certain degree of risk.

It is also worth noting that Essential Energy incorporates SPD’s and Over Head Earth Wires (O.H.E.W) within all newly constructed Substations to minimize the risk of damage to plant and equipment from lightning strikes (Essential Energy, 2012) [4]. These methods combined with lightning protection masts placed within the Substation as per the design guidelines and using the rolling sphere method have been proven to be very effective in preventing damage of expensive Substation equipment.

3.6.2 IEEE Method

3.6.2.1 Fixed Angles

This protection method relies on the use of vertical angles measured from the top of the lightning mast to provide a protected circular area surrounding the base of the lightning mast, this allows the mast protection areas to be overlapped by correct positioning and to provide full coverage of Substation plant and equipment.

As stated in the IEEE lightning standard – Guide for direct lightning stroke shielding of Substations, it is not known when this method began but it was being used prior to 1924 and is still in use today (IEEE Standards Association, 2013) [17]. This method could easily be implemented by a Substation designer to allow for an overall safety distance from ground similar to the Essential Energy standard or from the maximum height of plant and equipment required to be protected. The IEEE standard does not provide any recommended safety clearance distances, only the recommended vertical angles which should be used at specific mast heights, and ground safety clearance is not mentioned throughout the IEEE document.

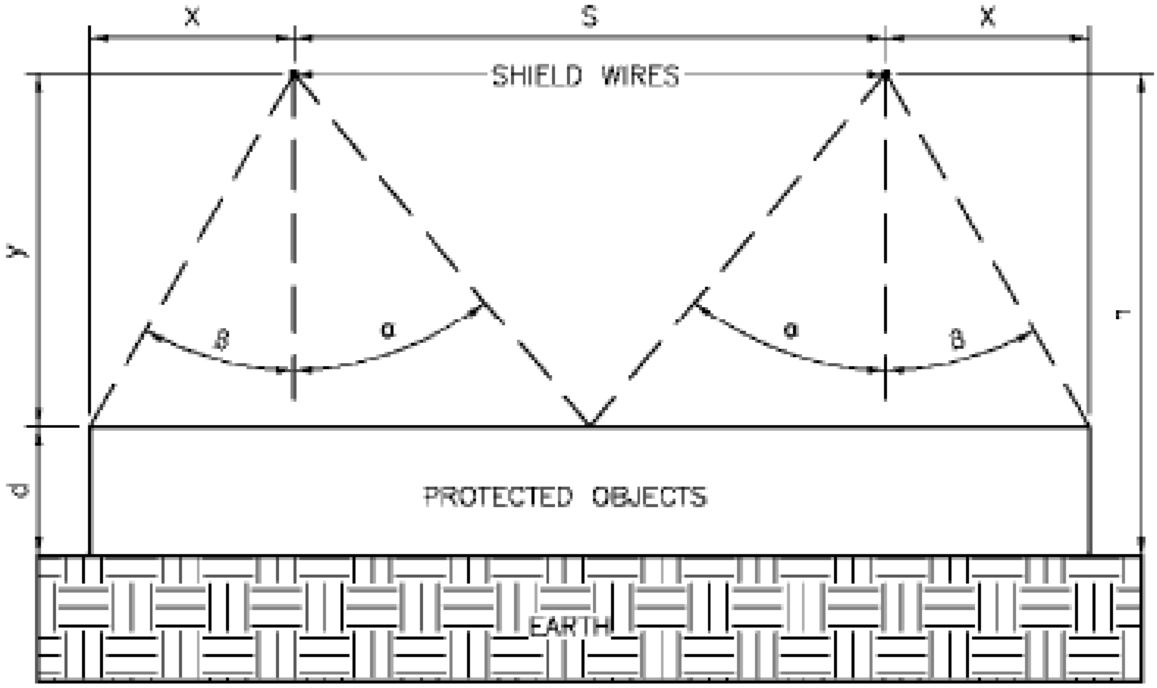


Figure 10: Fixed angle lightning protection method.

3.6.2.2 Empirical curves

This method was developed by conducting scale model tests, and from these tests a series of curves were developed and produced for use which could determine the requirements for shielding wires and masts for a particular site (IEEE Standards Association, 2013) [17]. The empirical curves were developed for differing levels of coverage or shielding failure rates. The IEEE lightning standard describes how the curves can be implemented for a given value of protected object height, it would therefore be quite possible to implement this method in a similar way to which the Essential Energy design guidelines are used, although the use of this method does not provide the user with a pictorial representation of the coverage as do the other methods mentioned.

This method again does not provide a system voltage related distance from ground which should be used, although it would be possible to use this method to design for a particular ground safety clearance value as the curves are setup to be able to do this. This method would therefore require further input on preferred ground clearance values before being used or additional tolerance height added to the structures required to be protected.

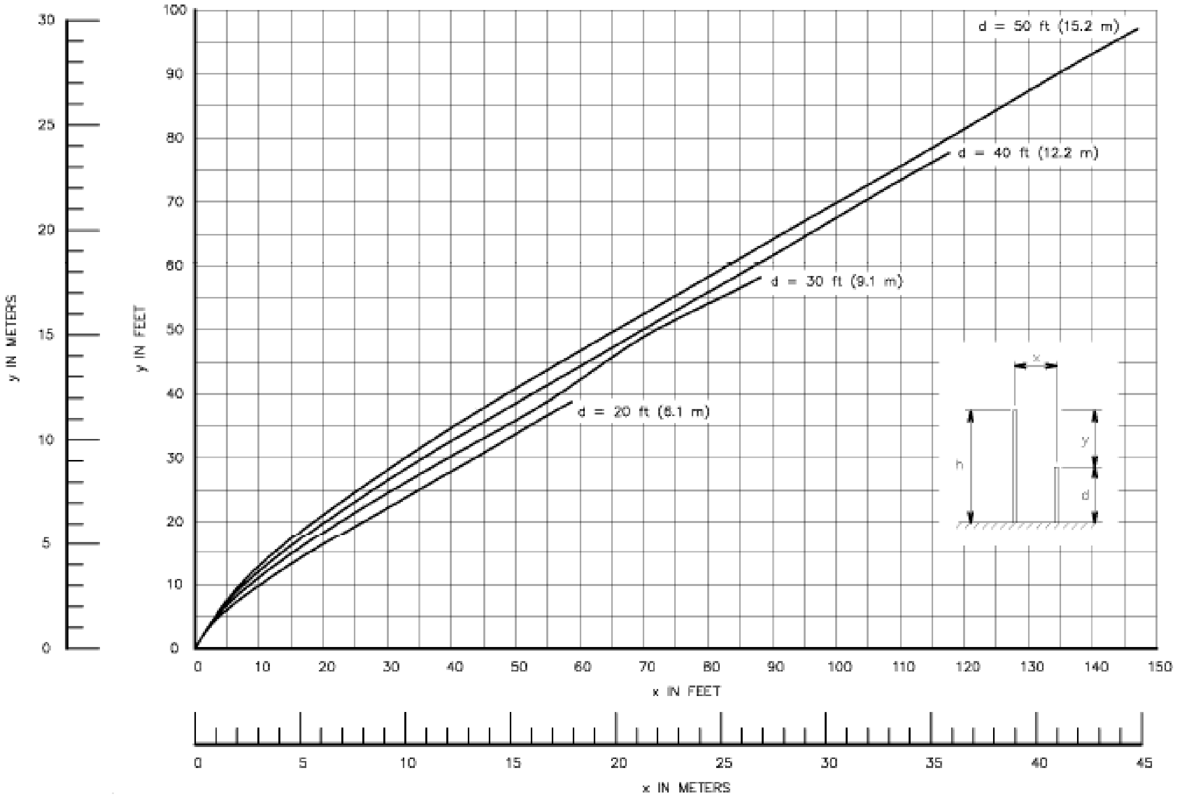


Figure 11: An example of an empirical curve (IEEE standard 998-2012).

3.6.2.3 Rolling Sphere

This method of protection was an extension of another protection method known as the Electrogeometric (EGM) model, and was developed specifically for the protection of Substations. The basic principal of the rolling sphere method is to position enough lightning masts or overhead protection wires so that if a sphere of a designated diameter would to be placed on top of the lightning protection and rolled around over the top of the protected electrical plant and equipment, the sphere would remain supported by the lightning protection structures and wires and not come into contact with the plant and equipment and ensure that it was in a protected area.

The rolling sphere method as described in the IEEE standard 998-2012 [17] “Guide for Direct Lightning Stroke Shielding of Substations” relies on the value of S which is the sphere radius, using this document this value varies for individual sites and requires calculations based on site specific values such as:

- I_S = Lightning return stroke in kA.
- K = coefficient for striking distance to mast, shield wire or ground.

A ground safety clearance value is not included within calculations for this method and provided that plant and equipment does not come into contact with the sphere as it is being supported then it is assumed to be in the protected zone. Therefore a designated ground safety clearance value would still need to be calculated where and if required.

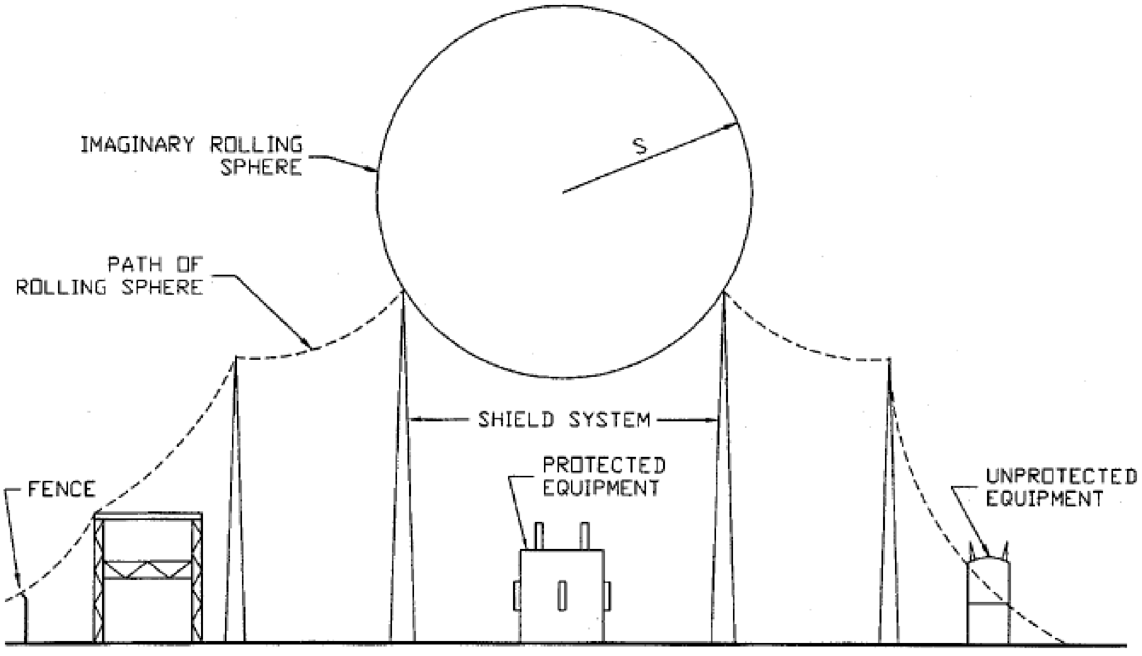


Figure 12: Implementation of rolling sphere method (IEEE standard 998-2012).

3.6.3 Australian Standard Method

The Australian Standard document AS 1768-2007 [24] is not specifically related to Substation lightning protection but does provide good information on lightning protection methods and also includes good technical insight into risk management of lightning including risk to structures, people, installations and equipment, which is the generally the first step undertaken prior to beginning a lightning analysis.

This standard makes use of an excel spread sheet which is used in calculation of the estimated lightning risk, although for specialised areas such as Zone Substations a detailed lightning risk analysis should be carried out.

The level of protection required should also be determined following the risk analysis, it is this determined level of protection that allows the lightning protection system (L.P.S) to be designed, to prevent damage to plant and equipment.

Section four of the Australian Standard provides details of the various requirements for lightning protection of structures and it is this section that has the most relevance to the protection of Substations. In designing the LPS the standard provides the reader the requirements for air terminals, down conductors and earthing requirements associated with these elements.

The air terminals or in the case of Zone Substations, the lightning masts are positioned and the coverage of the plant and equipment is then checked using the rolling sphere method, with the radius of the sphere determined by the level of protection required as per table 4.2 of the standard. This section and standard provides far more detail on the configuration and setup of LPS's then is required for the purpose of this literature review.

The effective protection zone which is produced by utilising the rolling sphere method and the calculations of section four of the Australian Standard can be directly compared to the rolling sphere method used by the IEEE standard, both of these methods do not require any set distance of clearance from the highest point on any equipment or plant, as long as the sphere does not make contact with an object it is deemed to be in the protected area.

The Australian Standard document AS1768-2007 [24] does not provide standard lightning safety clearance distances either from ground or from the highest point of plant and equipment at specific system voltages. The standard does backup the methods of lightning protection presented by the IEEE standard 998-2012 [17] and provides the background to the methods which have been adopted within Essential Energy design guidelines document.

3.7 Conclusion

The clearance values which are used by Essential Energy line up well with the same areas in the documentation examined and will therefore be appropriate to use as a baseline for analysis and results values. The section safety clearances as described within the Essential Energy standard are aligned to the Australian Standard and these will be used as part of the formulation of analysis and results.

The ground safety clearance values as used by Essential Energy when designing Zone Substations for the purpose of lightning protection is deemed as organisation specific to the type of equipment used. These clearances are also used to simplify the implementation of lightning design and allow for the use of generic drawing sets which improve design times and create consistency. The design distances used are not an industry standard but an organisation standard.

These values as used by Essential Energy for lightning design will be used in the assessment of the existing lightning protection and the formulation of analysis and results for the purpose of this Dissertation.

4 Methodology

4.1 Site Selection

To highlight and prove the benefits of examining safety clearances using 3D imaging, one of the key requirements was to find a Zone Substation site which may possibly have clearance issues.

This requirement also meant that the site would likely need to have a construction date prior to the use of electronic designs and have minimal existing site drawings which could be relied upon for accuracy.

Another important requirement in producing this Dissertation was choosing a site which would have financial backing from the sponsor, to meet this requirement a site was needed where Essential Energy had already made a preliminary commitment to in the form of options reporting or scoping documents.

Nevertire Zone Substation met these initial technical requirements and as the Substation is geographically only approximately 100km’s from Dubbo, site visits for the purpose of data collection were able to be carried out with minimal impact to normal work, and this also allowed for the site to be accessed whenever required for the additional data capture, which was needed during the analysis phase.

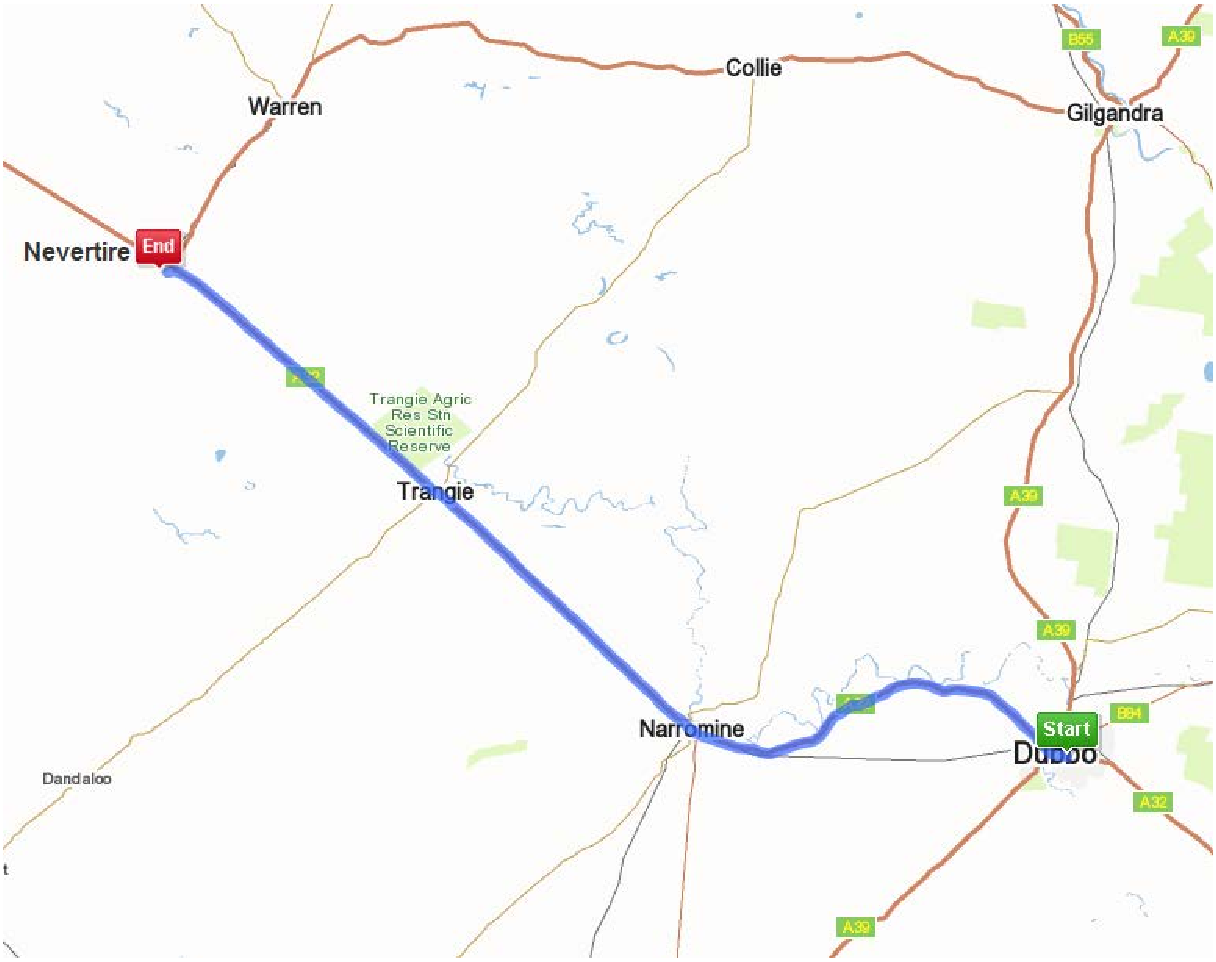


Figure 13: Nevertire to Dubbo geographic location (www.whereis.com).

4.2 Site Survey Methods

4.2.1 Conventional Survey

As part of the initial design scoping of the Zone Substation site, a local Dubbo surveyor was contracted to assist in the survey of the existing Substation configuration. The site was surveyed on a single day with a Leica TCRP 1203 plus theodolite, an experienced Essential Energy staff member was responsible for handling the prism for all of the measurements taken to maintain consistency. Extra care was taken with all measurements to produce a result which was with minimal error.

Measurements taken on all concrete pads were done at the same level on each pad, and these points are recorded, which means that when comparing this method to actual measurements and against other models, similar locations can be selected to measure from.

Some error was expected, due to the poor line of site between the theodolite and the target point, often this was overcome by using a different staff height, and unfortunately this has an ultimate bearing on the accuracy.

It was unknown at the time of surveying the site that it would be utilised as part of this Dissertation, had this been known additional survey stations could have been utilised, this would further increase the labour component of the job which is not favourable.

Locations of structure footings and other major features of the site to be surveyed included:

- Transformer blast walls.
- Transformer bund areas.
- Control building.
- Distribution poles.
- Sub transmission poles.
- Site services.

The resulting raw data from a survey such as this provides the dimensions of the surveyed objects and the Reference Level (R.L) of the object which are predominantly concrete equipment footings, the reference point being the Top Of Concrete (T.O.C).

Due to the amount of structures within a Zone Substation which impede the direct line of site (as required by a theodolite), it is often difficult to capture enough points on an object to get the exact shape. In the event that only a single point could be captured, the remaining points required for the footing are measured manually using a fibreglass tape measure.

The manually taken measurements are recorded using a reference to the surveyed point so they can be input electronically when the raw survey data is “reduced” by drafters.

This results produced from this type of survey can be easily obscured by human error, which can be attributed to the accuracy of the person holding the prism. This process needs to be done consistently, otherwise any inaccuracies that occur at site when levelling and positioning the prism on the specific measurement point, will be reflected in the raw data, and the resulting dimensions of objects will be affected.

In most cases the data produced from surveying a Substation by this method is adequate to:

- Check the location of existing footings
- Check site drawings for accuracy.
- Check as built locations.

The biggest downfall to surveying the site with this method is the actual detail which is included in the CAD drawings that are produced from the survey, this issue is overcome by taking photos of individual footings to use as a reference. Surveying the rag bolts in each footing can also be done to include more detail, but this increases survey time significantly and ultimately cost.

4.2.2 Manual Data Capture

In addition to surveying the Zone Substation site by theodolite, critical height measurements and steelwork detail not able to be captured by the survey but which is required by design scoping, is done using fibreglass measuring tapes and hand sketches.

This is a time consuming process which is also only as accurate as the person operating the tape measure, but for existing sites it is the only way to obtain measurements and due to safety clearance issues many distances cannot be measured due to their close proximity to high voltages, to take these measurements by hand would require electrical isolation of the equipment concerned.

Laser hand held measuring devices can be utilised under these circumstances, measurements taken using these types of devices will only be used for producing layout drawings and not for construction drawings.

4.2.3 TLS

The data which was captured using a laser scanner was a major element of this Dissertation and this task was completed with the assistance of surveyors, who have experience with this type of equipment to ensure that the best possible result could be obtained for the purpose of analysing safety clearances.

4.2.3.1 Scanner Type

The scanner used to perform the scans at Nevertire Zone Substation was a Leica HDS7000 phase based scanner, this device is capable of capturing over 1 million points per second and operating at distances up to 180.0m.

The aim when scanning the Substation was to choose a number of scan positions within the boundary fence of the Substation, and perform a scan at each of these positions to capture the majority of the site within a 10 metre radius of the scanner.

Capturing the points within this range limited the amount of noise introduced into the data and allowed for the greatest accuracy. The model accuracy is very important for the analysis stage and when comparing to other scanning methods which have been used at site. The point cloud file produced from scan data needs to be as accurate as possible to avoid building error into subsequent models produced using the point cloud file.

Figure 14: Leica HDS7000.TLS

4.2.3.2 Hardware and Software

The data captured using a T.L.S can be quite large, the full scan of Nevertire Zone Substation was approximately 10 Gigabytes, and transferring data of this size can be a task in itself. The raw data is imported from the scanner directly into purpose designed Leica 3D modelling software (Cyclone Model) which is run on a laptop dedicated to 3D modelling with the following specifications:

- Dell Precision M4600
- Processor Intel ® Core™ i7- 2720QM CPU 2.20Ghz
- 16Gb RAM
- 64 bit operating system.

4.3 Zone Substation Health and Safety

A major influence for producing this project is the importance of Zone Substation safety, and one of the clear focuses of safety is ensuring that existing infrastructure provides adequate clearance from Substation staff when constructing, testing, commissioning and maintaining equipment in all areas of the site.

4.3.1 Site Safety

Any person who is required to enter into a Zone Substation site controlled by Essential Energy needs to be correctly authorised to do so, or will need to be under direct supervision of an Essential Employee who is qualified to instruct and supervise.

For the purpose of conducting any surveying or measuring work within Nevertire Zone Substation as part of this project, an Essential Energy representative holding the appropriate qualification was required to be on site at all times.

A worksite hazard and risk assessment (HIRAC) was completed by the Essential Energy representative and any person signing onto this document is required to adhere to Essential Energy minimum dress code requirements as described in Essential Energy's electrical safety rules.

While on site no metal tape measures are to be used and all surveying equipment is to be carried below shoulder height at all times, particular care should be taken when under and around the 22kV side of the Substation.

All laser emitting survey devices are to be operated by a person qualified to operate such equipment and any hazards associated with these pieces of equipment are to be identified on the HIRAC, any other minor hazards were identified by the risk assessment process on the day of the work and recorded on the HIRAC.

4.3.2 Office Safety

As a large portion of this project was completed sitting in front of a computer at work and at home, ergonomics were very important and the correct computer setup shall be used to eliminate the risk of strain injuries which can be caused by poor posture and body position when operating a computer for hours.

As part of this process Essential Energy's Regional Health Co-ordinator was contacted and consulted to ensure that correct workspace setup and ergonomics were being used.

4.3.3 Safety in Design

Any project design work which is completed for the Nevertire Zone Substation as a result of this project is to be designed to the appropriate ground, section and phase clearances as detailed within the literature review.

4.4 Data

4.4.1 Acquisition

Obtaining the data to create a 3D model of Nevertire Zone Substation was the first major step which needed to be completed to ensure there would be enough time to create a usable model of the site, in the event that the initial scan of the site did not produce the desired result.

The aim was to engage the help of a local surveyor who had access to the required equipment, because the work was related to a current active project the scanning of the site was able to be conducted within work time which made it a little easier to persuade a surveyor to assist.

The Nevertire Zone Substation was scanned at a total of 16 positions around the yard to minimise shadows in the final result, a high definition TLS was used and special scan targets are placed around the Substation to be used as reference points within each scan, and as this Zone Substation is not very large this allowed a minimum of 4 scan targets to be captured in each scan which produced greater accuracy when bringing the scans together.

Once the entire yard has been captured with the TLS device, the targets used for the 3D scan are surveyed using conventional methods to match the targets with a reference value, this is used to position the individual 3D scans together in a single file. Approximately 6 hours was required to capture the data and this included travel to site.

4.4.2 Data Registration Process

The registration process is done using targets, this method allows the created point clouds (scan worlds) to be accurately geo-reference to a nominated coordinate system. There are eight basic steps for performing registration process using targets and they are as follows:

1. **Create registration**

This is the process of creating a new folder in cyclone model, this is the software area that is used to complete the registration process.

2. **Add scan worlds**

Within this step the required scan worlds that need to be registered, and the control coordinates are added. For each and every scan position selected within the boundary of the Zone Substation a new scan is performed and a scanworld created. The scanworld contains the overall point cloud information as well as any fine scans on the targets including their vertices which were done in addition to the initial scan.

The reason that targets are fine scanned in the field is that the completed projects overall accuracy is dependent on the availability of targets and their accuracy. Normally targets are fined scanned at a very high density (e.g. 1.2mm to 2mm point-to-point spacing). This allows the targets centre coordinates to be extracted for extremely accurate registration.

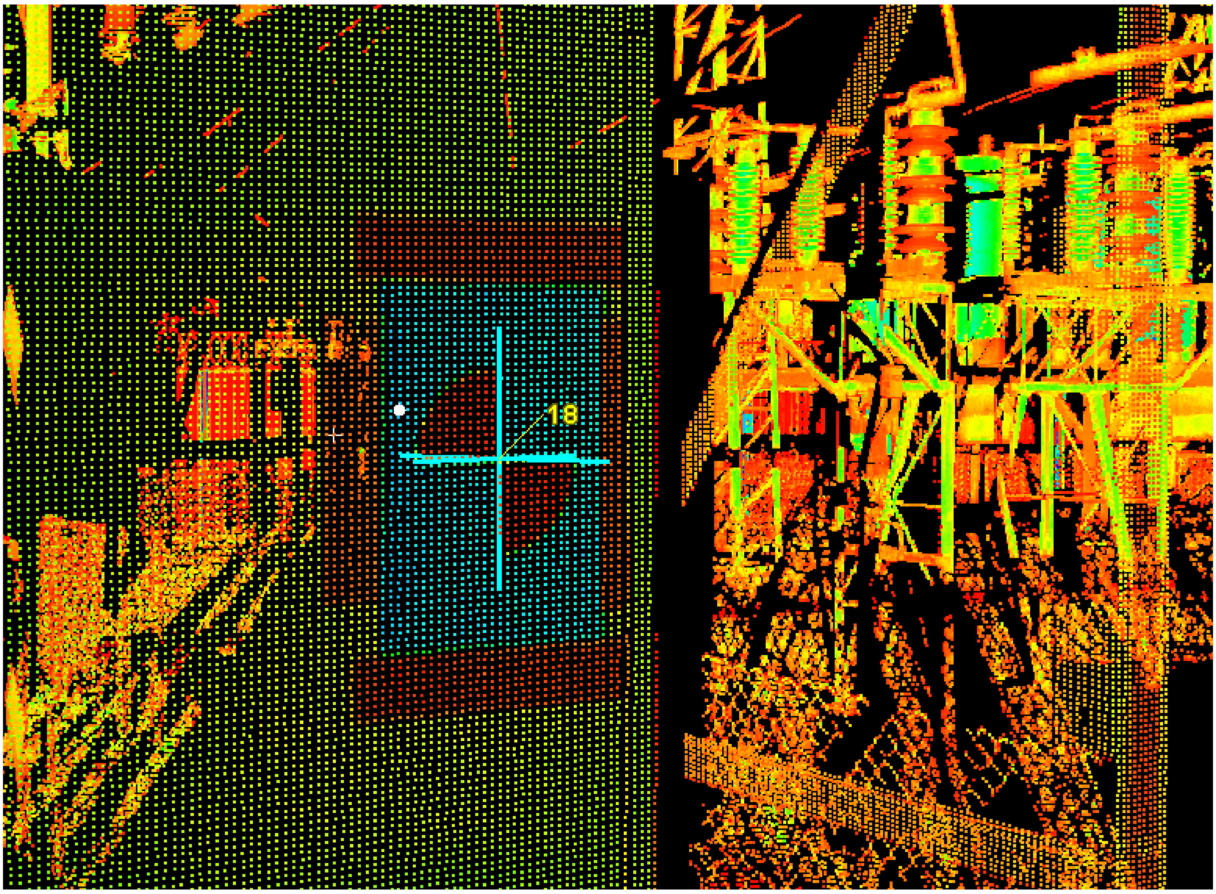


Figure 15: Black and white target displaying vertice.

3. Add constraints

During this process Cyclone model searches all the Scanworld control spaces for objects with the same registration labels. This is an automatic process run within cyclone model which searches for targets within the scan worlds that are referenced to the control space.

4. Register

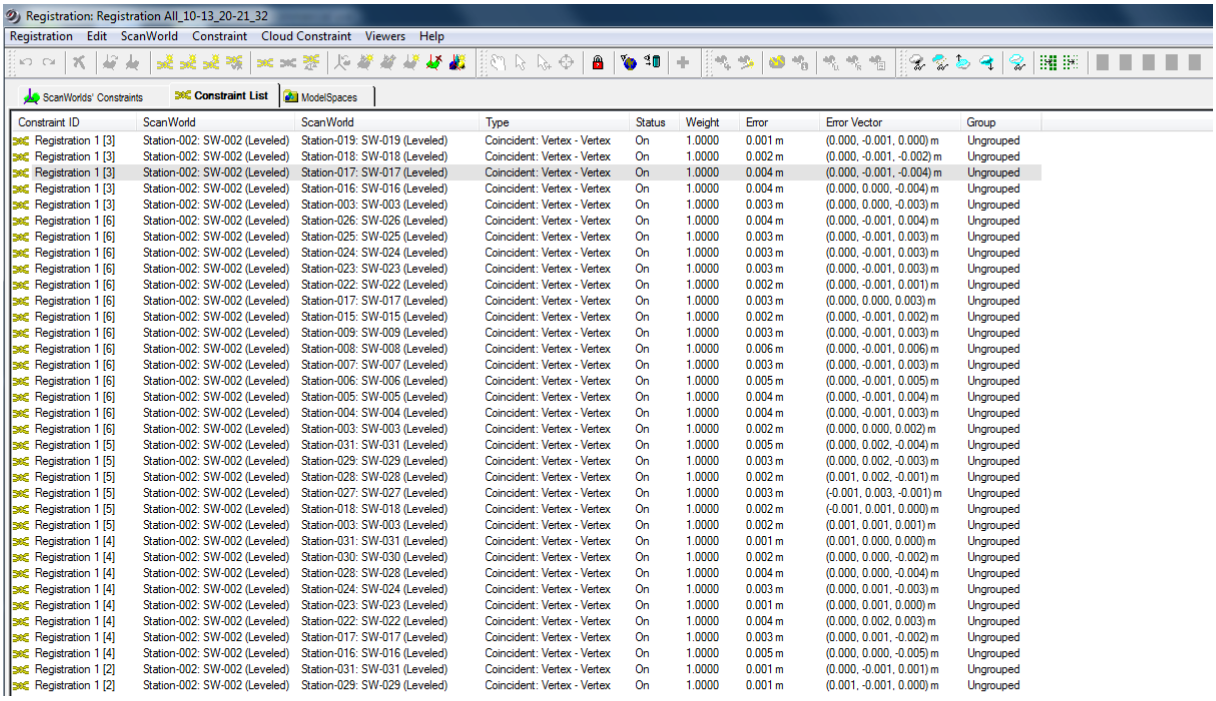
After the constraints have been added, the next step is to register the scan worlds. In this process cyclone computes the optimal alignment transformations for each scanworld. Before registration, the error column has “n/a” listed under it. After registration, the error column is filled in as shown in the figure 16.

To improve the accuracy of the registration process, it is desirable that during the survey a minimum of 4 targets are captured in each scan, the targets must also have a good geometrical spread.

5. Error check

As shown in the figure 16 the listed errors are the distances between constraints (or control points), and each is listed in the scanworld after registration. The next column to the right contains the X,Yand Z error vectors. These errors must be checked, if there is anything greater than approximately 7mm then there might be a target that is labelled wrong or perhaps one scanworld contains bad target geometry.

Other checks are overall fit (mean Absolute error), horizontal and vector errors. A good final check is to view the registered scans in one combined model space. Within this model space the raw data can be graphically checked to see that the scans look right and are aligned.



Constraint ID	ScanWorld	ScanWorld	Type	Status	Weight	Error	Error Vector	Group
Registration 1 [3]	Station-002: SW-002 (Leveled)	Station-019: SW-019 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.000, -0.001, 0.000) m	Ungrouped
Registration 1 [3]	Station-002: SW-002 (Leveled)	Station-018: SW-018 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.000, -0.001, -0.002) m	Ungrouped
Registration 1 [3]	Station-002: SW-002 (Leveled)	Station-017: SW-017 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.000, -0.001, -0.004) m	Ungrouped
Registration 1 [3]	Station-002: SW-002 (Leveled)	Station-016: SW-016 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.000, 0.000, -0.004) m	Ungrouped
Registration 1 [3]	Station-002: SW-002 (Leveled)	Station-003: SW-003 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, 0.000, -0.003) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-026: SW-026 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.000, -0.001, 0.004) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-025: SW-025 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, -0.001, 0.003) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-024: SW-024 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, -0.001, 0.003) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-023: SW-023 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, -0.001, 0.003) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-022: SW-022 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.000, -0.001, 0.001) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-017: SW-017 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, 0.000, 0.003) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-015: SW-015 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.000, -0.001, 0.002) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-009: SW-009 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, -0.001, 0.003) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-008: SW-008 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.006 m	(0.000, -0.001, 0.006) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-007: SW-007 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, -0.001, 0.003) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-006: SW-006 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(0.000, -0.001, 0.005) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-005: SW-005 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.000, -0.001, 0.004) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-004: SW-004 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.000, -0.001, 0.003) m	Ungrouped
Registration 1 [6]	Station-002: SW-002 (Leveled)	Station-003: SW-003 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.000, 0.000, 0.002) m	Ungrouped
Registration 1 [5]	Station-002: SW-002 (Leveled)	Station-031: SW-031 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(0.000, 0.002, -0.004) m	Ungrouped
Registration 1 [5]	Station-002: SW-002 (Leveled)	Station-029: SW-029 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, 0.002, -0.003) m	Ungrouped
Registration 1 [5]	Station-002: SW-002 (Leveled)	Station-028: SW-028 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.001, 0.002, -0.001) m	Ungrouped
Registration 1 [5]	Station-002: SW-002 (Leveled)	Station-027: SW-027 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(-0.001, 0.003, -0.001) m	Ungrouped
Registration 1 [5]	Station-002: SW-002 (Leveled)	Station-018: SW-018 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(-0.001, 0.001, 0.000) m	Ungrouped
Registration 1 [5]	Station-002: SW-002 (Leveled)	Station-003: SW-003 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.001, 0.001, 0.001) m	Ungrouped
Registration 1 [4]	Station-002: SW-002 (Leveled)	Station-031: SW-031 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.001, 0.000, 0.000) m	Ungrouped
Registration 1 [4]	Station-002: SW-002 (Leveled)	Station-030: SW-030 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.000, 0.000, -0.002) m	Ungrouped
Registration 1 [4]	Station-002: SW-002 (Leveled)	Station-028: SW-028 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.000, 0.000, -0.004) m	Ungrouped
Registration 1 [4]	Station-002: SW-002 (Leveled)	Station-024: SW-024 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, 0.001, -0.003) m	Ungrouped
Registration 1 [4]	Station-002: SW-002 (Leveled)	Station-023: SW-023 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.000, 0.001, 0.000) m	Ungrouped
Registration 1 [4]	Station-002: SW-002 (Leveled)	Station-022: SW-022 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.000, 0.002, 0.003) m	Ungrouped
Registration 1 [4]	Station-002: SW-002 (Leveled)	Station-017: SW-017 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, 0.001, -0.002) m	Ungrouped
Registration 1 [4]	Station-002: SW-002 (Leveled)	Station-016: SW-016 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(0.000, 0.000, -0.005) m	Ungrouped
Registration 1 [2]	Station-002: SW-002 (Leveled)	Station-031: SW-031 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.000, -0.001, 0.001) m	Ungrouped
Registration 1 [2]	Station-002: SW-002 (Leveled)	Station-029: SW-029 (Leveled)	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.001, -0.001, 0.000) m	Ungrouped

Figure 16: Cyclone Model screen capture showing constraint error distance.

6. Create scanworld freeze registration

After a successful registration process, a single scanworld is created that includes the combined scan worlds in one coordinate system. Freezing the registration of the raw data prevents any further manipulation of registered scan worlds.

7. Create Model space

After freezing the registration, a new model space is created.

8. Creating a model space view

The newly created model space is used to create a model space view, this is where the point cloud is now able to be manipulated. Point clouds can contain many millions of points making it difficult for most desktop or laptop computers to handle.

The Cyclone model software has an option to unify (decimate or filter) the point cloud making it easier to handle the diagram below shows the combined point cloud within the model space view.

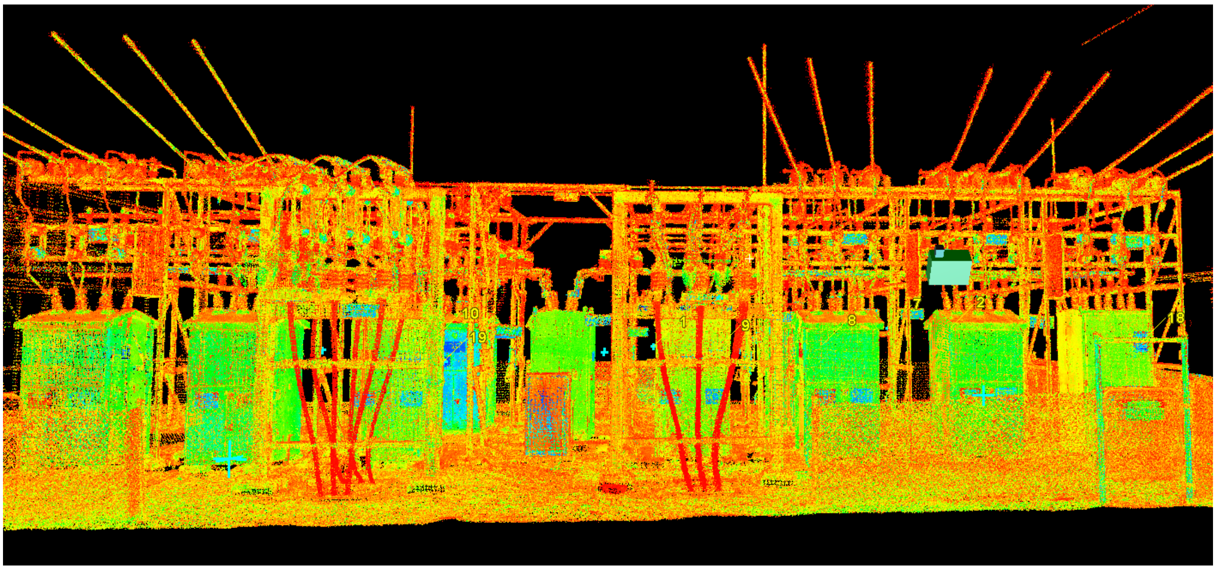


Figure 17: Point cloud file, model space view.

4.4.3 Data Manipulation

Once the point cloud file of the full Zone Substation is complete it may require cleaning up of any unwanted data within the file, the amount of editing will depend on the quality and calibration of the TLS device. Once the file has been cleaned up a usable point cloud file will be the result, point cloud files are typically large and the final produced point cloud file of the Nevertire job was approximately 10GB.

4.4.4 Processing for Display

Due to the large size of point cloud files and the large amount of processing power they require it would not be possible to access and use a point cloud file from a remote server without huge bandwidth and purpose built computers. To enable the 3D image produced to be fully utilised by Essential Energy designers in different areas of the state the file size needs to be reduced.

This can be done by filtering the point cloud data down which will mean a reduction in detail of the file or the point cloud image of the Nevertire Zone Substation site can be used to produce a vectorised 3D wireframe model of the site, this will eliminate the processing power required by a point cloud file, and give the ability to analyse a wire frame model of the site which can be used by designers and Essential Energy staff.

4.4.5 Analysis

Using the Nevertire Zone Substation point cloud file and 3D wireframe model, the safety clearances “as built” at Nevertire Zone Substation site are to be assessed against the current Essential Energy and Australia Standards. The current lightning protection configuration of the site which will also be compared to the Essential Energy and Australian Standards.

The point cloud file and 3D wireframe model of Nevertire Zone Substation will be used for taking direct measurements of the site conditions which are required in the analysis of the electrical safety clearances within the site.

Every area within the Substation is able to have the actual measurements taken from live sections of the Substation to the ground, phase clearances and section clearances.

The ability to conduct these types of measurements is a very useful tool in the analysis of existing sites as the electrical clearance distances are critical ones which should be designed correctly to ensure that the Substation meets the required standards.

The results of section 6 will determine the accuracy of the point cloud file and 3D wireframe model and confirm which one is to be used as the primary model for measurement.

Four models are to be assessed for their accuracy compared to on-site measurements, only the point cloud file and wireframe model will be used for analysis measurements and these results will be reported in section 7.

The Nevertire Zone Substation will be split into 8 sections to enable the measurements and recording of results easier, these sections will be:

- Section 1 – 132kV feeder bay circuit breaker 4422
- Section 2 – 66kV feeder bay circuit breaker 3412
- Section 3 – 22kV feeder bay circuit breaker 12
- Section 4 – 22kV feeder bay circuit breaker 22
- Section 5 – 22kV transformer circuit breaker 2412 and associated 22kV busbar and jack bus.
- Section 6 – 22kV transformer circuit breaker 2422 and associated 22kV busbar and jack bus.
- Section 7 – 22kV feeder bay circuit breaker 32

- Section 8 – 22kV feeder bay circuit breaker 42
- Zone Substation lightning protection.

Results will be reported on each of these sections individually for electrical safety clearance, lightning protection will be reported as a separate section over the full site for lightning protection.

5 Accuracy and Precision

Although not the primary purpose of this Dissertation, verifying the accuracy of the model to be used in the analysis was very important, to confirm that it was as close as possible to the true values measured at site and to ensure that the model could be relied upon to produce the same accuracy consistently.

Figure 18: Leica TCRP 1203 plus theodolite

5.1 Model Types

Four different modelling types were used for comparison against the actual on site measurements and against each other to prove which method was the most accurate and precise, these methods were:

- Conventional survey.
- Point cloud file.
- 3D Wireframe model.
- Leica TruView.

It was expected that the point cloud file and wireframe models would be the most accurate when compared to the actual site measurements, as these models are produced using highly accurate laser scanning equipment which is designed and manufactured to produce accurate 3D replications of real life.

The basis of comparing the 3D models was to determine the accuracy over different measured distances as well as the types of item being measured across the Zone Substation site, the error of each method for individual items is calculated as a distance and also a percentage and this is used to prove the accuracy of each method against the site measurements.

5.2 Items

The items to be measured were all chosen from the 132/66kV side of the Zone Substation due to the ease at which they could be measured accurately on site, the ease at which they could be measured in each model and the availability of the item in each model.

All of the measurements taken as part of the assessment of each model for accuracy were done by the same person, this ensured that each model could be compared with each other and against the on-site measurements fairly. All of the desktop models were able to be measured using Microstation Select Series 3, except the Leica TruView which runs as an internet based software program produced by Leica.

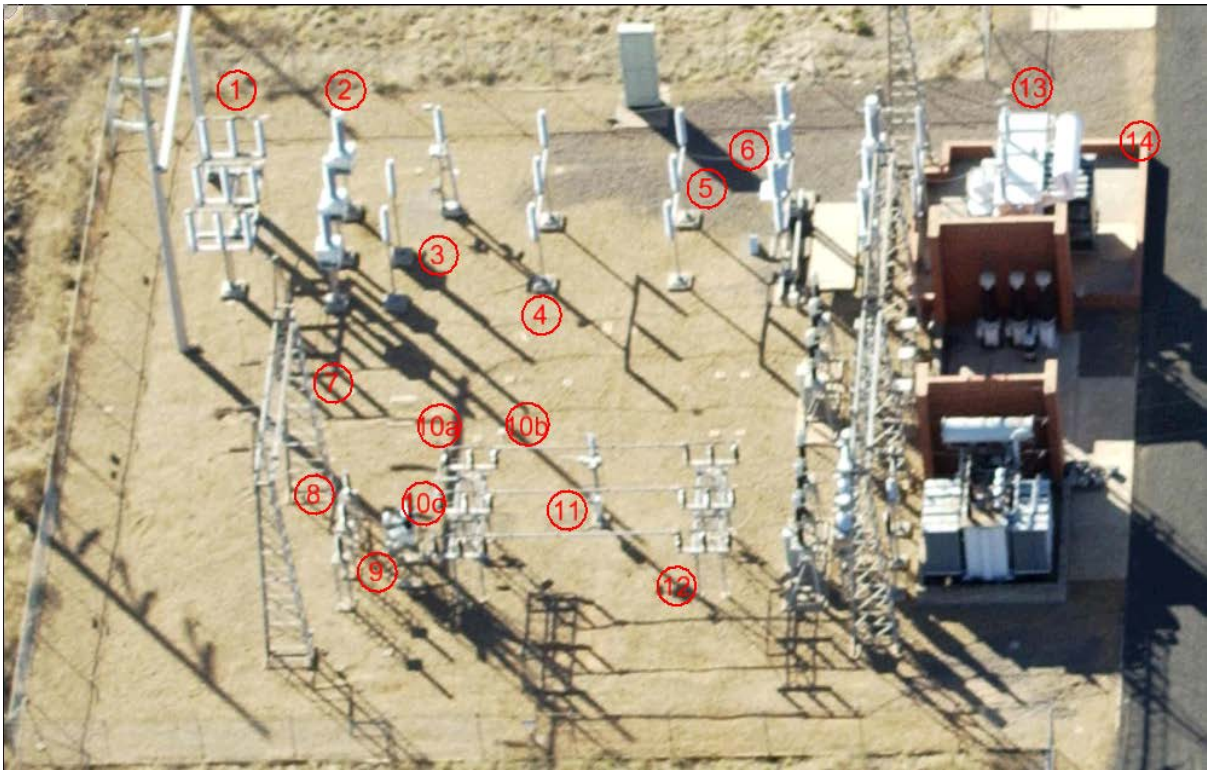


Figure 19: 132/66kV side of Nevertire Zone Substation showing item locations.

Analysing measurements over a broad area as shown in Figure 20 allowed for a more comprehensive result, because several scan positions are used to create the 3D model of this side of the Substation, as well as more than one survey station location in the conventional survey. The method used in bringing the different sections of data into a single file is also therefore tested as a result.

The items identified by numbers and measurements taken were:

Item 1 – 132kV Disconnector.

- Left and right concrete pads (all sides).
- Left and right steel upright columns (all sides).
- Left and right steel base plates (all sides).
- Outside of left concrete pad to outside of right concrete pad.

Figure 20: Item 1 132kV disconnector, left concrete pad left side measurement.

Item 2 – 132kV Line Voltage Transformers.

- Left, right and centre concrete pads (all sides).
- Left, right and centre steel upright columns (all sides).
- Left, right and centre steel base plates (all sides).
- Outside of left concrete pad to outside of right concrete pad.

Item 3 – 132kV Centre phase busbar support.

- Concrete pad, all sides.

Item 4 – 132kV Busbar support.

- Right steel base plate, all sides.

Figure 21: Item 4 132kV busbar support, right steel base plate rear measurement.

Item 5 – 132kV Busbar support.

- Left steel upright column, all sides.

Item 6 – 132kV Circuit breaker control cabinet.

- Plan view, all sides.

Item 7 - 66kV Gantry @ brace height (75mm EA posts).

- Left support column outer dimensions, all sides.

Item 8 - 66kV Surge Arresters (50mm EA posts).

- Left support column outer dimensions, all sides.

Item 9 - Voltage Transformer cubicle.

- Back of cubicle dimensions, all sides.

Item 10a – Disconnector sign.

- Height and width.

Item 10b – Earth switch sign.

- Height and width.

Item 10c – 66kV Disconnector.

- Left back concrete pad, all sides.

Item 11 – 66kV fault thrower.

- Steel base plate, all sides.

Item 12 – 66kV Disconnector.

- Outside of left steel column to outside of right steel column.

Item 13 – 132kV Transformer HV cable box width.

- Measurement taken from front to back.

Item 14 – 132kV Transformer bund wall.

- Front length.
- Left side length.

Figure 22: Item 14 132kV transformer front and side bund wall.

5.3 Measurements

5.3.1 On Site

All measurements were taken on the same day using a consistent method to eliminate the possibility of error. Each measurement was taken, recorded and re-measured, this was done as a self-check as many of the measurements were not whole numbers and precision could be increased by this method.

The measurements were done using only fibreglass (non-conductive) tape measures which is a site safety requirement, when obtaining measurements using these types of tapes careful attention was given to making sure the tape is kept taught to eliminate measurement error.

The biggest disadvantage with onsite measuring done using a tape measure is that the areas which can be measured are limited by their proximity to live electrical conductors, this Dissertation will attempt to prove that essentially this can be overcome by the use of scanning technology.

5.3.2 Conventional Survey

Taking measurements within the Microstation file of the conventional survey were able to done quite easily because the 2D model is produced using only lines and shapes. The layout of the 132kV feeder bay in the CAD file of the survey can be seen in the figure below in figure 23.

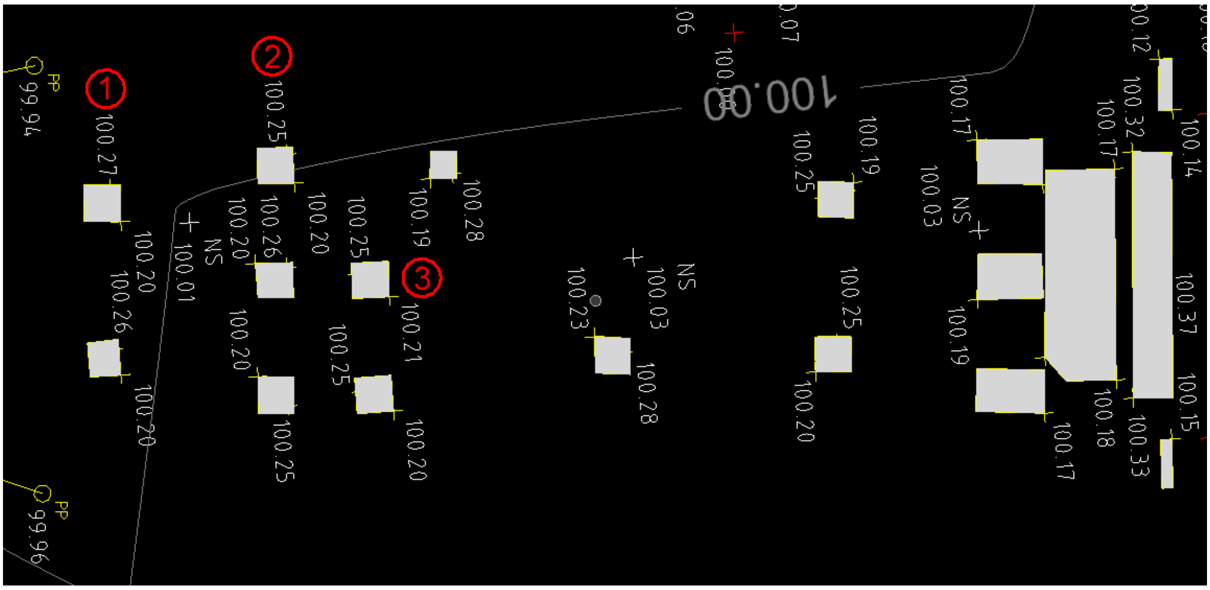


Figure 23: CAD file which shows surveyed footings.

Measurements and spacing of all bay footings are able to be measured straight off this file, but only detail which was captured as part of the on-site survey is available within the file. Footing reference levels within the file are shown as a data point with text these values relate to a common base reference point within the Zone Substation site.

5.3.3 Point Cloud File

The laser scan of the site was performed with specific attention to detail, as the primary function of the resultant point cloud file was the main focus point of the Dissertation. A total of 16 scan positions were used across the Zone Substation site to capture all possible detail, for maximum accuracy within the cloud file, this would also produce a better start point for the wireframe model to be produced.

Measuring within the point cloud file is definitely not as straight forward as measuring within a standard 2D file, measurements within a 3D point cloud file should always be done by a competent user. The 3D software being used to display the point cloud file also has a bearing on how easily the required measurements can be obtained.

Highly accurate measurements can be achieved by competent 3D users who have a good understanding of point cloud files and are familiar with the software which is being used to display the file. In addition to this, being familiar with the equipment which has been scanned would be an advantage, otherwise photographs can be used to assist.

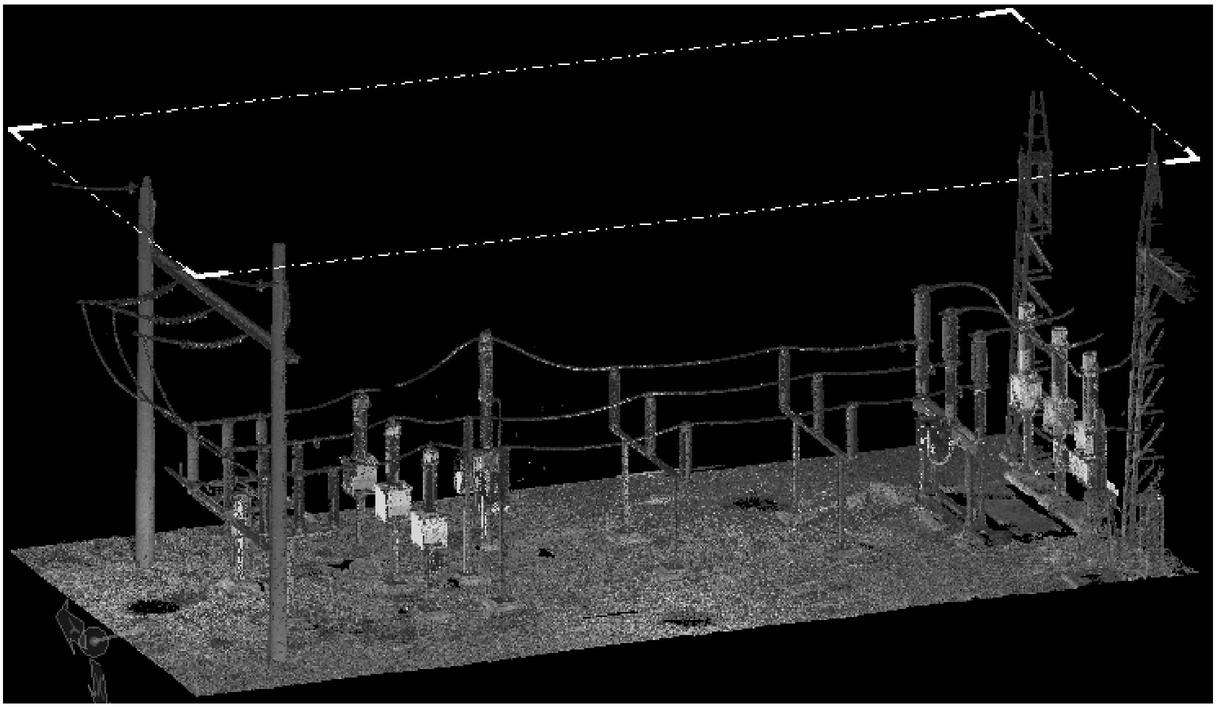


Figure 24: Point cloud file clipped to display 132kV feeder bay.

5.3.4 Wireframe Model

The wireframe model which is produced from the 3D point cloud file makes things a lot neater when taking direct measurements, because the wireframe is made up of surfaces instead of thousands of dots, the selection of starting and finishing points for measurements can be done very easily.

This model provides a similar level of accuracy to the point cloud file with the increased ability to manoeuvre the file and measure without the processing lag that the point cloud file suffers from.

Measuring the wireframe model with accuracy can be done with minimal software and 3D drafting experience which makes working with a wire frame model an advantage over the point cloud file, the wire surfaces and shapes of the 3D objects gives the user starting and finishes points which can be picked up with a measuring tool.

The detail of the wireframe model can be increased or decreased depending on the time spent processing the point cloud file, but for the purposes of this Dissertation the wire frame model produced excellent results without the need to produce finer detail down to a nut and bolt level.

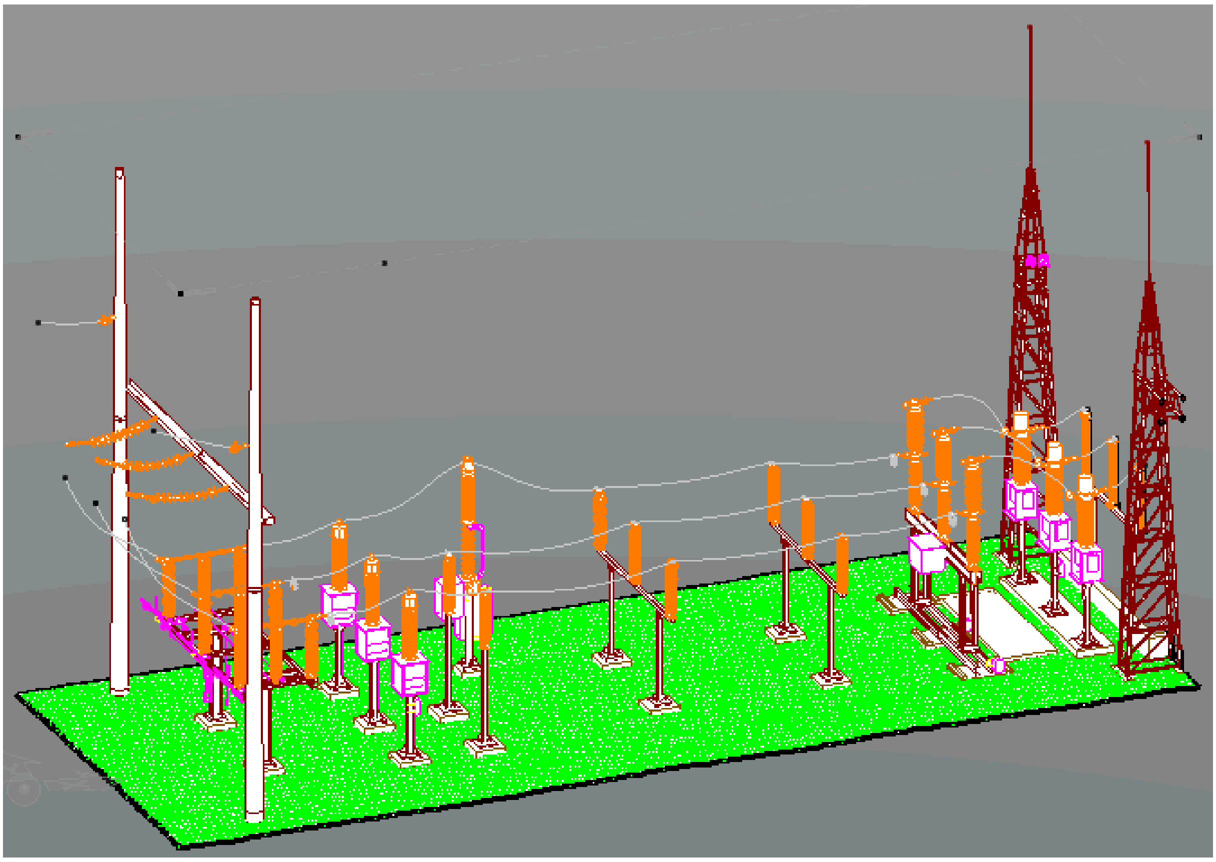


Figure 25: Wire frame model file clipped to display 132kV feeder bay.

5.3.5 Leica TruView

This model is an interesting and useful extra which is provided by Leica at no cost to the user which enables the point cloud file to be viewed within an internet or web based viewer. Because this model uses the point cloud file information running in the background measurements can be very accurate, depending on how far away from the scan position the measurement within the model is.

Figure 26: Leica TruView file screen shot displaying 132kV feeder bay.

This model is more of a handy tool rather than a method which would be relied upon to produce design information from. Obtaining the required measurements within the model was straight forward providing there had been a scan taken from relatively close to the measurement and in a direct line from scanner to measurement position.

Many of the required measurements were difficult to get from the model and this ultimately affected the error percentage for this model type. This model is still a very useful tool and there is greater potential to produce a more comprehensive model if site scan position were chosen with this in mind.

For the purpose of this Dissertation extra time was spent within the Leica TruView in an attempt to obtain an accurate measurement, as part of the assessment of this system for future project work.

5.4 Analysis and Results

Measurement results from all desktop models and on site data capture were compiled in a spread sheet to allow the data to be analysed and viewed. The spread sheet was initially setup to compile the data and allow for a quick comparison of each model against the onsite measurements and quickly select a modelling method which was the most accurate, it was expected that this would be the scanned model

Comparison of individual measurements was used as the basis for results, but this was not providing enough information for someone unfamiliar with the site and further calculations were soon formulated per item number based on:

- Item average mm variance.
- Item average per cent variance.
- Total mm error.

These results provided a much better and clearer overall view of how each Item was performing in terms of accuracy against the onsite “real” values. As seen in the tabulated results below, the results of the four methods can be assessed quickly and it is easy to see exactly how accurate the scanned models are.

Model	Survey		Cloud		Render		Leica TruView	
Accuracy average	Distance	Percent	Distance	Percent	Distance	Percent	Distance	Percent
Item 1 - 132kV Line Disconnector	65.06	8.06%	4.57	0.84%	3.80	0.93%	31.13	5.60%
Item 2 - 132kV Line Voltage Transformers	46.38	5.46%	3.27	1.20%	4.29	1.56%	37.32	10.32%
Item 3 - 132kV white phase busbar support concrete pa	42.29	5.29%	4.13	0.52%	6.45	0.81%	26.67	3.33%
Item 4 - 132kV busbar support base plate			1.90	0.42%	4.57	1.02%	22.88	5.09%
Item 5 - 132kV busbar support column			2.48	2.52%	2.85	2.90%	26.67	27.08%
Item 6 - 132kV circuit breaker control cabinet			4.00	0.61%	34.20	4.36%	72.00	11.34%
Item 7 - 66kV Gantry @ brace height (75mm EA posts)			3.32	0.35%	4.65	0.64%	18.50	1.55%
Item 8 - 66kV Surge Arresters (50mm EA posts)			5.63	1.25%	3.43	0.75%	26.25	5.85%
Item 9 - Voltage Transformer cubicle			1.40	0.22%	24.95	3.82%	20.50	3.23%
Item 10a - Disconnector sign dimensions			4.30	1.87%			9.00	3.02%
Item 10b - Earth switch sign dimensions			1.30	0.39%			14.00	5.17%
Item 10c - 66kV Disconnector left rear concrete pad	21.54	7.02%	3.95	1.29%	12.10	3.94%	38.00	12.37%
Item 11 - 66kV Fault Thrower			7.90	2.63%	4.45	1.48%	45.00	14.97%
Item 12 - 66kV Disconnector			1.1	0.04%	1.7	0.06%	19	0.64%
Item 13 - 132kV Transformer			1.4	0.09%	2.9	0.18%	1	0.06%
Item 14 - Transformer bund wall Front	32.68	0.40%	3.7	0.05%	9.8	0.12%	16	0.20%
Item 14 - Transformer bund wall Side	12.4	0.18%	9.6	0.14%	0.7	0.01%	42	0.60%
Total Average Method Type Error	36.73	4.40%	3.76	0.85%	8.06	1.50%	27.41	6.50%

Table 1: Model average error showing all items.

5.4.1 Conventional Survey

The comparison of the data from the original site survey against the onsite measured values provided some interesting results, this can be attributed to the type of survey and that the only results that were available for comparison were concrete footing dimensions.

Over the study of 4 major items 1, 2, 3 and 10c the average percent variance ranged from 5.25% through to 8.06%, initially these values seemed reasonably accurate until the distance of error is analysed, and calculated into the average percent variance.

In the four items used there were values of error up to a maximum of 159mm over a surveyed distance of 640mm and down to a low of 16.8mm over a surveyed distance of 782.2mm. The remaining results were all quite similar in error/distance ratio except for Item 14 (Transformer bund wall), the two wall length measurements were extremely close with a percent variance of 0.4% for the front wall measurement and 0.18% for the left side wall measurement.

The use of this type of survey method has been to date, utilised quite extensively for civil design to allow as built drawings to be marked up for positioning and for further upgrade works to be designed.

These results indicate that when using this type of survey for Substation design, critical measurements should still be checked on site manually, to avoid designing error into drawings. In instances where only the location and size of a footing is required the error may be acceptable.

Model	Measured Distance	Survey Error	Cloud Error	Render Error	TruView Error
Item 1 - Left concrete pad	3191.50	139.08	15.5	17.7	108.5
Item 1 - Right concrete pad	3194.50	438.47	29.5	6.3	199.5
Item 2 - Left concrete pad	3199.00	207.87	10.8	16.2	97
Item 2 - Middle concrete pad	3191.00	204.27	18	22.2	76
Item 2 - Right concrete pad	3192.00	148.62	5.7	25.2	172.5
Item 3 - Left concrete pad	3200.00	169.16	16.5	25.8	80
Item 10c - Left rear concrete pad	1227.00	86.16	15.8	48.4	114
Total Measured distance	20395.00	1393.63	111.80	161.80	847.50
Total Percent error		6.83%	0.55%	0.79%	4.16%

Table 2: Model error for concrete footings

5.4.2 Point Cloud File

The results from comparison of the point cloud file against on site measurement proved without doubt, that using this method to capture the actual as built condition from site is very accurate. The majority of average percent variance values were less than 1% error.

This type of accuracy was seen not just on concrete footings but over the whole range of items listed under heading 6.2. There were several of the point cloud file measurements which contained less than 1mm of error over lengths of up to 800mm, this level of accuracy within a desktop model could not realistically be achieved without the technology being utilised in this Dissertation.

There were also some very minor measurement errors within the point cloud file, the two worst measurement results were found on item 1 and item 8 of 13.1mm over a distance of 435.9 and 10.6mm over a distance of 454.6 respectively. As with the results of the conventional survey individual results such as these do not represent the overall accuracy of the model.

The overall results for this type of model provide sufficient evidence that this type of scanning technology could be further utilised within Zone Substation sites and with confidence that the data files being produced are well within the expected accuracy tolerances stated by the machine manufacturers.

5.4.3 Wireframe Model

As this model is produced directly from the point cloud file, the accuracy provided in the results of the analysis was expected to be very similar to the point cloud file. Across all of the measurements taken the wireframe model performed almost as well as the point cloud.

The wireframe model produced an error of less than 1% over the majority of the individual components of each of the measured items, in addition to overall model accuracy, the low error result provides re-assurance that the methods and wireframe components which were used to produce the wireframe model from the point cloud file were sound.

Even though the average error was very low within the results, there were three individual components results that were not desirable from a design perspective. These three poor results were contained across two items, causing the resultant error to be 4.36% and 3.82% respectively on item 6 and 9.

- Item 6, 132kV Circuit breaker control cabinet.
- Item 9, 66kV Voltage transformer marshalling box.

These types of errors can be directly attributed to the 3D modelling technique as the error is not seen within the point cloud file, this result does not affect the usability of this model for the purpose of the Dissertation as this error is contained to a non critical item within the Zone Substation.

Overall the accuracy of the wireframe model is high and the usability of the model due to the increased processing speed of this type of file is excellent. The use of this modelling method provides a very useful tool for design purposes, and with further refinement the error due to modelling could be removed completely.

5.4.4 Leica TruView

The Leica TruView results were very accurate in some of the measured items, and when compared to the conventional survey very similar in accuracy, this model is able to provide reasonable accuracy by utilising the information contained within the point cloud file it is produced from.

As already stated this model is more of a handy display tool rather than a purpose built design tool, many of the measurements were “hit and miss” and prior site knowledge contributed to this model providing better accuracy then could generally be expected.

Some unexpected accuracy could be obtained from the file providing the object to be measured had been in close proximity to the scanner position at site. A lot more scan positions could be used at site to make the most of this type of model, accuracy ranged from within 1.55% of real value, up to 27% error for individual items.

Even with the inconsistent result from the use of this method, it definitely provides a lot of value for its ability to provide a realistic image from which indicative measurements can be taken. When used in conjunction with site knowledge and additional scan data is a very useful add on package.

5.5 Evaluation

In the evaluation of the different models and techniques, the intention was not to discredit any particular method but instead to provide justification that the use of laser scanning technology could indeed provide a model which had the required accuracy for Substation design purposes.

TLS methods had not been used within Essential Energy Substations prior to being used in this Dissertation, they have however had minor use for Sub Transmission line modelling where a moderate level of accuracy is required (the data is usually filtered down from scan) , but not at the level which would be required to model a Zone Substation.

The manufacturer claimed accuracy of the Leica HDS7000 unit which was used for the laser scanning is measured in angular accuracy in the vertical and horizontal directions of 125µ Radians vertical/125µ Radians horizontal.

To allow for machine error in the evaluation requires conversion of these values to degrees and then calculation of the error distance in the vertical and horizontal direction. The angular error will vary linearly in relation to the scanner distance from the scanned object. To simplify calculations across a range of distances a spread sheet was used as shown in Table 3

			Distance from Scanner in mm									
		Radians(0)	5000	10000	15000	20000	25000	30000	35000	40000	45000	50000
Machine Error	Angular Accuracy											
	Vertical (125µ Rad)	0.000125	0.625	1.250	1.875	2.500	3.125	3.750	4.375	5.000	5.625	6.250
	Horizontal (125µ Rad)	0.000125	0.625	1.250	1.875	2.500	3.125	3.750	4.375	5.000	5.625	6.250
	Max point error		0.884	1.768	2.652	3.536	4.419	5.303	6.187	7.071	7.955	8.839
	Angular resolution											
	Vertical (7µ Rad)	0.000007	0.035	0.070	0.105	0.140	0.175	0.210	0.245	0.280	0.315	0.350
	Horizontal (7µ Rad)	0.000007	0.035	0.070	0.105	0.140	0.175	0.210	0.245	0.280	0.315	0.350
	Max point error		0.049	0.099	0.148	0.198	0.247	0.297	0.346	0.396	0.445	0.495
	Total Angular Error H+V		0.933	1.867	2.800	3.734	4.667	5.600	6.534	7.467	8.400	9.334

Table 3: Leica HDS7000 expected machine error.

Using the results of the analysis spread sheet, a total of 106 individual measurements were taken within the point cloud file and compared against the on-site measurements. The maximum distance of scanner from object for the Nevertire Zone Substation model is expected to be 35m.

At 35m a machine angular error value of 6.534mm is possible, any of the values which have an error of less than this will not be considered as they are within the specifications of the machine.

Out of the 106 measurements taken within the point cloud file only 13 measurements were outside the manufacturers specifications for the machine, and of these 13 the maximum error was 13.1mm or 2.92%

For the purpose of this Dissertation these accuracy levels are deemed to be within the accuracy level required, therefore the site phase clearances and lightning protection of the site will be assessed using the point cloud file.

6 Results

The Zone Substation site analysis results are provided as 8 sections to ensure a more detailed analysis due to being able to easily define and separate the differing voltage level areas within the site. Section 1 and 2 are the incoming line bays and sections 3 to 8 are the 4 x 22kV feeder bays and the 2 x 22kV transformer bays.

As can be seen in the following results obtained from analysis of the point cloud file, the major area of concern is the 22kV area of the site which in its current configuration has poor electrical clearances and ground clearances across sections of this area.

These measurement results provide evidence to the initial concerns which were raised in a “Site Options Report” produced by Essential Energy, only areas of poor clearance within each section will be discussed within these results.

The Zone Substation site lightning protection analysis results are provided separately to the electrical safety clearance results. The findings of this analysis clearly show that for the existing lightning mast configuration the Nevertire Zone Substation has good protection coverage over the majority of electrical plant.

6.1 Section 1 – 132kV Feeder Bay

Figure 27: Nevertire 132kV feeder bay circuit breaker 4422

The 132kV feeder bay at Nevertire Zone Substation is configured as a transformer ended feeder, the line bay spans approximately 24.0m before terminating on the 132kV power transformer. Equipment within the bay is well set out to ensure adequate clearances are met in relation to the highest voltage at this site (132kV).

This bay was initially constructed as a 66kV regulator bay which was rebuilt in the early 90’s as a 132kV feeder bay. This was done as part of a large augmentation project to improve poor voltage levels in the network west of the Dubbo.

Due to the set out of the feeder bay there are no horizontal and vertical work safety clearances effecting any equipment within the bay, they have been omitted from the results.

Section 1	Phase to Earth			Phase to Phase			Gnd Clearance			Section Safety		
Required	1300			1495			2440			3870		
Measured (A,B,C)	A	B	C	A-B		B-C	A	B	C	A	B	C
Circuit Breaker	1468	1463	1457	2097		2054	4178	4177	4122			
Busbar Support	1539	1499	1491	2404		2696	4197	4166	4202			
Busbar Support	1514	1461	1472	2527		2680	4371	4049	4020			
Fault Thrower	1486	1510	1508	2391		2433	4606	4324	4294			
Voltage Transformer	1770	1741	1759	2469		2381	4276	4309	4269			
Disconnector	1565	1678	1564	2381		2382	4192	4161	4198	3971	4004	4014

Table 4: 132kV Feeder bay circuit breaker 4422 clearance measurement results.

As can be seen in the spread sheet results (Table 4) there are zero potential issues affecting the 132kV feeder bay, all recorded measurements are in excess of the required values and no further analysis is required,

6.2 Section 2 – 66kV Feeder Bay Circuit Breaker 3412

Figure 28: Nevertire 66kV feeder bay circuit breaker 3412.

The 66kV feeder bay at Nevertire Zone Substation is also configured as a transformer ended feeder, the line bay spans approximately 21.0m before terminating on the 66kV power transformer. The current bay layout is not the original construction which allowed for a 66kV busbar and associated disconnectors.

The 66kV feeder bay configuration was updated with the installation of the 132kV feeder bay and the 66kV rigid busbar was removed as it could no longer be used, due to differing feeder bay voltages.

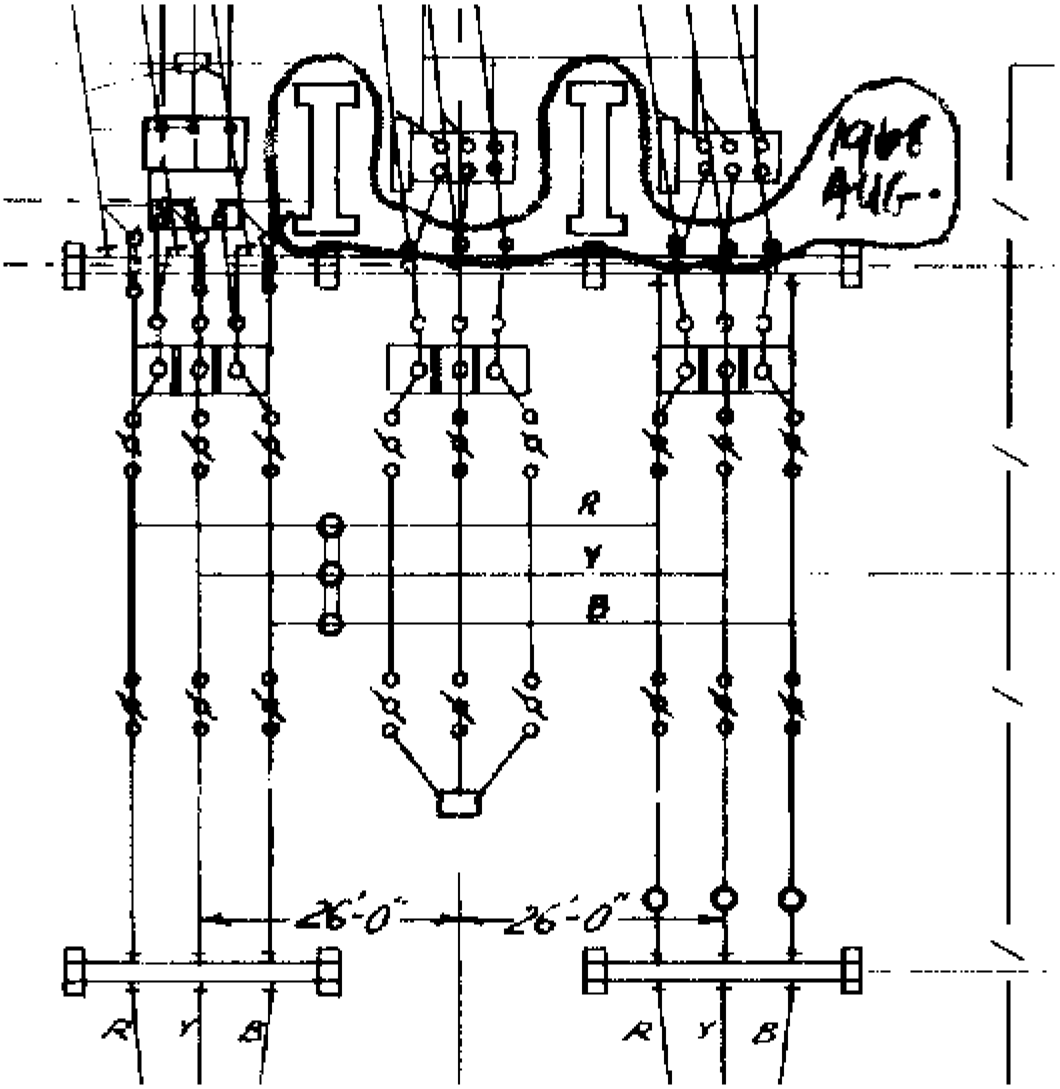


Figure 29: Nevertire 66kV feeder bay configuration when originally constructed.

For this reason the current layout of the bay is not ideal and this has also been highlighted within the “Site Options Report”. Due to the set out of the 66kV feeder bay there are no horizontal and vertical work safety clearances effecting any equipment within the bay, they have been omitted from the results.

Section 2	Phase to Earth			Phase to Phase			Gnd Clearance			Section Safety		
Required	630			725			2440			3135		
Measured (A,B,C)	A	B	C	A-B		B-C	A	B	C		A	
Power Transformer	1340	1657	1868	916		908.7	3256	3283	3312			
Surge Arrester	998	889.7	981.2	1478		1465	3806	3746	3836			
Current Transformer	843.9	830	862.3	1506		1495	3746	3788	3768			
Circuit Breaker	870.2	899.1	979.8	1543		1530	3316	3325	3307			
Disconnector	735.5	719.4	728.7	2112		2105	3474	3519	3524		3381	
fault Thrower	718.5			2145		2124	3542	3384	3459		4025	
Disconnector	974.5	915.5	909.1	2179		2119	3556	3590	3579			
Voltage Transformer	886.6	941.6	748.8	662.5		651.4	3176	3191	3049			
Surge Arrester	1070	1103	1105	1572		1507	3139	3129	3144			

Table 5: 66kV Feeder bay clearance measurement results.

The majority of the 66kV feeder bay does not have any clearances problems which was the expected result, the one major concern in the bay is due to the old 3Ø line voltage transformer which was initially installed on the centre feeder bay as can be seen in figure 29, it has since been repositioned as in figure 28.

Figure 30: 66kV feeder bay voltage transformer.

6.3 Section 3 – 22kV Feeder Bay Circuit Breaker 12

Figure 31: 22kV Feeder bay circuit breaker 12.

Feeder circuit breaker 12 is fed via the 22kV main busbar, circuit breaker 12 is a dead tank unit which can be isolated by opening a 22kV isolator on each side. The outgoing side of circuit breaker 12 exits the Substation using a 22kV line which is strung between the Substation gantry and the first feeder pole.

The arrangement of this feeder allows access to the jack busbar to be able to feed the load of any of the other feeders, the feeder configuration can be seen in figure 31

The overall length of the circuit breaker 12 feeder bay is approximately 17.0m but a large portion of this space is taken up by the main 22kV busbar and the 22kV jack busbar which are constructed using a busbar rigid configuration, this only allows 7.5m for the spacing of disconnectors and circuit breaker.

Section 3 CB-12	Phase to Earth			Phase to Phase			Gnd Clearance			Section Safety			H Work Safety			V Work Safety		
Required	280			325			2440			2750			2210			1650		
Measured (A,B,C)	A	B	C	A-B		B-C	A	B	C	A	B	C	A	B	C	A	B	C
Main Busbar Support	413.4	388.9	402.5	866.3		704.7	2829	2829	2864	3538	3580	3457	Not Applicable			Not Applicable		
Bus Disconnector	336	377.8	390.5	850		751.7	2659	2664	2684	1831	1873	1951	4542	3239	2400	Not Applicable		
Circuit Breaker	764.2	577.9	799.9	550.7		555.1	2915	2985	2965	Not Applicable			Not Applicable			Not Applicable		
Line Disconnector	466.2	507.4	507.8	875.1		846	2831	2779	2880	2855	2698	2941	Not Applicable			Not Applicable		
Jack Bus	369.5	396.4	390	800.2		758.5	2702	2705	2690	Not Applicable			2661	3260	2322	3692	3611	3636
Jack Bus Disconnector	330.8	297.4	333.1	842		816.6	2255	2289	2319	Not Applicable			Not Applicable			Not Applicable		

Table 6: 22kV Feeder bay, circuit breaker 12 clearance measurement results.

6.3.1 Phase to Earth Clearances

The minimum clearance for phase to earth at a B.I.L of 145kV @ 22kV is 280mm, all phase to earth clearances within this section of the Substation are within the required limits. The minimum ‘B’ phase clearance on the jack bus disconnector is only 297.4mm, this has been highlighted but is still acceptable.

6.3.2 Ground Clearance

The minimum ground clearance is good across the entire feeder except the jack bus disconnector, the line surge arresters are mounted on the out-going side of this disconnector and the connection to earth on the base of the arresters encroaches into the ground safety clearance across all of the three phases.

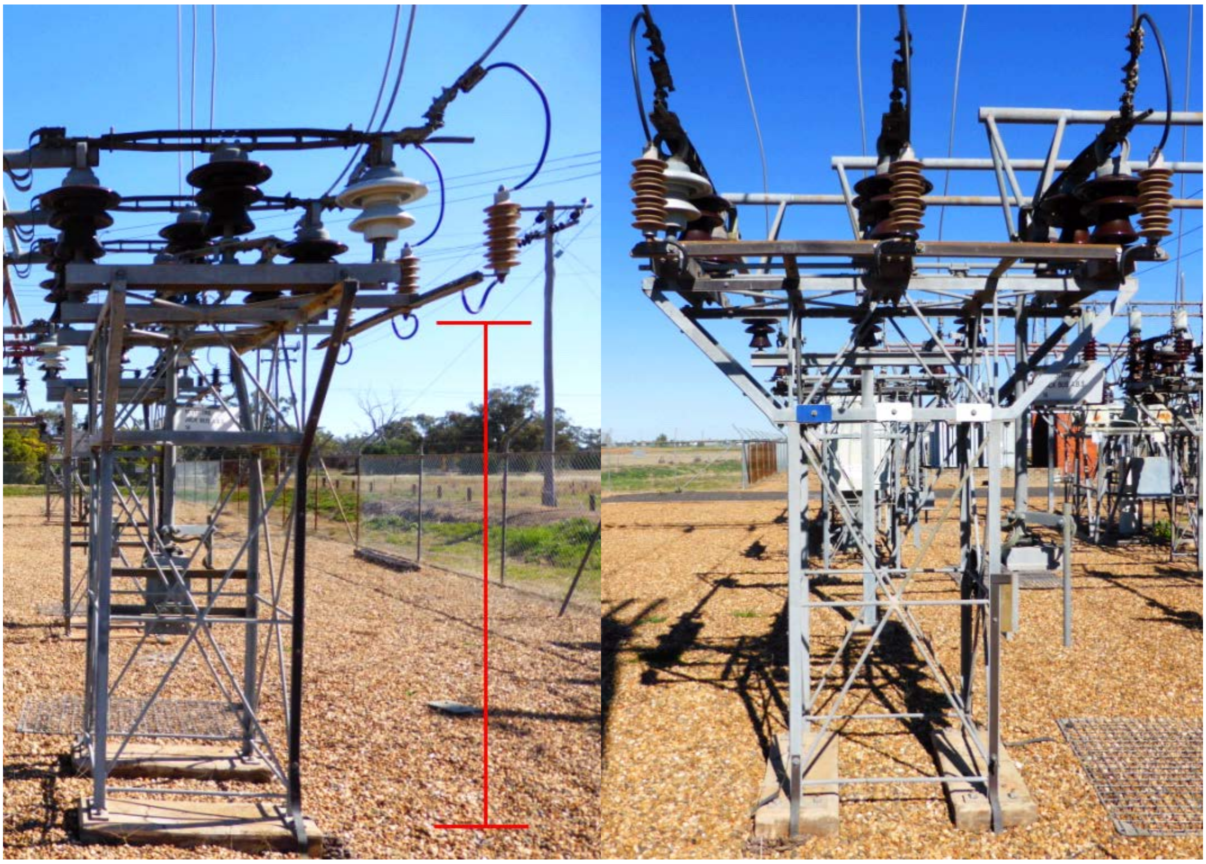


Figure 32: 22kV circuit breaker 12 jack bus disconnector ground clearance.

6.3.3 Section Safety Clearance

The safety clearance area created when the disconnectors either side of circuit breaker 12 are opened do not provide the required clearance distance on the bus side of the circuit breaker across all three phases and also on the centre phase on the line side of circuit breaker 12.

Figure 33: Circuit breaker 12 Section Safety Clearance.

As can be seen in figure 33 the line side clearance could be acceptable based on operational techniques, this is still a managed risk which is not desirable. The bus side clearance is approximately 900mm less than the required 2750mm across all phases.

6.4 Section 4 – 22kV Feeder Bay Circuit Breaker 22

Figure 34: 22kV Feeder bay circuit breaker 22.

Feeder circuit breaker 22 is fed via the 22kV main busbar, circuit breaker 22 is a live tank unit with separate single phase current transformers for each phase, these pieces of equipment can be isolated by opening a 22kV isolator on each side. The outgoing side of circuit breaker 22 exits the Substation using an overhead 22kV line which is strung between the Substation gantry and the first feeder pole.

The arrangement of this feeder allows access to the jack busbar to be able to feed the load of any of the other feeders, the feeder configuration can be seen in figure 34

The overall length of the circuit breaker 22 feeder bay is approximately 17.0m but a large portion of this space is taken up by the main 22kV busbar and the 22kV jack busbar which are constructed using a busbar rigid configuration, this only allows 7.5m for the spacing of disconnectors, circuit breaker and current transformers.

This limited spacing has a negative impact on the required section safety clearances in this feeder, this is highlighted in figure 36

Section 4 CB-22	Phase to Earth			Phase to Phase			Gnd Clearance			Section Safety			H Work Safety			V Work Safety		
Required	280			325			2440			2750			2210			1650		
Measured (A,B,C)	A	B	C	A-B		B-C	A	B	C	A	B	C	A	B	C	A	B	C
Main Busbar Support	427	437	437.5	772.9		775.1	2704	2694	2684	Not Applicable			Not Applicable			Not Applicable		
Bus Disconnector	578	543.9	550.1	823.1		840	2964	2973	2969	2077	2003	2096	Not Applicable			Not Applicable		
CB and CT's	623.6	600.3	695.8	735.3		723.4	2696	2686	2646	Not Applicable			Not Applicable			Not Applicable		
Line Disconnector	610	605.8	516.7	828.8		855.3	2826	2916	2861	2153	2117	2129	Not Applicable			Not Applicable		
Jack Bus	364.5	363.3	356.4	702.7		721.3	2662	2667	2650	Not Applicable			2737	2725	2533	3699	3633	3956
Jack Bus Disconnector	300.2	307.3	307.5	870.5		847.1	2287	2289	2319	Not Applicable			Not Applicable			Not Applicable		

Table 7: 22kV Feeder bay, circuit breaker 22 clearance measurement results.

6.4.1 Phase to Earth Clearances

The minimum clearance for phase to earth at a B.I.L of 145kV @ 22kV is 280mm, all phase to earth clearances within this section of the Substation are within the required limits. The minimum clearances on the jack bus disconnector across all phases is 300.2mm, this has been highlighted but is acceptable.

6.4.2 Ground Clearance

The minimum ground clearance is good across the entire feeder except the jack bus disconnector, the line surge arresters are mounted on the out-going side of this disconnector and the connection to earth on the base of the arresters encroaches into the ground safety clearance across all of the three phases.

Figure 35: 22kV Circuit breaker 22 jack bus disconnector ground clearance.

6.4.3 Section Safety Clearance

The safety clearance area created when the disconnectors either side of circuit breaker 22 are opened, do not provide the required clearance distance on the bus side of the circuit breaker across all three phases which all have a clearance distance of less than 2100mm.

All three phases on the load side of the current transformers do not have an acceptable clearance distance, the best clearance across the three phases is 2153mm which is still significantly less the required value of 2750mm.

Figure 36: 22kV Circuit breaker 22 bus side section safety clearance.

Figure 37: Circuit breaker 22 line side section safety clearance.

This feeder bay has poor electrical safety clearances on the bus and line side, this can be attributed in part to the live tank circuit breaker and associated current transformer construction being used instead of a dead tank circuit breaker. As seen in the circuit breaker 12 feeder bay, the use of a dead tank circuit breaker only improves the line side clearances.

6.5 Section 5 – 22kV Transformer Circuit Breaker 2412

Figure 38: 22kV Transformer circuit breaker 2412.

This section of the 22kV area contains three key elements of the 22kV supply, the 22kV supply from the 66/22kV power transformer is fed via overhead conductors from the transformer, which drop down to the transformer circuit breaker 2412 and through onto the 22kV busbar.

This section also contains the No.1 415V AC auxiliary supply and the No.1 bus voltage transformer, which are both supplied through fuse links from the main 22kV busbar.

The transformer circuit breaker is isolated by a 22kV bus disconnector and the 66kV transformer circuit breaker and 66kV transformer disconnector, this section is only 11.5m in length which means equipment spacing is at a minimum particularly around the voltage transformer and auxiliary.

Section 5 CB-2412	Phase to Earth			Phase to Phase			Gnd Clearance			Section Safety			H Work Safety			V Work Safety		
Required	280			325			2440			2750			2210			1650		
Measured (A,B,C)	A	B	C	A-B		B-C	A	B	C	A	B	C	A	B	C	A	B	C
Auxilliary VT	275.6	268.7	275.1	487.9		487.6	2436	2493	2435	1952	1820	1857	Not Applicable			3357	3969	4887
Bus VT	427	374.5	486.6	381.2		356.9	2746	2775	2650	1347	1202	1330	Not Applicable			3297	3762	3649
Bus Support	456.8	471.2	488.2	906.3		909.4	2738	2781	2857	3704	3292	3531	Not Applicable			3176	2943	2764
Bus Disconnector	383.2	378.7	354.9	913.4		901.1	2570	2498	2558	Not Applicable			Not Applicable			3207	2951	2712
Transformer CB & CT's	290.1	323.1	307.7	669.4		655.1	3619	3401	3466	2591	2534	2305	2770	2789	2665	2805	2338	2984
Jack Bus Support	636.4	653	533.5	840		828.6	3575	3565	3540	Not Applicable			Not Applicable			Not Applicable		
Bus Section Disconnector	429.6	378.4	403.1	871.7		865.3	3663	3693	3698	3924	3945	3892	Not Applicable			Not Applicable		

Table 8: 22kV Transformer, circuit breaker 2412 clearance measurement results.

6.5.1 Phase to Earth Clearances

The minimum clearance for phase to earth at a B.I.L of 145kV @ 22kV is 280mm, within this section there is a problem across all three phases at the auxiliary voltage transformer, there is also highlighted marginal clearances within the circuit breaker and current transformer arrangement.

The circuit breaker and current transformer clearance is acceptable as the minimum in service clearance of 290.1mm is still greater than required to achieve a B.I.L of

145kV, the phase to earth clearance at the auxiliary voltage transformer is less than the required 280mm across all phases to achieve the required B.I.L.

6.5.2 Ground Clearance

The required ground clearance for this section is achieved across the majority of the equipment, highlighted marginal clearances exist at B phase of the bus disconnector and B phase of the auxiliary voltage transformer.

The clearances on ‘A’ and ‘C’ phase at the auxiliary transformer is 2436mm and 2435mm respectively, these values are less than the required value of 2440mm, these distances are very close to the required limit however when viewed on site it becomes quite obvious that they are not within acceptable limits, this can also be seen within figure 39.

Figure 39: No.1 22kV/415V auxiliary voltage transformer.

6.5.3 Section Safety Clearance

The limited spacing within this section produces three section safety clearance problems, the two worst clearances are the No.1 auxiliary transformer and voltage transformer. The position of both of these pieces of equipment places them well within the required clearance area when using the expulsion drop out (E.D.O) fuses as an isolation point.

Figure 40: No.1 22kV/415V Aux. and VT section safety clearance.

The third clearance problem exists with the transformer circuit breaker, isolation to work on this circuit breaker with the required clearances would mean isolation of half of the 22kV main busbar and the 66/22kV Power transformer, therefore supplying the Substation via the 132kV Power transformer.

The minimum section safety clearances at the transformer circuit breaker is 2305mm which is well below the required value of 2750mm @ 22kV, this distance can be seen in figure 41

Figure 41: Transformer 2412 section safety clearance.

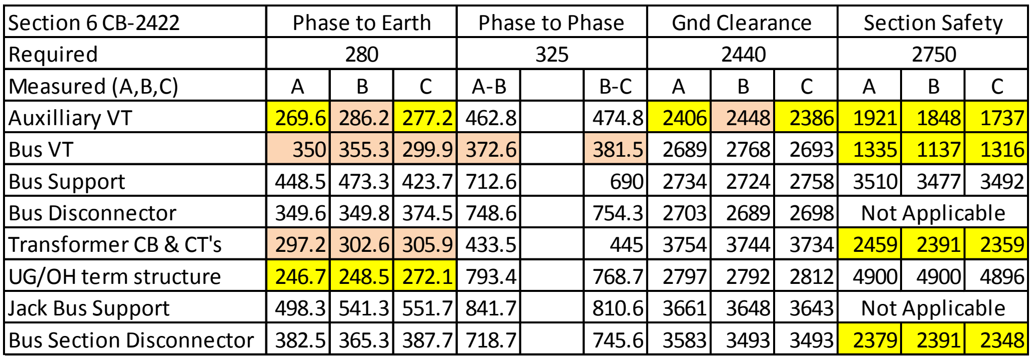
6.6 Section 6 – 22kV Transformer Circuit Breaker 2422

Figure 42: 22kV Transformer CB 2422 and No.2 22kV/415V Aux. and VT.

This section of the 22kV area contains three key elements of the 22kV supply, the 22kV supply from the 132/22kV power transformer is fed via underground cables from the transformer, which are terminated onto a underground to overhead structure then to circuit breaker 2412 via copper busbar through onto the 22kV main busbar.

This section also contains the No.2 Substation 415V AC auxiliary supply and the No.2 bus voltage transformer, which are both supplied through fuse links from the main 22kV busbar.

The transformer circuit breaker is isolated by a 22kV bus disconnector and the 132kV transformer circuit breaker and 132kV transformer disconnector, this section is only 12.0m in length which means equipment spacing is at a minimum particularly around the voltage transformer and auxiliary.



Section 6 CB-2422	Phase to Earth			Phase to Phase			Gnd Clearance			Section Safety		
Required	280			325			2440			2750		
Measured (A,B,C)	A	B	C	A-B		B-C	A	B	C	A	B	C
Auxilliary VT	269.6	286.2	277.2	462.8		474.8	2406	2448	2386	1921	1848	1737
Bus VT	350	355.3	299.9	372.6		381.5	2689	2768	2693	1335	1137	1316
Bus Support	448.5	473.3	423.7	712.6		690	2734	2724	2758	3510	3477	3492
Bus Disconnector	349.6	349.8	374.5	748.6		754.3	2703	2689	2698	Not Applicable		
Transformer CB & CT's	297.2	302.6	305.9	433.5		445	3754	3744	3734	2459	2391	2359
UG/OH term structure	246.7	248.5	272.1	793.4		768.7	2797	2792	2812	4900	4900	4896
Jack Bus Support	498.3	541.3	551.7	841.7		810.6	3661	3648	3643	Not Applicable		
Bus Section Disconnector	382.5	365.3	387.7	718.7		745.6	3583	3493	3493	2379	2391	2348

Table 9: 22kV Transformer, circuit breaker 2422 clearance measurement results.

6.6.1 Phase to Earth Clearances

The minimum clearance for phase to earth at a B.I.L of 145kV @ 22kV is 280mm, within this section there is poor clearance on two of the three phases of the auxiliary voltage transformer, all three phases at the underground to overhead termination structure, there is also highlighted marginal clearances within the circuit breaker and current transformer arrangement and the busbar voltage transformer.

The circuit breaker and current transformer clearance is acceptable as the minimum in service clearance of 297.2mm is still greater than required to achieve a B.I.L of

145kV, the phase to earth clearance at the busbar voltage transformer is also acceptable as the minimum value is 299.9mm.

The earth clearances on this auxiliary are similar to the No.1 auxiliary, they are close to the required value of 280mm but not adequate to achieve the required B.I.L of 145kV. All phases of the underground to overhead termination are significantly less than the required value of 280mm, the 'A' phase clearance is the worst at 246.7mm

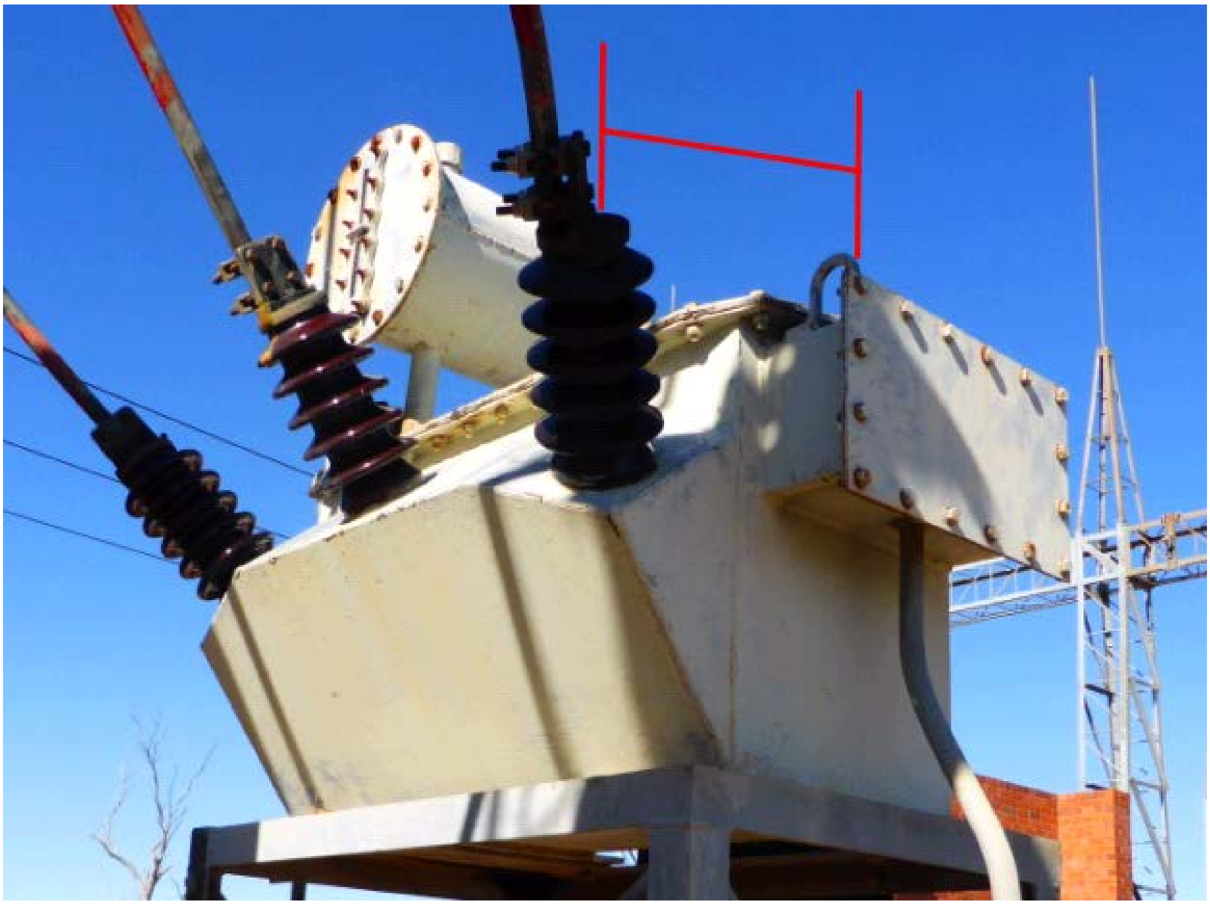


Figure 43: No.2 22kV/415V auxiliary transformer phase to earth clearance.

6.6.2 Ground Clearance

The required ground clearance for section 6 is achieved across the majority of the equipment, highlighted marginal clearances exist at B phase of the auxiliary voltage transformer.

The clearances on ‘A’ and ‘C’ phase at the auxiliary transformer is 2406mm and 2386mm respectively, these values are less than the required value of 2440mm, this is a similar result when compared to the poor ground clearance result at the same structure in section 5.

6.6.3 Section Safety Clearance

The configuration of the auxiliary voltage transformer and busbar voltage transformer is the same as ‘section 5’, all of the poor clearance areas across these two pieces of equipment in ‘section 5’ are the same issues which are seen in Figure 40 of 6.5.3

This arrangement of the live tank circuit breaker and current transformers is also very similar to the No.1 and the poor clearances are the same as seen in ‘section 5’, this section does make use of an underground to overhead cable termination structure for the transformer cables.

As can be seen in figure 44 this does not improve the clearance values in comparison to the ‘No.1 section’ as they are still below the required value of 2750mm with the worst being a minimum of 2391mm on the centre phase.

Figure 44: Transformer circuit breaker 2422 section safety clearance.

Also assessed as part of this section was one of the bus section disconnectors, the resulting section clearances values of ‘A’ phase 2379mm, ‘B’ phase 2391mm and ‘C’ phase 2348mm are well below the required distance of 2750mm which would be required to obtain access for maintenance.

Figure 45: 22kV Main busbar disconnectors section safety clearance.

6.7 Section 7 – 22kV Feeder Bay Circuit Breaker 32

Figure 46: 22kV Feeder bay circuit breaker 32.

Feeder circuit breaker 32 is fed via the 22kV main busbar, circuit breaker 32 is a live tank unit with separate single phase current transformers for each phase, the configuration and operation to isolate equipment in this bay is identical to feeder bay circuit breaker 22, including the jack bus arrangement.

The overall length of the circuit breaker 32 feeder bay is approximately 17.0m which is also identical to the measurement of circuit breaker 22 feeder bay, again this only allows 7.5m for the spacing of disconnectors, circuit breaker and current transformers.

This limited spacing has a negative impact on the required section safety clearances in this feeder, this is highlighted in figure 46 and from the results of analysis it can be seen that the circuit breaker 22 and circuit breaker 32 feeder bays have been constructed exactly the same, and they therefore carry the same clearance issues.

Section 7 CB-32	Phase to Earth			Phase to Phase			Gnd Clearance			Section Safety			H Work Safety			V Work Safety		
Required	280			325			2440			2750			2210			1650		
Measured (A,B,C)	A	B	C	A-B		B-C	A	B	C	A	B	C	A	B	C	A	B	C
Main Busbar Support	432.2	450.2	445.2	815.4		840.4	2778	2689	2754	Not Applicable			Not Applicable			Not Applicable		
Bus Disconnector	375	378.5	371.8	752.5		767.3	2719	2708	2693	2259	2262	2240	Not Applicable			Not Applicable		
CB and CT's	624.8	608.6	634.2	711.1		733.3	2598	2683	2679	Not Applicable			Not Applicable			Not Applicable		
Line Disconnector	507.7	572.2	560.6	883		891.9	2858	2903	2918	2220	2106	2105	Not Applicable			Not Applicable		
Jack Bus	434.4	521.9	577.9	888.5		828.2	2708	2713	2713	Not Applicable			2553	2528	2531	3969	3970	4323
Jack Bus Disconnector	295.6	304.3	308	910.1		902.7	2375	2345	2335	Not Applicable			Not Applicable			Not Applicable		

Table 10: 22kV Feeder bay, circuit breaker 32 clearance measurement results.

6.7.1 Phase to Earth Clearances

The minimum clearance for phase to earth at a B.I.L of 145kV @ 22kV is 280mm, all phase to earth clearances within this section of the Substation are within the required limits. The minimum clearances on the jack bus disconnector across all phases is 295.6mm, this has been highlighted but is acceptable.

6.7.2 Ground Clearance

Low clearances exist on the jack bus disconnector in this section, the line surge arresters are mounted on the out-going side of this disconnector and the connection to earth on the base of the arresters encroaches into the ground safety clearance across all of the three phases.

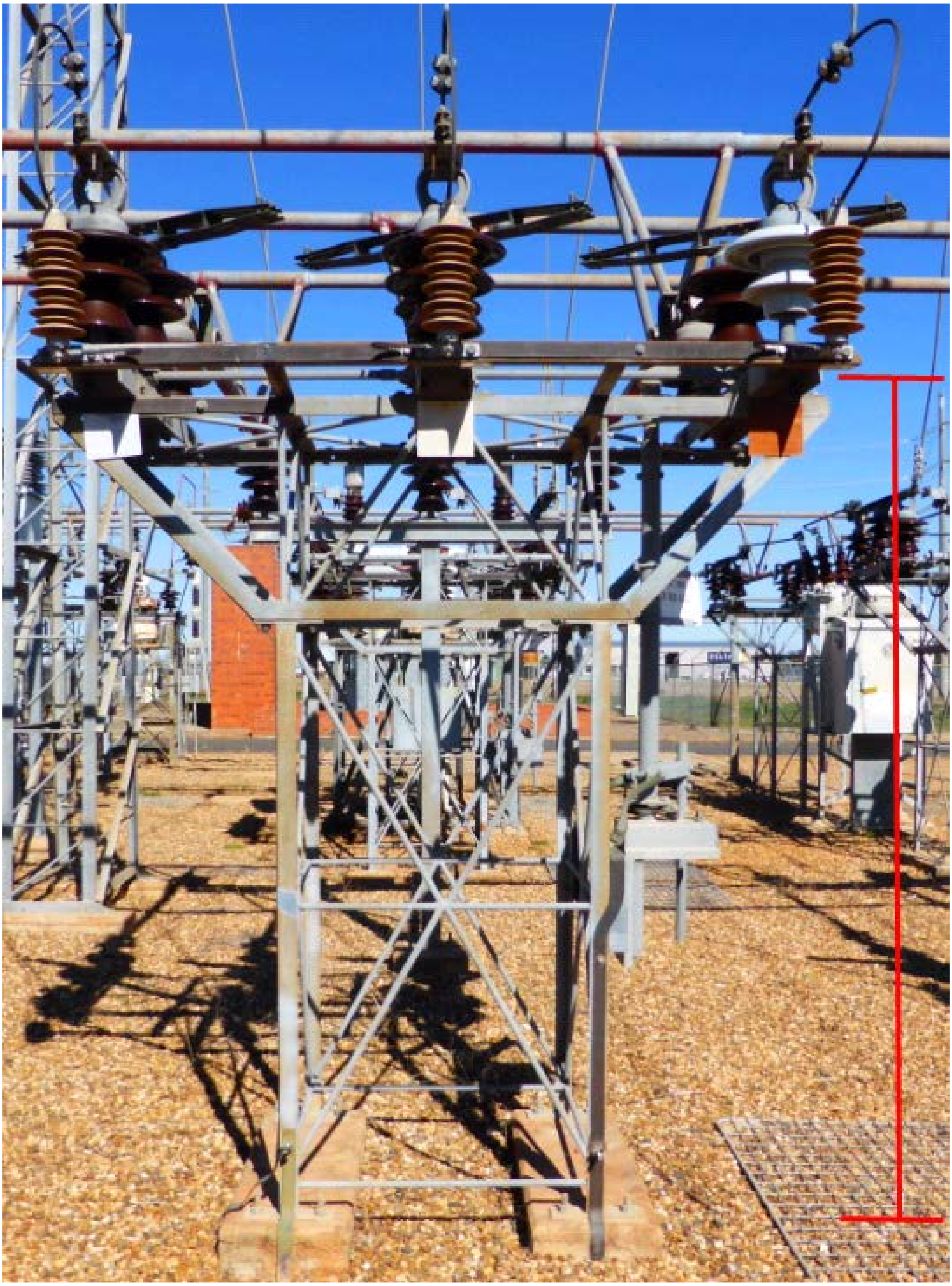


Figure 47: 22kV Circuit breaker 32 jack bus disconnector ground clearance.

6.7.3 Section Safety Clearance

The safety clearance area created when the disconnectors either side of circuit breaker 32 are opened, do not provide the required clearance distance on the bus side of the circuit breaker across all three phases, with a maximum distance being achieved of 2262mm.

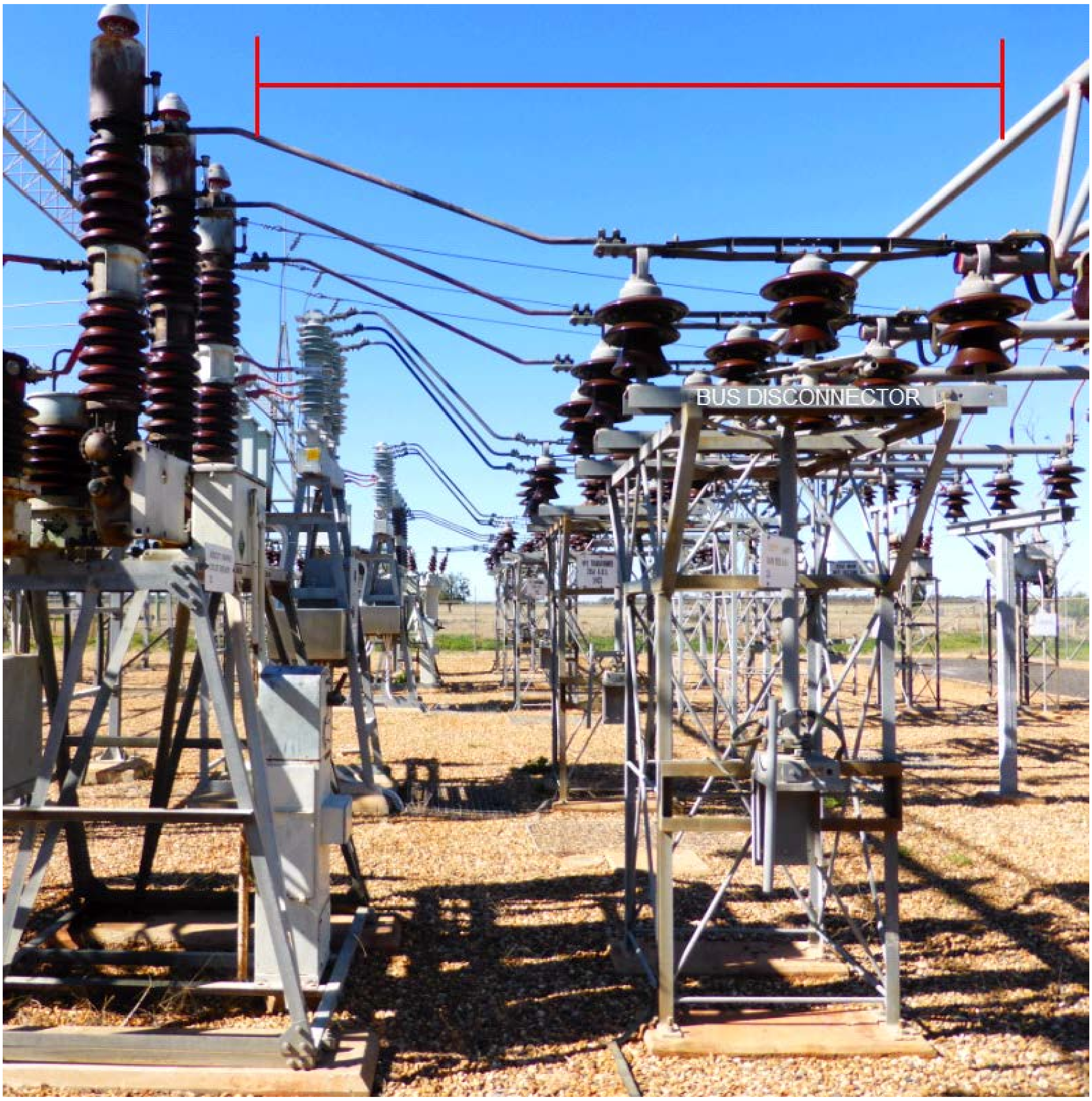


Figure 48: Circuit breaker 32 bus side section safety clearance.

Poor clearances also exist on all three phases of the load side of the current transformers, the best clearance across the three phases is 2220mm which is still significantly less the required value of 2750mm.

Figure 49: Circuit breaker 32 line side section safety clearance.

6.8 Section 8 – 22kV Feeder Bay Circuit Breaker 42

Feeder circuit breaker 42 is fed via the 22kV main busbar, circuit breaker 42 is a dead tank unit which can be isolated by opening a 22kV isolator on each side. The configuration and operation to isolate equipment in this bay is identical to feeder bay circuit breaker 22, including the jack bus arrangement.

The overall length of the circuit breaker 42 feeder bay is approximately 17.0m and from the results of analysis it can be seen that the circuit breaker 42 and circuit breaker 12 feeder bays have been constructed exactly the same, they therefore carry the same clearance issues, due to only allowing 7.5m for the spacing of disconnectors and circuit breaker.

Section 8 CB-42	Phase to Earth			Phase to Phase			Gnd Clearance			Section Safety			H Work Safety			V Work Safety		
Required	280			325			2440			2750			2210			1650		
Measured (A,B,C)	A	B	C	A-B		B-C	A	B	C	A	B	C	A	B	C	A	B	C
Main Busbar Support	430.6	432.6	417.5	842.9		853.1	2721	2708	2703	3357	3262	3425	Not Applicable			Not Applicable		
Bus Disconnector	384.7	375.7	388.2	717.1		687.2	2792	2782	2733	2163	1876	1988	Not Applicable			Not Applicable		
Circuit Breaker	599.8	496.4	612	555.9		558.8	2999	2989	2998	Not Applicable			Not Applicable			Not Applicable		
Line Disconnector	506.3	491.1	508.1	844.6		873	2959	2964	2984	2739	2573	2715	Not Applicable			Not Applicable		
Jack Bus	395.6	417.5	409.7	908.2		903.7	2719	2699	2724	Not Applicable			3128	2996	3002	3543	3574	3730
Jack Bus Disconnector	322.2	339.3	308.1	897.1		925.6	2385	2370	2380	Not Applicable			Not Applicable			Not Applicable		

Table 11: 22kV Feeder bay circuit breaker 42 clearance measurement results.

6.8.1 Phase to Earth Clearances

The minimum clearance for phase to earth at a B.I.L of 145kV @ 22kV is 280mm, all phase to earth clearances within this section of the Substation are within the required limits. The minimum ‘C’ phase clearance on the jack bus disconnector is only 308.1mm, this has been highlighted but is still acceptable.

6.8.2 Ground Clearance

The minimum ground clearance is acceptable across the entire feeder except the jack bus disconnector, the line surge arresters are mounted on the out-going side of this disconnector and the connection to earth on the base of the arresters encroaches into the ground safety clearance across all of the three phases.

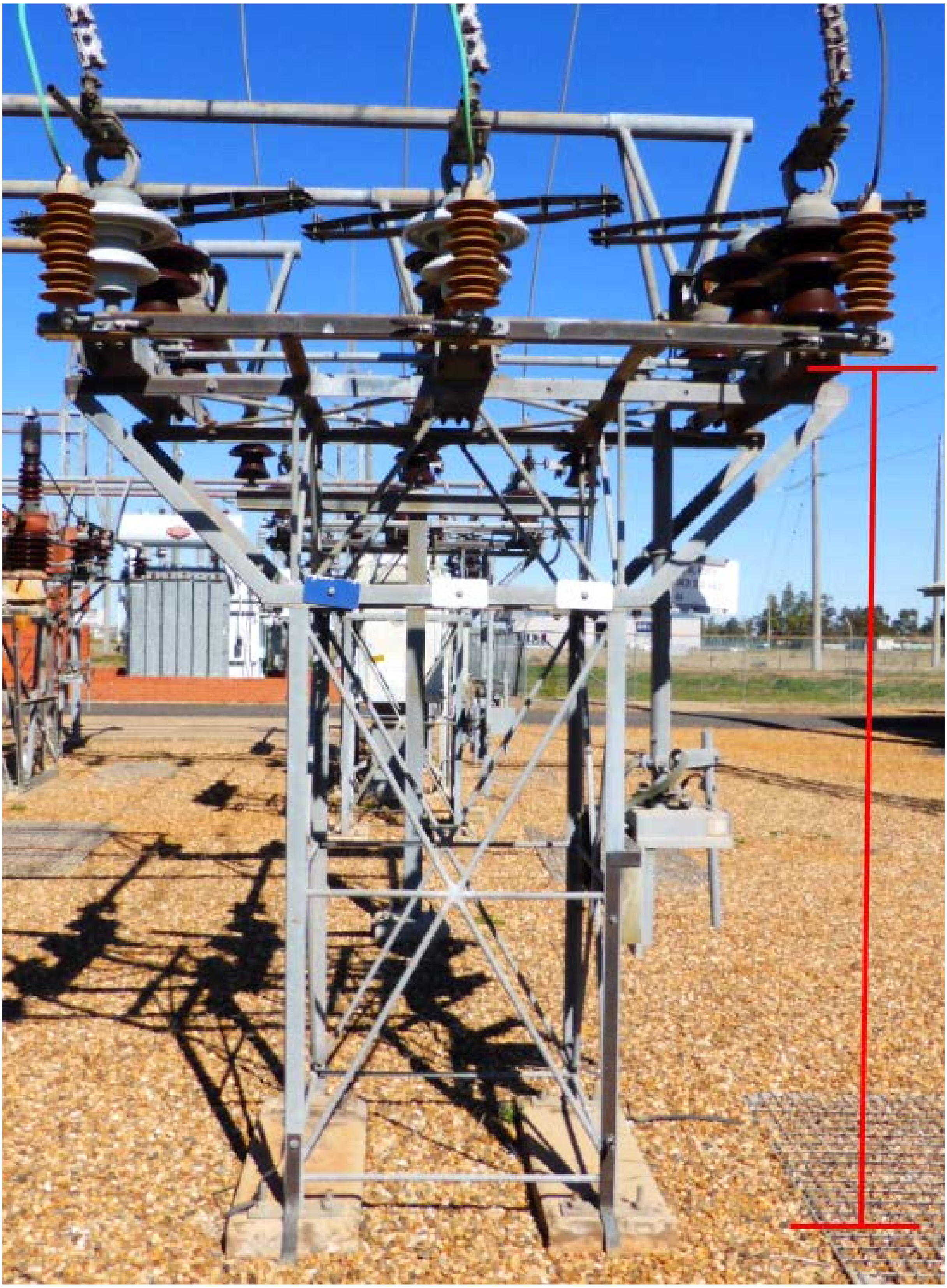


Figure 50: 22kV Circuit breaker 42 jack bus disconnector ground clearance.

6.8.3 Section Safety Clearance

Poor clearances exist on either side of the dead tank circuit breaker 42, the bus disconnector side has the low clearances across all of the three phases with the lowest of 1876mm on ‘B’ phase.

As this bay configuration is identical to the circuit breaker 12 feeder bay, the line side disconnector clearances are similar with ‘A’ and ‘C’ phases being close to an acceptable level of 2739mm and 2715 respectively, ‘B’ phase is the lowest with a clearance of only 2573.

Figure 51: Circuit breaker 42 section safety clearance.

6.9 Zone Substation Lightning Protection

To analyse the lightning protection coverage for the Nevertire Zone Substation, the same point cloud file was used. Using the point cloud file a 2D CAD model and a 3D wireframe model were created to predict the lightning coverage for the entire site.

The Nevertire Zone Substation has an extensive layout of 8 dedicated lightning masts positioned throughout the 132/66kV side of the site and 4 dedicated and 1 dual purpose lightning mast positioned throughout the 22kV side of the site.

The 2D CAD model was split into 6 elevation cross sections and used as the primary model to conduct the analysis, the 3D wireframe model was used as a secondary checking model to confirm clearances where the distance between the equipment and line of protection was close.

Using a rolling sphere method with a sphere 30.0m in radius, each cross section was tested to ensure a clearance of 7.0m across the 22/66kV equipment and 8.0m across the 132kV equipment was maintained, yard equipment is represented by a rectangular hatched clearance area with clearance height shown above this.

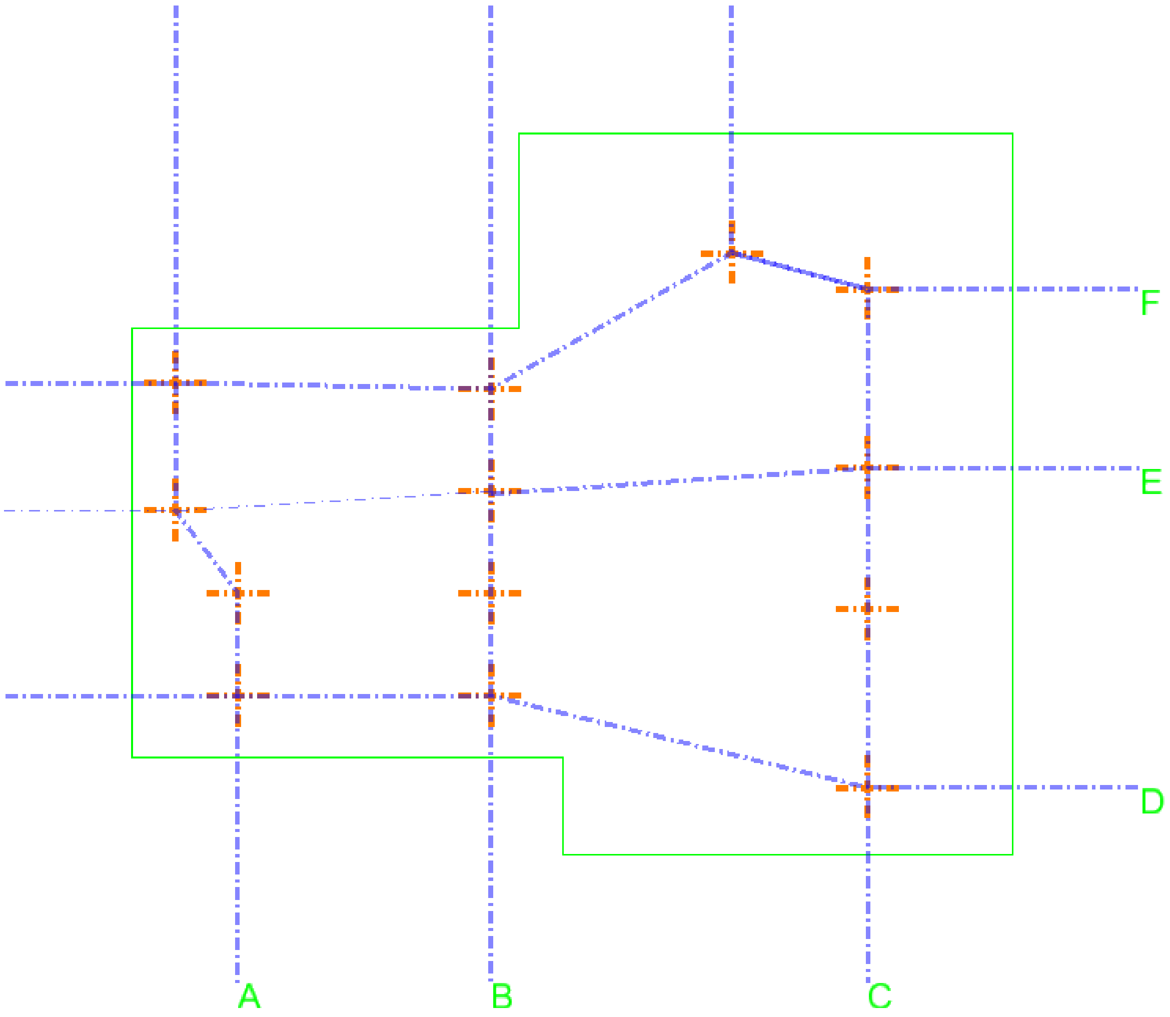


Figure 52: Zone Substation plan view showing elevation cross sections.

6.9.1 Rolling Sphere Cross Sectional Clearances

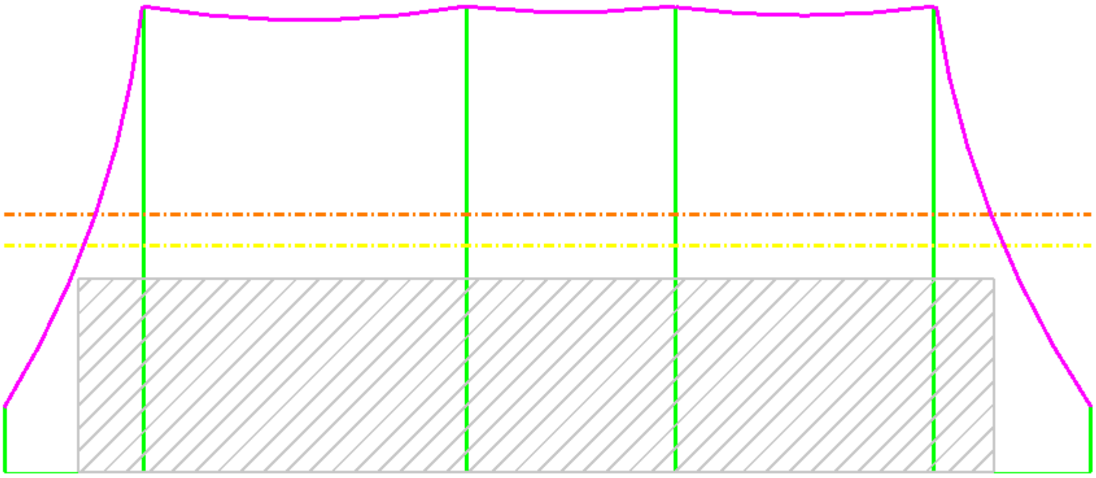


Figure 53: Section ‘A’ lightning clearance

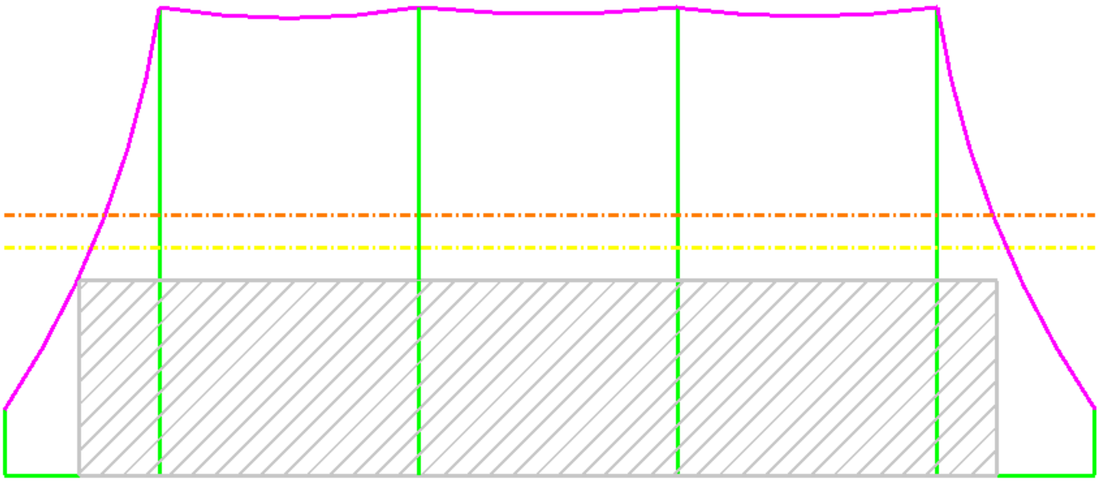


Figure 54: Section ‘B’ clearance

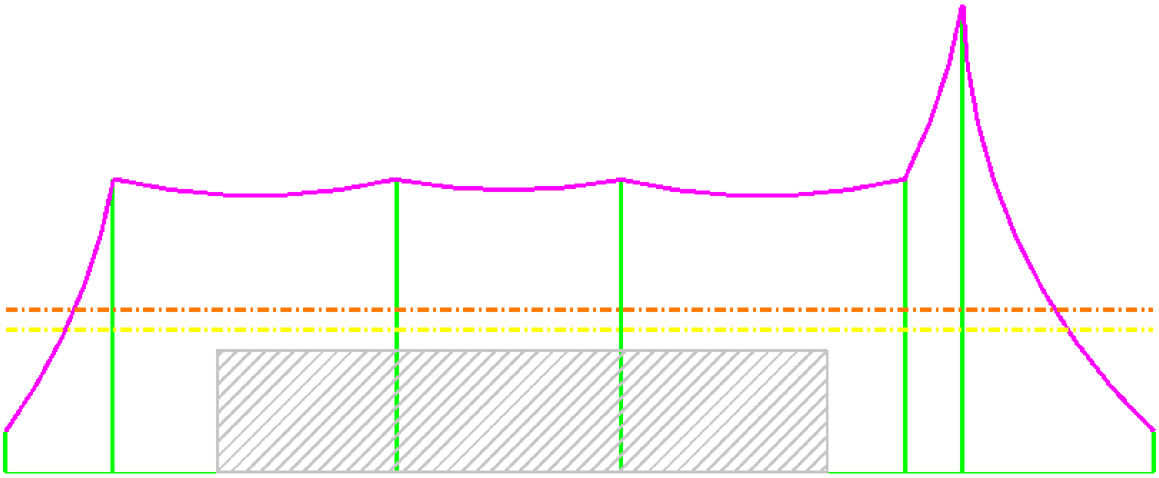


Figure 55: Section ‘C’ clearance

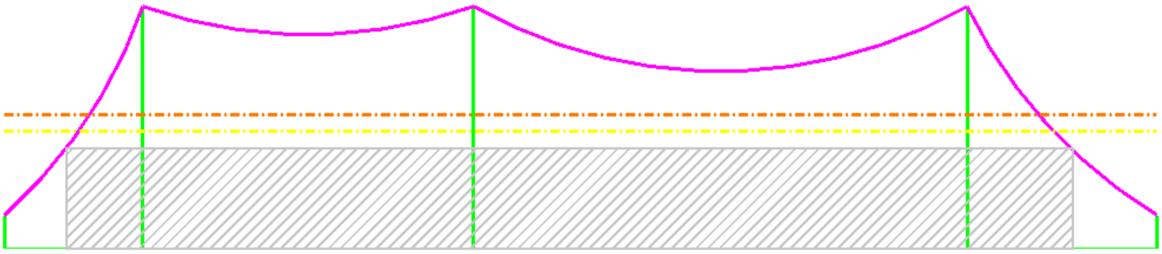


Figure 56: Section ‘D’ clearance

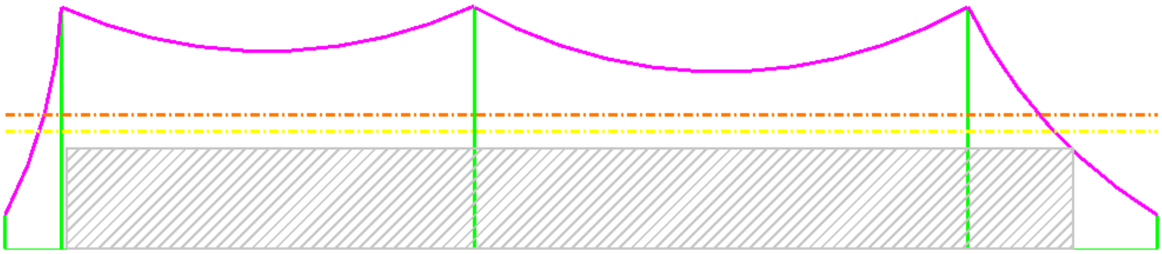


Figure 57: Section ‘E’ clearance

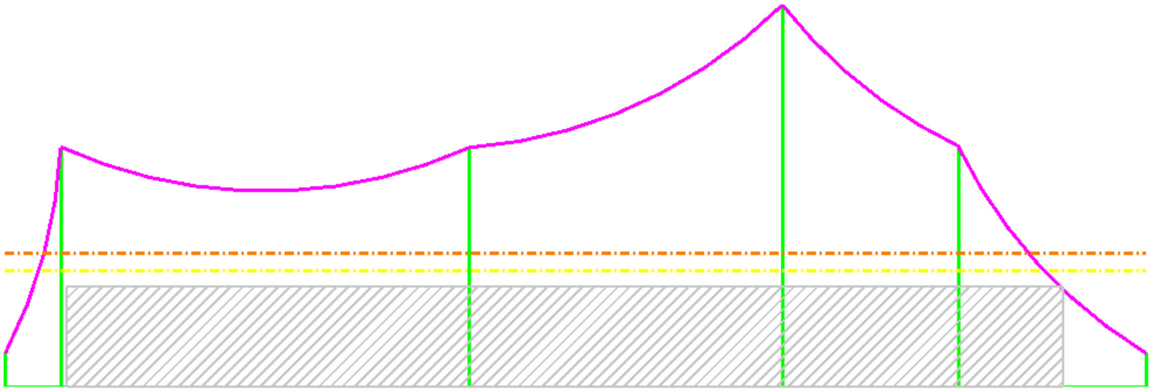


Figure 58: Section 'F' clearance

From the various cross sections taken of the Zone Substation site, it can be seen that there is adequate coverage over all of the major areas. From visual inspection of the 2D CAD model the only areas in which the rolling sphere touches is the last structure in each of the 22kV feeder bays.

Using the point cloud file it can be proven visually that the rolling sphere does indeed have clearance over the potentially problem areas seen in the right hand side of cross section 'D', 'E' and 'F'.

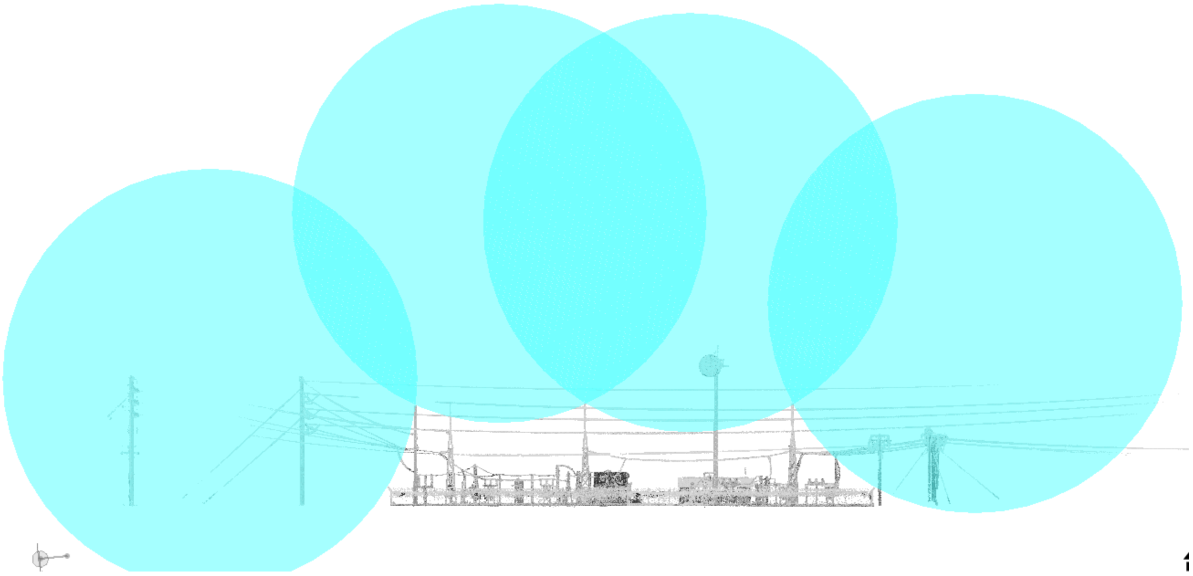


Figure 59: Section ‘E’ clearance shown on the point cloud file.

From this elevation view of the point cloud file the clearance of the sphere over the 22kV feeder bays can be seen, proving that the equipment will have adequate protection on the outgoing edge of all 22kV feeder bays.

6.9.2 Rolling Sphere Plan View Clearance Area

Once the clearance elevation models areas have been created using a CAD package, they are able to be transposed onto a plan view layout of the Substation. This involves determining the clearance area for a given height above ground (7.0m or 8.0m), this detail is able to be shown for each individual lightning mast and then merged together to create a visible clearance area provided by the Substation lightning masts.

Figure 60: Plan view clearance area shown on point cloud file.

The Substation plan view layout of the lightning design shows the extent of the protected area incorporating a defined height above the ground. For this particular site the lightning masts provide excellent protection for all of the existing electrical plant.

7 Conclusions

Due to the symmetrical construction of the 22kV area of this Substation the clearance problems which are seen on the 22kv No.1 main busbar section are in general reflected on the 22kv No.2 main busbar section for a similar type of feeder configuration.

For the purposes of this Dissertation all assessments on this area have been conducted on an individual feeder basis. The section symmetry can be seen in the following 22kV relationships:

- ‘Section 3’, feeder bay circuit breaker 12 and ‘section 8’ feeder bay circuit breaker 42.
- ‘Section 4’, feeder bay circuit breaker 22 and ‘section 7’ feeder bay circuit breaker 32.
- ‘Section 5’, transformer circuit breaker 2412 and ‘section 6’ transformer circuit breaker 2422.

‘Sections 3’, ‘4’ and ‘5’ make up the 22kV No.1 main busbar section and ‘sections 6’, ‘7’ and ‘8’ make up the 22kV No.2 main busbar section.

7.1 Section 1 – 132kV Feeder Bay Circuit Breaker 4422

The construction of this section of the Substation contains zero electrical safety clearance problems, the construction fully complies with the Australian Standard - (Standards Australia, 2008) [22] and Essential Energy standard - (Essential Energy, 2011) [3].

7.2 Section 2 – 66kV Feeder Bay Circuit Breaker 3412

This section of the Substation has been re-configured since its original construction, the majority of the construction still complies with Australian Standard - (Standards Australia, 2008) [22] and Essential Energy standard - (Essential Energy, 2011) [3].

The single safety clearance issue within this section is the line voltage transformer, due to age this piece of equipment has not been manufactured to comply with the current required phase to phase clearances in AS2067-2008 [22] for the required site B.I.L. This voltage transformer should be replaced to ensure the feeder bay complies with current construction standards.

7.3 Section 3 – 22kV Feeder Bay Circuit Breaker 12

This section is the first of the four 22kV feeder bays it has two construction arrangements relating to ground clearance and section safety clearance, which are non-compliant with the Australian Standards (Standards Australia, 2008) [22] and Essential Energy standards (Essential Energy, 2011) [3].

The ground clearance of the line surge arresters does not comply with current standards, the configuration has a level of risk which can however be managed by modification of the cable termination arrangement, mounted on the base of the surge arrester.

Current design standards would provide a minimum of 2500mm of clearance from the Top of Concrete (T.O.C) to ensure correct clearances are maintained.

With the existing bay configuration section safety clearances on either side of the dead tank circuit breaker are also non-compliant, further isolation would be required to enable maintenance to be conducted on the circuit breaker with the required safety clearances. This would mean isolating the 22kV No.1 main busbar section supplying the feeder bay, resulting in unwanted isolation of the adjacent circuit breaker 22 bay.

7.4 Section 4 – 22kV Feeder Bay Circuit Breaker 22

This section is the second of the four 22kV feeder bays, this bay has two construction arrangements relating to ground clearance and section safety clearance, which are non-compliant with the Australian Standards (Standards Australia, 2008) [22] and Essential Energy standards (Essential Energy, 2011) [3].

The ground clearance of the line surge arresters does not comply with current standards, the configuration has a level of risk which can be managed by modification of the cable termination arrangement, on the base of the surge arrester. Current design standards would provide a minimum of 2500mm of clearance from the Top of Concrete (T.O.C) to ensure correct clearances are maintained.

Due to the arrangement of this feeder bay using a live tank circuit breaker and current transformers this further reduces the section safety clearances below the values which are seen on feeder bays constructed with dead tank circuit breakers. This bay needs to be re-configured to comply with current standards.

To enable maintenance to be conducted on the circuit breaker and current transformers would require isolation of half of the 22kV busbar which is not an ideal situation as it creates unwanted risk.

7.5 Section 5 – 22kV Transformer Circuit Breaker 2412

This section is the first of the two 22kV transformer circuit breaker bays, it has several construction arrangements relating to, phase to earth clearance, ground clearance and section safety clearance, which are non-compliant with the Australian Standards (Standards Australia, 2008) [22] and Essential Energy standards (Essential Energy, 2011) [3].

The phase to earth clearance of the auxiliary voltage transformer does not comply to achieve the required B.I.L @ 22kV, this is due to the physical construction of the unit, and to comply with current standards this unit must be replaced.

The ground clearance of the auxiliary voltage transformer also does not comply, combined with the poor phase to earth clearances, this further reinforces the need to replace this unit.

Section safety clearances for both the auxiliary voltage transformer and bus voltage transformer cannot be achieved, without a large outage. The Isolation to work on these two pieces of equipment would mean switching off half of the 22kV main busbar No.1 section.

Section safety clearance for the transformer circuit breaker and current transformers cannot be achieved without switching off half of the 22kV main busbar, and the 66/22kV power transformer that supplies the circuit breaker. This bay should be re-configured to provide better operational flexibility and compliance with current standards.

7.6 Section 6 – 22kV Transformer Circuit Breaker 2422

This section is the second of the two 22kV transformer circuit breaker bays, it has several construction arrangements relating to, phase to earth clearance, ground clearance and section safety clearance, which are non-compliant with the Australian Standards (Standards Australia, 2008) [22] and Essential Energy standards (Essential Energy, 2011) [3].

The phase to earth clearance of the auxiliary voltage transformer does not comply to achieve the required B.I.L @ 22kV, this is due to the physical construction of the unit, and to comply with current standards this unit must be replaced. In addition the underground cable termination structure does not provide adequate phase to earth clearance on all phases of the cable terminations.

The ground clearance of the auxiliary voltage transformer also does not comply, combined with the poor phase to earth clearances, this further reinforces the need to replace this unit.

Section safety clearances for both the auxiliary voltage transformer and bus voltage transformer cannot be achieved without a large outage. The Isolation to work on these two pieces of equipment would mean switching off half of the 22kV main busbar No.2 section.

Section safety clearance for the transformer circuit breaker and current transformers cannot be achieved without switching off half of the 22kV main busbar (No.2 section), and the 132/22kV power transformer that supplies the circuit breaker. This bay should be re-configured to provide better operational flexibility and compliance with current standards.

Section safety clearances are also unable to be achieved for each of the 22kV busbar disconnectors due to their close physical distance from each other. Maintenance on either of these pieces of equipment would require a full outage of the 22kV area of the Substation. These disconnectors need to be re-positioned to comply with the required section safety clearances for maintenance purposes.

7.7 Section 7 – 22kV Feeder Bay Circuit Breaker 32

This section is the third of the four 22kV feeder bays, this bay has two construction arrangements relating to ground clearance and section safety clearance, which are non-compliant with the Australian Standards (Standards Australia, 2008) [22] and Essential Energy standards (Essential Energy, 2011) [3].

The ground clearance of the line surge arresters does not comply with current standards, the configuration has a level of risk which can be managed by modification of the cable termination arrangement, on the base of the surge arrester. Current design standards would provide a minimum of 2500mm of clearance from the Top of Concrete (T.O.C) to ensure correct clearances are maintained.

Due to the arrangement of this feeder bay using a live tank circuit breaker and current transformers this further reduces the section safety clearances below the values which are seen on feeder bays constructed with dead tank circuit breakers. This bay needs to be re-configured to comply with current standards.

To enable maintenance to be conducted on the circuit breaker and current transformers would require isolation of half of the 22kV busbar which is not an ideal situation as it creates unwanted risk.

7.8 Section 8 – 22kV Feeder Bay Circuit Breaker 42

This section is the last of the four 22kV feeder bays it has two construction arrangements relating to ground clearance and section safety clearance, which are non-compliant with the Australian Standards (Standards Australia, 2008) [22] and Essential Energy standards (Essential Energy, 2011) [3].

The ground clearance of the line surge arresters does not comply with current standards, the configuration has a level of risk which can however be managed by modification of the cable termination arrangement, mounted on the base of the surge arrester. Current design standards would provide a minimum of 2500mm of clearance from the Top of Concrete (T.O.C) to ensure correct clearances are maintained.

With the existing bay configuration section safety clearances on either side of the dead tank circuit breaker are also non compliant, further isolation would be required to enable maintenance to be conducted on the circuit breaker with the required safety clearances. This would mean isolating the 22kV main busbar No.2 section supplying the feeder bay, resulting in unwanted isolation of the adjacent circuit breaker 32 bay.

7.9 Zone Substation Lightning Protection

The design and installation of the lightning protection at this site provides excellent lightning coverage over the electrical equipment for the entire site at the specified ground clearances required by Essential Energy's Substation design document CEOP 8032 [5].

This document also specifies that "All equipment inside the Substation fence, including buildings, is to be protected by lightning masts". As can be seen in section 6.9 the Substation control building does not have the required coverage and additional masts would be required to ensure the lightning protection is extended to provide cover to the control building.

Further lightning design will be required for any augmentation work detailed within the options report for this site to ensure that all newly installed equipment is covered. As part of any augmentation work the lightning protection should be upgraded to provide coverage over the control building and comply with Essential Energy Substation design guidelines [5].

7.10 Conclusion Summary

From a technical perspective, the point cloud file and wireframe model which have been produced as the basis of this Dissertation have been successfully used to analyse and investigate Nevertire Zone Substation in regards to:-

- Phase to earth clearances.
- Ground clearances.
- Section safety clearances.
- Work safety clearances.
- Lightning protection.

As part of this analysis, several areas which do not comply with the current standards of Essential Energy have been discovered. These areas of non-compliance have been recorded and recommendations given as to how they can be rectified to allow this Substation to comply with the required B.I.L and effectively the Essential Energy and Australian standards.

From a practical perspective, it has been shown that existing Zone Substations can be effectively modelled using a TLS to provide accurate desktop models which could be further utilised for the purpose of detailed Substation design.

In addition to the point cloud file and wireframe model produced as part of this Dissertation Leica TruView has been investigated and results indicate that it could be used as a Substation design tool moving into the future.

Further work on 3D modelling within Essential Energy would be required to enable the wireframe model produced in this Dissertation to be included as part of design drawings, in particular general arrangement drawings.

Use of TLS for the purpose of modelling existing Zone Substation sites is a completely new initiative, and new technology which has not been used for Substation modelling across the business prior to this Dissertation.

The findings within this Dissertation will be presented to Essential Energy upon final completion of the document to determine whether this method can be further utilised by the organisation.

It should also be noted that, as part of the development process of this dissertation, the Network Development group within Essential Energy has recently made use of TLS technology for preliminary project work.

The use of this technology comes as a direct result of this dissertation, and the technology has now been used at an additional two Essential Energy sites for the purpose of preliminary design and estimation.

8 Cost Benefit Analysis

This analysis relates to the use of conventional survey to capture data from existing Zone Substation sites, versus the use of Terrestrial Laser Scanning.

The approximate cost of each method when used at Nevertire Zone Substation, and the value which each method provides to Essential Energy.

To enable a fair comparison to be made, approximate costs to survey Nevertire Zone Substation have been used from a single supplier, this will eliminate the possibility of differing fixed cost items which may affect the result and outcome of the analysis.

8.1 Conventional Survey Costs

Items, prices and quantities required specific to Nevertire are as follows:

8.1.1 Travel

Travel costs include, fuel, labour and vehicle maintenance, charged at $2.35/km.

8.1.2 Field Work

This cost includes, labour for two staff members, all onsite equipment, site specific requirements as needed to complete the task, charged at $235/hour.

8.1.3 Office Work

All costs related to producing a file which can be presented to the client and used straight away without further drafting, presented electronically via email, charged at $185/hour.

Item	Travel	Field Work	Office Work	Project Cost
Price	$2.35/km	$235/hour	$185/hour	
Quantity	200	8	4	
Total	$470	$1,880	$740	$3,090

Table 12: Conventional survey total cost.

8.2 Conventional Survey Benefits

Data captured using this method will be limited to the extent at which Essential Energy requests, the following items are standard detail items which would be captured as part of a typical site survey, they also reflect what was completed at Nevertire Zone Substation.

- Individual footing dimensions.
- Individual footing reference levels (R.L’s)
- Perimeter fence.
- Ground level services.
- Control building outer dimensions only.
- The First 22kV feeder pole outside Zone the Substation fence (all feeders).
- Surface contours.
- Transformer blast/bund walls.

8.3 TLS Survey Costs

As with “conventional” the items, prices, quantities and costs below are specific to Nevertire Zone Substation as follows:

8.3.1 Travel

Travel costs include, fuel, labour and vehicle maintenance, no difference in requirements, compared to conventional costs and charged at $2.35/km.

8.3.2 Placing Control

This is specific to laser scanning and is part of the field work required prior to operation of the TLS, charged the same as conventional field work at $235/hour.

8.3.3 Scanning

This includes setup and shut down of the TLS and all scanning done with the machine after setup, charged at $450/hour.

8.3.4 Office Work

These cost relate to the computer work required to produce a point cloud file and “TruView” file, this work is charged at $185/hour.

8.3.5 Modelling

This is the process of taking the point cloud file and turning it into a more useable CAD model done by a specialist wireframe modelling company, charged at $22/hour.

Item	Travel	Placing Control	Scanning	Office Work	Modelling	Project Cost
Price	$2.35/km	$235/hour	$450/hour	$185/hour	$22/hour	
Quantity	200	1	2	8	120	
Total	$470	$235	$900	$1,480	$2,640	$5,725

Table 13: TLS survey total cost.

8.4 TLS Survey Benefits

Data captured using this method will typically be well above what is required and can be filtered down afterwards, the area captured at Nevertire Zone Substation extended well outside the Substation fence.

This meant that the 132kV, 66kV and 22kV overhead power lines leaving the Substation were all scanned and included in the file, the immediate and additional benefits captured using this method are listed below.

- All footings.
- All Steelwork.
- All electrical plant and equipment.
- All buildings.
- All conductors, busbars and fittings.
- All structures.
- All fences.
- All Substation services.

- Leica TruView.
- Full 3D point cloud file.
- Full 3D wire frame model.

8.5 Placing Value on Benefits

Estimating or placing a value on the benefit provided by each method of data capture is necessary to provide justification of the initial financial outlay required.

The first and simplest method of highlighting the value provided by each method is to calculate the cost saving provided by avoiding repeat site visits to capture information or measurements which were missed. The cost of subsequent site visits can be calculated using the base costs for each survey method.

8.5.1 Site Visit Cost

Using a base cost of $470.00 for return trip from Dubbo to Nevertire, this amount will be the same regardless of the amount of time spent at Nevertire Zone Substation gathering data.

Item	Field Work					
Price	$235/hour					
Hours	1	2	3	4	5	6
Cost	$235	$470	$705	$940	$1,175	$1,410
Travel	$470	$470	$470	$470	$470	$470
Total	$705	$940	$1,175	$1,410	$1,645	$1,880

Table 14: Site visit cost.

As can be seen in table 17 spending a full day (6 hours plus travel) in the field capturing additional data which is either not captured initially or in addition to what was captured can be assigned an approximate figure of $1880.

This added cost would apply to conventional survey for everything except footings and as seen in section 6 the accuracy captured by conventional surveying may not be adequate for detail design and only used for placement. TLS survey would avoid this added cost in most circumstances by providing a very accurate 3D wireframe model of the entire Substation.

8.5.2 Travelling to Site

For sites which are in close proximity to an Essential Energy design office this may not be a huge problem, however Essential Energy covers an extremely large regional area and often overnight accommodation may be required for the purpose of site visits to collect data.

Using the same supplier rates accommodation is charged at $290/day (2 staff).

Item	Travel Distance return					
Price	$2.35/km					
km's	100	200	300	400	500	600
Cost	$235	$470	$705	$940	$1,175	$1,410
Overnight	$290	$290	$290	$290	$290	$290
Total	$525	$760	$995	$1,230	$1,465	$1,700

Table 15: Travel and accommodation cost.

It can be seen from table 18 that for sites greater than a 500 km's return trip accommodation is more than likely required due to the amount of hours of work available in a single day. Additional site visits like this can be quite costly as a minimum cost is $1465.

Essential Energy has Substation designers working out of three offices:

- Port Macquarie.
- Orange.
- Dubbo.

Sharing work across these offices still requires designers to travel large distances to gather field information. Utilising TLS can minimise the design project costs by capturing the full Zone Substation detail in a single day and eliminating subsequent visits.

This also eliminates the hazard of employees travelling longer distances and working longer hours which can lead to fatigue and allows designers more office time to design leading to improved productivity.

8.5.3 Safety in Design

As shown in section 7, TLS allows accurate measurements of live portions within Substations to be taken using a 3D model for the purpose of determining safety clearances, this provides an efficient design tool for a Substation designer which follows Essential Energy's No.1 priority of safety.

There is no monetary figure that can be placed on the lives of the employees and with the use of onsite laser scanning the risk can be engineered out of the equation, hence the value is priceless.

8.6 Practical Applications for TLS

8.6.1 Scenario 1

A civil contractor has been engaged to work in an existing Essential Energy Zone Substation, the project has been designed internally by Substation designers. During the civil construction phase of this project a major design error has been found in the issued construction drawings.

It has been discovered that inaccuracies in the existing site drawings used for the design have led to several new equipment footings being incorrectly formed up and poured. The civil contractor has highlighted the error to Essential Energy on further inspection of the construction drawings.

An error such as the one described results in additional costs to Essential Energy to rectify the problem, the additional costs may include:

- Reproduction of construction drawings priced at $1000 per drawing.
- Design labour cost to rectify design drawings.
- Contractor stand down time.
- Removal of incorrect footings.
- Pouring of footings in the correct position.
- Project scheduling.
- Possible impact on additional contractors.

Major design errors such as the one described have an occurrence of 1 in every 10 to 15 projects based on historical data provided by Essential Energy's Network Development group. This type of error leads to significant additional costs being put onto a project.

With the use of TLS at existing sites, the flow on effect from old inaccurate drawings can be eliminated, avoiding the unwanted internal cost of re-designing projects and the external cost (stand down) of contractors on site unable to proceed.

8.6.2 Scenario 2

A Zone Substation refurbishment project is being conducted at a large 132kV Zone Substation, the civil component of the work is being completed by a contractor but internal staff members are also at site assisting the civil contractor and completing the primary and secondary electrical component of the project.

A new voltage transformer footing is required to be formed up as part of augmentation of an existing 132kV feeder bay. The drawing places the footing overlapping a portion of an existing brick trench system which is not shown on the overall footing layout drawing or any general arrangement drawings.

As a result a Request for Information (RFI) needs to be raised and issued to the Substation designer to provide advice on what to do. This is classified as a minor design error which results in delays and added costs such as:

- On site delays to stop and complete an RFI document.
- Design time to provide an answer to the RFI.
- Contractors may be forced to stop work and wait for direction.
- Internal staff may be impacted.
- Minor delays to project schedule.

Minor design errors such as this have an occurrence rate of 8-9 in every project, based on historical data provided by Essential Energy's Network Development group. With many of these occurring due to incorrect existing drawings or sometimes inaccurate existing survey data.

Use of TLS technology would prevent some of these incidents occurring, in particular errors involving site specific information which is not shown on any existing drawings but could have the potential to impact on construction times and cost.

8.7 Cost Benefit Conclusion

The typical scenarios provided clearly show the huge benefits of how having accurate information can prevent design errors impacting within a project construction phase.

Also shown is how quickly design costs can add up on a project from additional site visits required for gathering data due to poor quality drawings.

Add to this the safety improvements and ease of obtaining data by utilising TLS technology and it becomes clear that the many benefits of terrestrial laser scanning has huge potential for use within Essential Energy and the cost are clearly justified by the added benefits.

9 Further Work

9.1 Presentation to Essential Energy

The findings of this Dissertation are to be presented to Essential Energy to highlight the many benefits that could be provided within the various work groups in the business.

Also the many non-complying areas which were found within the Nevertire Zone Substation which need rectification work are to be presented to Essential Energy in support of the Nevertire Zone Substation options report.

Obtaining management support is the first major hurdle that needs to be achieved to enable any further use of modelling with TLS to proceed.

9.2 3D Modelling

The possibility of conducting a trial of TLS modelling and 3D drafting techniques for Substation general arrangement drawings, this would involve getting drafters involved and internal training may need to be provided, this hinges on Essential Energy management and their verdict on the contents of this Dissertation.

9.3 LiDAR Technology

Investigation of the use of LiDAR technology within Zone Substations may be worthwhile, and also the possibility of using the existing contracts which are currently in place to provide Zone Substation point cloud data for comparison against the data provided by TLS.

Further to this the possibility of geo referencing 3D models which could include LiDAR and TLS data.

9.4 Wire Frame Modelling

With management approval I believe it would be beneficial to investigate the possibility of modelling further existing sites to be able to provide better quality information in regards to design project drawings and estimations.

Project development and estimation is an area which TLS technologies could provide significant benefit to provide cost savings to the organisation in a time where minimising costs are of an extremely high priority.

9.5 As Time Permits

Investigation into these items of the project specification may prove beneficial from a Substation design perspective. Due to time constraints they were not able to be included within this Dissertation.

Essential Energy may allow this additional work to be included as part of further investigation on the use of TLS in existing Zone Substation sites.

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Appendix A (Project Specification)

University Of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/ ENG4112 RESEARCH PROJECT SPECIFICATION.

AUTHOR:	Darrin Edwards	Student No. 0061006063
TOPIC:	Terrestrial laser scanning for 3D zone substation modelling and safety clearances.	
SUPERVISOR:	Mark Norman.	
SPONSORSHIP:	Essential Energy.	

PROJECT AIMS:

1. To produce a 3D computer model of an existing substation that can be utilised for substation design purposes.
2. Using a 3D substation model examine the existing ground and phase to phase safety clearances against the current Essential Energy and Australian standards.
3. Using a 3D substation model examine the lightning protection of an existing site and compare the results against the current Essential Energy and Australian standards.

PROGRAMME:

1. Travel to site and using a high definition short range TLS, obtain scan data of an existing substation, then use this data and software to produce a 3D CAD model, which will be a point cloud type image.
2. Using the point cloud data from file, create a rendered image of the substation using a self-created surface library which will be created within software.
3. Research current standards for ground, phase and section safety clearances for comparison against actual as built collected data, this will include a review of the current Essential Energy and Australian standards.
4. Research current standards for lightning protection for comparison against actual as built collected data, this will include a review of the current Essential Energy and Australian standards.
5. Create a comparison of conventional survey methods against TLS method and actual on site measured data (where possible), provide a cost analysis of the TLS data capture method against conventional survey data capture.
6. Examine the existing site safety clearances and lightning protection, by utilising the data captured from the 3D scan.
7. Make a determination on the construction standard of the existing substation site, and whether it meets current industry standards.

As Time Permits:

1. Examine the current values of safety clearance and phase distance and determine whether they are indeed appropriate values.
2. Examine the current design standards for lightning protection and determine whether they provide adequate protection and if they are over engineered.

Appendix B (AS 2067 Electrical Clearances)

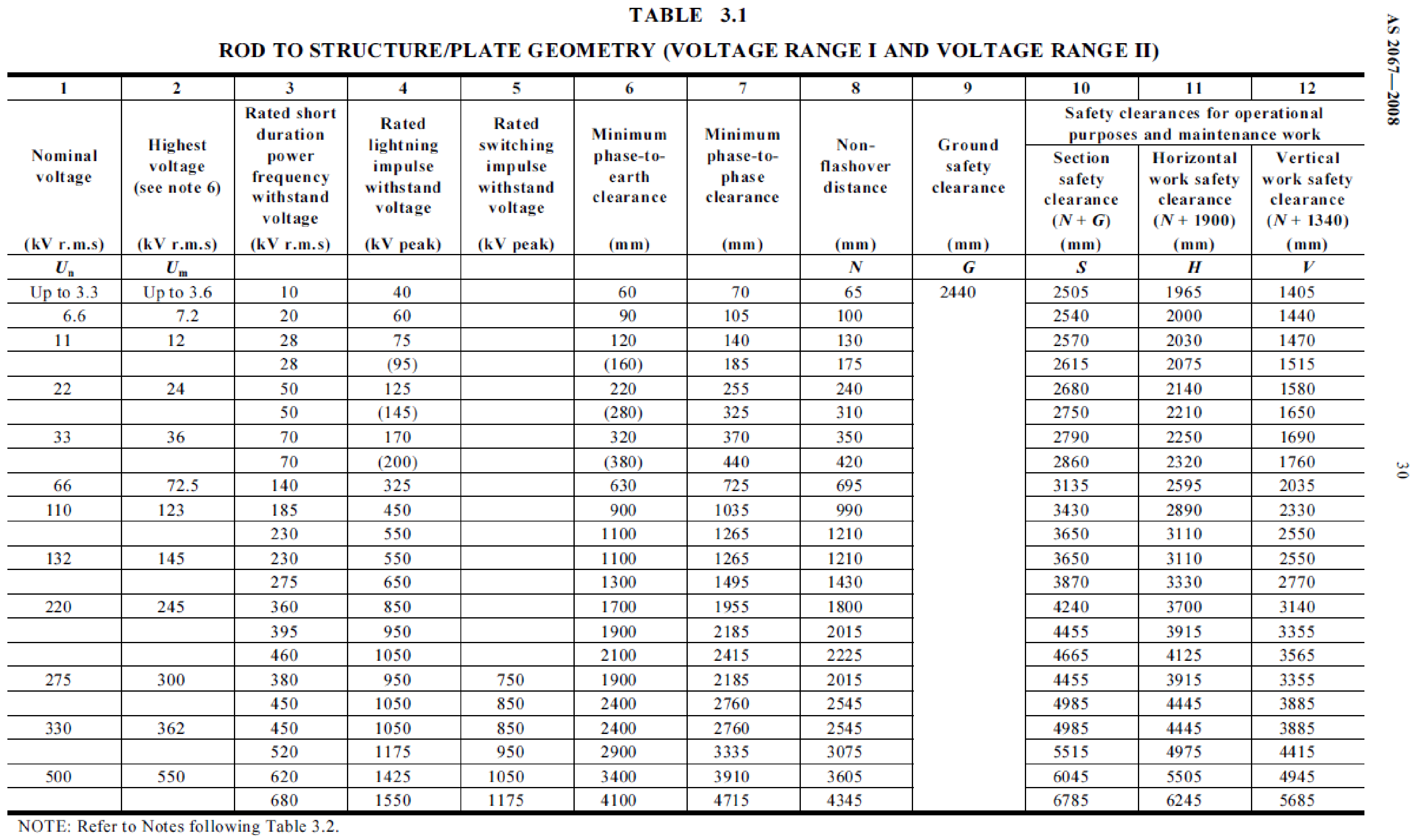


TABLE 3.1

ROD TO STRUCTURE/PLATE GEOMETRY (VOLTAGE RANGE I AND VOLTAGE RANGE II)

1	2	3	4	5	6	7	8	9	10	11	12
									Safety clearances for operational purposes and maintenance work		
Nominal voltage (kV r.m.s)	Highest voltage (see note 6) (kV r.m.s)	Rated short duration power frequency withstand voltage (kV r.m.s)	Rated lightning impulse withstand voltage (kV peak)	Rated switching impulse withstand voltage (kV peak)	Minimum phase-to-earth clearance (mm)	Minimum phase-to-phase clearance (mm)	Non-flashover distance (mm)	Ground safety clearance (mm)	Section safety clearance ($N + G$) (mm)	Horizontal work safety clearance (N + 1900) (mm)	Vertical work safety clearance (N + 1340) (mm)
U_n	U_m						N	G	S	H	V
Up to 3.3	Up to 3.6	10	40		60	70	65	2440	2505	1965	1405
6.6	7.2	20	60		90	105	100		2540	2000	1440
11	12	28	75		120	140	130		2570	2030	1470
		28	(95)		(160)	185	175		2615	2075	1515
22	24	50	125		220	255	240		2680	2140	1580
		50	(145)		(280)	325	310		2750	2210	1650
33	36	70	170		320	370	350		2790	2250	1690
		70	(200)		(380)	440	420		2860	2320	1760
66	72.5	140	325		630	725	695		3135	2595	2035
110	123	185	450		900	1035	990		3430	2890	2330
		230	550		1100	1265	1210		3650	3110	2550
132	145	230	550		1100	1265	1210		3650	3110	2550
		275	650		1300	1495	1430		3870	3330	2770
220	245	360	850		1700	1955	1800		4240	3700	3140
		395	950		1900	2185	2015		4455	3915	3355
		460	1050		2100	2415	2225		4665	4125	3565
275	300	380	950	750	1900	2185	2015		4455	3915	3355
		450	1050	850	2400	2760	2545		4985	4445	3885
330	362	450	1050	850	2400	2760	2545		4985	4445	3885
		520	1175	950	2900	3335	3075		5515	4975	4415
500	550	620	1425	1050	3400	3910	3605		6045	5505	4945
		680	1550	1175	4100	4715	4345		6785	6245	5685

NOTE: Refer to Notes following Table 3.2.

Appendix C (IEEE Electrical Clearances)

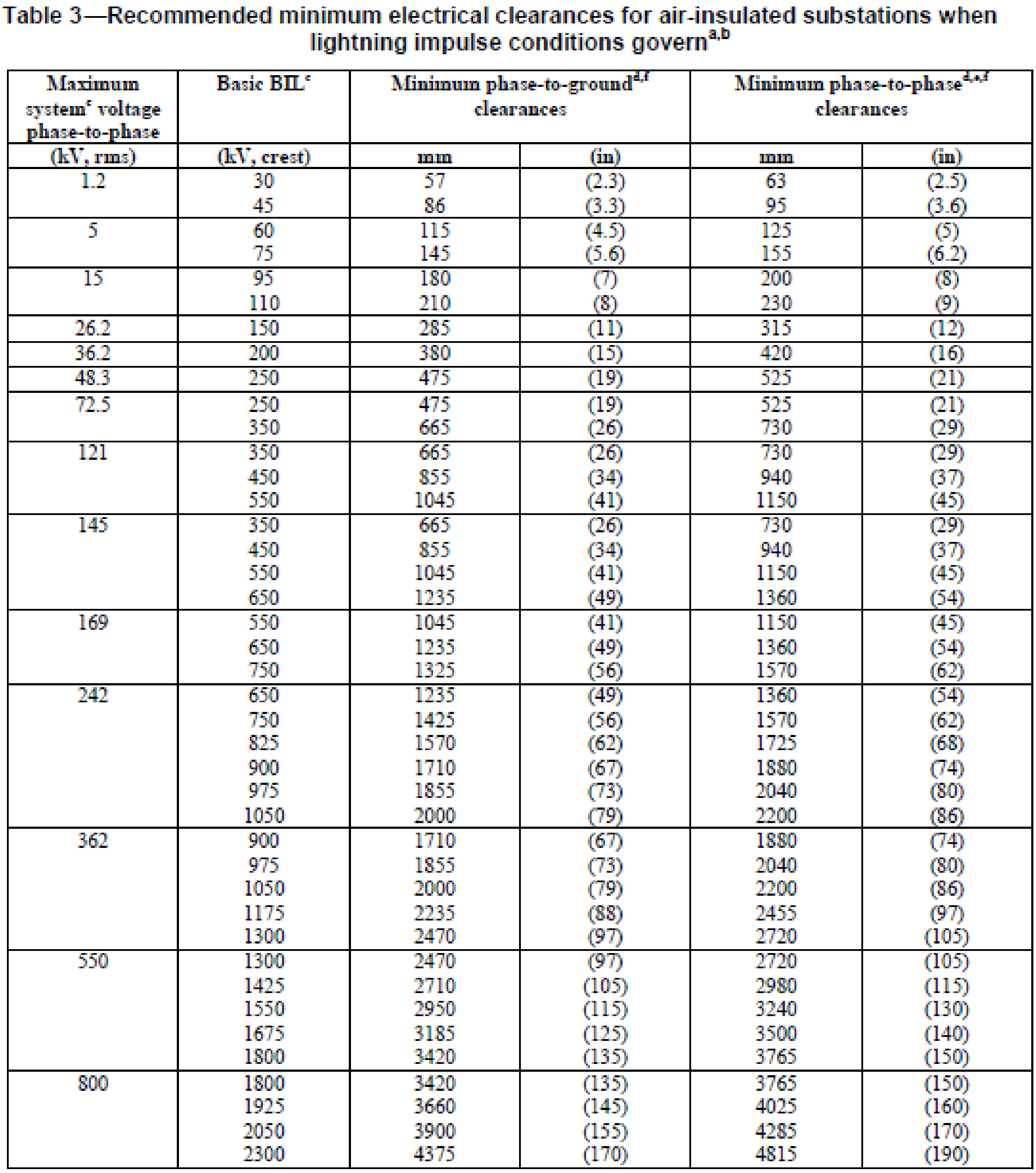
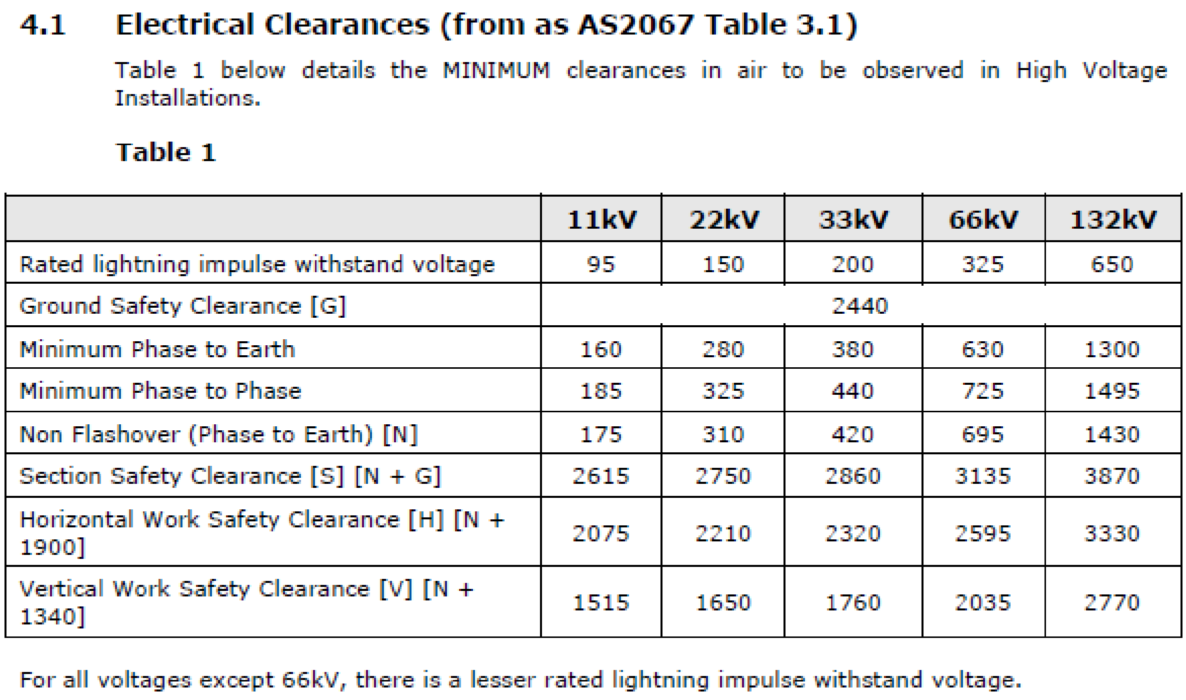


Table 3—Recommended minimum electrical clearances for air-insulated substations when lightning impulse conditions govern[a,b]

Maximum system[c] voltage phase-to-phase	Basic BIL[c]	Minimum phase-to-ground[d,f] clearances		Minimum phase-to-phase[d,e,f] clearances	
(kV, rms)	(kV, crest)	mm	(in)	mm	(in)
1.2	30	57	(2.3)	63	(2.5)
	45	86	(3.3)	95	(3.6)
5	60	115	(4.5)	125	(5)
	75	145	(5.6)	155	(6.2)
15	95	180	(7)	200	(8)
	110	210	(8)	230	(9)
26.2	150	285	(11)	315	(12)
36.2	200	380	(15)	420	(16)
48.3	250	475	(19)	525	(21)
72.5	250	475	(19)	525	(21)
	350	665	(26)	730	(29)
121	350	665	(26)	730	(29)
	450	855	(34)	940	(37)
	550	1045	(41)	1150	(45)
145	350	665	(26)	730	(29)
	450	855	(34)	940	(37)
	550	1045	(41)	1150	(45)
	650	1235	(49)	1360	(54)
169	550	1045	(41)	1150	(45)
	650	1235	(49)	1360	(54)
	750	1325	(56)	1570	(62)
242	650	1235	(49)	1360	(54)
	750	1425	(56)	1570	(62)
	825	1570	(62)	1725	(68)
	900	1710	(67)	1880	(74)
	975	1855	(73)	2040	(80)
	1050	2000	(79)	2200	(86)
362	900	1710	(67)	1880	(74)
	975	1855	(73)	2040	(80)
	1050	2000	(79)	2200	(86)
	1175	2235	(88)	2455	(97)
	1300	2470	(97)	2720	(105)
550	1300	2470	(97)	2720	(105)
	1425	2710	(105)	2980	(115)
	1550	2950	(115)	3240	(130)
	1675	3185	(125)	3500	(140)
	1800	3420	(135)	3765	(150)
800	1800	3420	(135)	3765	(150)
	1925	3660	(145)	4025	(160)
	2050	3900	(155)	4285	(170)
	2300	4375	(170)	4815	(190)

Appendix D (EE Electrical Clearances)



4.1 Electrical Clearances (from as AS2067 Table 3.1)

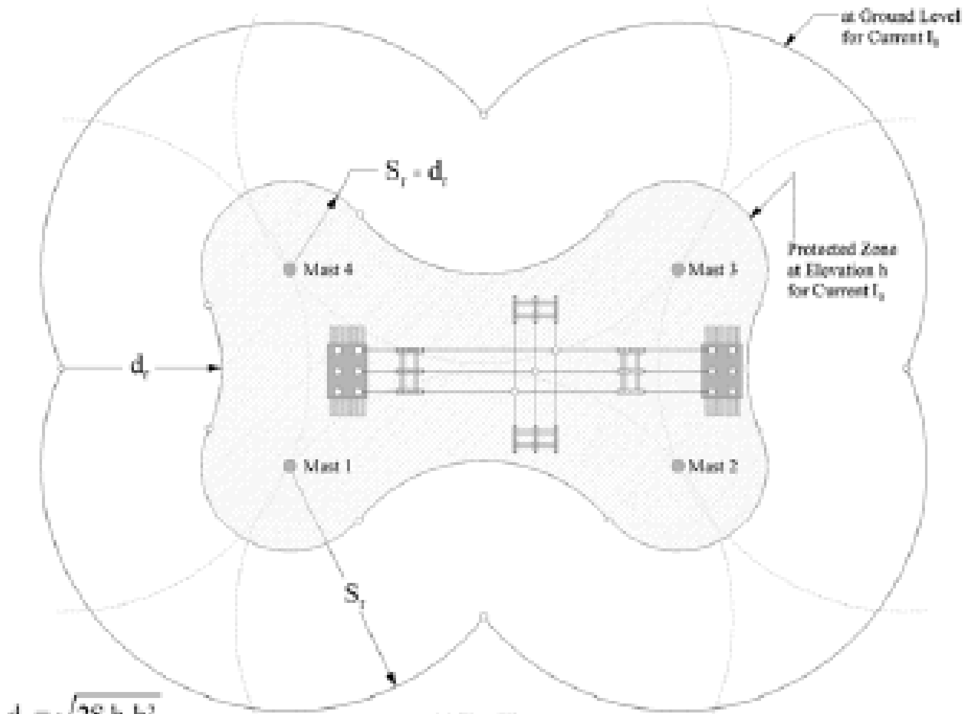
Table 1 below details the MINIMUM clearances in air to be observed in High Voltage Installations.

Table 1

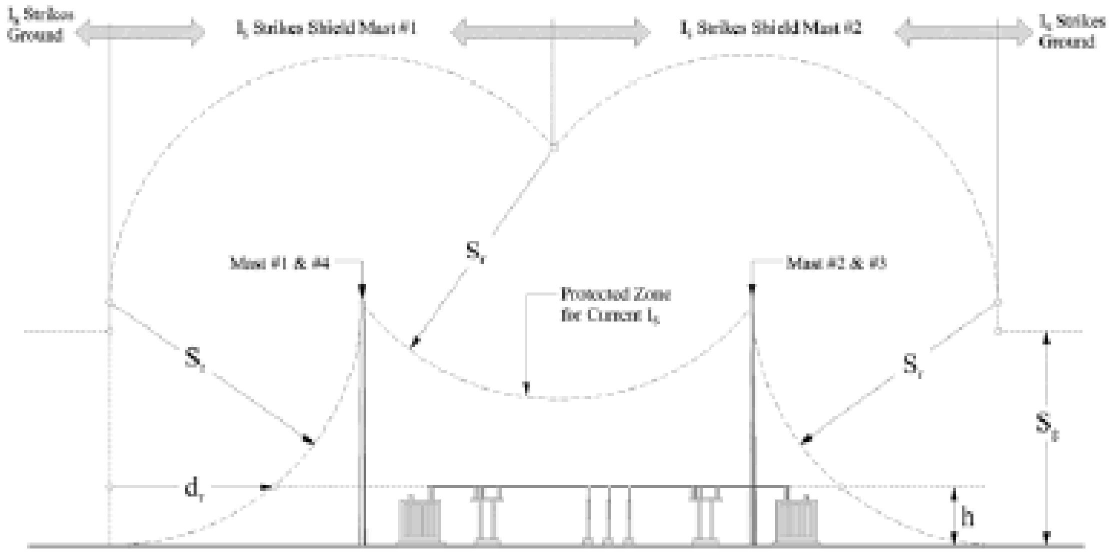
	11kV	22kV	33kV	66kV	132kV
Rated lightning impulse withstand voltage	95	150	200	325	650
Ground Safety Clearance [G]	2440				
Minimum Phase to Earth	160	280	380	630	1300
Minimum Phase to Phase	185	325	440	725	1495
Non Flashover (Phase to Earth) [N]	175	310	420	695	1430
Section Safety Clearance [S] [N + G]	2615	2750	2860	3135	3870
Horizontal Work Safety Clearance [H] [N + 1900]	2075	2210	2320	2595	3330
Vertical Work Safety Clearance [V] [N + 1340]	1515	1650	1760	2035	2770

For all voltages except 66kV, there is a lesser rated lightning impulse withstand voltage.

Appendix E (IEEE Lightning Protection)



(a) Plan View

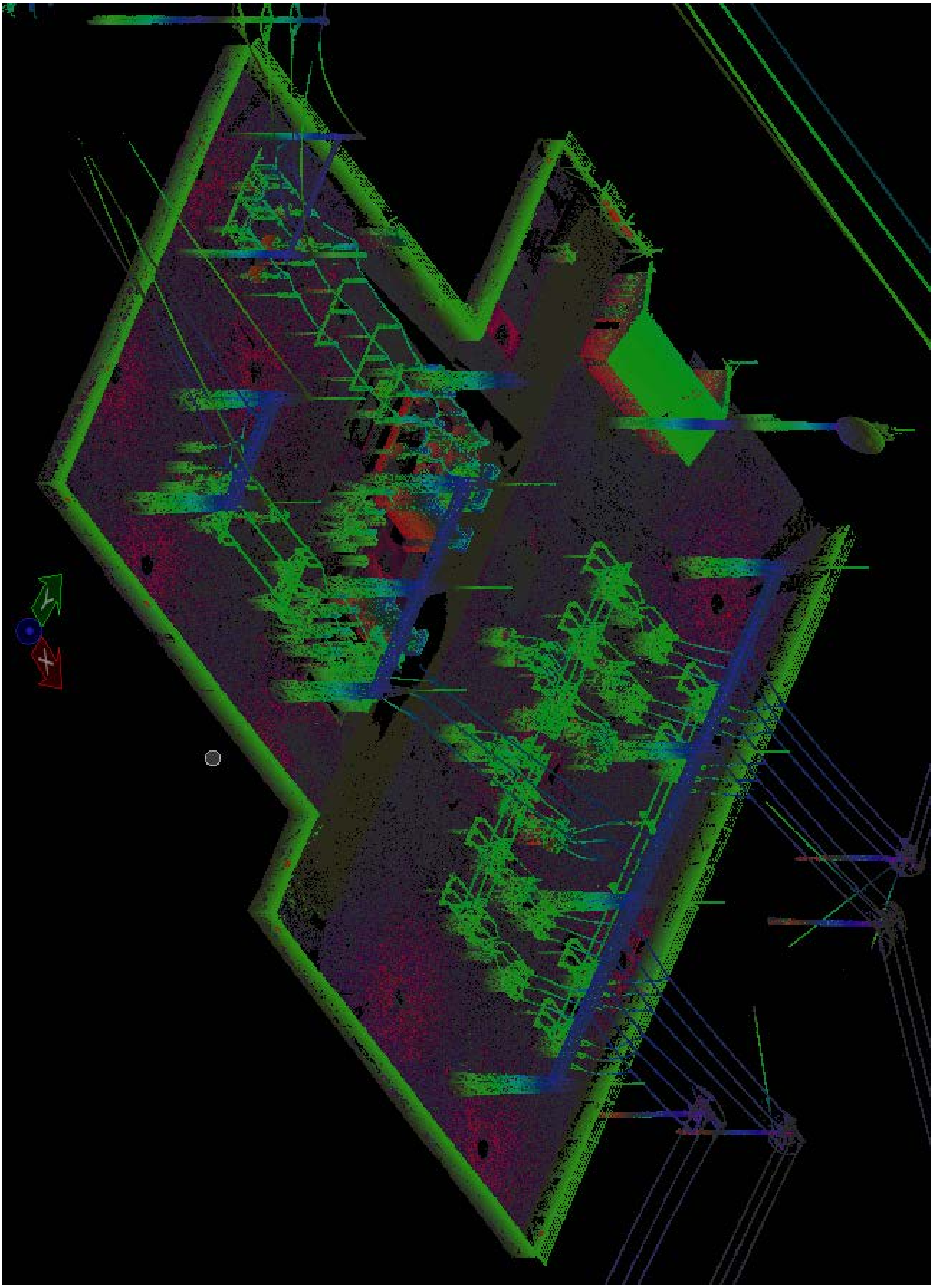


(b) Elevation View

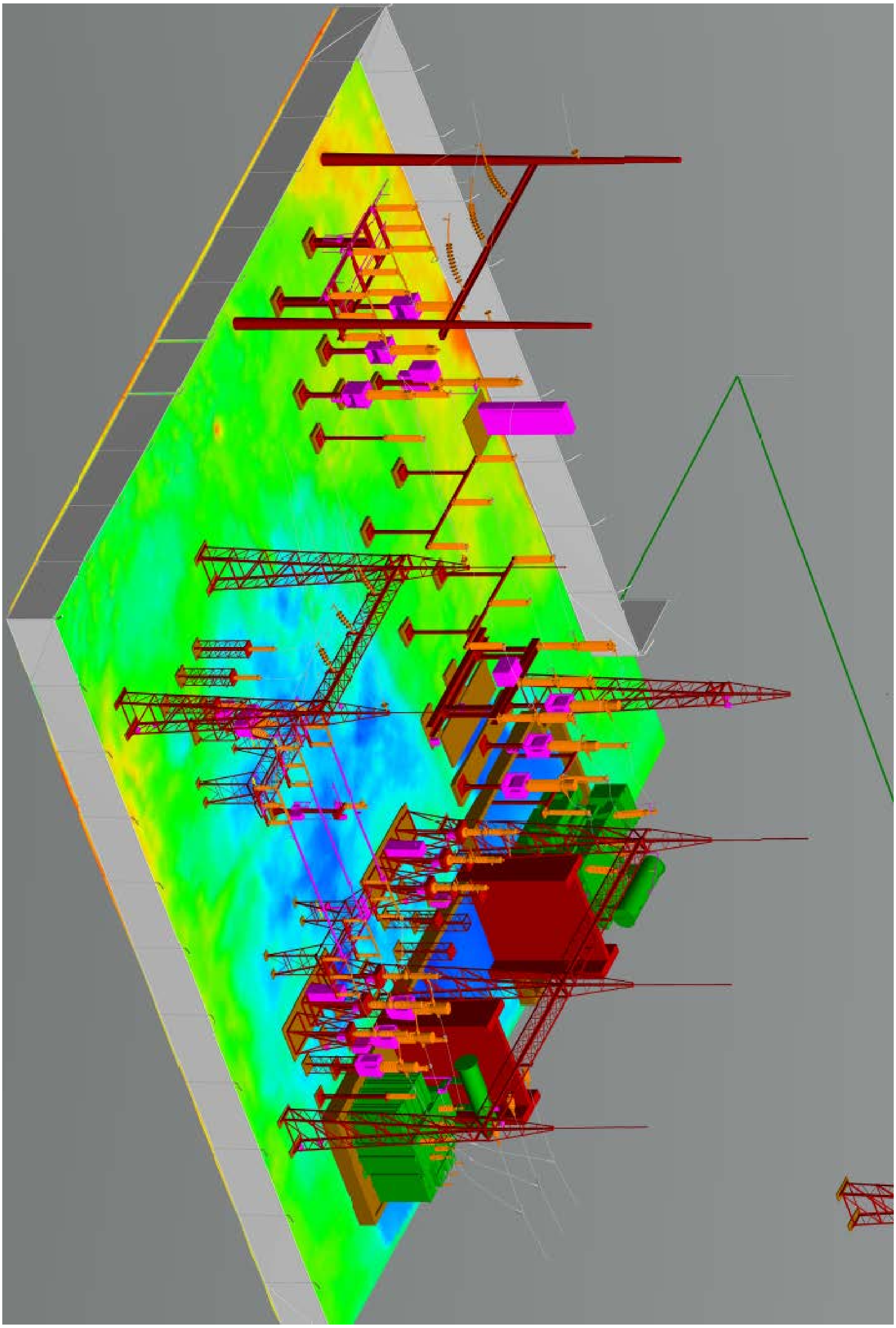
Figure 28 —Multiple shield mast protection for stroke current I_S

Appendix F (Nevertire Aerial Photo)

Appendix G (Nevertire Point Cloud File)

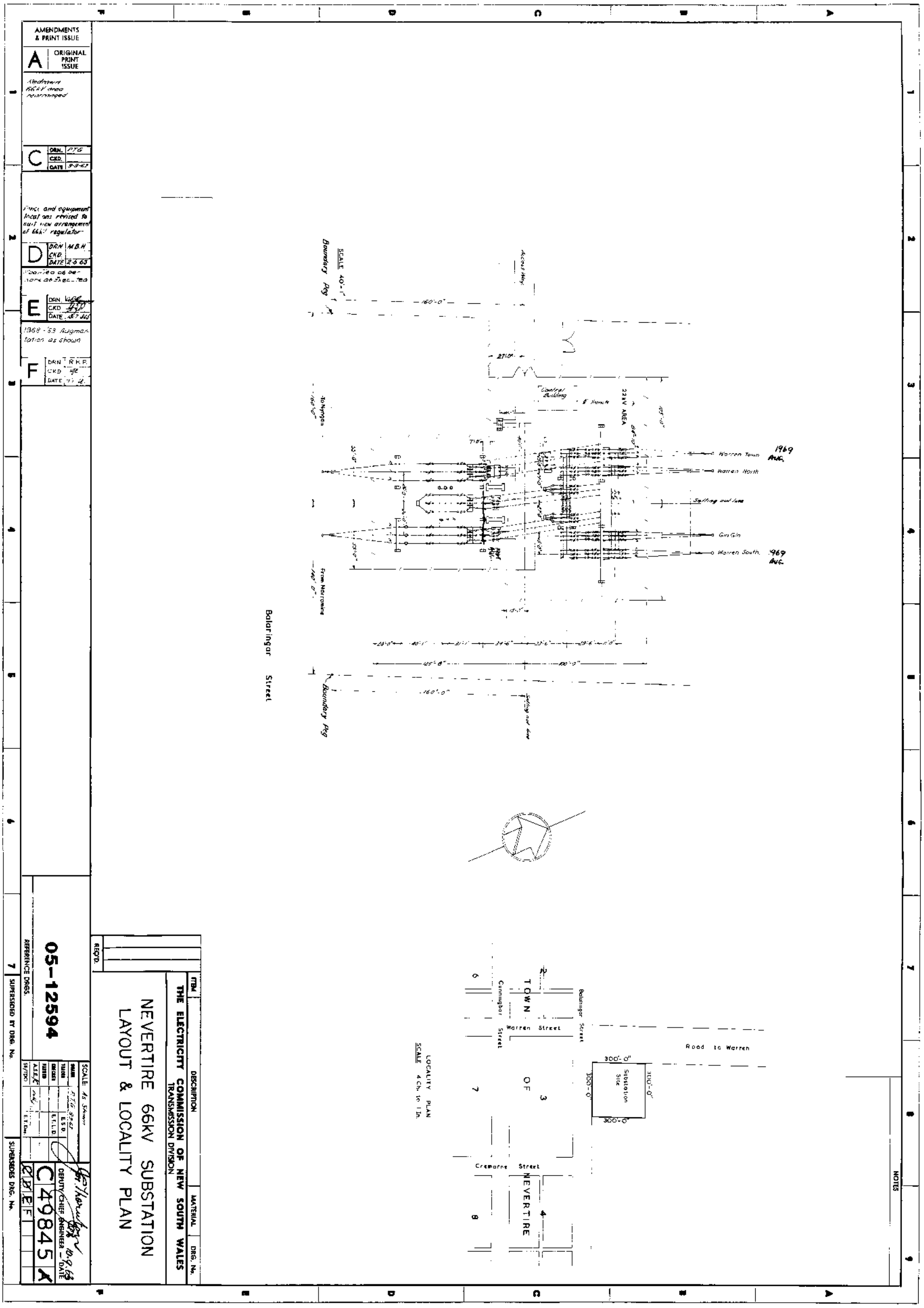


Appendix H (Nevertire Wire Frame Model)

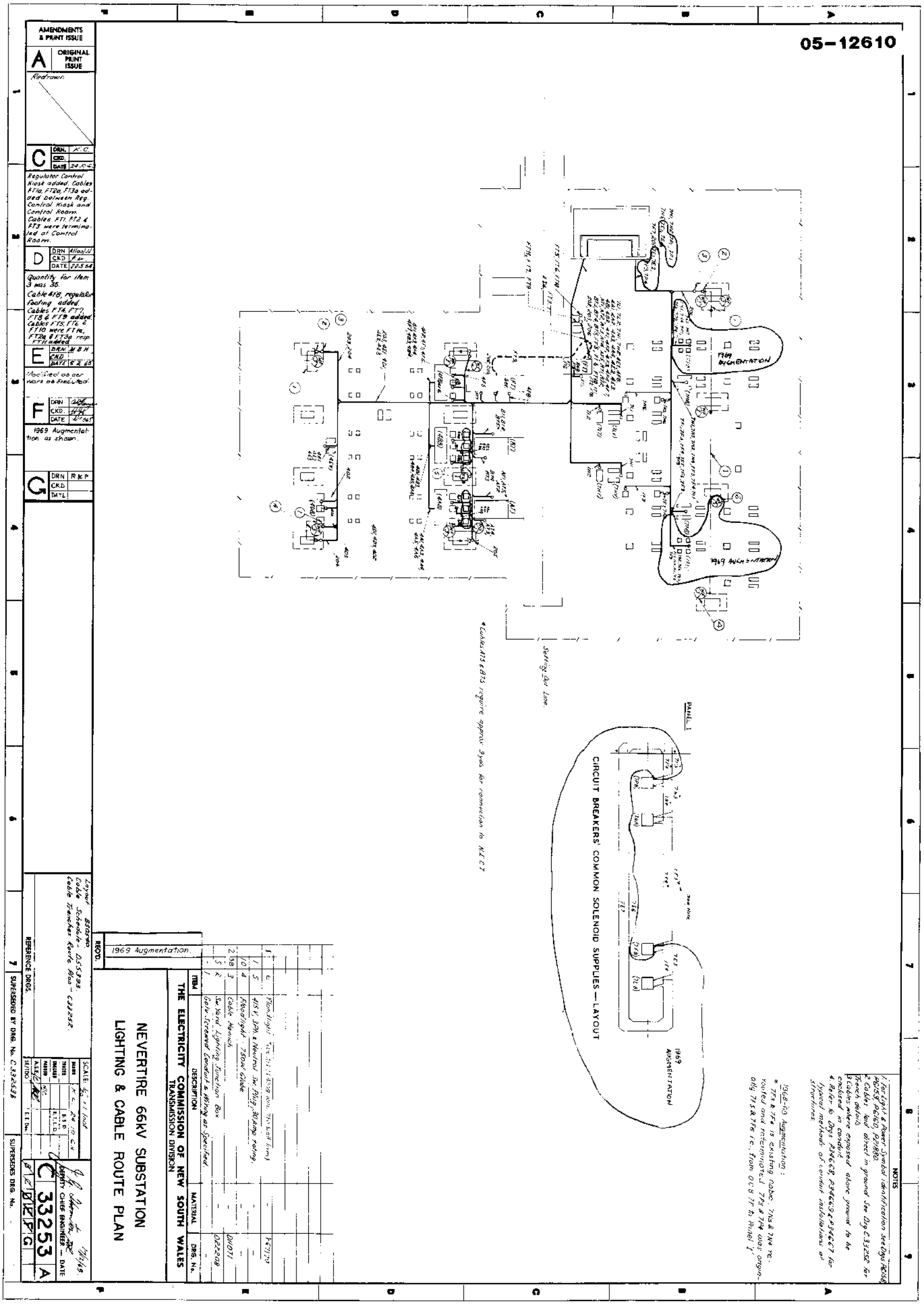


Appendix I (Nevertire Leica TruView)

Appendix J (Nevertire Existing Layout Plan)



Appendix K (Nevertire Existing Cable Route Plan)



Appendix L (Onsite Accuracy Measurements)

Actual onsite measurement taken 4/7/2014	Left	Right	Front	Back	Overall		Total
Item 1 - 132kV Line Disconnector							
Left concrete pad	797.00	796.50	800.00	798.00			3191.50
Left Steel base plate	448.50	449.50	450.00	448.00			
Left steel column	252.00	252.00	253.50	253.50			
Right concrete pad	799.00	799.00	798.50	798.00			3194.50
Right steel base plate	450.00	450.00	449.00	448.50			
Right steel column	254.00	253.00	254.50	253.50			
outside to outside (L-R)					4026.00		
Item 2 - 132kV Line Voltage Transformers							
Left concrete pad	799.00	802.00	801.00	797.00			3199.00
Left Steel base plate	499.00	499.50	497.00	497.50			
Left steel column	123.00	123.00	123.00	123.00			
Centre concrete pad	799.00	795.00	797.00	800.00			3191.00
Centre steel base plate	500.50	500.00	501.00	500.00			
Centre steel column	125.00	125.00	124.00	125.00			
Right concrete pad	798.50	797.00	799.00	797.50			3192.00
Right steel base plate	498.50	498.00	499.00	500.00			
Right steel column	124.00	124.00	124.00	125.00			
outside to outside (L-R)					5588.00		
Item 3 - 132kV white phase busbar support							
Concrete pad	801.00	799.00	800.00	800.00			3200.00
Item 4 - 132kV busbar support							
Right steel base plate	452.50	450.00	448.00	450.00			
Item 5 - 132kV busbar support							
Left steel column	98.00	99.00	98.00	98.00			
Item 6 - 132kV circuit breaker control cabinet							
Plan view	633.00	640.00	810.00	806.00			
Item 7 - 66kV Gantry @ brace height (75mm EA posts)							
Left column outer dimensions	1358.00	1358.00	605.00	605.00			
Item 8 - 66kV Surge Arresters (50mm EA posts)							
Left support column outer dimensions	458.00	450.00	444.00	450.00			
Item 9 - Voltage Transformer cubicle							
Back of cubicle dimensions	655.00	655.00	628.00	628.00			
Item 10a - Disconnector sign dimensions	460.00		175.00				
Item 10b - Earth switch sign dimensions	459.00		175.00				
Item 10c - 66kV Disconnector							
Left back concrete pad	310.00	306.00	305.00	306.00			1227.00
Item 11 - 66kV Fault Thrower							
Steel base plate	300.00	301.00	301.00	300.00			
Item 12 - 66kV Disconnector							
Outside column to outside column							
Measured @ rear and 170 above TOC					2982.00		
Item 13 - 132kV Transformer							
Cable box width					1638.00		
Item 14 - Transformer bund wall							
Front length					8124.00		
Left length					7046.00		

Appendix M (Conventional Survey Accuracy Measurements)

Conventional Survey measurement	Left	Right	Front	Back	Overall	Difference in length to Actual measurement	Left	Right	Front	Back	Overall	Percentage variance	Left	Right	Front	Back	Overall	Item average mm variance	tem average percent varianc	Total Error
Item 1 - 132kV Line Disconnector																				
Left concrete pad	764.35	764.35	761.86	761.86			32.65	32.15	38.14	36.14			4.10%	4.04%	4.77%	4.53%		65.06	8.06%	139.08
Left Steel base plate	0.00	0.00	0.00	0.00			0	0	0	0										
Left steel column	0.00	0.00	0.00	0.00			0	0	0	0										
Right concrete pad	652.68	640.00	748.92	714.43			146.32	159	49.58	83.57			18.31%	19.90%	6.21%	10.47%				438.47
Right steel base plate	0.00	0.00	0.00	0.00			0	0	0	0										
Right steel column	0.00	0.00	0.00	0.00			0	0	0	0										
outside to outside (concrete L-R)					4017.98						8.02						0.20%			
Item 2 - 132kV Line Voltage Transformers																				
Left concrete pad	743.25	759.38	751.52	736.98			55.75	42.62	49.48	60.02			6.98%	5.31%	6.18%	7.53%		46.38	5.46%	207.87
Left Steel base plate	0.00	0.00	0.00	0.00			0	0	0	0										
Left steel column	0.00	0.00	0.00	0.00			0	0	0	0										
Centre concrete pad	782.20	742.73	740.45	721.35			16.8	52.27	56.55	78.65			2.10%	6.57%	7.10%	9.83%				204.27
Centre steel base plate	0.00	0.00	0.00	0.00			0	0	0	0										
Centre steel column	0.00	0.00	0.00	0.00			0	0	0	0										
Right concrete pad	747.33	747.33	774.36	774.36			51.17	49.67	24.64	23.14			6.41%	6.23%	3.08%	2.90%				148.62
Right steel base plate	0.00	0.00	0.00	0.00			0	0	0	0										
Right steel column	0.00	0.00	0.00	0.00			0	0	0	0										
outside to outside (L-R)					5545.81						42.19						0.76%			
Item 3 - 132kV white phase busbar support																				
Concrete pad	772.71	772.71	742.71	742.71			28.29	26.29	57.29	57.29			3.53%	3.29%	7.16%	7.16%		42.29	5.29%	169.16
Item 4 - 132kV busbar support																				
Right steel base plate	0.00	0.00	0.00	0.00			0	0	0	0										
Item 5 - 132kV busbar support																				
Left steel column	0.00	0.00	0.00	0.00			0	0	0	0										
Item 6 - 132kV circuit breaker control cabinet																				
Plan view	0.00	0.00	0.00	0.00			0	0	0	0										
Item 7 - 66kV Gantry @ brace height (75mm EA posts)																				
Left column outer dimensions	0.00	0.00	0.00	0.00			0	0	0	0										
Item 8 - 66kV Surge Arresters (50mm EA posts)																				
Left support column outer dimensions	0.00	0.00	0.00	0.00			0	0	0	0										
Item 9 - Voltage Transformer cubicle																				
Back of cubicle dimensions	0.00	0.00	0.00	0.00			0	0	0	0										
Item 10a - Disconnector sign dimensions	0.00		0.00				0		0											
Item 10b - Earth switch sign dimensions	0.00		0.00				0		0											
Item 10c - 66kV Disconnector																				
Left back concrete pad	282.75	282.75	287.67	287.67			27.25	23.25	17.33	18.33			8.79%	7.60%	5.68%	5.99%		21.54	7.02%	86.16
Item 11 - 66kV Fault Thrower																				
Steel base plate	0.00	0.00	0.00	0.00			0	0	0	0										
Item 12 - 66kV Disconnector																				
Outside column to outside column																				
Measured @ rear and 170 above TOC					0.00						0									
Item 13 - 132kV Transformer																				
Cable box width					0.00						0									
Item 14 - 132kV Transformer bund wall																				
Front length					8091.32						32.68						0.40%			
Left length					7033.60						12.4						0.18%			

Appendix N (Point Cloud File Accuracy Measurements)

Point cloud file measurement	Left	Right	Front	Back	Overall	Difference in length to Actual measurement	Left	Right	Front	Back	Overall	Percentage variance	Left	Right	Front	Back	Overall	Item average mm variance	Item average percent variance	Total Error
Item 1 - 132kV Line Disconnector																				
Left concrete pad	791.00	790.00	798.90	796.10			6	6.5	1.1	1.9			0.75%	0.82%	0.14%	0.24%		4.57	0.84%	15.5
Left Steel base plate	0.00	439.90	0.00	452.90			0	9.6	0	4.9				2.14%		1.09%				
Left steel column	0.00	252.50	0.00	253.20			0	0.5	0	0.3				0.20%		0.12%				
Right concrete pad	790.00	792.30	791.20	791.50			9	6.7	7.3	6.5			1.13%	0.84%	0.91%	0.81%				29.5
Right steel base plate	446.60	449.10	435.90	443.50			3.4	0.9	13.1	5			0.76%	0.20%	2.92%	1.11%				
Right steel column	250.20	252.30	252.40	251.80			3.8	0.7	2.1	1.7			1.50%	0.28%	0.83%	0.67%				
outside to outside (L-R)					4021.00						5						0.12%			
Item 2 - 132kV Line Voltage Transformers																				
Left concrete pad	805.10	804.10	802.60	796.00			6.1	2.1	1.6	1			0.76%	0.26%	0.20%	0.13%		3.27	1.20%	10.8
Left Steel base plate	0.00	496.10	493.40	0.00			0	3.4	3.6	0				0.68%	0.72%					
Left steel column	0.00	121.00	127.60	0.00			0	2	4.6	0				1.63%	3.74%					
Centre concrete pad	806.20	795.10	800.80	806.90			7.2	0.1	3.8	6.9			0.90%	0.01%	0.48%	0.86%				18
Centre steel base plate	497.40	497.30	493.70	498.30			3.1	2.7	7.3	1.7			0.62%	0.54%	1.46%	0.34%				
Centre steel column	122.10	129.00	121.40	121.40			2.9	4	2.6	3.6			2.32%	3.20%	2.10%	2.88%				
Right concrete pad	797.00	796.30	801.90	796.90			1.5	0.7	2.9	0.6			0.19%	0.09%	0.36%	0.08%				5.7
Right steel base plate	491.80	498.20	492.80	496.60			6.7	0.2	6.2	3.4			1.34%	0.04%	1.24%	0.68%				
Right steel column	128.20	123.90	130.20	121.00			4.2	0.1	6.2	4			3.39%	0.08%	5.00%	3.20%				
outside to outside (L-R)					5588.80						0.8						0.01%			
Item 3 - 132kV white phase busbar support																				
Concrete pad	797.80	804.70	802.40	805.20			3.2	5.7	2.4	5.2			0.40%	0.71%	0.30%	0.65%		4.13	0.52%	16.5
Item 4 - 132kV busbar support																				
Right steel base plate	449.70	447.90	445.60	449.70			2.8	2.1	2.4	0.3			0.62%	0.47%	0.54%	0.07%		1.90	0.42%	
Item 5 - 132kV busbar support																				
Left steel column	99.10	97.00	101.40	101.40			1.1	2	3.4	3.4			1.12%	2.02%	3.47%	3.47%		2.48	2.52%	
Item 6 - 132kV circuit breaker control cabinet																				
Plan view	637.30	634.30	812.00	0.00			4.3	5.7	2	0			0.68%	0.89%	0.25%			4.00	0.61%	
Item 7 - 66kV Gantry @ brace height (75mm EA posts)																				
Left column outer dimensions	1362.30	1362.60	605.80	608.60			4.3	4.6	0.8	3.6			0.32%	0.34%	0.13%	0.60%		3.32	0.35%	
Item 8 - 66kV Surge Arresters (50mm EA posts)																				
Left support column outer dimensions	454.90	447.70	454.60	456.50			3.1	2.3	10.6	6.5			0.68%	0.51%	2.39%	1.44%		5.63	1.25%	
Item 9 - Voltage Transformer cubicle																				
Back of cubicle dimensions	653.80	653.80	629.60	629.60			1.2	1.2	1.6	1.6			0.18%	0.18%	0.25%	0.25%		1.40	0.22%	
Item 10a - Disconnector sign dimensions	456.70		180.30				3.3		5.3				0.72%		3.03%			4.30	1.87%	
Item 10b - Earth switch sign dimensions	461.00		175.60				2		0.6				0.44%		0.34%			1.30	0.39%	
Item 10c - 66kV Disconnector																				
Left back concrete pad	314.10	308.30	296.60	305.00			4.1	2.3	8.4	1			1.32%	0.75%	2.75%	0.33%		3.95	1.29%	15.8
Item 11 - 66kV Fault Thrower																				
Steel base plate	307.70	293.50	0.00	308.50			7.7	7.5	0	8.5			2.57%	2.49%		2.83%		7.90	2.63%	
Item 12 - 66kV Disconnector																				
Outside column to outside column																				
Measured @ rear and 170 above TOC					2980.90						1.1						0.04%			
Item 13 - 132kV Transformer																				
Cable box width					1639.40						1.4						0.09%			
Item 14 - Transformer bund wall																				
Front length					8120.30						3.7						0.05%			
Left length					7036.40						9.6						0.14%			

Appendix O (Wire Frame File Accuracy Measurements)

Wire frame model measurement	Left	Right	Front	Back	Overall	Difference in length to Actual measurement	Left	Right	Front	Back	Overall	Percentage variance	Left	Right	Front	Back	Overall	Item average mm variance	Item average percent variance	Total Error
Item 1 - 132kV Line Disconnector																				
Left concrete pad	801.80	801.80	802.80	802.80			4.8	5.3	2.8	4.8			0.60%	0.67%	0.35%	0.60%		3.80	0.93%	17.7
Left Steel base plate	447.10	447.10	456.30	456.30			1.4	2.4	6.3	8.3			0.31%	0.53%	1.40%	1.85%				
Left steel column	255.10	255.10	258.40	258.40			3.1	3.1	4.9	4.9			1.23%	1.23%	1.93%	1.93%				
Right concrete pad	796.70	796.70	797.40	797.40			2.3	2.3	1.1	0.6			0.29%	0.29%	0.14%	0.08%				6.3
Right steel base plate	452.50	452.50	443.20	443.20			2.5	2.5	5.8	5.3			0.56%	0.56%	1.29%	1.18%				
Right steel column	255.10	255.10	260.00	260.00			1.1	2.1	5.5	6.5			0.43%	0.83%	2.16%	2.56%				
outside to outside (L-R)					4020.70						5.3						0.13%			
Item 2 - 132kV Line Voltage Transformers																				
Left concrete pad	806.60	806.60	797.80	797.80			7.6	4.6	3.2	0.8			0.95%	0.57%	0.40%	0.10%		4.29	1.56%	16.2
Left Steel base plate	502.20	502.20	498.00	498.00			3.2	2.7	1	0.5			0.64%	0.54%	0.20%	0.10%				
Left steel column	126.50	126.50	110.40	110.40			3.5	3.5	12.6	12.6			2.85%	2.85%	10.24%	10.24%				
Centre concrete pad	806.60	806.60	797.80	797.80			7.6	11.6	0.8	2.2			0.95%	1.46%	0.10%	0.28%				22.2
Centre steel base plate	502.20	502.20	498.00	498.00			1.7	2.2	3	2			0.34%	0.44%	0.60%	0.40%				
Centre steel column	126.50	126.50	121.50	121.50			1.5	1.5	2.5	3.5			1.20%	1.20%	2.02%	2.80%				
Right concrete pad	805.10	805.10	793.00	793.00			6.6	8.1	6	4.5			0.83%	1.02%	0.75%	0.56%				25.2
Right steel base plate	503.90	503.90	495.00	495.00			5.4	5.9	4	5			1.08%	1.18%	0.80%	1.00%				
Right steel column	126.50	126.50	121.50	121.50			2.5	2.5	2.5	3.5			2.02%	2.02%	2.02%	2.80%				
outside to outside (L-R)					5594.40						6.4						0.11%			
Item 3 - 132kV white phase busbar support																				
Concrete pad	808.80	808.80	804.10	804.10			7.8	9.8	4.1	4.1			0.97%	1.23%	0.51%	0.51%		6.45	0.81%	25.8
Item 4 - 132kV busbar support																				
Right steel base plate	458.20	458.20	446.80	446.80			5.7	8.2	1.2	3.2			1.26%	1.82%	0.27%	0.71%		4.57	1.02%	
Item 5 - 132kV busbar support																				
Left steel column	102.50	102.50	99.70	99.70			4.5	3.5	1.7	1.7			4.59%	3.54%	1.73%	1.73%		2.85	2.90%	
Item 6 - 132kV circuit breaker control cabinet																				
Plan view	644.10	644.10	868.80	868.80			11.1	4.1	58.8	62.8			1.75%	0.64%	7.26%	7.79%		34.20	4.36%	
Item 7 - 66kV Gantry @ brace height (75mm EA posts)																				
Left column outer dimensions	1363.20	1358.20	615.20	608.00			5.2	0.2	10.2	3			0.38%	0.01%	1.69%	0.50%		4.65	0.64%	
Item 8 - 66kV Surge Arresters (50mm EA posts)																				
Left support column outer dimensions	449.60	452.10	446.70	450.50			8.4	2.1	2.7	0.5			1.83%	0.47%	0.61%	0.11%		3.43	0.75%	
Item 9 - Voltage Transformer cubicle																				
Back of cubicle dimensions	656.90	565.90	632.40	632.40			1.9	89.1	4.4	4.4			0.29%	13.60%	0.70%	0.70%		24.95	3.82%	
Item 10a - Disconnector sign dimensions	0.00		0.00				0		0											
Item 10b - Earth switch sign dimensions	0.00		0.00				0		0											
Item 10c - 66kV Disconnector																				
Left back concrete pad	290.70	290.70	298.60	298.60			19.3	15.3	6.4	7.4			6.23%	5.00%	2.10%	2.42%		12.10	3.94%	48.4
Item 11 - 66kV Fault Thrower																				
Steel base plate	298.10	298.10	294.00	294.00			1.9	2.9	7	6			0.63%	0.96%	2.33%	2.00%		4.45	1.48%	
Item 12 - 66kV Disconnector																				
Outside column to outside column																				
Measured @ rear and 170 above TOC					2980.30						1.7						0.06%			
Item 13 - 132kV Transformer																				
Cable box width					1640.90						2.9						0.18%			
Item 14 - Transformer bund wall																				
Front length					8114.20						9.8						0.12%			
Left length					7046.70						0.7						0.01%			

Appendix P (Leica TruView Accuracy Measurements)

True view viewing package measurement	Left	Right	Front	Back	Overall	Difference in length	Left	Right	Front	Back	Overall	Percentage	Left	Right	Front	Back	Overall	Item average mm variance	Item average percent variance	Total Error
Item 1 - 132kV Line Disconnector						to Actual measurement						variance								
Left concrete pad	760.00	756.00	773.00	794.00			37	40.5	27	4			4.64%	5.08%	3.38%	0.50%		31.13	5.60%	108.5
Left Steel base plate	415.00	432.00	458.00	439.00			33.5	17.5	8	9			7.47%	3.89%	1.78%	2.01%				
Left steel column	0.00	259.00	0.00	251.00			0	7	0	2.5				2.78%		0.99%				
Right concrete pad	775.00	720.00	727.00	773.00			24	79	71.5	25			3.00%	9.89%	8.95%	3.13%				199.5
Right steel base plate	439.00	257.00	391.00	441.00			11	193	58	7.5			2.44%	42.89%	12.92%	1.67%				
Right steel column	247.00	242.00	246.00	253.00			7	11	8.5	0.5			2.76%	4.35%	3.34%	0.20%				
outside to outside (L-R)					4060.00						34						0.84%			
Item 2 - 132kV Line Voltage Transformers																				
Left concrete pad	0.00	711.00	0.00	791.00			0	91	0	6				11.35%		0.75%		37.32	10.32%	97
Left Steel base plate	0.00	470.00	0.00	0.00			0	29.5	0	0				5.91%						
Left steel column	0.00	105.00	0.00	0.00			0	18	0	0				14.63%						
Centre concrete pad	789.00	736.00	791.00	801.00			10	59	6	1			1.25%	7.42%	0.75%	0.13%				76
Centre steel base plate	365.00	450.00	461.00	550.00			135.5	50	40	50			27.07%	10.00%	7.98%	10.00%				
Centre steel column	101.00	119.00	140.00	98.00			24	6	16	27			19.20%	4.80%	12.90%	21.60%				
Right concrete pad	0.00	751.00	760.00	710.00			0	46	39	87.5				5.77%	4.88%	10.97%				172.5
Right steel base plate	474.00	445.00	453.00	505.00			24.5	53	46	5			4.91%	10.64%	9.22%	1.00%				
Right steel column	79.00	94.00	107.00	112.00			45	30	17	13			36.29%	24.19%	13.71%	10.40%				
outside to outside (L-R)					5518.00						70						1.25%			
Item 3 - 132kV white phase busbar support																				
Concrete pad	747.00	805.00	780.00	0.00			54	6	20	0			6.74%	0.75%	2.50%			26.67	3.33%	80
Item 4 - 132kV busbar support																				
Right steel base plate	441.00	430.00	415.00	423.00			11.5	20	33	27			2.54%	4.44%	7.37%	6.00%		22.88	5.09%	
Item 5 - 132kV busbar support																				
Left steel column	90.00	62.00	0.00	63.00			8	37	0	35			8.16%	37.37%		35.71%		26.67	27.08%	
Item 6 - 132kV circuit breaker control cabinet																				
Plan view	525.00	604.00	0.00	0.00			108	36	0	0			17.06%	5.63%				72.00	11.34%	
Item 7 - 66kV Gantry @ brace height (75mm EA posts)																				
Left column outer dimensions	1338.00	1312.00	599.00	603.00			20	46	6	2			1.47%	3.39%	0.99%	0.33%		18.50	1.55%	
Item 8 - 66kV Surge Arresters (50mm EA posts)																				
Left support column outer dimensions	433.00	442.00	392.00	430.00			25	8	52	20			5.46%	1.78%	11.71%	4.44%		26.25	5.85%	
Item 9 - Voltage Transformer cubicle																				
Back of cubicle dimensions	645.00	645.00	659.00	659.00			10	10	31	31			1.53%	1.53%	4.94%	4.94%		20.50	3.23%	
Item 10a - Disconnector sign dimensions	448.00		169.00				12		6				2.61%		3.43%			9.00	3.02%	
Item 10b - Earth switch sign dimensions	443.00		187.00				16		12				3.49%		6.86%			14.00	5.17%	
Item 10c - 66kV Disconnector																				
Left back concrete pad	265.00	282.00	260.00	0.00			45	24	45	0			14.52%	7.84%	14.75%			38.00	12.37%	114
Item 11 - 66kV Fault Thrower																				
Steel base plate	0.00	349.00	0.00	342.00			0	48	0	42				15.95%		14.00%		45.00	14.97%	
Item 12 - 66kV Disconnector																				
Outside column to outside column																				
Measured @ rear and 170 above TOC					2963.00						19						0.64%			
Item 13 - 132kV Transformer																				
Cable box width					1639.00						1						0.06%			
Item 14 - Transformer bund wall																				
Front length					8108.00						16						0.20%			
Left length					7004.00						42						0.60%			