Murdoch University

Engineering Internship Final Report

Mumbida Wind Farm Project

"A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering"

Luke Jankowska

June 2012

Executive Summary

As part of my final year studies I was fortunate enough to participate in an Internship program with Leighton Contractor's. During the internship I was placed in a small electrical design team, responsible for the design and procurement of the Mumbida Wind Farm project. The Mumbida Wind Farm is being constructed as a turnkey package by a consortium agreement with Leighton Contractors and General Electric (GE) Energy. With a bachelor in engineering with majors in renewable energy and power engineering – this project was perfect; combining elements of both majors.

The following report provides a background on the successful operation of Leighton Contactors and their involvement on the Mumbida Wind Farm. In addition it details the work performed by myself as an intern including the tools and methodology used to do so. The 5 core tasks of the internship include;

- Meteorological Mast Design & Installation
- SCADA System Management
- 22kV Counterpoise Cable Design
- Primary Electrical Equipment Procurement
- Wind Farm Earthing Network Design

In addition to these points I was involved in a number of administrative and general duty activities which will be discussed later. Each task was required to be completed over the 16 week between September 2nd and December 23rd 2011. In order to successfully reach this deadline I was required to apply knowledge obtained during my studies as well as develop new skills in the workplace. This was mostly done so with the cooperation and guidance of team members Surendran Nair and Siva Vadiveloo.

As detailed in the report, each task did have its own challenges and problems – fortunately all were eventually satisfied as required. The internship itself can be considered just as successful having developed the industry skills to apply myself as a prominent engineer of the future.

Disclaimer

This report has been prepared on behalf of and for the exclusive use of Murdoch University, following an agreement with the author. Distribution of this document is not permitted without prior permission. In the event of, neither party accept any liability or responsibility for use or reliance on the following content.

All of the contained information and accounts is the sole work of the author unless otherwise referenced.

Luke Jankowska

June 2012

Acknowledgments

I would firstly wish to acknowledge Leighton Contractor's Pty Ltd for providing the opportunity and resources to participate in a work placed internship with their esteemed electrical design department - In doing so they have given me the opportunity to apply myself in a practical environment. Special thanks to Brian McEvoy for placing me with the Mumbida Team, particularly Surendran Nair, Siva Vadiveloo and Peter Gibson, all of whom provided well received guidance both in and out of the workplace. All staff members at Leighton Contractor's have provided a supportive environment, often giving the encouragement to complete my studies.

In addition, I would also like to thank Murdoch University for establishing the Internship program as well as all previous learning outcomes. Again, special thanks to internship coordinators Doctor Martina Calais and Doctor Gareth Lee for their continued support and significant contribution of time.

A sweeping declaration to all fellow Murdoch University students, family and friends all of whom have contributed to my academic and professional development to date.

"Nothing can stop the man with the right mental attitude from achieving his goal; nothing on earth can help the man with the wrong mental attitude. "

Thomas Jefferson

Contents

List of Figures

List of Tables

List of Abbreviations & Acronyms

AC	Alternating Current
AIS	Air Insulated Switchgear
AS	Australian Standard
ATS	Automated Transfer Switch
BOP	Balance of Plant
CAD	Computer Assisted Drawing
CB	Circuit Breaker
CDEGS	Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis
CSA	Cross Sectional Area
CT	Current Transformer
DB	Distribution Boards
DC	Direct Current
DNP3	Distributed Network Protocol
ENA	Energy Networks Association
EPC	Engineer, Procure, Construct
EPR	Earth Potential Rise
GA	General Arrangement
GE	General Electric
GPO	General Purpose Outlet
HDPE	High Density Polyethylene
HMI	Human Machine Interface
HV	High Voltage
I&E	Infrastructure and Energy
IEC	Intelligent Electrical Device
IED	Intelligent Electric Device
IO	Input/Output
ITP	Inspection and Test Plan
LCPL	Leighton Contractors Party Limited
LOA	Letter of Award
LOI	Letter of Interest
LV	Low Voltage
MALZ	Frequency Domain Grounding / Earthing Analysis
MWA	Motherwell Automation
MWFP	Mumbida Wind Farm Project
NEMA	National Electrical Manufacturers Association
PLC	Programmable Logic Controller
PM	Project Manager
PPM	Pre-Assembled Power Module
PTA	Public Transport Authority
PV	Photovoltaic
PVC	Poly Vinyl Chloride
RFI	Request for Information
RFQ	Request for Quotation
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SWIN	South West Interconnected Network
TQ	Technical Query
UPS	Uninterruptable Power Supply

VT	Voltage Transformer
WPC	Western Power Corporation
WTG	Wind Turbine Generator
WTGS	Wind Turbine Generator System
XLPE	Cross Linked Poly Ethylene

1. Introduction

In order to gain practical engineering experience, Murdoch University students have the option to participate in a workplace internship. This opportunity allows students to apply previous learning outcomes on a more practical level. I was fortunate enough to be offered a place at Leighton Contractors (LCPL), the main subsidiary of Leighton Holdings Pty Ltd. LCPL provide an extensive contracting services in mining, construction, telecommunications and most recently; energy generation. In order to competitively enter the power generation industry, LCPL formed an Infrastructure & Energy (I&E) division. This division provides multi-disciplined projects to various clients in the power, energy and process industry fields. Recently I&E have been responsible for the delivery of multiple hybrid gas/diesel systems in remote locations. In addition to this, I&E have made a move into the renewable energy sector in order to promote the reduction of carbon emissions. Most recent projects include the Macarthur and Mumbida Wind Farms, both of which are currently under construction. The Macarthur Wind Farm, located in western Victoria was LCPL's first wind farm – this project provided a standard for the Mumbida Wind Farm. The 420 MW wind farm is the largest in the southern hemisphere, with an estimated investment of approximately $1 Billion. The project is expected to be completed in early 2013 – after the Mumbida Wind Farm. The contract was awarded as an Engineer, Procure, and Construct (EPC) contract to the Leighton Contractors/Vestas consortium. The Mumbida project is logistically and commercially similar to the Macarthur project, on a much smaller scale.

The Mumbida Wind Farm is located 40km south east of Geraldton on a semi remote farming property. The property is atop a naturally occurring plateau making it ideal for wind power generation. The area is notorious for its summer southerly; it is also common to observe moderately easterly winds. The combination of two wind pockets provides a more reliable, year round power source. The Mumbida Wind Farm is to be constructed to produce a stage A output of 55MW. However system design is to be for a possible stage B expansion to 85MW. Stage B expansion is dependent on expected future local load demands and will not be confirmed until the completion of Stage A. The wind farm is to be supplied as part of an EPC contract which was awarded to LCPL in consortium with General Electric (GE) Energy.

GE is to supply 22 self manufactured wind turbines, each with a guaranteed rated output of 2.5MW at the down tower transformer. The installation of these turbines as well as substation construction and all remaining balance of plant (BOP) is to be performed by LCPL. A centrally located substation steps up the voltage from 22kV to 132kV for distribution. This conversion is performed by two parallel configured transformers which feed into the neighbouring western power yard. As lead consortium partner, LCPL will be held mostly accountable for all electrical design.

Throughout my internship I was directly involved in 5 tasks, chronologically listed in **Table 1** below. My level or involvement and the amount of time spent on each task varied as shown by the weightings. In general my Internship included two major tasks and three minor tasks; additional responsibilities listed in Section 3 do not contribute to the weightings but represent a significant contribution of time.

Table 1: Internship Task Summary

Project	Description	Weighting
Meteorological Masts Design and Erection	Meteorological masts are used to measure local climatic conditions which are transmitted to the wind farm's SCADA system for interpretation. This makes them useful for wind turbine power curve verification. A subcontractor was awarded the design, construction and installation which were to be compliant to IEC61400. This process had to be managed by the electrical design team, including myself. Temporary masts were also erected for site calibration before power curve verification could be performed.	10% Contract award and design confirmation took place over a 2 week period.
Mumbida Wind Farm Central SCADA System	The wind farm SCADA system is responsible for monitoring and control of the wind farm. Consortium partners GE installed an onsite SCADA system specifically for wind turbine control. These values are obtained from the mediator SCADA system provided by LCPL which will also be responsible for substation control and protection. A nearby Western Power system will be used for monitoring at the point of connection to the SWIN. A local subcontractor was required to design, install and commission the substation SCADA system. In addition to this, the successful vendor would require constant liaison with both GE and Western Power engineers to finalise IO lists and operational philosophy. This process had to be coordinated by a LCPL representative and myself. A separately supplied generator was purchased and installed on site. This component required integration into the SCADA network to ensure careful monitoring and emergency operation. In order to do so, the generator's control system had to be compatible and formatted to the wind farm's SCADA system.	10% Contract award was finalised over a week however coordination and liaising was constant over the internship.
Interconnecting Turbine Power Cable and Counterpoise Earthing Arrangement	Due to the large area covered, a significant amount of underground high voltage cable had to be procured. This cable had to be suitably sized with appropriate derating factors considered. These values and corresponding cable sizes were calculated by a sub contracted design consultant, which I reviewed and submitted to client. I was also responsible for calculating the lengths	20% Calculation of cable lengths and supplier nomination was conducted over a 4 week period.

	required, considering ground topology and termination lengths.	
Primary Electrical Equipment Design	Primary electrical equipment includes all long lead substation equipment including; • 132kV Disconnector & Earth Switch • Instrument transformers • 132kV Circuit Breaker • 22kV Switchboard Each of which required an individual specification defining system ratings and minimum construction requirements. Once the specification was delivered I was responsible for procuring and managing the delivery of all items from overseas manufacturers. Upon arrival, installation and testing is performed by a separate subcontractor.	30% Component specification construction and review occurred over a 4 week period. Suppliers were then nominated for each item in the following 3 weeks.
Earthing Design	In order to satisfy Australian requirements for lightning and fault protection, a suitable earthing design was produced by our design consultant. This design was then managed by myself and the design team, any variations or comments from the construction team had to be approved following an internal review. The earthing system electrically combines the wind turbines, met masts and substation providing fault and lightning protection. It will also be integrated into the neighbouring Western Power switchyard when it is constructed.	30% The final earthing design report was drafted by a design consultant based on information provided by LCPL. The initial report was issued after 4 weeks. However further studies were required.

A more in depth analysis of the above tasks will be considered in section 2, the detail of which will correspond to the above weighting and technical content. I will begin by providing a background on each of the above points before describing the methodological approach used to complete the task. This process often identified additional problems which were addressed on a needs be basis. As a final review, the outcome of each task will be assessed to determine key learning points which can be linked to previous studies.

Following this, section 3 will outline any additional tasks undertaken – these tasks are largely project management based. During my internship I was increasingly responsible for chairing and keeping minutes of weekly meeting with multiple parties. In doing so I also created a series of action registers in which I delegated subtasks to individuals; delegations I had to constantly track. Finally I have provided the outlook for future works on both an individual and project level.

2. Technical Description

The following section details the technical aspects of the internship introduced previously. It begins with a background on each task, including what was my eventual objective. It also includes the approach and assumptions I used to reach my final outcome. Not all content is technical based, a significant amount of the work involved managing subcontractors and coordinating teams which will be discussed in more detail throughout this chapter.

2.1 Meteorological Mast Design & Installation

2.1.1 Background

In order to conduct wind turbine power curve verification, wind data is to be collected over a 3 month period and compared to wind turbine output. This task is known as power curve verification, in which the wind turbine generator (WTG) supplier must prove that the guaranteed wind/power output ratio is being produced. The met masts should be appropriately located that they are not affected by wind turbine blocking but close enough that wind conditions can be assumed the same.

In addition this data will also be used to verify 3 existing on site met masts which are to be decommissioned on project completion. As stated in the EPC contract, this cannot occur until the 3 new masts have been erected and continuously recording for 3 months. As a result two of the new met masts have to be installed with the existing masts considered. This will result in some logistical problems that have to be considered before erection commences. One met mast can be installed without issue as the existing met mast location is no longer suitable.

As wind farm operators and turbine suppliers consortium partner General Electric Energy is responsible for power curve verification. However, as lead partner LCPL is responsible for coordinating this. Power curves will be constructed for 3 separate turbines, those closest to each meteorological mast – these curves must verify the output guaranteed by GE during tendering. These masts will also be used for future weather monitoring and studies.

LCPL is ultimately responsible for the design and installation of these met masts as specified in the EPC contract;

"All new meteorological masts will be instrumented according to the requirements of IEC 61400-12-1 and including measurement of wind speed, wind direction and air temperature at 30m."

2.1.2 Methodology

The EPC contract specification differed slightly from that of IEC61400 as it requested that wind speed and direction instruments be installed at 30m. After approaching the client it was agreed that the additional instruments at 30m were no longer required; as such the only construction requirement of the masts is that they are manufactured and erected to all relevant standards. In this instance the international standard; *IEC61400: Wind Turbines Part 12-1: Power performance measurements of electricity producing wind turbines* provided the required information on met mast orientation, location and instrument arrangement. In order to ensure all requirements are met, an experienced met mast supplier was to be selected in order to assist with any technical aspects. As such request for quotations (RFQ's) were drafted and sent to a number of reputable vendors who were to provide a preliminary design with their quotation.

On receival of the quotations an evaluation sheet was drafted – in which the technical aspects and corresponding costs were broken down and compared. This process involved comparing each vendor's design against the EPC contract and IEC61400, noting any non compliances. In addition each vendor was contacted individually to clarify or substantiate particular costs. If a quotation seemed unnecessarily high, the vendor must be contacted to discuss whether scope creep had occurred. Scope creep occurs when the project requirements are not accurately defined, as such some people may allow for additional works – increasing their apparent cost. On the other hand, if a quotation seemed unusually low, a review of their design and deliverables would be conducted, in which event they would be informed of any missed aspects and request a re-quotation. If a vendor delayed returning information, LCPL was to assume they were not properly resourced and unsuitable for delivering the met masts.

Section 3.2 of IEC 61400:12 lists the minimum requirements for wind speed measurements which state;

"The anemometer shall be mounted within +-2,5% of hub height..."

The clause also states that the anemometer is to be calibrated twice, before installation and following power curve verification. Ideally this would want to be avoided, fortunately the clause continues;

"The second calibration can be replaced by an in situ comparison against another calibrated reference anemometer, mounted at a distance of 1,5m to 2m from hub height anemometer, during the measuring period."

On this basis, LCPL performed a feasibility assessment, which concluded that the installation of a second anemometer would be cheaper than a recalibration.

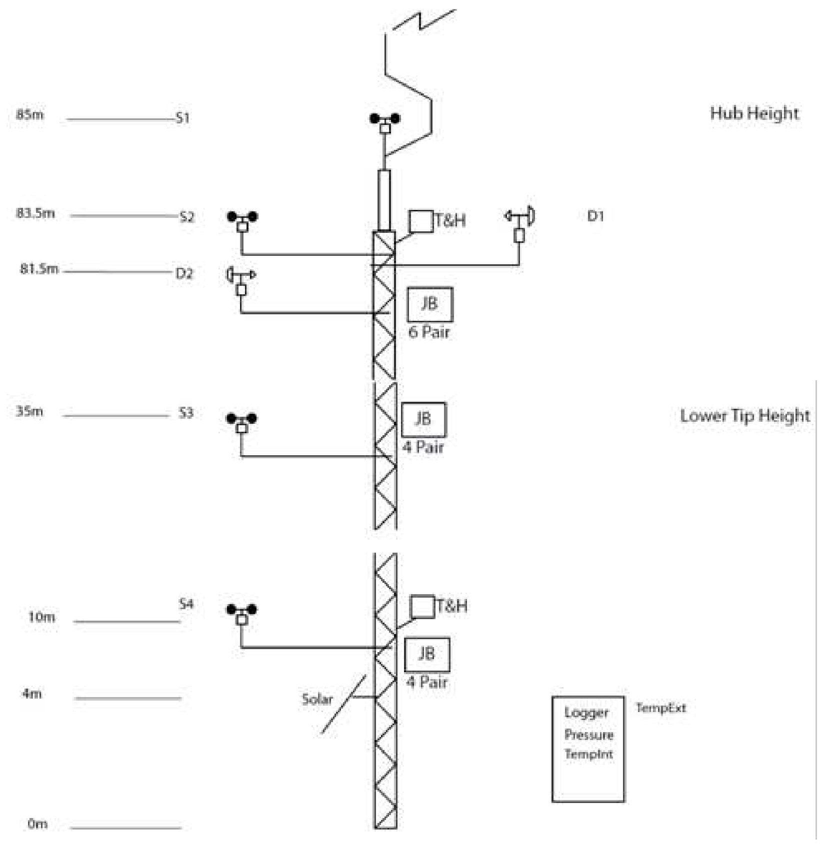
Section 3.3 states the minimum requirement for wind vane installations...

"...Wind Vane that is mounted on the meteorological mast within 10% of the hub height."

The positioning of the wind vane should also consider predominant wind direction as to minimise effect of structure blocking. On this basis, the orientation of all instruments was suggested by a technical team from GE.

In addition, air temperature and pressure values are to be recorded at each met mast at 10m above ground level as to section 3.4 of IEC 61400. The overall met mast instrument arrangement is as **Figure 1** below.

Figure 1: Met Mast Instrument Arrangement



- S# - Wind Speed Sensor # (Anemometer)
- D# - Wind Direction Sensor # (Wind Vane)
- T – Temperature Sensor (1-Wire Digital)
- H – Humidity Sensor (Probe)
- JB – Junction Box

Following the letter of award (LOA), the Vendor then had 2 weeks to submit a detailed design which was to be submitted to the client for approval before the final contract could be signed. This design had to include structure, instrument and earthing layout drawings. The structural details were submitted to a third party design consultant to ensure load and structural integrity.

On receival of design checks had to be completed to ensure it was compliant to the EPC contract and relevant standards. Once iterating this process a number of times, the evaluation sheet would be completed to the most detail provided. Upon completion of the evaluation sheet, normally to a deadline, the LCPL Design Manager would make the final selection. The decisive factors are price, cooperation during tendering and experience on similar projects – all of which also have to be researched.

During the design phase, the vendor informed LCPL that a site calibration may be necessary as site conditions were similar to that of another project. The requirement for site calibration is defined in annexure A of IEC 61400: Assessment of Test Site. The table specifies the maximum vertical variation in surface topology for varying distances from the met mast. The variation is dependent on the rotor diameter at a distance that is related to the distance between the wind turbine and correlating met mast. **Table 2** below specifies the maximum terrain variations for increasing distances from the met mast.

Table 2: Site Calibration Requirements

Distance	Sector	Maximum Slope	Maximum Terrain Variation
<500m	360deg	<3%	<8m
500m-1000m	Measurement sector	<5%	<15m
500m-1000m	Outside Measurement Sector	<10%	NA
1000m-2000m	Measurement Sector	<10%	25m

This information was then relayed to the site surveyor, who obtained contour maps of the three proposed met mast locations. On receiving a CAD file and performing some measurements it became apparent that at least two locations required site calibration. After consulting the possible project implications with the electrical superintendent, this matter was taken to the Project Manager.

After consulting appendix 2 of IEC61400 it was recommended that a professional opinion be obtained as the surface topology varied significantly enough to affect wind flow over a 250m distance. Following discussions between Project Managers; GE confirmed that site calibration is required. *Appendix 3: Site Calibration Procedure* of the same standard defines how this calibration is to be performed, which includes the erection of 3 temporary masts at the exact coordinates of turbines to obtain a correlation relationship. These temporary masts are to be identical to the permanently installed masts, ensuring accurate data correlation.

With these points considered, it was evident that a third party professional opinion was required. As wind farm operators and consortium partners, GE were contacted by management and further studies were undertaken. The project electrical superintendant then coordinated with a team in Germany on the issue, their studies concluded that temporary masts would need to be erected.

The standard also requires that;

"The WTGS under test and the meteorological masts shall not be influenced by neighbouring and operating wind turbines. The minimum distance from the WTGS under test and the meteorological mast to neighbouring turbines shall be two rotor diameters of the neighbouring wind turbine."

"The meteorological masts shall be positioned at a distance from the WTGS of between 2 and 4 times the rotor diameter D of the WTGS. A distance of 2,5 times the rotor diameter D is recommended.

This requirement is to minimise the wake effect of neighbouring turbines which may result in turbulence and reduced wind speeds, affecting data collection. This being considered, meteorological masts were placed between 250m to 300m from its applicable turbine. After consulting finalised CAD files I was also able to confirm that no breach of this requirement existed.

On the assumption that site calibration was required, the PM requested a list of appropriate steps to take. Annex B of IEC61400 defines how a calibration of test site can be performed, stating;

"Calibration of a test site should be performed by collecting wind speed and wind direction data at hub height on a temporary meteorological mast erected at the foundation where the WTGS to be tested will be erected..."

As turbine foundations were currently being prepared, programme dates were changed to allow the affected turbine foundations to be poured first, allowing erection of the temporary masts as soon as possible. The temporary masts had to remain erected long enough to comply with the following two requirements of IEB61400:

"Data should be sorted in wind direction sectors of a maximum of 30deg width. For each wind direction sector, a minimum of 24 h of data at wind speeds ranging from 5m/s to 10m/s should be acquired.

"For the meteorological masts, flow distortion correction factors should be established for each wind direction sector by regressing the measured wind data from the wind turbine location on the measured wind data from the reference mast".

During normal wind farm operation, there is a dedicated Circuit breaker (CB) in the wind turbine PPM. This 230V AC source is used for supplying the mounted instruments. Due to the requirement that these masts be monitoring prior to turbine erection, this power source was not yet available. To accommodate this; a variation to the original contract was issued, this would include the incorporation of PV cells and battery banks to provide the required DC power. Upon tower erection, a permanent power cable is to be installed and current PV arrays are to be decommissioned.

2.1.3 Current Status

The Meteorological masts were originally programmed to be erected in December, to allow additional monitoring over the Christmas break. Unfortunately due to the altered erection method as well as the requirement for site calibration – erection did not commence until late March. It is currently being confirmed whether this erection method was a world first for a mast of this height.

2.2 SCADA System Design

2.2.1 Background

The SCADA system collects, interprets and communicates the operating status of the entire wind farm. In addition it is required to maintain reliability and quality of electricity supply as required by the Western Power Technical Rules. The system is to be designed with the capability of both automatic and manual control where necessary. The Human Machine Interface (HMI) shall provide visualisation of the operating parameters recorded by the SCADA system. As this function is required for wind farm operation; a redundant system must be designed to minimise the possibility of downtime. This redundant system must be complete with back up historian and operating servers, uninterruptable power supply and dual operating stations. The SCADA system is to also allow for wind farm monitoring and control from a remote server to be operated by Verve Energy.

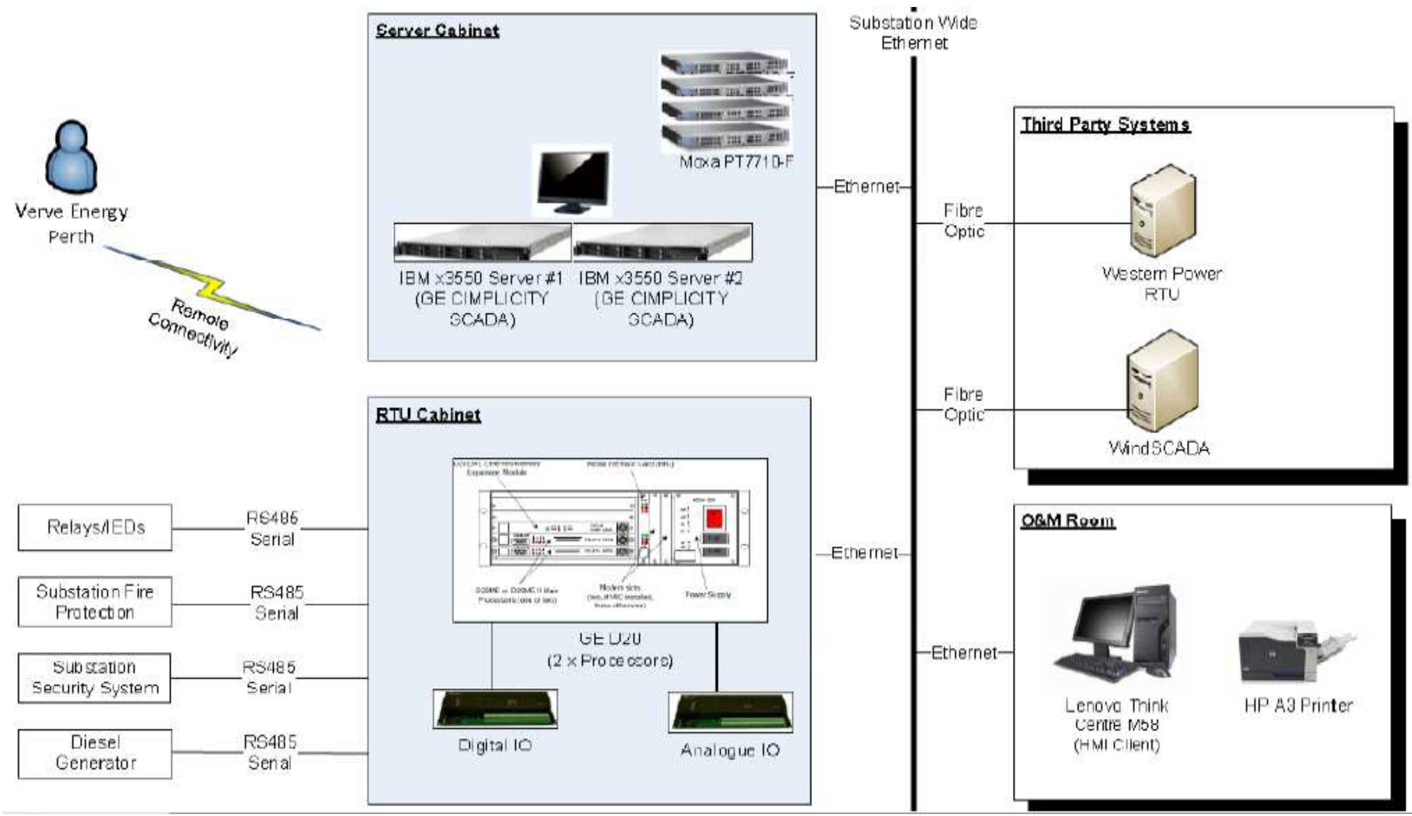
Due to the operating requirements of the wind farm, multiple SCADA systems were to be installed on, each with a different purpose. A central SCADA system within the substation was to be provided by Leighton, that would communicate with the neighbouring GE and Western Power (WPC) systems. The Topology diagram given below provides a clearer representation of the system.

The LCPL substation SCADA system will be connected to the wind farm's Ethernet network. The substation remote terminal unit (RTU) will have RS485 serial communication with the following substation intelligent electronic devices (IEDs):

- 7xProtection Relays
- 6xSwitchgear Feeders (via the Substation Wide Ethernet)
- 1xSubstation Fire Protection System
- 1xSubstation Security
- 1xDiesel Generator

The RTU will send and receive data with these IEDs and interface to Western Power and GE SCADA via DNP3 protocol as required.

Figure 2: SCADA System Topology Diagram



An onsite diesel generator was to be installed during construction, providing back up power in the event of mains failure. This generator would need to begin an automatic start up sequence in the event of a power failure. To ensure this system is well maintained and suitable for operation, a number of parameters would need to be strictly monitored by the substation SCADA system. Again due to the multiple parties involved, I was responsible for finalising a control philosophy through discussions with multiple parties.

2.2.2 Methodology

Similarly to the met masts, RFQ's are submitted to at least 3 competitive suppliers who returned a quotation with a breakdown of their system. I was again responsible for comparing the different systems through an evaluation sheet. During this process it became clear that one of the vendors had overestimated the scope of work, resulting in an inflated quotation. By highlighting this to the vender, they were able to produce a reduced quotation.

Once the vendor had been chosen, each party had to be coordinated by a central LCPL employee. Requests for Information (RFI) were submitted by each vendor, which were then appropriately conveyed to the relevant party. All technical requests submitted to LCPL were then forwarded to the SCADA contractor, having the technical knowledge.

Before any external coordination could commence, a preliminary IO list was drafted by the intern and submitted to each of the following parties for review & comment;

- General Electric – Wind Farm Operators
- Motherwell Automation – SCADA vendor
- Verve Energy – Client's representative
- Western Power – Power Distributor

Only upon finalisation of this IO list would a group teleconference be possible. In addition to this, GE required some customer inputs from Western Power. This included a number of parameter values and the option of voltage droop. Unfortunately we did not have any direct contact with Western Power, with all queries and arrangements to be communicated through a representative at Verve. In addition to this Western Power were unable to commit to any conference until an agenda and time had been prepared. GE SCADA engineers, located in India were themselves difficult to contact and we were unable to proceed with design until the customer input information had been complete. A stalemate had developed which was not helped by the existing communication complexities. After weeks of little to no progress, a caution was raised noting that project delays would ensue if no meeting was raised – a date was set for an 'open talk' conference chaired by LCPL and led by technical representatives, Motherwell Automation.

As specified in the EPC contract, LCPL were required to supply a diesel generator. This generator would act as a back up in the event of mains power failure. Most modern day generators have what is called black start capability, this automated start up process triggers during a mains blackout. The process is as follows;

- Upon mains power failure a contact is tripped – Auto Transfer Switch (ATS) Panel
- This allows the standby battery bank to power the generator start up.
- After generator start up a contact switches to the generator, powering the load.

At the advice of the systems design consultant, this method was rejected for its higher failure rate. Instead the SCADA system would detect a power failure via switchgear relays and coordinate this back to the UPS powered substation SCADA system. On detection, a hard wired signal would then be sent to the diesel generator, beginning the start up sequence. This process would take approximately 10 seconds, in which time the vital monitoring and control components will be powered by a separately supplied UPS. This process had to be coordinated with the diesel generator supplier, whose electrical engineer suggested the addition of a Micrologix 1400 PLC to assist with the additional inputs and logic.

The Diesel Generator has an in built control panel, allowing for hard wired monitoring and control. Unfortunately, this control is via an Ethernet connection whereas the preferred form of communication is via DNP3 protocol. To accommodate this, a standard Ethernet to DNP3 converter was required.

In the event of a power failure, the SCADA will control the start up sequence of the generator. The 415V changeover board located in the control building will use volt free contacts to provide the status of each supply. In this event, the changeover board will disconnect from the 315kVA auxiliary transformer. The SCADA system will wait 3 seconds before issuing a start up command to the generator. Once the SCADA detects that the generator is operating at an acceptable output, the changeover board will automatically connect. If this sequence fails the SCADA system will generate a remote alarm for the wind farm operator.

When main supply returns, the changeover board will disconnect from the generator and reconnect to the 315kVA auxiliary transformer. 3 seconds after this connection stabilises, SCADA will shut down the generator.

As the diesel generator was to be supplied by a separate vendor, a separate IO list had to be generated. The SCADA system would require the following information;

- Fuel Level
- Operating Temperature
- Oil Pressure
- Fault Status via 4pole CB
- Operating RPM
- Voltage
- Current
- Power Factor

2.2.3 Current Status

SCADA system design and testing is being performed at the vendor’s head office in Perth. In order to do so, relays had to be procured and sent to their office ahead of schedule. A team of engineers will travel to site upon control building arrival for onsite works and final testing.

The diesel generator has arrived on site, however the PLC will have to be configured in liaison with SCADA engineers on site arrival.

2.3 Interconnecting Turbine Power Cable and Counterpoise Earthing Arrangement

2.3.1 Background

22kV rated underground power cables are to be used to connect each turbine to the substation. As seen in **Appendix a,** the turbines are gathered into 6 groups; 5 in stage A and another to be added in stage B. The turbines are generally connected in series, with the collective output being fed to the substation switchgear. To prevent later rework, the cables were to be sized and constructed with stage B output considered. A subcontracted design consultant was used to determine cable sizing and insulation, whilst two different vendors were contacted for manufacture and installation.

These power cables would be installed underground at a depth determined by heat rise calculations. The cables would then be gradually lowered to a depth of approximately 6m as they approached the turbine foundations. Pre installed conduits then run from the base of the foundations to the top. The orientation and size of these conduits had to be determined and ordered before foundations could be poured.

In addition to these power cables, earthing and communication cable had to be purchased and installed. A single run of 12 core fibre optic cable would connect each turbine similarly to the power cables – via conduits in the foundation. The communication cables will be terminated at the Main Control Cubicle (MCC) at the base of each WTG, from which additional control cables run up the tower to the Nacelle, gathering power output values.

Bare earthing cable would also be installed between WTGs; however additional earthing had to be installed around each WTG. The interconnecting earthing is to run through conduits, connecting to a common busbar at the base of the tower. Additional lengths would then run into the foundations where it is bonded to the steel reinforcement as discussed in section 2.5.

Met masts must also be connected to both the earthing and communications network.

2.3.2 Methodology

Multicore cables consist of multiple conductors insulated in a single sheath. They are generally more cost effective than single core cables due to the reduced amount of insulation required. They are however, generally larger than single core cables and as such, much less flexible. On this basis it became apparent that GE's compact Ring Main Unit (RMU) supplied within the downtowner PPM would not be compatible with multicore terminations. Instead, a single core run would have to be installed per phase – resulting in triple the cable procurement and installation length. The use of single core cable would make terminating the cable much easier in the space restricted PPM.

Fortunately the opted ploughing installation method allowed for all three power cables as well as earthing cables to be installed simultaneously, despite separation distances of at least 1m between phases. In some shorter lengths multiple runs will have to be made as shown in **Appendix b.**

During the tendering stage, the civil project engineer requested details on the HV cable bending radius. These values were required so conduit order placement could be finalised, allowing for installation and steel fixing ahead of foundation pour. In order to compromise, I decided to size the conduits on a worse case basis, keeping a uniform size for all cables. As a general rule, the bending radius can be calculated from the cable diameter by a scaling factor, dependant on the cable insulation. The bending radius varies significantly depending on material, cable size, arrangement etc. A table of recommended scaling factors is given below; typically these values vary slightly between manufacturers.

Table 3: Cable Bending Radius Coefficients

Type	Voltage	Bending Coefficient
PVC/XLPE Single Core	<22kV	12
Nylon Covered	All	30
HDPE Sheathed	All	25

At this stage in design it had not been confirmed whether nylon jacketing was required, it was assumed required for the time being. From OLEX datasheets; overall cable sizes can be estimated. After contacting a representative from GE it became apparent that GE's RM6 (compact RMU) was suitable for terminations of 630mm^2 CSA or less – on this basis it was assumed that conduits are required to be sized for 630mm^2 cables. Referring to OLEX datasheets; 630mm^2 conductors had an estimated overall cable outer diameter of 57-60mm for nylon jacketed cables. Applying the values from **Table 3**;

$$Minimum\ Bending\ Radius = 30(Coefficient) \times 60mm\ (Cable\ OD)$$

$$Minimum\ Bending\ Radius = 1800mm$$

$$Bending\ Radius \cong 2000mm$$

After calculating a minimum required bending radius of 1.8m, a reasonable tolerance can be applied - concluding 2m was acceptable. In addition to this conduits of 200mm ID were required based on maximum current carrying capacity of cables. Table 1 of AS 1345 states that all power conduits are coloured orange whilst communication cables be white. Noting this, a conduit schedule spreadsheet was created; detailing the total quantity, size and colour of all conduits. This table can be found in **Appendix c.**

This information was then submitted to the civil project engineer and conduit ordering was able to proceed.

Cables had to then be procured and manufactured as per tables 4, 5 and 6 below.

Table 4: 22kV Power Cable Specification

Cable Rating	12.7/22kV
Conductor	Circular, stranded Aluminium
Size	Various: 185mm^2-630mm^2
Conductor Screen	Semi conductive conductor screen
Insulation	X90-XLPE (non porous)
Insulation Screen	Semi conductive insulation screen
Shield	Heavy Duty Plain Annealed Copper Wire
Inner-sheath	PVC
Outer-sheath	HDPE
Termite Protection	Chemically Treated – Cypermethrin
Sheath Colour	Black

Table 5: Control Cable Specification

Cable Rating	600/1000V for 24, 48 & 110 VDC systems
Conductor	Circular, stranded annealed copper
Size	Various
Armour	Single helical galvanised steel wire armour
Insulation	V90-PVC
Outer-sheath	V90-PVC
Termite Protection	Nylon Sheath
Sheath Colour	Black

Table 6: Copper Earthing Cable Specification

Conductor	Circular, stranded annealed copper
Size	Various: 95mm^2 – 185mm^2
Outer-Sheath	Various: Bare (up to 120mm^2), V90-PVS (185mm^2)

During this stage of design, minimal site works had commenced, as such current cable lengths had been estimated from a Portable Document Format (PDF) overview. Obviously, these values were just for preliminary information and much more accurate values would have to be calculated.

A final quotation could not be obtained until we had finalised the exact cable lengths required, as discussed previously this was a great opportunity to save a lot of money while it also posed a giant risk to the entire project if the lengths were too short. Ideally a surveyor would be able to calculate exact cable lengths via topological mapping. Unfortunately roads, hardstands and turbine locations had not been completed at this stage so we were solely dependent on the CAD files. To obtain a CAD file, I first had to get confirmation of turbine coordinates and road configuration from the civil team. Using CAD's 'measure' function, cable lengths between turbines could be calculated. This process was quite slow as it involved taking dozens of straight line measurements along often winding roads. This step was also repeated at least 3 times for every turbine to ensure the lengths were accurate. Another limitation of this is that is only provided the 2D overhead distances, it did not consider changes in surface topology or feeding the cables through foundation conduits. From the geotechnical report, an overall topology variation of 3% was stated acceptable. In liaison with the civil team; conduit arrangement and orientation drawings could be drafted. From these drawings the electrical department was able to allow additional lengths to orientate the cables the correct direction before being lowered to the base of the foundations and being fed through conduits up to the RMU. From GE drawings, I then determined the above ground termination height.

Repeating this step for each turbine gave accurate, theoretical lengths for each run. To ensure nothing had been missed; the lengths were reviewed with the electrical superintendent. Initial reactions were to add more allowance to guarantee cables did not fall short during installation. After having spent weeks calculating these lengths and rechecking, the team was confident in this cost saving opportunity. Almost 2 more metres were added per termination due to the industry practice of cutting drum cables. After providing the lengths to the design team and substantiating them, LCPL was able to proceed with obtaining accurate pricing.

The MWFP design consultant specified the cable insulation and sizing based on conductivity heat rise simulations using soil properties obtained during the feasibility stage. As limited values were available, the most onerous situation was considered which resulted in quite large cable sizes.

Cable sizes are dependent upon the current carrying capacity of the cable, more current means a large cable CSA. In addition to this, there are dozens of derating factors that also have to be considered. Some to these include soil properties, insulation and conductor type. Our sub contracted design consultant was able to determine appropriate cable sizes, with all things considered using heat dissipation software.

As specified in the EPC contract;

"All cables are to be suitably termite protected"

This clause, although not clearly defined, states that some form of termite protection is required. Standard industry practice is to apply a nylon coating to the insulation which is then covered in a sacrificial HDPE layer. Due to the chemical structure of nylon, it forms a smooth surface. The nature of this surface makes it difficult for termites to chew, protecting the insulation and cabling within.

Due to current world shortages in nylon, the use of this will increase both the cost and cable lead time. As a substitute, the vendors suggested the use of chemical doping that would ensure the repellent of termites over a 20 year design life. The chemical was compliant to *AS/NZS 1429.1:2006 - Electric cables - Polymeric insulated - For working voltages 1.9/3.3 (3.6) kV up to and including 19/33 (36) kV* after long term testing in Australia and South Africa by the CSIRO. Nylon coating can only be guaranteed if installed correctly and without issues, any damage to the nylon coating will interrupt the smooth surface and make it vulnerable to termite penetration. As the specification was not clear and as the lead contractor we have a professional obligation to comply with acceptable engineering practice. The decision was made in agreement with the client. With this obligation in mind we presented the two options to the client to approve, independent of cost. After their decision, we proceeded with Cypermethrin doping in all cable insulation.

In order to satisfy the client, a Technical Query (TQ) was submitted requesting whether Termitex doping is an acceptable means of termite protection. Before a decision could be made, the client required details on the treatment as well as references for similar use. Fortunately, the most competitive vendor had successfully supplied termite treated cables within Australia. In addition they were willing to provide a written guarantee ensuring termite protection for 20 years. After reviewing the Termitex Treatment Specification, the client was satisfied. Following this the contract was awarded to the vendor based on this compliancy rather than having the lowest price.

In order to assist with installation and handover to the construction team, I decided to draft a detailed cable spreadsheet – see **Appendix d**. This spreadsheet would include lengths of each drum and be labelled accordingly. Since each run was varying in lengths and sizes, each drum would also vary, in some cases shorted lengths were combined to fit on a single drum. In some cases, up to 1500m of cable was required on a single drum to avoid in line joints. Being able to supply these lengths on a single drum is another reason the suitable vendor was selected.

After creating the detailed cable schedule, I was able to determine the maximum cable length per drum for each cable size. I then requested the maximum lengths manufacturable by each vendor, thus determining whether in line joints were required. I then estimated an in line joint cost for each size and added this value to the quotations that required joints. By identifying this risk we were able to eliminate this future expense.

After cable routes were marked with a plough run, I had the surveyor calculate actual cable routes. Using rope, I was then able to calculate the precise length to be run through the now installed conduits. These values were placed on a spreadsheet and compared to the original estimations, with results in **Appendix e**. From these results we can see that in no case did my estimations exceed 10% of the actual distance, and in only 1 case I underestimated by 1m, an easily manageable value. This represents a significant saving on unnecessary cable expenditure.

Based on preliminary per metre quotations received, minimising excess cable ordering would greatly reduce costs. On the other hand, if cables were not long enough we would not be able to terminate which would instantly delay the project by weeks.

The successful cable installer must also install post markers which identify the existence of underground cables. Clause 3.11.4.6 of AS3000 states that cable markers shall be installed but does not detail to what minimum requirements. Western Power Network Standard NS 14.2-2003: Underground Cable Installation Manual instead requires that cables be marked according to *AS4799-2000: Installation of underground utility services and pipelines within railway boundaries.* To comply with good practise, AS4799 was applied as it is more onerous.

Cable markers shall be installed to indicate the location of all underground power cables.
The markers shall be located above or adjacent to the buried cable (AS 4799-2000, Clause 3.10.2):

- At points of entering and leaving the property of the Public Transport Authority (PTA).
- At changes of direction.
- At distance between consecutive markers of the lesser of 200m or line of sight.
- Where specified, at the ends of the under track crossing (the end of the under track crossing is taken as the point 3m beyond the outer rail or toe of the embankment).

The markers shall comply with the following requirements (AS 4799-2000, Clause 3.10.3):

- Stand at least 800mm out of the ground, to the bottom of the marker plate.
- Be of non-combustible material for the marker plates and of at least fire-resistant material for the pole.
- Wording on the markers to be legible, permanent, and formed in a non-combustible medium, or as otherwise approved by the PTA.

The descriptive wording and instructions shown on the markers shall face the railway (AS 4799-2000, Clause 3.10.4).
The wording on the markers shall include the following (AS 4799-2000, Clause 3.10.5):

- The owner's name.
- A warning of the presence of a buried service.
- The nature of the buried service.
- Contact advice in the event of an emergency.

Underground wiring systems can be categorised into three different categories, the category of which determines the depth of installation. Table 3.5 of AS3000 provides the classification requirements for each category which is dependent on the type of cable and method of protection. From this table the cables were classified as category B cables. Figure 3.13 of the same standard then suggests that mechanical protection is required to be installed above the cable. This will provided some protection from accidental mechanical damage that may occur. The cable installer will be responsible for the installation of this protection in addition to plastic marker tape.

2.3.3 Current Status

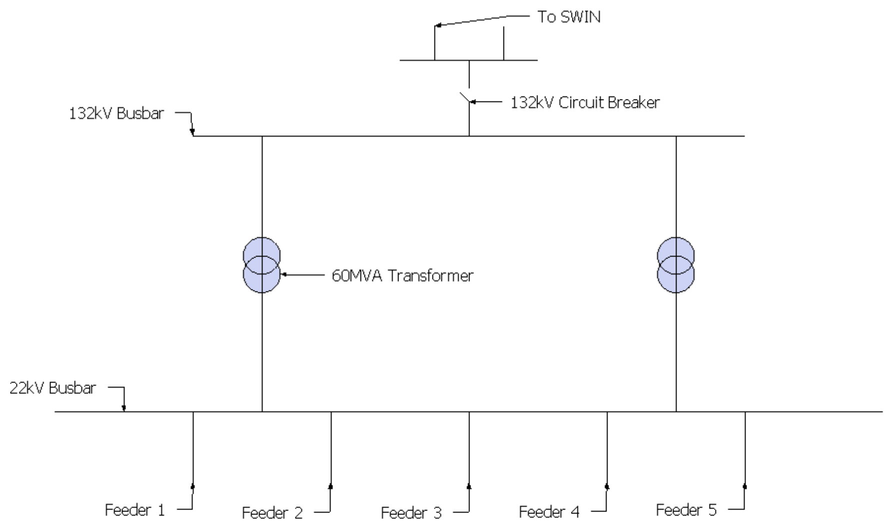
Cable delivery occurred throughout March, well ahead of the original schedule allowing cable installation to commence in April. The subcontractor has successfully installed all power, earthing and communication cables as required, including those between met masts and their corresponding WTG. Power cables were buried at a depth of 900mm, with mechanical protection slabs protecting them from below surface damage.

2.4 Primary Electrical Equipment Design

2.4.1 Background

The power station will consist of individual wind turbine generators grouped into several 22kV collector cable feeders that will be connected to a substation switchboard. The substation 22kV switchboard will supply two 22/132kV 60MVA transformers, which in turn will be connected via a 132kV circuit breaker to Western Power's 132kV switchyard consisting of two 132kV overhead powerlines feeding to the SWIN. This is shown in the single line diagram (SLD) in Figure 3 below.

Figure 3: MWF Single Line Diagram



Substation equipment including circuit breakers, disconnectors and instrument transformers are generally long lead items. These items need to be designed, rated, constructed and delivered before substation construction commences. Smaller components such as wiring, protection panels and lighting will be considered closer to the construction phase post internship. A complete list of substation equipment is per **Table 7** below;

Table 7: Primary Equipment Breakdown

Primary Equipment List	
Description	**Quantity**
132kV Disconnector & Earth Switch	2
132kV Combined CT/VT	3
132kV Voltage Transformer	3
132kV Current Transformer	3
132kV Circuit Breaker	1
22kV Switchboard	1

A substation general arrangement (GA) showing the exact locations of these components can be found in **Appendix f.** Circuit breakers and Disconnectors rated for 132kV are naturally designed for 3 phase systems. Instrument transformers on the other hand are constructed on a per phase basis, hence the need for 3 of each type.

Two 3-pole, manually and automatic operated Disconnectors with built on 3 pole gang operated earthing switches must be supplied as a combined unit. These units are used during maintenance to ensure that the system is mechanically earthed and isolated; they should not be operatable during normal operation.

Instrument transformers (ITs) are designed to transform voltage and current values on the 132kV side to more appropriate values that can be utilised by other components. The substation has three different ITs; Current Transformer (CT), Voltage Transformer (VT) and combined Current/Voltage Transformer (CTVT). Three individual current transformers are installed upstream of the Circuit Breaker, these convert current waveforms on the HV side to values suitable for relay protection. A single inductive voltage transformer is installed at the 132kV bus; this will be used for bus and tap voltage monitoring. The combined CTVT will be used for power metering, installed at the point of connection between Verve and Western Power switchyards.

The 132kV Circuit Breaker acts as the point of connection for the MWF to the SWIN. The 132kV circuit breaker is to operate in the event of a system fault, isolating the wind farm from the existing network. The purpose of the circuit breaker is to protect all wind farm equipment and components from dangerous fault contributions.

The 22kV Switchboard will be located inside the fire resistant control building. The switchboard will be comprised of 10 tiers, each contained air insulated core and bus modules. Each core module is to contain SF6 circuit breakers, CT's and cable sockets. The busbar module is to contain the busbars, bus earth switch and VT's for the bus. These compartments will allow for termination of the MV power cables, allowing each feeder to be individually isolated.

Before procurement of substation equipment can begin, a specification must be developed for each component. This specification details the minimum requirements that have to be met by the vendor. Included are component ratings as well as references to any applicable Australian Standard. Our sub contracted design consultant was responsible for drafting these specifications which would be reviewed by LCPL before being submitted for client approval. Ideally the components should not be purchased until the client has approved the specifications on the basis that the specification may be non compliant. Due to time constraints, we decided to proceed on our own risk, provided the only changes requested by the client were cosmetic and would not impact the technical operation of the relative component.

2.4.2 Methodology

Due to limitations in the design team, substation detailed design was to be performed by a local design consultant. All equipment had to have a specification, detailing the minimum operating and construction requirements. In addition to this, overall control and operation philosophies had to be submitted, these documents would detail the operation of the wind farm. Before procurement could commence, each product had to be researched to understand the operation and key parameters. Eventually all this information would be sent to vendors with RFQs for them to select the correctly rated equipment. The process for each primary equipment is as follows.

Disconnector

When submitting an RFQ, an equipment specification should also be provided. This specification describes the manufacture, test and delivery requirements. This includes a complete list of all Australian and local standards to be met. In some instances it is more appropriate be specific as to what clauses in particular must be satisfied – this reduces the response time. Clause 9.102 of *AS62271.102: HV switchgear and controlgear – AC disconnectors and earthing switches* list the information to be given in the tender. This information had to be obtained from the following sources;

- Equipment Specification
- AS62271.102 Recommendation Tables
- Consultation with Design Manager
- At special request from the Design Consultant

Appendix g states the disconnector's ratings and operating requirements, construction arrangement and operating mechanisms.

Clause *9.102.4 Overall Dimensions and other information* states that;

The manufacturer shall give the necessary information regarding the overall dimensions of the Disconnector or earthing switch in the open and closed positions. The fixing dimensions and mass of the disconnectors and earthing switches should also be given. The dimensions given in drawings of disconnectors and earthing switches are subject to tolerances as standardized by ISO 2768-1 unless otherwise specified.

These drawings were provided as requested; please refer to **Appendix h** for more information.

AS62271.102 requires that the disconnector is constructed with a phase separation of 2700mm. This differs from the equivalent IEC standard which states that a separation of 2400mm will be sufficient. Due to market demand, it is much more difficult to find a supplier that will comply with this phase separation. I was made aware that disconnectors with 2400mm separation had been supplied and installed to a number of mine sites throughout the Pilbara. After contacting on site personnel, we were informed that 2400mm separation is sufficient provided the disconnectors are type tested. On this basis we requested type test be performed and results submitted prior to importation.

Instrument Transformers

Similarly to disconnectors, certain operating parameters had to be provided to the Instrument Transformer suppliers. A complete list is found in **Appendix i** which were required as per the following standards;

- *AS60044.1: Instrument Transformers: Current Transformers* for current transformers.
- *AS60044.2 Instrument Transformers – Inductive Voltage Transformer* for inductive voltage transformers.
- *AS60044.3 Instrument Transformers – Combined Transformers* for combined CTVT transformers.

All Instrument Transformer GAs can be found in **Appendix j.**

Capacitive Voltage Transformers are also commonly available products; they operate with the same purpose except do so via a capacitance potential divider. They are generally more economical and have fewer harmonics at voltages above 132kV.

Circuit Breakers

A similar table was constructed, specifying minimum circuit breaker requirements. This table found in **appendix k** was created after consulting the following standards;

- ***AS 62271.100:*** *High-voltage switchgear and controlgear - High-voltage alternating-current circuit-breakers*
- ***AS 2650-2005:*** *Common specifications for high-voltage switchgear and controlgear standards*

Please refer to **Appendix l** for Circuit Breaker GA.

Post Insulators

The above equipment is to be mounted atop suitably rated station post insulators. These insulators will provide insulation between the active overhead components and their metallic structure. Post Insulator ratings are found in **Appendix m** and a GA is attached as **Appendix n.**

Switchboard

Finally, the switchgear operating parameters were determined as per ***AS62271.200:*** *High-voltage switchgear and controlgear – AC metal-enclosed switchgear and controlgear for rated voltages above 1kV and up to and including 52kV* and are included in **Appendix o**.

All official documents supplied by the design consultant have to be reviewed by a LCPL employee, marking any obvious mistakes and reviewing technical parameters against their relevant standards. Any changes or queries are then communicated back to the design consultant who must amend the document before it is submitted to the client for review. In doing so, a representative for the client lists any non compliance – either to the specification or the Australian standards. These comments must be amended if substantiated or challenged if not required. Minor cosmetic changes such as formatting and grammar can be amended straight away. If the representative has any issues with a technical point and LCPL wish to challenge it – a phone call or brief contact session is required to compromise a solution.

Once an equipment specification was technically approved by the client, including all information in the tables above; RFQs could be submitted to previously contacted vendors. During the final stages of finalising a vendor, a letter of award had been issued to a vendor based on previously offered pricing and delivery lead times. On award the vendor was then required to supply all equipment drawings within 10 business days – a deadline that was not often met. Drawings have to be reviewed to ensure the correct equipment is being supplied. This is most easily done by red lining a drawing series.

Although it was not identified during a due diligence assessment, it soon became apparent that the nominated vendor would not be able to meet the agreed delivery schedule. Fortunately, during vendor evaluation a second vendor is always kept as a contingency plan. Due to the delay in notifying this vendor however, programme dates which would not be met, to accommodate some HV components would need to be air freighted.

2.4.4 Current Status

Weekly interface meetings are still being held with the successful suppliers, currently there are minimal delays estimated for equipment delivery.

Switchgear is to be delivered to Perth to be installed within control building before mobilising to site to minimise on site works.

2.5 Earthing Design

2.5.1 Background

An earthing system is used to create a reference point to the earth's conductive surface. Due to this conductive nature, certain conditions may result in a dangerous potential being developed between a surface and the ground. A protective earth system will ideally reduce or remove the potential between any excited components and the earth nearby. As a safety precaution, earthing systems are a mandatory requirement as per AS2067: Substations and High Voltage Installations exceeding 1kV AC and AS3000: Wiring Rules.

All conductive components are required to be bonded to this earth reference; quite a challenge considering the spacing between turbines. As stated in section 3.3.1, bare annealed copper cable is used to connect each WTG to the centrally located substation. The 22kV system is then earthed via two zig-zag configured earthing transformers. In addition to this, each WTG as well as the substation must include a below ground grid constructed of cad welded copper cables. The final design should result in a commonly connected earthing system over the entire property.

Each wind turbine earthing grid consists of a number of earthing rings each varying radius and depth. Four rings are to be cast into the foundations and bonded to the internal steel reinforcement. Each ring has two tails on opposing sides which feed into the foundation's centre for termination on the ground level busbar. Two additional rings are to be located outside the foundation, with the tail running through small conduits cast into the foundations before being bonded to the same busbar. This arrangement minimises voltage potentials around the WTG in a fault or lightning strike event.

The substation is to be constructed with a buried rectangular earth grid, rather than the ring arrangement installed at the turbines. The grid is to be electrically bonded to all surrounding fences and any conductive components in between. Additional conductors will also connect to the neighbouring Western Power substation to result in an improved combined earthing system. Insulated copper tails are used to connect metallic support structures to the buried grid, preventing any accidental contact during a fault. In addition to the traditional earthing grid, deep earth rods will be required to further decrease the earthing resistance. As the soil model in **Figure 7** shows, soil resistance decreases with depth. Seasonal fluctuations are also less significant at greater depths, making those measurements more reliable. As such, deep driven electrodes provide a lower earth resistance, providing more protection for personnel and sensitive equipment.

The sizing of all cables as well as size of each grid is to be determined by the design consultant following a system simulation and a substantiation report. This report must consider future network growth and thus increases in grid fault contributions.

The key objectives are:

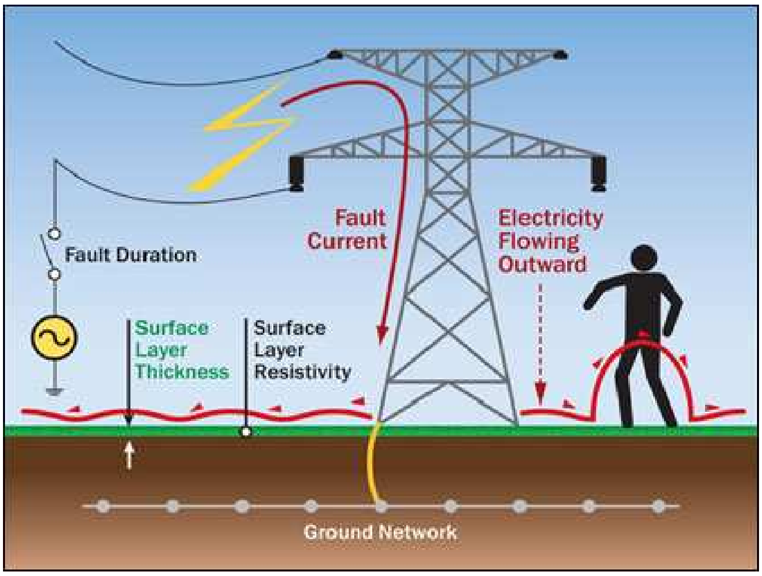
- Determination of the maximum allowable step and touch potentials based on a site-wide soil model for the WTGs, Met Masts and Substation;
- Calculation of the minimum conductor size required for both the 22 kV counterpoise system and the substation earth grid; and
- Simulate the Earth Potential Rise (EPR) and maximum step and touch potentials.
- Simulate touch potentials of fences via simulation of the fencing on site.

The combined earthing layout in **Appendix p** is required to have a resistance of less than 1 ohm as per AS3000. In the event that an earthing conductor connecting a WTG string to the substation is damaged, two separate earthing systems will be produced. Although this event depends on failure of the original system it is a high risk event due to the quantity of conductor, the farming activity on the land and the potential hazard it produces. As such, additional earthing consideration may need to be made.

An earth potential rise (EPR) is the event in which current flows through the Earth's surface via an earth grid. The voltage induced is greatest where current enters the ground; this dissipates with distance from this point. If the resulting potential is significant enough, it can be hazardous to personnel, animals, equipment and structures.

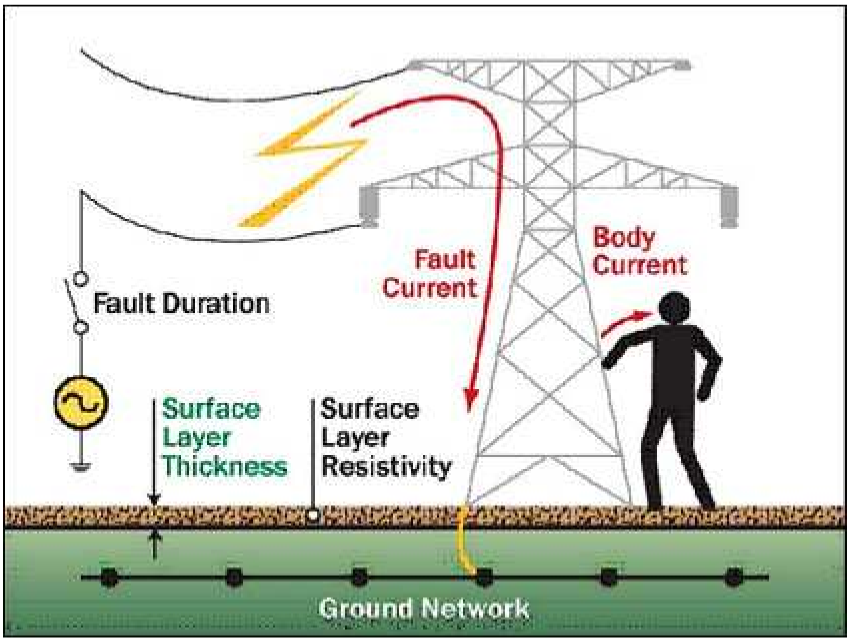
Dependant on the soil resistivity level, voltage will be distributed through the ground. If a person was to step towards the fault location, a hazardous voltage may be observed between their legs. This potential, known as 'step potential' will cause current to flow through the person, the magnitude of which is dependent on footwear and the person's size. – A larger voltage will typically induce larger currents. **Figure 4** below shows the current flow path for a generic step potential.

Figure 4: Step Potential



More dangerous than step potential is the 'touch potential' in which a person is exposed to dangerous potentials when physically contacting/touching a live component. This scenario is considered more serious as currents are typically more likely to flow through the heart and vital organs. **Figure 5** below shows the current flow path for a generic touch potential

Figure 5: Touch Potential



Typically 70mA is considered a fatal current, this should just be taken as a reference; actual value varies significantly. The longer a person is subjected to such currents, the more likely the heart is to enter a fibrillation state. As such, it is important to consider fault clearing time as longer fault clearing times will increase the rate of fibrillation.

2.5.2 Methodology

Once an appropriate soil model was computed using CDEGS (Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis), tolerable safety limits of touch and step potentials could be determined. The limits were based on the resistivity of the surface layer and simulated for a person to be 50kg, the more onerous technique suggested in IEEE80-2000.

Touch & Step potential limits for 310ms 132kV fault clearance time

Table 8: 132kV Touch and Step Potential Safety Limits

Touch Potential Limit (V)	862.3
Step Potential Limit (V)	2897.7

Touch & Step potential limits for 450ms 22kV fault clearance time

Table 9: 22kV Touch and Step Potential Safety Limits

Touch Potential Limit (V)	735.4
Step Potential Limit (V)	2456.1

Once determined CDEGS software module MALZ was then used to model;

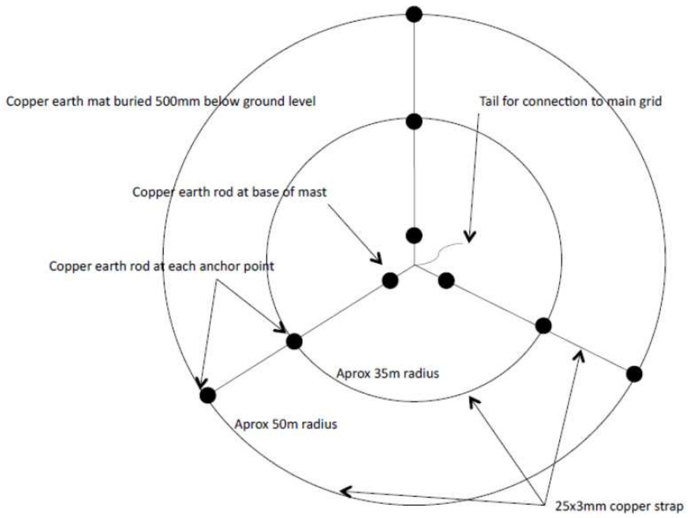
- Substation earth grid
- Met-Mast earth grid
- WTG earth grid

MALZ is a sub module that analyses buried conductor networks and calculates their earthing properties. Using this software, the above 3 grids could be combined to simulate the combined earthing system. Once the system was developed an earth fault current is then simulated to determine the Earth Potential Rise (EPR) in the soil. From the EPR, expected step and touch potentials can be calculated which are then compared to the values above to ensure the safety limits are not exceeded. Finally, conductor cross sectional area (CSA) size is then determined from temperature rise requirements.

It should also be notid that the simulations were only based on Stage A construction. The installation of additional wind turbines will reduce the overall grid resistance and consequently reduce the EPR.

Figure 6: Meteorological Mast earthing grid

A lightning protection design criteria is to have the MetMast grid resistance R_G below 10 Ohms.



As a wind farm operator and a turbine supplier, GE provided a WTG earthing design shown in figure 6 above. This design was adopted by the design consultants who simulated it with their own substation earthing grid. When the project originally commenced, AS3000 required that the earthing system had to be tested to confirm an earthing resistance below 1 ohm as per Appendix K in AS3000. It also continues that if these values could not be met, step and touch potentials must be calculated to confirm that they are at acceptable limits. During earthing design however, Appendix K had been deleted and was now superseded by the requirements of AS2067. In order to comply with our professional obligation, we decided to achieve both standards where possible.

On this basis the design consultant proceeded with the design, using in-house simulation software to simulate various fault situations. On concluding their studies they provided a report detailing the conductor type and size with an overall expected resistance of just less than 1 ohm. These values were calculated assuming the most onerous soil conditions, previously accepted by Western Power. Included in this report was a suggested substation earthing grid which included 7 deep earth rods, each at 45m. In anticipation of these earth rods a local drilling service had been contacted and discussion had begun to locate them to site.

On the basis that an overall system earth impedance of less than 1 ohm was required, this earthing report was submitted for approval. After reviewing, the client expressed concern regarding the system earthing resistance. It was their interpretation that AS3000 specified that a resistance of 1 ohm should be achieved for each individual WTG. The standard also stated that if these values could not be reasonably obtained then step and touch potential calculations had to prove the system was safe. The interpretation of what defined 'reasonably obtained' was not clear. As such supportive calculations were also submitted. Due to the confusion regarding this requirement and the fact that this standard is now superseded, a compromise solution had to be agreed upon. Delays in reaching an agreement would result in delays in foundation pouring and eventually turbine erection.

The required cross-sectional area for a copper conductor must be sized according to the ENA (Energy Network Association) EG1 (Earthing Guide 1) methodology as follows;

$$A = I\left[\frac{T_c \alpha_r p_r \times 10^4 / TCAP}{ln[1 + (T_m - T_a)/(K_o + T_a)]}\right]^{\frac{1}{2}}$$

Where;

$I = RMS\ current\ (kA)$

$T_m = Maximum\ allowable\ temperature\ (°C)$

$T_a = Ambient\ temperature\ (°C)$

$T_r = Reference\ Temperature\ from\ Table\ 10\ of\ ENA\ EG1 - 1\ (°C)$

$\alpha_o = Thermal\ coefficient\ of\ resistivity\ @\ 0°C$

$\alpha_r = Thermal\ coefficient\ of\ resistivity\ @\ T_r$

$p_r = Resistivity\ of\ the\ earth\ conductor\ @\ T_r$

$K_o = \frac{1}{\alpha_o} = \frac{1}{\alpha_r} - T_r$

$T_c = Fault\ Clearing\ Time\ (s)$

$TCAP = Thermal\ Capacity\ Factor\ (J/cm^3/°C)$

A number of coefficients used are found in **table 10** below.

Table 10: Earth Conductor Material Constants

Conductor	Conductivity (%)	α_r (at 20°C)	K_o ($1/\alpha_o$-at 0°C)	Fusing Temp. (°C)	p_r (at 20°C-μΩ/cm)	TCAP ($J/cm^3/°C$)
Standard Annealed Soft Copper Wire	100	.00393	234	1053	1.7241	3.422

The results of applying this sizing method are shown in **Table 11** below;

Table 11: Conductor Sizing Results

	Horiztonal Conductor	Grid Risers	Counterpoise
I (kA)	40	40	2.4
Tc	0.31	0.31	0.45
αr	0.00393	0.00393	0.00393
ρr	1.7241	1.7241	1.7241
TCAP	3.422	3.422	3.422
Tm	450	160	450
Ta	40	50	40
Ko	234	234	234
CSA (mm^2)	**103.61**	**173.20**	**7.49**

To provide an additional margin of safety; 120mm^2 sized horizontal conductor will be used and 185mm^2 tails will be used – this sizing is based on the worst case 132kV fault levels. 95mm^2 copper will be suitable for the interconnected counterpoise system.

As international wind farm operators and designers, GE's recommended earthing grid was to IEC standards. It was originally decided that this design would be suitable provided touch and step potentials were deemed acceptable. Following the rejection of the original design, a meeting was arranged to resolve this issue. This meeting was held in Perth and included LCPL, GE, the client and the design consultants. As the standards were not clear and had since been superseded, a compromised design was agreed upon. The revised design included additional earthing rings inside the foundations. Once poured, the earthing system of each WTG was then tested. The intent being that if any values were too high, additional earthing rings would be installed, decreasing the overall resistance.

During the earthing design, the consultants were required to calculate Earth Potential rises (EPR) that can occur during fault or lightning strike scenarios. An EPR occurs when a large current source is flows through the ground, which is a surprisingly good conductor. These flowing currents can result in a high potential over small distances. These potentials may be dangerous to people and can occur hundreds of metres away from the fault location.

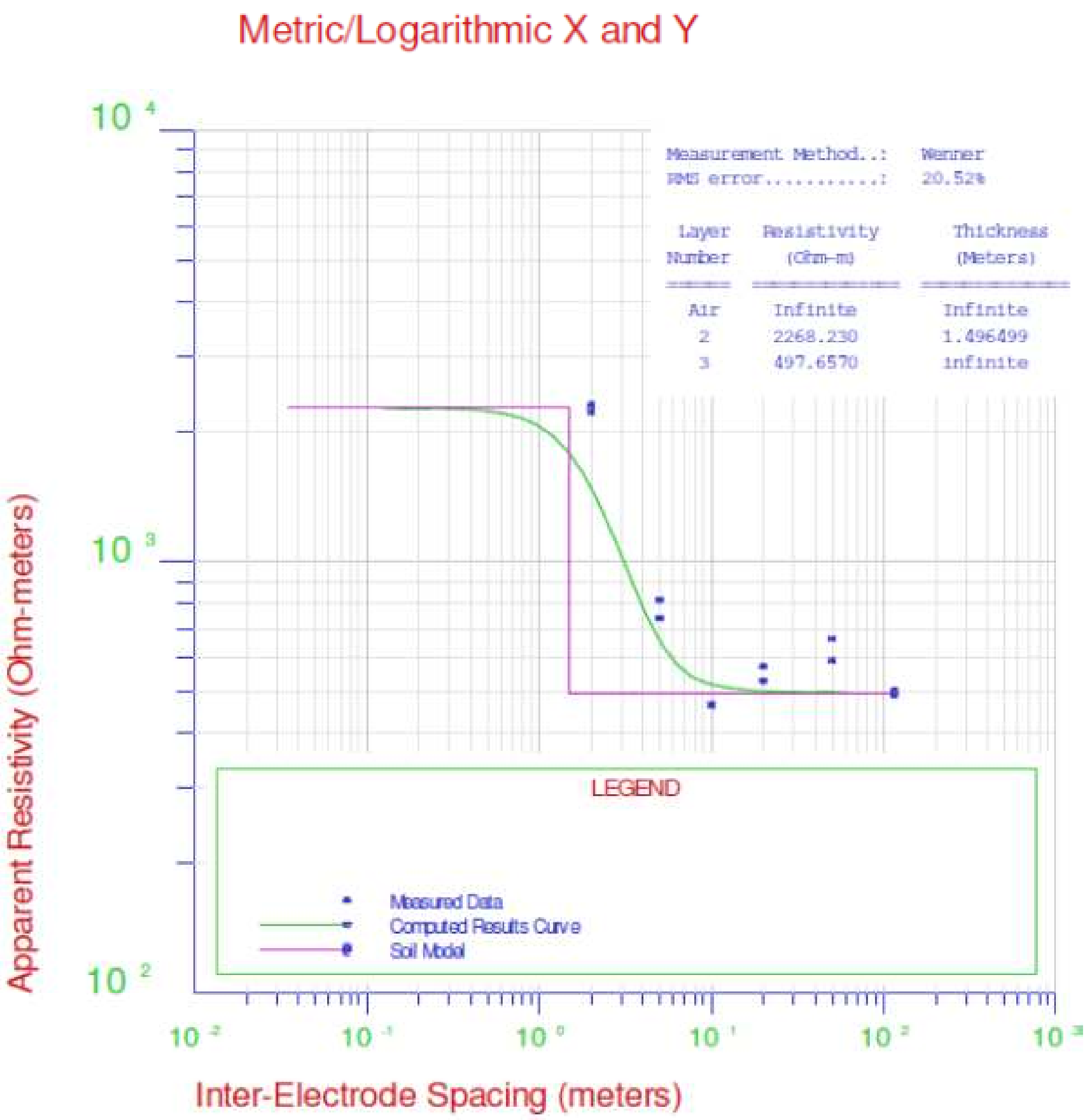
Step potential occurs when a voltage potential is observed between a person's feet, hence the term 'step' potential. Step potentials are normally greater near the grounding point, dissipating with distance. In some fault situations, metallic components may become energised briefly. If a person was to contact this component, a large potential may be observed between the energised component and the ground. This potential is called a 'touch' potential and is often greater if the grounding point of that component is further away.

During original studies, the existing fence lines were not considered – an oversight in the design. Following the submission of design, this issue was highlighted by the client's representative. This point was then relayed back to the design consultants. As the consideration of fence lines were not identified in the kick off meeting, the design consultant insisted additional time and resources would be required to re conduct the studies with fence lines included. As experienced design consultants, it was expected that these studies be performed as per good engineering practise. Commercial issues were then discussed by management as the engineers continued to liaise on a mitigation process. The first idea was to electronically isolate the fence lines at an appropriate distance, likely reducing the touch potential magnitudes. As the wind farm would continue to be operated and maintained as a farm following project completion this idea was rejected by the land owner as it would not allow fence lines to be replaced or moved without additional studies and assistance. Additional studies were not concluded during my internship duration.

Any mitigation measures such as fence breaks and insulation are not practical protection measures in long-term. Given the property is a working farm, farm workers knowledge of electrical safety is limited, and therefore there is a high risk that these measures may be bypassed and will not be maintained.

A two-layer soil model was developed in CDEGS (Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis) software based on the soil resistivity values taken from the geotechnical report developed by a subcontractor. The resultant soil model is shown in **Figure 7** below – the model produces a 1.5m surface layer with a resistivity of 2268 Ohm.m and with a 498 Ohm.m resistivity layer below. The CDEGS soil model is shown in **figure 7** below.

Figure 7: Soil Resistivity Properties



The soil resistivity measurements were obtained using the Wenner four-pin method. In this process, four shallow earth electrodes are inserted into the ground. A current is observed between the two outer pins and the resulting voltage between the two middle pins is then recorded.

2.5.4 Current Status

Following the multiple design changes, a compromised design was agreed upon. This design was re simulated and a revised earthing report was issued. WTG earthing installation commenced during January, with the first results being obtained in February. The overall system impedance is expected to be well below 1 ohm. The same is true if any WTG becomes isolated via conductor damage etc.

To minimise the threat of voltage rise along the fences, a decision was made to insulate the counterpoise conductor each time it crossed a fenceline. At each crossing the conductor would be insulated 5m each side of the fenceline, for a total of 10m. Additional modelling with MALZ to include fencelines confirmed that acceptable touch potentials would still be maintained.

3. Additional Responsibilities

In addition to the aforementioned projects, I was indirectly responsible for a number additional duties. These duties, although not critical to electrical design effectively consumed up to 30% of my time.

The most prominent task was regarding document controlling mentioned previously. Due to the large amount of electrical documents and my understanding of the commercial responsibilities of ourselves as well as the client – I was given the responsibility of internal document control. This task involved keeping a document numbering and document status register. The numbering register was used to allocate a LCPL document number as well as client document number to all equipment specification. These numbers varied between disciplines and originator. The document status register monitored the revision status of all design consultant documents as well as who had received it for review. Upon a revision of a document, it would have to be re reviewed and re submitted to the client. This register also tracked the status of client comment documents.

As our team was responsible for monitoring the progress of up to a dozen subcontractors at any time in addition to liaising with the client and consortium partner, we decided it was a good idea to have weekly meetings with each vendor to track construction progress. In addition to chairing these meetings, I was responsible for keeping a minute's record as well as an action register which allocated responsibilities to many individuals. Between meetings, I was then responsible for ensuring each responsibility was being attended.

Weekly design meetings were also held with our consortium partner, a similar process was followed in this case. In most instances the client or subcontractor requested electrical drawings from GE, being lead contractor; this request had to pass through us. Effectively, I was acting as a 'middle man' for electrical drawings and technical details.

Due to LCPL's health and safety policy, all tasks require a Safety, Health & Environment Works Method Statement (SHEWMS) to be completed. This involves breaking down each task of a job, identifying any health, safety or environmental risk in the process. These risks are then rated according to a risk matrix. If the risk was rated 'moderate' or above, control measures had to be implemented to reduce the risk. Once finished, these SHEWMS had to be reviewed and signed by an engineer as well as the onsite safety manager. Each person then undertaking the specific task is required to read and sign onto the SHEWMS.

During tendering stages, an estimated cost is calculated – this estimation provides the original budget for a project. A budget is then allocated to separate cost codes, which can be broken down into various sub projects, i.e. control building, primary electrical equipment, cable supply etc. To monitor expected expenditure and remaining budget, the current and forecasted costs must be updated on a monthly basis. This monthly process is called forecasting, It is perhaps the most important tool in monitoring a project expenditure and commercial health.

4. Conclusion

From an electrical design perspective, the MWFP was very heavily front loaded due to the long lead items. This in turn reflected to the internship, meaning there was a lot of work to be done in just 16 weeks. Admittingly, there were significant variances between the original project schedule and what was actually achieved. This is not necessarily due to any fault of my own. Instead there were a number of factors including;

- Changes in design
- Adoption of additional tasks in section 3
- Distance from site – approximately 45 minutes
- Delays in receiving information – internally & externally

All things considered, the original tasks outlined in the project were not completed to the extent anticipated. From those tasks completed however, a great deal was learned from a technical and managerial perspective. I was able to learn about wind farm earthing requirements and cable size determination whilst managing a number of onsite subcontractors and chairing weekly meetings with others located all over the world.

With this considered I can already conclude that the overall internship was a great success. I was able to apply my studies in a practical environment, with my background in renewable energy and power engineering being well suited to the MWFP. Working within a small team was very rewarding; I was able to receive a lot of direction and coordination from my direct supervisor.

The meteorological masts appeared to be a very sensitive topic from the start. There was initially some criticism from the management on why an interstate vendor was selected. Fortunately, the due diligence and detail obtained during the evaluation stage paid off. The selected vendor was very cooperative, identifying a number of issues early – particularly the need for site calibration. In addition to this there was minimal on site issues on their behalf. From a design perspective, there were no significant issues regarding the met masts, the process ran quite smoothly.

SCADA coordination was a little more difficult however. I identified this early in the internship. There were no issues with this as a subcontracted vendor handles all technical aspects; I was simply required to coordinate with the parties detailed in section 2. The nominated SCADA subcontractor was well suited to the task, having years of experience and a reputable background in Perth. The amount of liaison and technical exchange between parties was much greater than expected – fortunately it did not significantly impact project delivery.

Although not major tasks of the internship; the additional tasks listed in section 3 provided me with an insight to the additional tasks required of engineers. Particularly the level of management and coordination that is required – this was probably the most challenging due to my age and experience. I often found many contractors were quite uncooperative initially, as they lacked confidence and sometimes respect. Forecasting was another interesting task, from which I became more aware of how a company is run from a commercial perspective. The need to forecast expenditure months before construction is crucial to ensure the project is properly funded and expenses are managed.

5. Future Works

Currently, the Mumbida Wind Farm is in the premature stages of construction, with the bulk of substation electrical works to be conducted throughout June. This includes erection and installation of all HV primary electrical equipment and installation of switchgear at site.

Substation commissioning will then commence, with initial energisation expected during August. Practical completion and project handover is projected to occur during December.

Plans for a stage 2 expansion to 85MW have not yet been confirmed but may be required for 2015.

6. Bibliography

E&S Grounding Solutions. (2012). *Reducing Resistance to Ground*. Retrieved April 27th, 2012, from E&S Groudning Solutions: http://www.esgroundingsolutions.com

International Standards Organisation. (2005). *IEC 61400-12-1 : Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines.* Geneva: International Standards Organisation.

Motherwell Automation. (2012). *Functional Design Specification.* Perth: Motherwell Automation.

Standards Australia. (2005). *AS 62271.102: High voltage switchgear and controlgear - Alternating current disconnectors and earthing switches .* Sydney: Standards Australia.

Standards Australia. (2005). *AS 62271.200: High-voltage switchgear and controlgear - A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV.* Sydney: Standars Australia.

Standards Australia. (2008). *AS2067: Substations and High Voltage Installations Exceeding 1kV AC.* Sydney: Standards Australia.

Standards Australia. (2005). *AS2650: Common specifications for high-voltage switchgear and controlgear standards .* Sydney: Standards Australia.

Standards Australia. (2007). *AS3000: Electrical Installations.* Sydney: Standards Australia.

Standards Australia. (2000). *AS4799: Installation of underground utility services and pipelines within railway boundaries.* Syndey: Standards Australia.

Standards Australia. (2008). *AS62271.100: High-voltage switchgear and controlgear - High-voltage alternating-current circuit-breakers .* Sydney: Standards Australia.

Verve Energy. (2011). *Engineer, Procure, Construct Specification.* Perth: Verve Energy.

Western Power. (2007). *Network Standard 14.2: Underground Cable Installation Manual.* Jandakot: Asset Management.

Western Power. (2007). *Technical Rules.* Perth: Western Power.

Worley Parsons. (2011). *22kV Earthing Study Report.* Perth: Worley Parsons.

Worley Parsons. (2011). *Equipment Specification - 132kV Circuit Breaker.* Perth: Worley Parsons.

Worley Parsons. (2011). *Equipment Specification - 22kV Metalclad Switchboard.* Perth: Worley Parsons.

Worley Parsons. (2011). *Equipment Specification - Disconnector & earth Switch.* Perth: Worley Parsons.

Worley Parsons. (2011). *Equipment Specification - Instrument Transformers.* Perth: Worley Parsons.

7. Appendices

a. Cable Connection Diagram

b. Cable Installation Drawing

c. Conduit Arrangement

CONDUIT ENTRIES INTO EACH WTG				
WTG	**POWER 150mm Orange HDPVC**	**EARTH 50mm Orange HDPVC**	**COMMUNICATIONS 50mm White**	**LV POWER TO MET MAST 50mm Orange HDPVC**
1	3 SOUTH	2 opposing	1 SOUTH	
2	6 SOUTH	2 opposing	1 SOUTH (2)	
3	3 WEST	2 opposing	1 WEST	
4	6 NORTH	2 opposing	1 NORTH (2)	
5	3 SOUTH	2 opposing	1 SOUTH	
6	3 SOUTH	2 opposing	1 SOUTH (2)	1
7	6 EAST	2 opposing	1 EAST (2)	
8	3 WEST	2 opposing	1 WEST	
9	3 NORTH + 6 SOUTH	2 opposing	1 SOUTH (2) + 1 NORTH	
10	3 WEST	2 opposing	1 WEST	
11	6 NORTH + 3 EAST	2 opposing	1 NORTH (2)	
12	3 EAT + 6 WEST	2 opposing	1 EAST + 1 WEST (2)	
13	3 NORTH + 6 SOUTH	2 opposing	1 NORTH + 1 SOUTH (2)	
14	3 WEST	2 opposing	1 WEST	
15	3 EAST + 3 WEST	2 opposing	1 WEST + 1 EAST	
16	6 SOUTH	2 opposing	1 SOUTH (2)	
17	3 NORTH + 3 SOUTH	2 opposing	1 NORTH + 1 SOUTH	
18	3 SOUTH	2 opposing	1 SOUTH	
19	6 NORTH + 3 SOUTH	2 opposing	1 NORTH (2) + 1 SOUTH	
20	3 NORTH	2 opposing	1 NORTH	
21	3 EAST + 3 SOUTH	2 opposing	1 EAST + 1 SOUTH	
22	6 SOUTH	2 opposing	1 SOUTH (2)	
23	6 SOUTH	2 opposing	1 SOUTH (2)	
24	3 EAST	2 opposing	1 EAST	
25	3 NORTH + 3 SOUTH	2 opposing	1 NORTH + 1 SOUTH	
26	9 NORTH	2 opposing	2 NORTH (3)	
27	3 EAST + 3 WEST	2 opposing	1 WEST + 1 EAST	
28	6 NORTH	2 opposing	1 NORTH + 1 SOUTH	1
29	6 SOUTH	2 opposing	1 SOUTH (2)	
30	6 SOUTH	2 opposing	1 SOUTH (2) + 1 EAST	1
31	3 NORTH + 3 SOUTH	2 opposing	1 NORTH + 1 SOUTH	
32	3 WEST	2 opposing	1 WEST	
33	6 WEST	2 opposing	1 WEST (2)	
34	3 WEST	2 opposing	1 WEST	

d. Detailed Cable Spreadsheet

e. Cable Length Comparison

Luke	Surveyed+20m	Difference	%
1245	1207	38	3.052209
799	776	23	2.878598
1324	1274	50	3.776435
1443	1359	84	5.821206
950	932	18	1.894737
1968	1926	42	2.134146
825	769	56	6.787879
1617	1528	89	5.50402
647	638	9	1.391036
565	566	-1	-0.17699
592	590	2	0.337838
874	850	24	2.745995
1059	1012	47	4.438149
749	748	1	0.133511
574	557	17	2.961672
593	572	21	3.541315
1003	978	25	2.492522
1252	1212	40	3.194888
1363	1319	44	3.228173
831	789	42	5.054152
761	731	30	3.942181
927	882	45	4.854369
239	223	16	6.694561

f. Substation Layout

g. Disconnector Ratings

9.102.1 Rated values and characteristics

Table below states the disconnector's ratings and operating requirements;

Number of Poles	3
Installation: Indoor/outdoor	Outdoor
Rated Voltage	145kV
Rated Insulation level & Switching Impulse withstand voltage	650kV peak
Rated frequency	50Hz
Rated normal current (Disconnectors)	1600A
Rated short-time withstand current and peak current	40kArms for 1 sec
Rated short-circuit making current (Earth Switch)	40kArms for 1 sec
Rated bus-transfer current switching to annex B	80% Rated normal (<1600A)
Rated induced current switching by earthing switches to annex C	$50A_{RMS}$
Rated mechanical endurance of disconnectors (class M);	M0 – 1000 cycles M1 – 2000 M2 – 10 000 operating cycles
Rated electrical endurance of earthing switches (class E).	Not Rated

9.102.2 Constructional features

Table below states the disconnector's ratings construction arrangement;

Mass of complete Disconnector or Earthing switch	Approx 585kg
Minimum clearance in air: – between poles, – to earth, – for isolating distance (for disconnectors only)	 2400mm 2700mm 1500mm
Corrosion protection	C - Medium

Disconnector Construction Requirements

9.102.3 Operating mechanism of a disconnector or earthing switch and associated equipment

Table below states the disconnector's operating mechanism characteristics;

type of operating mechanism	Manual
rated supply voltage and/or pressure of operating mechanism	110V DC

Disconnector Operating Parameters

h. Disconnector GA

i. Instrument Transformer Ratings

Instrument Transformers

Location: Outdoor/Indoor	Outdoor
Installation Type	Oil Immersed
Frequency	50Hz
Pollution Level	IV Very Heavy (31mm/kV creepage)
Nominal Voltage	132lV
Rated Voltage	145kV
System Earthing	Solidly Earthed
Rated Power Frequency Withstand	275kV
Rated lightning impulse withstand	650kV
Switching Impulse Withstand	N/A
Rated normal primary current	1600A
Winding Temperature Limit	Table 2
Continuous current ratings of secondary winding	1A
Continuous thermal current rating of secondary windings;	2A
Rated short time withstand current	40kA
Initial peak current	As per AS 60044.1
Partial Discharge at 1.2Um/√3	5 pC
Design Life	40 Years
Radio Interference Voltage (RIV)	As per AS 60044.1

CT Ratings

Nominal Voltage	132kV
Rated Voltage	145kV
Operating Frequency	50Hz
Number of Phases	Single
Number of Secondary Windings	2
Rated Primary Voltage (phase to Neutral)	132/√3 V
Rated Secondary Voltage (Phase to Neutral)	110/√3 V
System Earthing	Solid
Insulation Level (BIL)	650 kV
Power Frequency Withstand	275kV
Location	Outdoor
Ambient air temperature range	-5 to 50 C
Pollution Level	Very Heavy (AS4436)
Minimum creepage distance	4495 mm
Type of Construction	Oil Filled
Rated Mechanical Terminal Load	2500

IVT Ratings

1a). Current Transformer - Metering			
Core 1	Tariff Metering	Ratio Class	600/300/1 15VA class 0.5 all ratios
Core 2	Check Tariff Metering	Ratio Class	600/300/1 15VA class 0.5 all ratios
1b). Voltage Transformer – Metering			
Rated Secondary Voltage	1a, 1n	110/√3 V	

	2a, 2n	110/√3 V	
Secondary winding characteristics		Secondary (1)	Secondary (2)
Application		Tariff Metering	Tariff Metering
Class Designation		0.5 (metering)	0.5 (metering)
Rated Output		50VA	50VA
Lower Limit of Burden		0% rated	0% rated
2). Current Transformer Type 1			
Core 1	Buszone 1	Ratio Class	1000/500/1 0.05PC1200R4 @ 1000/1
Core 2	Buszone 2	Ratio Class	1000/500/1 0.05PC1200R4 @ 1000/1
Core 3	Wind Farm Control	Ratio Class	600/300/5 30VA class 0.2 all ratios
Core 4	Buszone 1 (Western Power)	Ratio Class	1000/500/1 0.05PC1200R4 @ 1000/1
Core 5	Buszone 2 (Western Power)	Ratio Class	
3). Capacitor Bus Voltage Transformer			
Rated Secondary Voltage	1a, 1n	110/√3 V	
Secondary winding characteristics			
Application		Wind Farm Control	
Class Designation		0.5/3P	
Rated Output		50VA	
Lower Limit of Burden		0% rated	

Combined Metering Transformer Ratings

j. Instrument Transformer GA

k. Circuit Breaker Ratings

Number of Poles		3
Application		Outdoor
Design		Auto Puffer Interrupter
Operating Mechanism		Spring Motor Drive
Pollution Class		IV Very Heavy
Insulation Medium		SF_6
Rated Voltage		145 kV
Rated Frequency		50Hz
Power Frequency Withstand Voltage	Phase to Earth Across Open Switching Device	275 kV_{RMS} 275 kV_{RMS}
Lightning Impulse Withstand Voltage	Phase to Earth Across Open Switching Device	650 kV_{peak} 650 kV_{peak}
Rated normal current		1600A
Rated short circuit breaking current	Symmetrical	40 kA_{RMS}
Rated short circuit breaking current	Figure 9 AS62271.1	Curve t_1=45ms
X/R Ratio		14
First pole to clear factor		1.3 pu
Rated Transient Recovery Voltage for terminal faults		115 kV_{peak}
Rated short time withstand current		40 kA_{RMS}
Circuit Breaker break time		<50ms
Rated short circuit making current		100kA peak
Rated operating sequence		0-0.3s-CO-3min-CO
Phase separation		1750mm
Rated line charging breaking current		Table 5 AS62271.1
Rated cable charging breaking current		Table 5 AS62271.1
Out of phase braking current		Table 5 AS62271.1
Minimum creepage		4495mm

132kV Circuit Breaker Rating

l. Circuit Breaker GA

m. Post Insulator Ratings

Rated Voltage	132kV
Bending Failing Load	10 kN
Torsion Failing Load	7 kN
Minimum Creepage	4495mm
Lightning Impulse withstand Voltage	650 kV
Power Frequency withstand Voltage	275 kV
Material	Porcelain

Post Insulator Construction Details

n. Post Insulator GA

o. 22kV Metal clad Switchgear Ratings

Type	Air Insulated, Metal Clad
Location	Indoor, non-hazardous
Rated Voltage	24kV
Rated Frequency	50Hz
Number of Phases	3
Rated Lightning Impulse Withstand Voltage	125 kV_{peak}
Rated short duration power frequency withstand voltage	50 kV_{RMS} for 1 min
Rated short time withstand current and time	25 kA_{RMS} for 3 secs
Internal arc fault withstand to AS62271.200	Annex A.6 Criteria 1 to 5
Duration of internal arc fault test	1 sec
Rated peak withstand current	63 kA_{oeak}
Earth busbar withstand current and time	25 kA_{RMS} for 3 secs

Switchboard Ratings

p. Overall Earthing Layout