Murdoch University
ENG450 – Final Year Internship – 2008

Final Report

Independent Engineering tasks in the Wind Farm Industry

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.

Internship Student:	Grant Wallace (30388257)
Company:	Garrad Hassan Pacific Pty. Ltd.
Industry Supervisors:	David Millar / Graham White
Academic Supervisor:	Martina Calais
Unit Coordinator:	Parisa Bahri

Table of Contents

List of Tables and Figures

Abstract

This report describes the various tasks undertaken during the Engineering Internship position with Garrad Hassan Pty Ltd, a global wind farm consultancy. The majority of tasks involved independent electrical engineering reviews of wind farm design and construction in Australia and Asia.

The larger tasks included an electrical due diligence review of a wind farm project in Asia, multiple turbine inspections at various Australian wind farms, and an electrical due diligence review of all pipeline and under-construction wind farm projects for a global wind farm developer.

There were also many small-medium tasks included in the Internship position, which covered a large range of engineering abilities. Each of the tasks resulted in greater knowledge and experience in common and not-so-common engineering problems, which has proved to be very worthwhile. A much better understanding of contracts, tenders and regulations have also come out of this position.

Acknowledgements

I would like to acknowledge the IE manager, David Millar, and the Managing Director, Graham White, my industry supervisors at Garrad Hassan, for all their assistance and patience throughout the Internship. Also, Philip Wong Too, the Electrical Engineer of GH Wellington and Paul Gardner, the Senior Electrical Engineer of GH Glasgow, have provided excellent support. I would also like to thank Martina Calais, my academic supervisor, and well as Parisa Bahri, the Unit Coordinator, for their support during the Internship.

Introduction

Internship Background

Murdoch University offers 4th year Engineering students the option of an Internship for the final unit (ENG450), to provide an opportunity for students to gain work experience while completing the final year of studies. The Internship requires at least sixteen (16) weeks of full time employment in an approved area, generally in the 2nd semester, and is intended to expose the student to a range of engineering practice issues and experiences.

Throughout my university degree, I have wanted to work as an Electrical Engineer in the Renewable Energy industry, particularly in the wind farm industry. So, in preparation for the Internship at the beginning of my final year at university, I contacted many Australian companies involved in development or consultation of wind farms. Several companies replied with an interest in my Internship proposal and, after interviews with three (3) of the most suitable companies, I agreed to sign with the Melbourne office of Garrad Hassan Pacific Pty. Limited.

Company Background – Garrad Hassan Pty. Ltd.

Garrad Hassan (GH) was established in 1984 to provide independent expert advice on wind energy. GH now employs over 300 full time staff around the world, with offices in 18 countries. The Melbourne office is part of the Garrad Hassan Pacific (GHP) group, which also includes two other offices: Newcastle in NSW, and Wellington in New Zealand. The Melbourne office is comprised of two teams: *Wind and Energy (W&E)*; and *Independent Engineers (IE).* The W&E team primarily focus on the wind resource and expected power output from proposed wind farm developments, whilst the IE team are employed by financial lenders (i.e. Bank's Engineer) and wind farm owners (i.e. Owner's Engineer) to fulfil various engineering tasks, such as reviewing engineering documents and practices, and advising on particular technical issues of wind farms. The majority of GH work involves different aspects of the wind farm industry, however GH have recently added solar and marine (wave/tidal) services to the global portfolio.

My Internship Role

I was selected to work within the Independent Engineer (IE) department for the duration of the Internship. Due to the nature of GHP’s IE role, it was not practicable to assign a single project to this 5-month Internship position. Instead, several tasks have been assigned to the position (3 large tasks, 4 medium tasks and 8 small tasks). There have also been several day-to-day tasks that will not be described in this report because of their short turnaround time, however these small tasks add up to a significant portion of the workload of an IE when all put together. The majority of tasks were not known at the beginning of the Internship since it was not possible to know which new or existing clients would require the services of GHP’s IE department. However, the department was kept very busy for the 5-month period and there were frequent additions to my list of tasks to complete.

The three other members of the IE department in the Melbourne office are mechanical engineers, so I was assigned all the tasks that were in the field of electrical engineering due to my university education in Power Engineering and Renewable Energy Engineering. Also, due to the abundance of non-electrical work in the list of IE tasks, there were other tasks assigned to me that did not require electrical engineering knowledge. However, almost all tasks required a report to be presented to a high standard and usually involved general engineering knowledge in the research and subsequent review process.

Larger Tasks

This section lists the three (3) largest tasks that I was involved in during the Internship.

> **Confidentiality** – Please note that as a consultancy, Garrad Hassan are provided with privileged information, such as developer and contractor documents, for each project and this information is usually not publicly available. Therefore, to protect client confidentiality, I have omitted all references to client names and specific project details from this report and have sometimes used a pseudonym in its place (i.e. *DeveloperA*).

Task 1 – Electrical Due Diligence for a wind farm in Asia

Before the beginning of the Internship, GHP was asked by the financial lender (the "Lender") for an Asian wind farm (exact location not provided to protect client confidentiality) to provide a Due Diligence review. This review was to include the electrical design, energy assessment, construction process and environmental impact. The Lender engaged GHP's services to accomplish this task in order to provide an independent and rigorous evaluation of contract and technical project risks. This allows the Lender to be in a better position to analyse the risks in investing in the wind farm, and to have certain risks extinguished before the project begins on advice of GHP's IE reports.

Due to my electrical engineering education, it was decided that I would be assigned the task of reviewing the electrical design, with assistance provided by Philip Wong Too, the Electrical Engineer of GHP in Wellington, NZ, and David Millar, GHP's IE Manager in Melbourne. The energy and construction reviews were to be handled by other GH departments, while the environmental impact review was to be handled externally [see Task 14]. However, the IE department of GHP Melbourne would be heavily involved in the project management for all tasks.

The particular areas of concern to the Lender in the electrical due diligence review are things that would cause a "blow-out" in the cost of the project (i.e. things that are expensive to fix or cannot be fixed). Common causes may be due to non-compliance with the technical requirements of the country's electrical network rules or interconnection agreement. Failure to comply with these could see the wind farm not being able to connect fully or require some expensive equipment that hasn't been budgeted for (e.g. reactive power compensation equipment). Another cause may be due to poor selection of cable sizes and other equipment ratings. Of particular concern is the sizing of underground cables, as these are very expensive to replace if the original calculation results were incorrect. Also, if the ratings on equipment are not taken into account, the equipment may be destroyed from overvoltages or overcurrents.

Some items, such as minor safety issues, can be fixed at relatively low cost so these are of lesser concern to the Lender, however the due diligence process should attempt to cover all aspects where possible.

This task progressed quite slowly for the first several weeks of the Internship, primarily because of the training that I needed for the role, particularly in electrical engineering. The Melbourne office employs several engineers, but currently has no electrical engineers to directly assist with this electrical due diligence. It had been decided from the start of the Internship that I would be sent to Garrad Hassan's Glasgow office in the U.K. for 4 weeks to work alongside their electrical engineering team. This trip was held during the month of September, where I worked under the supervision of the company's senior electrical engineer, Paul Gardner, along with the other members of the electrical team. The time spent in the Glasgow office mainly consisted of progressing through my own tasks from the Melbourne office, with assistance readily available when required. Electrical training was also provided by Paul Gardner, with the focus on an electrical due diligence procedure that is used by Garrad Hassan (GH). Therefore, I was able to make good progress on this task during the trip.

The first step in the review process was to sort through the large database of documents from the developer's electronic dataroom, and establish which documents were required for the electrical due diligence review. The documents then needed to be examined to establish what information was included and what information was missing. A particular focus, at this stage, was on the requirements of the Interconnection Agreement. Note that this was my first encounter with the numerous documents involved in a wind farm's electrical system design, so quite a few scans were required to achieve the desired result. A list of electrical documents still required for review was then created, as well as a list of documents requiring translation into English, as many of the documents were written in the local language of the country. This list was checked by the Electrical Engineer of GH Wellington (this step was achieved before I was sent to Glasgow), and then emailed to the developer.

One of the most critical documents for the electrical review was the *Regulations on the Use of Electrical Facilities for Power Transmission* [Ref 7] document from the country's electric power corporation. This document needed to be thoroughly scrutinised to establish any possible non-compliance issues that may arise from the wind farm development. A summarised version of the document was produced, listing only the applicable points, so a comparison could more easily be made when reading through the developer's documentation.

The training provided in GH Glasgow included a description of the Electrical Due Diligence procedure, which basically lists all the items that should be examined in the electrical review, as well as some important issues to watch out for. Once the answers to each of the items have been found from the documentation, the report can be written. Often, the answers to several items cannot be found in the provided documentation, so it must be decided whether to ask the developer to provide the answer (subject to time-constraints), or to simply notify the client of the level of risk due to the missing information, when writing the report. This step is the largest part of the due diligence process, since each point involves reading through all received documentation to find the appropriate requirement and then to check whether the requirements have been met. The main documents involved in this review are listed in the References section of this document [Ref 7 to 14].

Another part of the Due Diligence procedure involves calculating the power losses from the cables and transformers. The collector system cables of a wind farm are those cables that connect between the wind turbines to the substation. The voltage drop and electrical losses from the collector system were calculated by the electrical contractor, however GH use an internally-designed spreadsheet to independently calculate the losses from the collector network and the transformers, and to compare these results with the contractor's report.

Refer to Task 5 of this report for more information on the method used to calculate the electrical losses.

Once all of the points of the due diligence procedure list were answered as completely as possible, the report could be written. In order to provide a report to the high standard expected from a GH due diligence report, some earlier reports were studied from other projects and notes were taken in regards to the style used. All relevant items in the procedure were mentioned in the report, particularly those that do not comply with the Interconnection Agreement or the power corporation's Regulations.

The body of the Electrical Due Diligence report (Final Draft) that I produced is included below, however all names have been changed to protect client confidentiality.

LocationA Wind Farm – Electrical Due Diligence

Electrical System Overview

LocationA Wind Farm comprises forty one (41) *DeveloperA TurbineA ##*MW wind turbines, divided into ten 12kV underground collector groups (9 collector groups of 4 turbines and 1 group of 5 turbines), connected to a 60MVA/70MVA (154kV/12kV) transformer via protection circuitry. There is a 16km (approx.) 154kV transmission line connecting the wind farm substation to the grid at *SubstationA*, which includes an undisclosed length of underground line and 51 steel towers for the overhead line.

Primary Documentation Reviewed

- Transmission Interconnection Facilities Agreement

GH has reviewed the Interconnection Agreement [Ref 7] between *GridOperatorA* and *LocationA* Wind Energy (*LWE*). The agreement provides for a connection of a ##MW wind energy power production facility. It is important to note that the Interconnection Agreement did not specifically mention any reasons for curtailment to address any instability issues that may be caused by the wind farm.

- Contract for Electrical Engineering Construction Work

GH has reviewed the Electrical Contract [Ref 8] between *DeveloperA* and *ContractorA* relating to the *LocationA* Wind Farm Project. The Contract states that the electrical contractor, *ContractorA*, shall perform the electrical work for the wind farm, including the engineering, design, procurement and construction of electric works for the BOP (Balance of Plant) of the project. *ContractorA* has extensive experience in electrical engineering projects; however it is unknown to GH whether the company also has experience in wind farm development projects.

Several reports have been produced by *ContractorA* (using a reputable modeling program, "ETAP") for the project and have been reviewed by GH, including a Short Circuit Calculation study, Harmonic Analysis, Voltage Drop & Loss Calculation and the Cable Capacity Calculation for 12V cable. GH notes that the provided reports do not cover all the electrical studies normally undertaken for a wind farm, including a steady state load flow report for the full range of voltage and reactive power production/consumption, a transient study and an earthing report. The completion of these additional reports is recommended by GH, for the reasons described in the "Systems Studies" and "Earthing" sections of this document.

- Regulations on the Use of Electrical Facilities for Power Transmission

GH has reviewed the Power Transmission Regulations [Ref 9] from the *GridOperatorA.* The Regulations define the charges and other conditions of use for electrical facilities for power transmission with *GridOperatorA*.

Grid Connection

The Interconnection Agreement [Ref 7] states that the national electrical grid operator, *GridOperatorA*, has provided *LWE* with an interconnection point on the new 154kV transmission line (approx. 16km length) between *SubstationA* and the *LWE* wind farm, at the circuit breaker located at the *SubstationA* end of the new transmission line. The connection point of *DeveloperA* is at the circuit breaker located at the wind farm end of the new line. GH understands that *LWE* has responsibility for the construction and maintenance of the new transmission line (approx. 16km length).

Power Purchase Agreement

DeveloperA has advised that a Power Purchase Agreement (PPA) is not necessary in *CountryA*. Instead, an application for the sales of energy is submitted and the price applicable is the one established by law. *DeveloperA* stated that there is a tariff protection for wind power generation, where the government compensates the difference between the standard price for renewable energy and the system marginal price (if the market price is lower than the standard price). *DeveloperA* have also sent a yearly price chart [Ref 19] to GH, showing the price paid for wind power with annual decrements [2008 price 107.29 *X*/kWh; 2009 price 105.14 *X*/kWh; 2010 price 103.04 *X*/kWh; 2011 price 100.98 *X*/kWh]. GH believes that there may instead be a fixed price for the wind farm for the initial 15 year period, although no supporting documents were provided.

GH believes that the relevant document should be supplied stating the purchase price for the lifetime (or the initial 15-year period) of the project if such an agreement has been made.

System Studies

GH has not seen any documents showing a study on the grid impact from the *LocationA* wind farm project, apart from the harmonics analysis [Ref 11]. The grid impedance values provided by *GridOperatorA* [Ref 11] show that the fault levels are relatively high (at around 1470MVA at the connection point), so the grid should not suffer problems with flicker levels or power quality; however this is only a rough estimation.

GH notes that there is an absence of a **steady state flow study** showing that voltages and power flows within the grid network remain within limits for the full range of generation, loads and transfers expected on the transmission system. Also, there is an absence of a **transient study** to ensure that the system will remain stable and faults will be able to be tolerated after the connection of the wind farm.

GH recommends these studies be undertaken, however due to the strong short circuit ratio and the use of modern turbine technology, the studies are unlikely to reveal problems in either area. Note that if there were grid problems from the interconnection of the wind farm, relatively expensive compensation equipment may be required (e.g. capacitor bank or SVC). It is not clear from the Interconnection Agreement as to who would take the responsibility for these costs, however GH believe that it would fall to LWE.

Load Flow

The results of the load flow study for the wind farm system [Ref 12] by *ContractorA* show that the voltage drops at each bus are within the maximum 3% voltage drop standard, and also below the 10% limitation from the *TurbineA* turbine specifications (12kV±10%). However, GH notes that the calculations in the document are only based on a case where each turbine is at full load, nominal voltage, and 0.95 power factor.

GH recommends the study be repeated within limits for the full range of generation (particularly a more inductive power factor) to see if the bus voltages are still within the allowable levels.

Short circuits & Protection

The *DeveloperA TurbineA* turbine specifications [Ref 10] state that it is necessary to ensure a short circuit ratio of higher than 5 at the turbine terminals (i.e. >7.5MVA). From the short circuit study [Ref 13], the minimum 3-phase fault level at a turbine location is 5.3kA (WTG-41), which equates to a short circuit power of around 110MVA. GH is satisfied that this short circuit ratio requirement has been met.

The short circuit study [Ref 13] includes schematics that show the effects of 3-phase fault currents at the 12kV main bus after various cycle lengths. The protection equipment shown in the schematics appear to be appropriately rated for the fault currents shown.

Earthing

The *DeveloperA TurbineA* turbine specifications [Ref 10] state that the earthing system of the wind turbine has been designed following the indications of the Germanischer Lloyd Rules. It also states that the good performance of these systems is dependent of a local earthing system with a resistance lower than 10 ohms, even when the earth network is disconnected from the turbine.

The design and construction of the earthing of the collector system is included in the electrical contractor's scope [Ref 8], however no documents have yet been supplied to GH that show the method of earthing used or even if the soil resistivity tests have been performed.

GH recommends that the electrical contractor provide a full earthing report, since equipment could be damaged and fatalities could occur during over-voltages or lightning if the earthing system is inadequate.

Collection System

The 12kV collection system is comprised of 10 collector groups (9 of the groups contain four turbines and 1 group contains five turbines). GH is satisfied with selection of cable sizes that resulted from the cable capacity calculations [Ref 14] for the 12kV collector system.

Substation

The scope [Ref 8] of the electrical contractor, *ContractorA*, includes the electrical works of the substation. The substation includes an On-Load-Tap-Changing (OLTC) transformer that will isolate the wind farm from any steady state voltage problems on the *GridOperatorA* network, meaning that the wind farm can remain at rated voltage (steady state) during any steady state voltage disturbances on the grid. However, the tap-changing capability of the OLTC transformer is relatively slow, so it is not used to correct transient voltage fluctuations or to fix the overall grid system voltage. Again, GH recommends a transient study to be undertaken, as described in the “System Studies” section.

The Interconnection Agreement [Ref 7] states that in case of a problem in the transmission line between the substation and the wind farm, then *LWE* will bear the cost of the system breakdown and pay for the amount of power deficiency through interlocking cutoff device (Incidental costs, etc). GH interprets this as *LWE* to be responsible for all costs involved due to faults on the transmission line between *SubstationA* and the wind farm.

Metering

The Interconnection Agreement [Ref 7] states that *LWE* and *GridOperatorA* will agree on the installation of a metering system and the metering data acquisition terms following Electric Market Regulation.

The Substation Single Line Diagram [Ref a] includes a power meter on the HV side of the 12kV/154kV transformer, which is believed to be the revenue meter, although there were no supporting documents provided. There are also other power meters shown in the diagram, but these are assumed to be for internal use by the wind farm. The location of the revenue meter is important to understand whether the transmission line losses fall to *GridOperatorA* (i.e. located at *SubstationA*) or to *LWE* (i.e. located at the wind farm).

The Regulations [Ref 9] state that if “customers have violated these regulations, and a part or whole of fees were not calculated accurately, the customers shall pay a penalty for breach of contract up to three times the amount in shortage.”

GH notes the importance of an accurate metering system at the wind farm and recommends the electrical contractor provide details on the metering to be used, including its location.

System Performance

Frequency Range

There are several frequency requirements imposed by the Regulations [Ref 9] on the output of the wind farm, which are shown below:

- Ability to operate continuously at the rated output in the range of 58.5Hz to 61.5Hz
- Ability to operate for at least 20 seconds during a frequency drop in the range of 57.5Hz to 58.5Hz
- Generator disconnection allowed if the frequency drops under 57Hz

The *DeveloperA TurbineA* specifications [Ref 10] state that the turbines should only trip below 57Hz or above 63Hz. GH notes that this operating range is within the regulatory requirements.

Voltage Range

The Regulations [Ref 9] state that the generator must be able to operate continuously within ± 5% of the rated terminal voltage.

The *DeveloperA TurbineA* specifications [Ref 10] state that the turbine has been designed to work on steady state with voltages ±10% of rated voltage. The wind farm also includes an OLTC transformer that can adjust the voltage up to ± 10% of the rated voltage at the substation. GH notes that this operating range satisfies the regulatory requirements.

Power factor

The *DeveloperA TurbineA* specifications [Ref 10] state that the turbine has an adjustable power factor (maximum of 0.93 inductive to 0.93 capacitive).

The Regulations [Ref 9] require that generators must supply reactive power in the range of 0.9 to 0.95 for power factor at the rated voltage and power output. GH notes that the clause in the Regulations is somewhat unclear, as it could be interpreted as requiring a power factor of 0.95 or better, which the wind farm can achieve, or requiring the supply of reactive power in the entire range from 0.9 to 0.95, which the *DeveloperA TurbineA* turbines cannot achieve without compensation equipment (e.g. capacitor bank or SVC). It also does not mention where the power factor is measured (i.e. the generator terminals or the *DeveloperA* connection point, or even at the *GridOperatorA* connection point).

This is important, as the extensive cable network will cause the power factor to differ at each of the different points.

GH recommends establishing the correct interpretation of the requirement, due to the fact that there are no compensation devices included in the wind farm design and this can be a costly addition if found to be required at a later date. This could be in the order of €1m for a capacitor bank with switching, or significantly more for a STATCOM (however, the requirement of a STATCOM is unlikely).

Power Quality

Harmonics & Flicker

The harmonic study [Ref 11] of the wind farm produced by *ContractorA*, reveals the Voltage total harmonic distortion to be 0.4%, which is within the maximum 1.5% requirements of *GridOperatorA*. The Current total harmonic distortion was calculated to be 1.39%, which is also within the maximum 4.0% requirements of *GridOperatorA*.

The Regulations [Ref 7] state that *LWE* shall immediately submit to *GridOperatorA* the documents with the data regarding harmonics among the 154kV lines for *GridOperatorA* approval. *GridOperatorA* will review whether or not the harmonics comply with the permitted range at the place of origin and if the review concludes that the harmonic surpass the range limits, *LWE* must apply the adequate filters on the wind farm.

DeveloperA has stated in an email to GH (26/09/08) that they will forward the document to GridOperatorA for approval during the following week. GH has received no further information, however DeveloperA are confident that no use of filters will be required.

Electrical Losses

The electrical contractor calculated the electrical losses [Ref 12] within the wind farm by setting the maximum allowable voltage drop to 3% in a circuit between the substation and any wind turbine generator. The results of the study showed the 12kV branch cable total loss to be 923.7kW (around 1.5%) and 374.2kVAR at rated power and 0.95 power factor. GH notes that these results do not take into account the 12kV/154kV transformer losses, which are estimated to increase the total losses to around 1100kW (around 1.8%) at rated power. The losses from the 16km (approx.) 154kV transmission line to *SubstationA* are estimated to increase the total losses to around 1360kW (2.2%), and this should have also been included in the calculations if the location of the revenue meter is at *SubstationA* (see "Metering").

GH recommends that the loss calculation be repeated to allow for the transformer losses. This should also include the transmission line losses if the power is being measured at SubstationA. The wind speed distribution and the turbine warranted power curve should also be included, in order to produce an estimate of the annual electrical losses. This calculation would also highlight the amount of energy imported when the wind farm is not exporting.

Summary

The electrical works for *LocationA* Wind Farm are to be designed and constructed by the electrical contractor, *ContractorA*. Several studies have been performed by the contractor, however GH recommends some additional studies to be performed, namely a comprehensive steady state load flow study, a transient study and an earthing report.

The wind farm design currently does not include reactive power compensation equipment (e.g. capacitor bank or SVC), and if these were found to be required due to the effects on the grid network, large unexpected costs may result. The recommended studies would discover whether the additional equipment is required.

Current Status: QA process [Task Received 24/6/08, Completed 27/10/08]

The draft report shown above has passed through the internal QA process, which includes a review by GH's senior electrical engineer, Paul Gardner. Several suggestions were made in the QA review, such as: '*Include the estimated cost value for the capacitor bank with switching in the report (i.e. €1m), rather than just saying "relatively large costs"*'; and '*Use the term "more inductive power factor" rather than "lower power factor".'* The appropriate amendments have been made and the revised report was then submitted to another colleague in GH, who was responsible for collating the individual reviews of the electrical design, energy assessment, construction process and environmental impact. At the time of writing this Internship Report, the completed Due Diligence report was expected to be submitted to the client within the next few days.

Task 2 – Wind Turbine inspections

The IE team at GHP have been asked by the owners of several Australian wind farms to provide an engineering review regarding the condition of the wind turbines before and/or after handover from the developer to the owner. Particular areas of interest to the owner are components that are missing or showing signs of decreased longevity. Other areas reviewed include turbine power performance and occupational health and safety.

The inspection of an individual wind turbine usually takes 1 to 2 hours. Wind turbines are tall structures and inspecting them usually involves climbing the internal ladder to the top (although lifts are becoming more popular in new installations), which can become quite exhausting when climbing several in one day. Therefore, most turbine inspections are limited to 3 or 4 climbs per day per person. The location of the Australian wind farms that have recently been inspected by GH are in South Australia, Victoria and Western Australia. These locations all involve a significant amount of travel time, so multiple day trips (2 to 4 days) are common in order to increase the ratio of inspections to travel time. The majority of wind turbines that I have inspected have been on wind farms with over 40 wind turbines on the site, so there are often many turbines to inspect at each site and multiple visits are required.

The first set of inspections can be held during the construction stage, followed by the inspections after the completion of the first turbine/s, followed by the "take-over" inspections (independent inspections of the turbines before the wind farm is taken over by the owner from the developer), which are then followed by the end-of-warranty inspections. Some clients choose to utilise GH's services for only one or two of these stages, with a major focus on the take-over inspections.

Throughout the period of this Internship I have climbed and inspected 37 turbines, at two wind farms in South Australia, over five separate trips (17 days in total). There have also been three occasions when I have visited wind farms for other reasons, such as reviewing the site documentation [see Task 4], and observing the trouble-shooting methods used to deal with a metering discrepancy [see Task 9].

The first step of the inspection process was to liaise with the client and developer, in order to establish which turbines need to be inspected during the visit. The technician-in-charge was then notified of the intended visit, and a request was made to ensure technicians were available to climb with each of the visiting inspectors (climbing in pairs is compulsory for safety reasons). Prior to climbing any turbines, the inspector must obtain "Safety at Heights" training and must be wearing PPE (hardhat, work-boots, eye protection, long trousers and long sleeve shirt) and an appropriate safety harness with lanyard. The inspector also needs to be inducted at the site and obtain site-specific climbing equipment, which connects between the front of the safety harness and the ladder, to prevent falls.

Once the inspector has satisfied the above requirements, the turbine inspection could begin. An internal GHP inspection checklist was provided to the inspector that lists many of the items that require inspection, such as bolts with the incorrect torque, cabling in contact with sharp edges, oil leaks, blade damage, paint damage and unusual sounds from the generator or gearbox. The inspection also reviews the measures taken for Occupational Health and Safety inside the turbine, and comments are provided where improvements should be made, such as extra safety railing, signage, first aid equipment, fire extinguishers, lightning protection, etc.

For safety reasons, the turbine is always switched off during the tower climb, although it can be re-started again once the personnel have reached the nacelle (the top enclosure of the turbine) if this is necessary for the inspection. Digital photographs and notes are taken by the inspector for all items where an issue has been observed.

Once the group of turbine inspections have been complete, the inspector returns to the GHP Melbourne office and writes an inspection report. This report includes the details of the visit (personnel involved, dates, etc.), the turbine numbers that were climbed, the issues observed in each turbine (accompanied by a photo of each observation), and suggested actions. A spreadsheet can also be provided to the client that lists all issues that have been found, in order of the turbine numbers, so the inspection issues from the entire wind farm are summarised together, and then the future update process is more manageable, especially when monitoring which actions are yet to be completed.

The services of the IE team of GHP also include reviewing the site documentation, which often involves a review of the design, construction and service documents in regards to the civil, electrical [see Task 4] and turbine works. Another provided service is the witnessing of any large maintenance works, such as generator or high-speed-shaft changeover. A review of the JSA (Job Safety Analysis) is usually required for such works, and all observations are documented in a report for the client.

The main body of an inspection report that I produced is provided below, however some information has been hidden to protect client confidentiality. This particular inspection site visit involved the inspection of 8 wind turbines, and the witnessing of a generator replacement.

Turbine Inspection Report

A. Generator Replacement

Garrad Hassan (GH) arrived at the WTG # site at approximately 1:00pm on Tuesday 22 July 2008 in time to witness the commencement of the generator replacement works. This task had been delayed hitherto due to incorrect crane sizing and regular wind speeds above the crane maximum operating limit of 9 m/s.

Prior to GH arrival, the 300 tonne crane had been setup with a longer section of lattice fly boom in order to complete the task of nacelle roof removal and generator replacement. Two sets of tag-lines had been attached to vehicles below in order to hold the nacelle roof steady during raising and lowering. The wind speed was being constantly monitored by the leading technician and the crane operator. The works began once it was established that the wind speed was at a constant wind speed below 9 m/s. The meteorological forecast showed that the wind speed at the site should stay below 9 m/s for the duration of the task.

Radios were used for communication between the groups of workers, while the nacelle roof was raised and lowered to the ground by the large crane. The large crane was then used to remove the generator cowling, followed by the lower section of the existing generator to the ground. A smaller 50 tonne crane was used to remove the cowling of the new generator in order for the large crane to lift the lower section into the nacelle. The larger crane then subsequently lifted the remaining generator section and nacelle roof into position at the top of the turbine. This task was completed in approximately 3 hours during very low wind speeds as had been predicted. The connection of the high speed shaft to the generator was yet to be completed, as were other small tasks such as the cable reconnection. These tasks were still in progress at the completion of the GH site visit on Thursday 24 July 2008. *DeveloperC* advised that the generator was expected to be online by the following day, Friday 25 July 2008. At the time of writing, GH had not been informed whether this target was met; however GH is generally satisfied with the work witnessed while on site. **B. IWR follow-up inspections** During the period 22 to 24 July 2008, GH performed follow-up inspections on a total of eight turbines, these inspections were undertaken in reference to items listed as "complete" as per the latest Incomplete Works Register. Turbines inspected were WTG #, #, #, #, #, #, # and #. The outcome of these inspections is listed below on a turbine by turbine basis. Additional notes are also provided where required by additional issues or are otherwise relevant.

The example below shows the list of outcomes from the follow-up turbine inspections for a single turbine. However, bogus information has been entered in the table to protect client confidentiality (also, no photos are provided). Note that the "follow-up" inspections are intended to check the status of issues that have arisen from previous inspections and also to check for any new issues, so there are two tables (follow-up items and new items) for each wind turbine.

WTG #

Follow-	Complete	Comments	Figure

up Item			
S101	✔	Action complete	B101
S102	✖	Broken bracket on nacelle roof hatch not yet replaced	B102
S103	✔	Action complete	B103
S104	✔	Action complete (amalgamating tape to repair cable damage)	B104

New items
Fitting at rear of gearbox slowly leaking oil (Figure B105)
Checker plate raised in nacelle – potential trip hazard (Figure B106)

Table 1 – Example of Issues List following Turbine Inspection

Current Status:

All inspection reports have been submitted to the client following each of the turbine inspections. Both of the wind farms where I have inspected wind turbines have completed construction, but have not yet been handed over from the developer to the owner. Almost all turbines have been inspected at the two farms, with only 3 turbines still to be inspected. Even though these two projects are nearing completion, there are many more wind farms being constructed in Australia and Asia, so the experienced services of GHP’s IE inspection team will continue to be utilised.

Task 3 – Electrical Due Diligence for Australian and CountryA wind farms

GHP Melbourne had been asked to assist GH Spain with a due diligence review of all of the worldwide assets of a major wind turbine manufacturer/developer. GHP was specifically asked to review the pipeline and under-construction projects in Australia and *CountryA*. The tasks were divided into three groups (i) Wind and Energy; (ii) Interconnection; and (iii) Permitting issues. I was asked to look after the Interconnection review, but my colleague advised that I would only need to assess the pipeline projects and not the wind farms under construction.

We were given access to a small amount of information on projects under construction through the developer's electronic dataroom. However, all information available for the pipeline projects needed to be accessed from the developer's physical dataroom (PDR) in Europe. My colleague was sent to Europe to scan through the available documents in order to gather as much information as possible in the short access period of 3 days. No documents were allowed to be copied or borrowed, so the information relayed back to our Melbourne office consisted of the allowable notes of my colleague, which mainly comprised report titles and authors, as well as a few Executive Summaries and Conclusions. We were also able to visit one of the developer's Australian wind farms under construction in order to comment on its general progress.

I was provided with an "IE Template" from GH Spain that showed the type of information they require for the report. In order for my colleague to relay the most suitable information from the PDR, I created a short list of critical information to be acquired. I then used a spreadsheet to summarise the information received from my colleague for each of the countries. A score was to be provided for each project that reflects the interconnection status (completed studies, issues, permits), and the following list was provided as a guide for the status scores. Note that the highest score in the electrical review is 30%, which is intended to be added to the other aspects of the overall Due Diligence review to produce the total score out of 100%.

0% - Request not submitted

5% - Interconnection request submitted

10% - Feasibility Study under way/completed

15% - System Impact Study under way/completed

25% - Facility Study under way/completed

30% Interconnection Agreement executed

An example of the spreadsheet is shown below; however bogus information has been entered to protect client confidentiality.

Project	**State**	**Capacity (MW)**	**Utility**	**Point of Inter-connection**	**Documents Available**	**Inter-connection Status**	**Com-ments**
Albany Wind Farm	WA	18	Western Power	132kV Albany substation	1. "Albany Wind Farm - Grid Connection Study" (SKM - 09/06/03). 2. "Western Power Network Connection Report for Albany Wind Farm" (WP - 20/03/02).	30%	

Table 2 – Example of Interconnection Status Summary

As well as the interconnection spreadsheet, I was asked to provide a summary of the interconnection process and issues for the two countries. Since I have had very little experience in this area, I was required to read many reports and ask various questions to colleagues.

For the Australian review, I read through several NEMMCO documents to establish interconnection requirements that the local wind farms may encounter (*Connecting New Generation - A Process Overview* [Ref 2], *An Introduction to Australia's National Electricity Market* [Ref 3], *Wind Farm Model Guidelines and Checklist* [Ref 4], *Wind Farm Model Validation Test Requirements* [Ref 5], *Generating System Model Guidelines* [Ref 6]). I then wrote a draft summary of the Australian interconnection requirements. The main body of the summary is shown below.

Connecting Wind Farms in Australia

The Network Service Providers (NSPs) for each of the states' transmission networks are: Victoria – SP AusNet; South Australia – ElectraNet; New South Wales – TransGrid. There is also various distribution NSPs for each of these states.

These pipeline projects must adhere to the Australian electrical guidelines set out in the National Electricity Rules (the Rules), particularly "Chapter 5 – Network Connection". The Rules specify that each generating project must meet a number of technical requirements and that these form part of the technical terms and conditions of the Connection Agreement.

The interconnection process generally involves a connection enquiry, followed by an application, detailed design data and models, and negotiations with both the interconnecting NSP and the National Electricity Market Management Company (NEMMCO), before the Interconnection Agreement can be finalised. Garrad Hassan have noticed over the past several months that the provision of models have been a point of contention between NEMMCO and some wind turbine manufacturers, so compliance with the NEMMCO model requirements should be taken into early consideration. In addition to the Rules, NEMMCO have recently published a document summarising these requirements titled "Generating System Model Guidelines", which can be downloaded from their website.

The ease of the interconnection process should be relatively consistent across the range of pipeline projects, with some minor differences from the variety of NSP regions. However, even though the process is similar to connect to different NSPs, the technical requirements may vary, which could have a significant affect on interconnection costs. For example, TransGrid (NSW) usually require 3-breaker connections (more expensive), while other NSPs may allow hard-T connections (cheaper but less reliable).

The point of connection was not provided in the available information for the majority of pipeline projects. Garrad Hassan is aware that there are several locations in Australia that are close to transmission capacity, so connecting a wind farm may require a transmission line upgrade.

Garrad Hassan is aware of specific reactive power compensation requirements for wind farms installed in South Australia, (the ESCOSA requirements) which has effectively required both dynamic and static reactive compensation devices to be installed at all wind farms in South Australia since the requirements came into force. Other NSPs may have incorporated similar requirements, so the investigation of this is recommended during the feasibility stage of the projects.

Writing the summary of interconnection process and issues for *CountryA* was slightly easier than for Australia, because I had already studied the regulations and related requirements during the research for Task 1 (described at the beginning of this report). This summary is not provided in this report due to the confidentiality of the information.

I submitted drafts of each document to GHP's Electrical Engineer in Wellington, New Zealand, and he replied with various comments. After some more research and making some suggested changes, I had completed my section of the final IE report, but then it needed to be collated with the work from my colleague that included land agreements, environmental studies and permitting issues. Then, I submitted the completed report to GH Spain, so they could present it to the client together with all other reports from around the world.

The initial report was submitted on 19 September 2008, which summarised the status of the pipeline projects and the general issues for each country in wind farm constructions. However, GH Spain replied the following week to request that we also should include information on the under-construction projects in each of the reports. My colleague had initially misread the proposal, so I was placed under pressure to provide the additional work they required, before my flight out of Glasgow on the following afternoon (to begin my 1-week holiday in Germany). Fortunately, I was able to complete and submit the required work with just 15 minutes before my taxi to the airport arrived.

Current Status: Complete [Task received 14/8/08, Completed 27/9/08]
This completed report has been submitted to my colleagues in GH Spain, so they could present it to the client together with all the project reports from other GH offices around the world. No feedback has yet been received from the client at the time of writing this report.

Medium Tasks

This section lists several medium-sized tasks that generally took more than one day to complete.

Task 4 – Electrical "Operations and Maintenance" documents review

The construction work for a wind farm in Australia has recently been completed in which an electrical engineering contractor was to manage the design and construction of the electrical works. The contractor produced Operation and Maintenance (O&M) documentation (a 15-Volume catalogue) [Ref 26] for the handover to the developer. This was provided to GHP in electronic format and mostly consisted of electrical equipment descriptions and manuals, inspection reports, as-built documents and as-built drawings. I was assigned to perform a high-level review of the documentation.

The review involved going through every document, checking that everything was included as it should be, checking that all required signatures were present, and noting any other issues. I also met with the electrical contractor and the developer on-site to go through my findings of missing and erroneous documentation. Following the meeting and a review of the updated version of the documentation (including the review of the on-site hard-copy documentation), I produced a report that summarised all the relevant findings of the review, which was then submitted to the client. The main body of the report is shown below, however names have been omitted to protect client confidentiality.

High-Level Review of Electrical O&M Documentation

Garrad Hassan (GH) has performed a high level review of the Operations and Maintenance Manual documentation provided by the electrical contractor for *LocationB* Wind Farm, as received in CD format from the documentation controller of *DeveloperB* at the *LocationB* site on 21 August 2008. Generally, the content of the reviewed documentation is well-structured and of a satisfactory standard, however some comments have been highlighted below.

Please note that an earlier review by GH in Ref: 45008/PL/002 covered the preliminary documentation received on 1 July 2008, whereas this review covers an updated version of the O&M Manual documentation in preparation for handover to *DeveloperB.*

Documents Reviewed:

O&M Manual for LocationB Wind Farm Electrical Services (CD), *ContractorB*, 21 August 2008
O&M Manual for LocationB Wind Farm Electrical Services (hard copy), *ContractorB*, 21 August 2008 [Ref 26]

Comments:

The revised version of the documentation shows an improvement in the file structure, and there is also an inclusion of some previously missing documentation (in particular, As Built Drawings and As Built Documents). A comparison was made between the hard-copy documentation at the *LocationB* site office and the electronic documentation provided in CD format on 21 August 2008, which were found to be identical.

However, a number of comments have been noted by GH, mostly in regards to missing signatures on several forms, several missing documents, actions to be moved to *DeveloperB's* Incomplete Works Register, and suggested filename changes. A comment has also been noted in regards to *ContractorB* providing a component list for all ancillary equipment for Section 4 of the manual.

GH has revised the previously submitted list regarding the above comments, which can be found in the attached spreadsheet "45008 O&M comments register IssC”. GH believes that *ContractorB* should provide comment on each of the issues shown in the list and include the missing information in a revised document.

The example below shows a small section of the comments register; however bogus information has been entered in the table to protect client confidentiality. When each action is completed the spreadsheet can be updated, as shown in the last row of the table.

Item	Document	Comments	Complete	Check	Action Taken
S101	F56.24.80-Rev0	Remedial action not yet signed as complete "Fit label to terminal box of Reactor"			
S102	F34.12.01-Rev1	Document not yet supplied	21/08/08	GMW	Document Provided

Table 3 – Example of Issues List following Document Review

Current Status: Complete [Task received 8/7/08, Completed 22/8/08]

This electrical documents review has been completed and the report has been submitted to the client. Several of the erroneous documents have been re-submitted with the suggested actions completed by the developer. Subsequently, the comments register has been updated.

Task 5 – Electrical losses review

GH Germany does not employ any electrical engineers, so they send all relevant electrical reviews to the electrical engineering team in GH Glasgow. During my time in Glasgow, I was assigned to complete the electrical losses review for a portfolio of three wind farms in Germany. For this study, I used an internal calculation spreadsheet recently designed by one of the electrical engineers in the Glasgow office. The developer had provided some of their own spreadsheets showing losses calculations and they contacted GH to find out if their methodology and results were correct.

A summary of the steps involved in using the internal GH losses spreadsheet are given below.

- Input the power curve values for the wind turbine
- Input the wind speed distribution values for the site (adjust for hub height if different from mast height)
- Input number of turbines and collector system voltage
- Input ratings for wind turbine transformer and substation transformer
- Input details for each cable segment in the collector network (from/to nodes, number of turbines in load current, length, cross sectional area, kilometric resistance). The "number of turbines in load current" refers to the load current that increases along the collector feeder as each additional turbine is connected, so larger cables are required for the feeder sections closest to the substation. The diagram below shows this with a fictional wind farm of 10 wind turbines across two feeders, where current I_5 is greater than I_4, which is greater than I_3 and so on. In this case the cable from WTG01 to WTG02 only needs to be rated for the load current from 1 turbine (smallest cable), whereas the cable from WTG05 to the substation busbar is rated for the load current of 5 turbines (largest cable). Please note that the collector system diagram would normally also include symbols for protection equipment, but it is not required for this explanation.

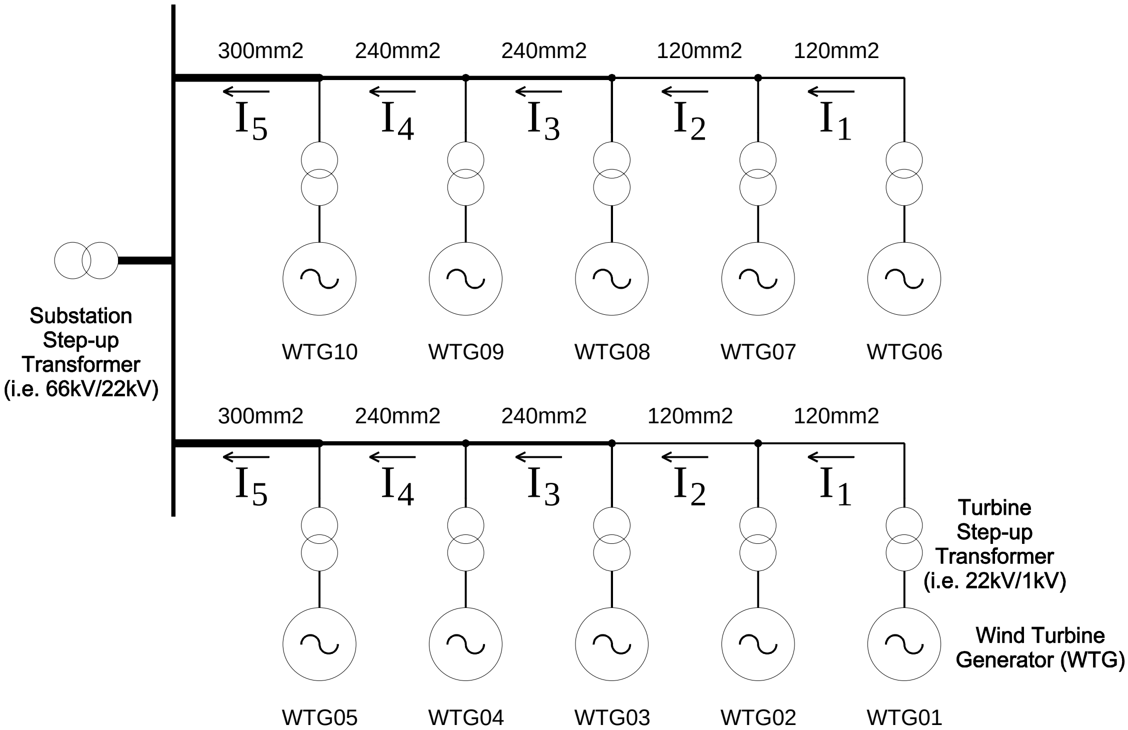

Figure 1 – Example of Wind Farm Collector Network showing Cable Sizing

After comparing the results with those calculated by the developer, I provided the following comments to my colleague in GH Germany.

Comments in regards to the provided losses calculations:

The loss calculation methodology appears correct (I have not checked all parts of the spreadsheet). The calculations ignore reactive power, but this would not make a big difference to the results. I have checked some of the arithmetic and found no errors.

The calculations use a single value for the entire cable length of the collector system and to the point of connection. They do not take into account the different cable sizes and lengths between the turbines. This is a somewhat conservative approach that can only give a ballpark losses figure.

When taking into account the actual lengths and cable sizes throughout the collector system, the losses figure is slightly lower for two of the wind farms

(*LocationC* 2.86%; *LocationD* 0.72%), but the *LocationE* wind farm losses value is higher: *LocationE* 1.08%. The provided *LocationE* calculations used only 7km's of cable length, but the actual amount is significantly more than this. If the 6.8km cable length from the nearby solar farm was for some reason to be ignored for the losses calculation, the losses value would drop to 0.47%, which is closer to the provided result of 0.58%.

As discussed, the calculations do not include the losses in the turbine transformers, which will probably be the major cause of electrical losses. The term 'static losses' may be intended to account for the losses in the transformers; however this term is not clear.

For these reasons, the results of these calculations do not represent the annual electrical losses in the electrical systems of these wind farms.

Note that the provided power curve values, Weibull parameters and cable dimensions as shown in the provided SLD's are assumed to correct, but have not been checked by GH.

Also note that the SLD for *LocationD* wind farm shows only 9 turbines, which calculates to losses of around 0.62%. However, the provided spreadsheet shows that the wind farm has 10 turbines – this calculates to losses of around 0.72% (assuming 400m for the additional cable length).

Current Status: Complete [Received 4/9/08, Completed 5/9/08]

This electrical losses review is complete and has been sent to my colleague in GH Germany. During the study, I was able to make adjustments to the spreadsheet calculator template, to make it more user-friendly for other electrical engineers of Garrad Hassan. I have since successfully used the spreadsheet for two other clients (not shown in this report).

Task 6 – Electrical review of tidal generator

GHP has been asked to provide an independent review of a tidal generator prototype in the coastal waters of Australia (exact location omitted to protect client confidentiality). I was asked to provide a high-level review of the electrical design, with assistance from the Electrical Engineer in GH Wellington when required. The developer provided several schematic diagrams and some presentation slides that contained some additional information.

Two of my colleagues were invited to inspect the site, so they asked me to provide some questions that hadn't been answered by the provided documents. These questions are listed below:

- Is the project already running and exporting electricity to the grid? If so, is there any electrical data available?
- The functional design specifications show a power flow diagram, with # turbines connected to # pylons. Is this all that has been constructed, or are there more of these?
- There doesn't seem to be any cable sizes (lengths and cross-sectional area) or calculations to work out these in the supplied documents. I believe these are important for our electrical review. Please provide this.
- Are any electrical components under-water? If so, what is the IP rating of the enclosures? What protection measures are in place for the underwater cables?

In response to my queries, the client provided the IP rating of the enclosures and the purchase orders for the cables. During the visit by my colleagues, they were able to photograph all the equipment, in order to provide me with a complete visual image of the system.

The results of my high-level review are provided below:

High level electrical review of the *NameA* Tidal Turbine

Garrad Hassan (GH) has performed a high level review of the supplied information regarding the *NameA* tidal turbine’s electrical system.

Main electrical components

[not included in this report to protect client confidentiality]

Comments

The Power Distribution schematic shows six loads connected to the 400V 630A Busbar, which include the two VSD's, hydraulic power pack, PLC / controller enclosure, VSD enclosure supply and services (A/C unit, GPO's, lights). This schematic is comprehensive and clearly shows labelling of connections to adjacent schematics. The VSD1 schematic shows the connection of one of the VSD's to the motor and AGSP power board - this schematic is also clear and comprehensive.

It was noticed that the land and subsea cables have different cross-sectional areas. The subsea cable is 120mm^2, however the land cable has a larger diameter of 150mm^2. This different sized cable is assumed to be because of the thermal rating characteristics (i.e. colder temperatures in water and better thermal conductivity), however the cable sizing calculations have not been provided so this has not been reviewed.

The subsea cable is protected from impacts using a “Protectorshell Articulated Pipe”. Also, the cable is rated for submersible conditions, so this protection method is considered to be sufficient.

The majority of the electronic components (VSD's, circuit breakers, I/O's, comms, PLC, etc.) are located in four cabinets in the pylon shelter above the turbine. The cabinets are polycarbonate and sufficiently rated to IP66. There is also an onshore cabinet for the revenue meter and comms.

The brief visual inspection showed that the electrical components appeared to have been installed as per the applicable electrical standards, although a thorough investigation was not performed by Garrad Hassan.

Current Status – Complete [Received 4/9/08, Completed 10/10/08]

This electrical review is complete and has been sent to my colleague to collate with the control review and energy review, which was then sent to the client. At the time of writing this report, no feedback has been received from the client.

Task 7 – Cable Layouts for wind farm collector systems

I was asked to provide cable schedules, cable layouts and basic SLD's for the collector systems of three approved wind farms in Australia, with assistance and QA checks from the Electrical Engineer from GH Wellington when required. Many steps were involved in establishing the most appropriate cable layout and which size cables should be used.

The first step of this process was to obtain the proposed wind turbine coordinates and insert them into an Excel spreadsheet. Also, the contour map of the area had to be obtained, showing the wind turbine locations, roads, proposed access tracks, site boundaries and substation location.

The next step was to obtain the maximum current capacity of various collector cables, in order to calculate the maximum number of wind turbines as the "load" on the line. These calculations are input into a spreadsheet in order to compare various cable sizes. If the model of turbine has not yet been decided, such as for pre-tender documents, it is common practise to choose a popular model, and recalculate the values when the specific model has been chosen. An example of this calculation is shown below, although several assumptions are not included due to the level of detail required in this report.

Maximum Current from an individual wind turbine

$P_n = 3MW$ (Power rating of the Vestas V90 3MW turbine)

$V_{coll} = 33kV$ (Collector system voltage for the wind farm)

$Derating = 0.9\,pu$ (Lowest steady state voltage required by National Electricity Rules 5.2.5.4(a) [Ref 20] is 90% of nominal voltage)

$pf = 0.98$ (Assuming voltage is at minimum then turbines will be at maximum capacitive power factor. Value found in the turbine specifications [Ref 21])

Maximum current expected from a single turbine:

$$I_{\max} = \frac{P_n}{\sqrt{3} \times V_{coll} \times Derating \times pf} = \frac{3MW}{\sqrt{3} \times 33kV \times 0.9 \times 0.98} = 59.5A$$

Cable Capacity Calculations

Current Ratings

Nominal conductor area mm²	Continuous current-carrying capacity, A — In air			In ground		Fault current carrying capacity for 1 second — Conductor kA	Screen kA
50	160	170	120	160	130	4.73	4.80
70	195	210	155	195	165	6.62	6.82
95	235	255	185	230	195	8.99	9.09
120	270	290	210	265	225	11.4	10.1
150	310	330	235	295	250	14.2	10.1
185	350	380	270	335	285	17.5	10.1
240	415	445	310	390	330	22.7	10.1
300	470	510	355	440	370	28.4	10.1
400	550	595	425	500	440	37.8	10.1
500	635	685	485	570	500	47.3	10.1

From the above chart, the cable current carrying capacity for 3-core Aluminium XLPE cables is shown below: (Olex HV catalogue [Ref 22])

I_{120mm} = 26 5A
I_{300mm} = 440A
I_{500mm} = 570A

Calculating the Maximum number of turbines per cable

Three Core Cables Laid Direct in Ground

Nominal conductor area mm²	Thermal resistivity (°C m/W) 0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0	3.5	4.0
16	1.16	1.12	1.08	1.05	0.93	0.84	0.77	0.72	0.66	0.62
25	1.17	1.13	1.09	1.05	0.93	0.83	0.77	0.71	0.65	0.61
35	1.17	1.13	1.09	1.06	0.92	0.83	0.76	0.71	0.65	0.61
50	1.17	1.13	1.09	1.06	0.92	0.83	0.76	0.71	0.65	0.61
70	1.18	1.14	1.09	1.06	0.92	0.83	0.75	0.70	0.64	0.60
95	1.18	1.14	1.09	1.06	0.92	0.83	0.75	0.70	0.64	0.60
120	1.19	1.14	1.10	1.06	0.92	0.82	0.75	0.69	0.64	0.60
150	1.19	1.14	1.10	1.06	0.92	0.82	0.75	0.69	0.63	0.59
185	1.19	1.14	1.10	1.06	0.92	0.82	0.74	0.69	0.63	0.59
240	1.20	1.15	1.10	1.07	0.92	0.81	0.74	0.69	0.63	0.59
300	1.20	1.15	1.10	1.07	0.92	0.81	0.74	0.69	0.63	0.59
400	1.20	1.15	1.10	1.07	0.92	0.81	0.74	0.69	0.63	0.59

From the above chart, the derating of the cables direct buried with a thermal resistivity of 2°C m/W (obtained from thermal resistivity tests at the wind farm site), is included in the equations below. Note that there is no derating value shown for the 500mm^2 cable so the conservative value is used from the 400mm^2 derating (Olex HV catalogue [Ref 22]).

$$N_{120mm^2} = \frac{265A \times 0.82}{59.5A} = 3\,\text{turbines}$$
$$N_{300mm^2} = \frac{440A \times 0.81}{59.5A} = 5\,\text{turbines}$$
$$N_{500mm^2} = \frac{570A \times 0.81}{59.5A} = 7\,\text{turbines}$$

The above calculations show that the maximum number of turbines in a feeder group can be 7, unless an even larger cable is used. However, the 500mm^2 cable size is often an upper limit due to the much greater expense and installation difficulties of larger cables.

The next step is to draw by hand the cable layout on a printout of the contour map described earlier. This is not an exact science, so several good results are possible. However, there are many important aspects to consider when designing the collector circuit, as listed in point-form below:

- Minimise cable costs by using smaller cables where possible
- Minimise collector groups to reduce the cost of feeder cables and protection equipment.
- Minimise cables crossing paths of other cables.
- Minimise cables crossing roads or access tracks, because heavy vehicles could otherwise damage the cables.
- Minimise creek crossings due to the large expense of constructing a bridge.
- Minimise paths through dense vegetation, due to the difficulty and environmental impact of a cable trench.
- Minimise hard T-junction connections, since they are an additional point of possible failure.
- Run cables trenches in parallel to other cable trenches where possible, to minimise the environmental impact. Note that the minimum distance between each pair of HV cables must also be calculated.
- Run the cables alongside the access tracks and roads where possible, to minimise the environmental impact.

The hand-drawn cable layout can sometimes take a few attempts to find the best design. Once the design has been determined, the cable layout can be drawn in MapInfo, or a similar drawing program, clearly showing the different feeder groups and cable runs back to the substation. This draft cable layout has not been included in this report in order to protect client confidentiality.

The information from the collector system can then be entered into the “cable schedule” spreadsheet. The cable sizes are found from the “Number of WTG's Load” (e.g. if there are 5 turbines as the “load” for a particular cable, then a $300mm^2$ cable can be used, as calculated earlier). The approximate length of the cables can either be calculated from the turbine co-ordinates (distance between co-ordinates, plus allowance for inaccuracy), or from the MapInfo information (length of the line drawn between nodes, plus 5% to account for contours and termination requirements, rounded up to the next 50m). An example cable schedule is shown below for a wind farm with 2 collector groups.

Feeder Number	Cable From	Cable To	Number of WTG's Load	Cable Size (cross-section)	Rough Distance using Turbine Coordinates [m]	MapInfo Distance [km]	Rough Distance using MapInfo [m]
1	1	2	1	120 Al	400	0.43	500
1	2	3	2	120 Al	400	0.38	400
1	3	4	3	120 Al	400	0.45	500
1	4	5	4	300 Al	500	0.45	500
1	5	6	5	300 Al	400	0.38	400
1	6	7	6	500 Al	1600	1.05	1150
1	7	sub	7	500 Al	4800	4.34	4600
2	8	9	1	120 Al	800	0.41	450
2	9	11	2	120 Al	800	0.51	550
2	11	12	3	120 Al	600	0.42	450
2	10	12	1	120 Al	400	0.43	500
2	12	13	5	300 Al	400	0.61	650
2	13	14	6	500 Al	700	0.44	500
2	14	sub	7	500 Al	2900	3.11	3300

Table 4 – Example of a Cable Schedule

A basic single line diagram (SLD) is then produced showing the turbine connections, as shown in the example below. Note that a lot of information is missing from the SLD (i.e. protection devices, substation, etc.), however GH has not been asked to provide these details. Rather, the basic SLD is provided as a guide for the contractor's electrical engineers in their task of creating a detailed schematic diagram.

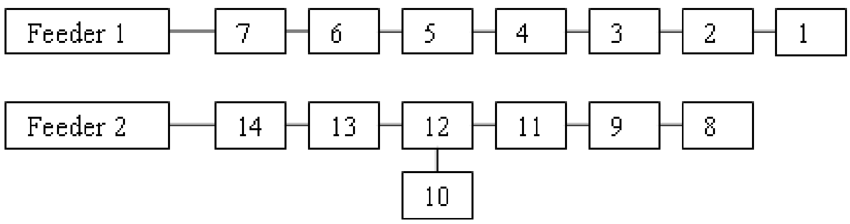

Figure 2 – Example of Simplified SLD

All documents are then provided to the client, including the cable layout (shown on the detailed contour map described earlier), the cable schedule and the SLD.

Current Status: Complete [each design took approx. 3-8 hrs to complete]

All tasks have been completed for the three wind farms that had required the cable layout design. During the completion of these jobs, I have been able to refine the method of approach and each time the results were produced in a much shorter turnaround time. In the early stages of the design, the noise constraints or wind profile data can change, forcing the client to provide a revised turbine layout, which requires a re-design of the cable layout. However, most designs can be completed and quality-checked within a few hours so this is not normally an issue. The clients have used the cable layout information for the pre-tender documentation. Afterwards, the electrical contractor assigned to the wind farm construction will reproduce the layouts and SLD in detailed design.

Smaller Tasks

This section lists several small tasks that mostly took me less than one day to complete, so only a summary is provided for this report. Note that there are several other tasks that I have assisted colleagues with that will not be included here.

Task 8 – Review of Protection SLD and document amendments

This task involved the review of a Single Line Diagram (SLD) for the wind turbines of a wind farm in Australia. The wind farm developer had merged two SLD's into one (the wind turbine SLD and the protection SLD). However there were several errors were found in the resultant SLD. These errors included such things as missing breakers, incorrect voltage levels and missing protection symbols. I provided a report to the client with a summary of my findings, in order to have an amendment made to the schematic. Unfortunately, the second and third revisions also showed errors, so I have provided further comments to the client, and we are currently waiting for a new revision.

Task 9 – Analysis of a wind farm's metering discrepancy

This task involved a metering discrepancy between a wind farm's revenue meter and the internal wind farm metering system. The two outputs have been intermittently logging different figures since commissioning (in both reactive power and real power) and the client was requesting an explanation, since it could be significantly costing the client if the revenue meter was giving an incorrect reading. Several engineers have looked at this issue from GH and outside of GH, and the reason is yet to be clearly identified. I have been asked to read over the reports and visit the site, in order to learn from the fault-finding approach used. It was not expected that I would be able to provide any assistance in the problem, however if a similar problem occurred elsewhere I would now be able to make various suggestions in what could be the cause of the problem due to my involvement, such as checking for earth-loops, incorrect wiring, CT performance, etc.

Task 10 – Current Transformer (CT) burden

GH was asked to supervise a power performance test for our client's wind farm in accordance with IEC 61400-12-1 standard [Ref 23]. A power performance test proves whether or not the wind turbine conforms to the specifications provided by the manufacturer. As part of the test, current transformers were required to determine the net active power being exported by the turbine. Rather than installing a new CT for the test, it was decided to check if the existing CT could handle the burden of a second transducer. These units are rated to 20VA and it needed to be confirmed that the impedance in the secondary loop was within this level. The developer provided some CT burden calculations and technical specifications, which I was required to review and provide comments.

After reviewing the information, I found that there should not be any issues with the burden (existing transducer + existing wire + new transducer + new wire < CT rating). The secondary current loop on the CT's needed to be extended to go through the new transducer as well as the existing transducer. The way to do this was to break the current loop where the loop at present returns to the CT and connect the new transducer in series, and then the return goes back to the CT. The Electrical Engineer of GH Wellington confirmed that my review conclusion was correct, so I then forwarded it to the client.

Task 11 – Analysis of turbine cut-out caused by UPS tripping

Several of the UPS's in the wind turbines were wired incorrectly at our client's wind farm, which had resulted in the overloading of the UPS's and tripping of the turbines. The terminals of the UPS and the primary power supply were found to be wired the wrong way around, which was believed to have caused the overload. It was presumed that the load of the UPS and the primary supply were the same, so I was asked to analyse the issue and discover why the UPS was overloaded. If the loads were the same, then the UPS shouldn't have been overloaded. The developer had provided schematic diagrams of the turbine wiring.

From the analysis of the schematics, I found that one of the terminals was fed from the 230V primary power supply, and connected to a 1.1kW fan. The other terminal was fed from the 230V UPS, and connected to a status crowbar. These were the two terminals that were wired the wrong way around (i.e. UPS should be connected to the fan and power supply connected to the crowbar). The fuse rating for the fan was 5.5A, whereas the fuse rating for the crowbar control circuit was 0.16A, therefore the load was significantly greater when wired to the fan (approximately 40W compared with 1.1kW). The conclusion that the

UPS overload was caused from the incorrect wiring was confirmed, and I forwarded the results of my review to the client.

Task 12 – Review of collector group schematic

GH was asked to undertake a review of a wind farm's collector group schematic and provide comments on compliance with contractual requirements. From my analysis, I found that not all the contractual requirements had been satisfied because more schematics were required, such as a Protection/Earthing SLD and a 33kV Switchroom SLD. I also found various inconsistencies with the proposed cable sizing in the collector groups. The schematic had shown a relatively low number of turbines being carried by a $240mm^2$ cable, while a large number of turbines were to be carried by only a $120mm^2$ cable. I provided the results of my review to the client and various amendments are currently being made to satisfy the requirements.

Task 13 – Review of lightning protection document

GH was asked by our client to undertake a review of a wind turbine lightning protection document that had been produced by the wind farm developer, and to check that it satisfied the regulatory requirements. From my research, I found that the Australian national requirements for lightning protection are listed in the standard AS1768:2007 "Lightning Protection" [Ref 25], and the IEC standard, "IEC 61400-24 Wind Turbine Generator System – Lightning Protection" [Ref 24]. However, the only standards mentioned in the document are "E DIN IEC 88/117/CD:2000-06" and "IEC 61400-24". The document claims to comply with "E DIN IEC 88/117/CD:2006-06", which it says is in agreement with IEC standard "IEC 61400-24". The way that this claim was interpreted was that "E DIN IEC 88/117/CD:2006-06" is a standard from Germany, which has been translated into English for inclusion as an IEC standard.

The "Employer Requirements" contract requested calculations to show compliance with the national requirements, however there were no calculations shown in the document. The calculations for the Earthing and Lightning Protection are necessary to ensure that the installation was safe to equipment and personnel.

Following some correspondence with the Electrical Engineer from GH Wellington, I submitted my response to the client.

Task 14 – LocationA Wind Farm documentation for the Environmental Consultant

The due diligence report, described earlier in this report [Task 1], included the review of the electrical design, energy assessment, construction process and environmental impact. I reviewed the electrical design [Task 1]; the energy assessment and construction process were being reviewed by my GH colleagues; and the environmental impact was being reviewed by an external environmental consultant (contracted by GH). Our client had asked for the environmental impact review to include a report on the levels of compliance with the Equator Principles, which are "*a set of environmental and social benchmarks for managing environmental and social issues in development project finance globally*" (Wikipedia - http://en.wikipedia.org/wiki/Equator_Principles, accessed 12 October 2008). The developer had provided GH with access to the project files in the electronic dataroom, so I was asked to sort through the large catalogue of documents to find all documents that were relevant to the environmental review. I stored these documents in our secure FTP server, and provided the consultant with access to the files. Since the environmental consultant had been contracted by GH, it was my task to liaise with both the consultant and the developer to obtain additional files not yet stored in the dataroom, as well as ask for several files to be translated into English, which were necessary for the environmental review. At the time of writing this report, we were waiting on a large environmental report to be translated into English, in order for the consultant to continue the review.

Task 15 – Western Power Access Application form for a wind farm

GH was asked by a client to assist in a Western Power Access Application to connect a wind farm to the South West Interconnected System (SWIS) electricity network of Western Australia. The client was hoping to join the queue of applicants and needed our assistance because they lacked technical details required for the application. I was asked to choose a wind turbine manufacturer that would enable me to fill out the application with as much information as possible. I found that the application form required a lot of technical details, with most of the required information not publicly available from any turbine manufacturer. GH has various technical specifications from turbine manufacturers, but these still do not provide all the required information. After answering as many of the requirements as possible from our in-house documents, I sought further assistance from the turbine manufacturer. Unfortunately, due to confidentiality reasons, they were only able to provide answers to a few other requirements. However, they suggested we should advise the client to submit the application in its present (almost complete) condition, and see if it would be accepted by Western Power. If it was not accepted, then they would consider providing further assistance in its completion.

The application was submitted on 14/10/08. We have not yet heard from the client on whether it has been accepted.

Final Comments

This Internship role definitely achieved its objective, in exposing the intern to a wide range of engineering practices and issues. The fifteen (15) tasks described in this report show the variety of projects that I was involved with, as well as providing some insight into the work of the Independent Engineering department of Garrad Hassan Pacific Pty Ltd.

Australia is currently seeing an unprecedented expansion of wind farms, so it is a very exciting time to join the wind farm industry. The nation's experience of wind farm design and construction is still in its early stages, so there are usually several issues that need to be addressed, but most issues are relatively minor. The construction team can only erect the towers during periods of low wind, which can be rare on sites specifically chosen for their high wind speeds, so the turbines are often constructed quickly and some items get missed. Also, some design documents do not meet the stringent Australian standards or Principal Requirements, so many issues are found by the IE team that needs to be corrected or updated.

Wind turbine technology has made vast improvements over the past couple of decades, but there are still many maintenance issues and breakdowns that can occur in each turbine over its lifetime. However, most wind farm developers provide an availability guarantee of around 97% or better for new wind farm projects, which I believe is quite remarkable.

Through visiting the wind farms in the remote areas of South Australia, I realized that there is an immense amount of land available in inland Australia that looks to be suitable for wind farms, so if the community continues to object to coastal wind farms, there are other possibilities. The ridges running through farming plains appear to be excellent sources of wind.

I enjoyed all tasks, although some were more pleasurable than others. The design of the cable layouts [Task 7] was most enjoyable, in that it allowed me to use my university knowledge of cable sizing methods, together with new knowledge of optimization of cable positioning on a detailed contour map. Also, turbine inspections at various wind farms happened almost every two (2) weeks, which provided a pleasant break from the office work. The due diligence reviews were also very interesting and a great deal of electrical engineering knowledge was learned from the experience.

I discovered early in the Internship experience that continual learning is required throughout the career of an Electrical Engineer. This appeared daunting at first, but as more knowledge was required throughout the Internship, I found that each problem could be understood. A large amount of knowledge could be obtained by reading about each subject, or asking the right questions to experienced engineers who were always happy to help.

The requirements in the early stages of the Internship included a project plan and a Gantt chart for "Task 1 – Electrical Due Diligence for a wind farm in Asia". This was submitted to the university as requested, however the project progressed somewhat differently to that predicted in the plan and the dates assumed in the Gantt chart. The main reason for the variations was due to the training that I needed in order to fulfil the task, since the training was postponed until I arrived in the Glasgow office in September. The other reason for the variation from the plan was the limited documentation that was provided, since there were some studies that had not been performed and therefore not all sub-tasks could be completed, such as a review of the thermal resistivity tests, reactive plant calculations and SCADA communications design. This practice of submitting a project plan will prove to be valuable for future projects, even though the outcome was somewhat different in this situation. It is expected that as my personal experience with projects develop in the industry, so will the accuracy of the project plans.

The education provided by Murdoch University in the Renewable Energy / Power Engineering units was very suitable to this position. Further comments in this regards are provided in "University Education and Engineering Competencies" [Appendix 1]. Also, some of the questions that required answers during my Internship have been provided in "Questions Asked or Researched" [Appendix 2].

References

Documents

1. *Regulations on the Use of Electrical Facilities for Power Transmission*, *CountryA* Electric Power Corporation, 13 September 2006.

2. *Connecting New Generation - A Process Overview*, National Electricity Market Management Company Limited (NEMMCO), Version No: 1.0

3. *An Introduction to Australia's National Electricity Market*, National Electricity Market Management Company Limited (NEMMCO), June 2005.

4. *Wind Farm Model Guidelines and Checklist*, National Electricity Market Management Company Limited (NEMMCO), March 2006.

5. *Wind Farm Model Validation Test Requirement*, National Electricity Market Management Company Limited (NEMMCO), March 2006.

6. *Generating System Model Guidelines*, National Electricity Market Management Company Limited (NEMMCO), 29 February 2008.

7. *Transmission Interconnection Facilities Agreement* between *LocationA* Wind Energy Co. (*LWE*) and *CountryA Electric* Power Corporation, 28 February 2008

8. *Contract for Electrical Engineering Construction Work* by and between *DeveloperA* and *ContractorA* Corp. relating to the *LocationA* Wind Farm project, signed 6 July 2007.

9. *Regulations on the Use of Electrical Facilities for Power Transmission*, *CountryA* Electric Power Corporation, 13 September 2006.

10. *Electric Grid Data – DeveloperA TurbineA*, RevJ, *DeveloperA* Windpower, dated 16 May 2008.

11. *HS07035-C03-R15 – Harmonic Analysis Report*, Rev0, *ContractorA* / *DeveloperA*, 28 February 2008.

12. *HS07035-C03-R09 – Voltage Drop & Loss Calculation*, Rev0, *ContractorA* / *DeveloperA*, 8 April 2008.

13. *HS07035-C03-R04 – Short Circuit Calculation*, Rev0, *ContractorA* / *DeveloperA*, 7 November 2007.

14. *HS07035-C03-R11 – Cable Capacity Calculation for 12kV CV-Al Cable*, Rev1, *ContractorA* / *DeveloperA*, 3 April 2008.

15. *Test Report of Transformer (in factory)*, Product No. TP70187401, *ContractorA*, May 2008.

16. *Calculated Power Curve – Wind turbine TurbineA, DeveloperA* Windpower, RevF, 7 June 2007.

17. *Wind turbine TurbineA Technical Description*, RevC, *DeveloperA* Windpower, 6 November 2006.

18. *Grid connection standard for renewable energy power plant*, Frequency, Voltage and Phase tolerances, received in email from *DeveloperA* on 17 July 2008.

19. *Standard Price for different sources of electricity*, Ministry of Knowledge and Economy, received in email from *DeveloperA* on 7 August 2008.

20. *National Electricity Rules Version 21*, 1 July 2008

21. *Vestas Electrical Data V90 – 3.0MW 50Hz*, Item no. 950017.R6, 16 June 2005

22. *Olex Cables Australia – High Voltage Catalogue*, downloaded from www.olex.com.au, accessed 29 June 2008

23. *International Standard IEC 61400-12-1 "Power performance measurements of electricity producing wind turbines"*, December 2005.

24. *Australian Standard AS1768:2007 "Lightning Protection"*, Standards Australia / Standards New Zealand, 2007

25. *International Standard IEC 61400-24 "Wind Turbine Generator Systems – Lightning Protection"*, First Edition, July 2002

26. *O&M Manual for LocationB Wind Farm Electrical Services*, *ContractorB*, 21 August 2008

27. *Economic Regulation of Transmission Services Supplementary Submission*, Energy Australia, September 2006.

Drawings:

a. HS07035-C03-D04-01 (Rev0) – 154kV/12kV Single Line Diagram (Substation), *ContractorA*

b. HS07035-C03-D04-02 (Rev0) – 12kV Single Line Diagram (WTG #MW * 41 sets) , *ContractorA*

c. HS07035-C03-D16-01 (Rev0) – 12kV WTG System Circuit Group Block Diagram – A/B/C/D/E, *ContractorA*

d. HS07035-C03-D16-02 (Rev0) – 12kV WTG System Circuit Group Block Diagram – F/G/H/I/J, *ContractorA*

e. HS07035-C03-R04-01 (Rev0) – Impedance Diagram, *ContractorA*

f. HS07035-C03-R04-02 (Rev0) – ½ Cycle Short Circuit Current Flow, *ContractorA*

g. HS07035-C03-R04-03 (Rev0) – 1.5-4 Cycle Short Circuit Current Flow, *ContractorA*

h. HS07035-C03-R04-04 (Rev0) – 30 Cycle Short Circuit Current Flow, *ContractorA*

i. HS07035-C03-D03 (Rev0) – General Layout, *ContractorA*

Appendix 1

University Education and Engineering Competencies

I am pleased with the majority of the units of study during my 4-year Renewable Energy / Power Engineering degree at Murdoch University. The renewable energy engineering units provided me with the background required to work in the *wind farm* industry, and the power engineering units provided me with the electrical knowledge required to begin work in the *electrical engineering* industry. This double-major degree appears to have been made for my Internship position (and now, my “occupation”), since the work involves a wide range of engineering tasks, both electrical and general, and many of the problems were similar to that undertaken in the university degree.

Of course, not everything can be taught in the limited time-frame of a degree, so some things, unfortunately, get left out. The main thing that I think was missing from the power engineering units was learning the basics of using the DIgSILENT software package (or PSS/E). I think that learning the basics of SCADA systems would also prove useful (although this is covered in other engineering units outside of my chosen double-major degree).

The tasks where my university knowledge was used have been provided below, for the purposes of feedback to the Engineering faculty of Murdoch University.

<u>Task 1</u>
Regulations requirements (Power unit [ENG455] / Renewable Unit [ENG421])
Cable sizing and losses (Renewable Unit [ENG421])
Wind Turbine specifications & grid requirements (Power unit [ENG455])

<u>Task 2</u>
N/A

<u>Task 3</u>
Wind Turbine specifications & grid requirements (Power unit [ENG455] / Renewable Unit [ENG421])

<u>Task 4</u>

Electrical units involving the study of SLD’s (Power unit [ENG455], others)

<u>Task 5</u>
Power Curve / Weibull parameters / wind speed distribution (Renewable unit [ENG352])
Cable sizing and losses (Power unit [ENG455] / Renewable Unit [ENG421])
Transformer losses (Power unit [ENG348])
Kilometric resistance (Power unit [ENG455])

<u>Task 6</u>
IP ratings (Renewable Unit [ENG421])
Cable sizing and losses (Power unit [ENG455] / Renewable Unit [ENG421])

<u>Task 7</u>
Cable sizing and losses (Power unit [ENG455] / Renewable Unit [ENG421])
Wind turbine layout (Renewable Unit [ENG421])
Distances between parallel cables (Power unit [ENG348])

<u>Task 8</u>
Electrical units involving the study of SLD’s (Power unit [ENG455], others)

<u>Task 9</u>
Real and Reactive power studies (Power unit [ENG455] / Renewable Unit [ENG421])

<u>Task 10</u>
CT’s (Power unit [ENG455])

<u>Task 11</u>
Electrical units involving the study of SLD’s (Power unit [ENG455], others)
Batteries / UPS (Renewable unit [ENG352])

<u>Task 12</u>
Electrical units involving the study of SLD’s (Power unit [ENG455], others)
Cable sizing and losses (Power unit [ENG455] / Renewable Unit [ENG421])

<u>Task 13</u>
Lightning Protection including AS1768:2007 (Renewable Unit [ENG421])

<u>Task 14</u>
N/A

<u>Task 15</u>
Wind Turbine specifications & grid requirements (Power unit [ENG455] / Renewable Unit [ENG421])

Appendix 2

Questions Asked or Researched

This section lists some of the questions that I asked or researched during my Internship. They have been included in this report to give the academic staff of Murdoch University's Engineering department some useful feedback as to the various subjects that I needed some answers that may, or may not, have been mentioned during the degree.

What happens to the power from a wind farm when the connection to the grid is unavailable?

When a wind farm is exporting power and there is a sudden disconnection from the grid (which must occur during a "blackout"), the turbine blades will initially continue spinning in the wind. However, as soon as the wind farm senses that the grid is off-line, the turbine blades must immediately "feather" out of the wind (only takes a few seconds), because the electric torque provide by the windings of the stator and rotor of the generator can no longer prevent the turbine blades from over-spinning (because the grid power is off-line). Often, the wind turbine will include re-chargeable batteries inside the hub of the nacelle to pitch the blades when the grid is off-line.

What are ONAN / ONAF in relation to transformers?

These acronyms refer to different types of cooling methods for transformers. ONAN is the acronym for Oil Natural Air Natural where thermosiphon is used to cool the oil in the transformer. ONAF is the acronym for Oil Natural Air Forced, where thermosiphon is also used to cool the oil, but fans are used to blow air over the cooling fins.

What is a CT burden?

The burden is the load which may be imposed on the secondary winding by cables and connected devices without causing error greater than the stated accuracy classification. For example, a CT may be rated at 1200:5 (±1.2%), with a burden of 12.5VA and 0.5 ohms.

Providing the burden of the connecting cables and devices are lower than 12.5VA (or 0.5 ohms), then the stated accuracy of the CT should still be reliable.

What is a Crowbar in relation to protection circuits?

A crowbar circuit is a power supply protection circuit that short-circuits the supply line if the current and/or voltage exceed the allowable limits. The resulting short blows a fuse or triggers other protection, effectively shutting down the supply.

What is wind farm "Availability"?

Availability is a measurement of the reliability of the entire wind farm. It refers to the percentage of time that the wind farm is ready to generate (that is, not out of service for maintenance or repairs). The developer of a wind farm would usually sign a contract with the employer that includes a guaranteed availability (often around 97%), in which the developer must make up the difference in revenue when the availability falls below this agreed value. The availability formula can be very complicated in the attempt to pre-determine which party will be responsible for when a turbine is unavailable.

What is OLTC in relation to transformers?

OLTC is an acronym for On-Load-Tap-Changing transformers. In a wind farm application, an OLTC transformer can be used to isolate the wind farm from any steady state voltage problems on the network, meaning that the wind farm can remain at rated voltage (steady state) during any steady state voltage disturbances on the grid. However, the tap-changing capability of the OLTC transformer is relatively slow, so it is not used to correct transient voltage fluctuations or to fix the overall grid system voltage.

Where do I find the "No-Load" losses and the "Full-Load" losses from transformer specifications?

Transformer losses are comprised of losses in the windings ("copper" losses), and losses in the magnetic circuit ("iron" losses). Winding resistance dominates load losses, so the value for the transformer's "Copper" losses can be used for "Full-Load" losses. Hysteresis and eddy currents losses contribute to the majority of no-load loss, so the value for "Iron" losses can be used for "No-Load" losses.

What are the differences between the reactive power devices commonly used in wind farms?

There are three main varieties, which are listed below in order of cheapest to most expensive:

- Capacitor Banks with switching to inject reactive power. The act of switching-in multiples of capacitors allows for different levels of reactive power to be injected. The steps are discrete and the switching in/out of capacitor banks is restricted by the speed of SCADA signals. When a better response is required for voltage transients, SVC or DVAR / STATCOM should be used.
- Static VAR Compensators (SVC) provides dynamic reactive power compensation based on thyristor technology. The components commonly include reactors (to consume reactive power), capacitors (to inject reactive power), a transformer, thyristor valves and a control system.
- D-VAR / STATCOM systems can detect and instantaneously compensate for voltage disturbances by injecting leading or lagging power precisely where it is needed on the grid. They use advanced power electronic converters (IGBT's) to achieve this. The advantage of using this technology over SVC is that it is not subject to "V^2 derating" at lower voltages (in SVC's the reactive output is proportional to the square of the voltage, therefore the reactance decreases rapidly as the voltage increases, thus reducing its stability).

How much power does a wind farm consume while the wind is not blowing?

It depends on the situation, anywhere between 1kW/turbine to 30kW/turbine. If the heaters are operating to prevent freezing during the winter of a cold country, then it may reach the upper levels of around 30kW. In warmer countries the fans may bring the power to around 20kW, although the fans would not usually be operating during long period of wind speeds below cut-in. The topography of the site also has an affect on the wind farm power – if the topography is a flat plain, then all turbines may prepare-to-start together as the wind-speed rises towards cut-in, which will cause all fans/heaters to start at once, causing the largest peak power of a non-export situation.

What is amalgamating tape and what distinguishes it from standard electrical tape?

The simple explanation is that amalgamating tape combines itself into one big sticky mess, so generally cannot be unwound. Amalgamating Tape is a tough and elastic tape with very strong resistance to water and other liquids, which include a wide range of chemicals, including acids, alkalis, hydraulic fluids and vegetable oils. Amalgamating Tape has no adhesive side and needs to be stretched during application to create a complete bond to itself and other materials

The terms "transmission network" and "distribution network" do not seem to have a defined point of cross-over, why is that?

Typically, the distribution network goes up to 33kV, and then the transmission system is from 66kV and above.

However, according to a report from the Australian Energy Marketing Commission (AEMC), a transmission network operates at nominal voltages of 220 kV and above plus:

(a) any part of a network operating at nominal voltages between 66 kV and 220 kV that operates in parallel to and provides support to the higher voltage transmission network;

(b) any part of a network operating at nominal voltages between 66 kV and 220 kV that does not operate in parallel to and provide support to the higher voltage transmission network but is deemed by the Regulator to be part of the transmission network. [Ref 27]

How do I work out the grid fault levels? Data provided from the network operator at the 154kV substation was: $\%Z_1 = 0.844 + j6.745$ **on** $S_{base} = 100MVA$ **?**

Apparent power fault level:

$$Z_1 = \sqrt{0.844^2 + 6.745^2} = 6.8\% \text{ on } S_{base} = 100MVA$$

$$S_{fault} = \frac{100MVA}{6.8\%} = 1470MVA$$

Current fault level:

$$I_{base} = \frac{100MVA}{\sqrt{3} \times 154kV} = 375A$$

$$I_{fault} = \frac{375A}{6.8\%} = 5.5kA_{rms}$$

Generally a high fault level at the point of connection is good, as it makes it easier to achieve good power quality. If fault levels get too high, it can cause problems for protection equipment. Since the wind farm is rated at 61.5MVA (at unity p.f.), then it is well below the fault levels of the grid connection of 1470MVA, so good power quality would be expected.

What are the implications of mixing two different types of turbines in the one wind farm to assist with noise constraints?

Many wind farms are equipped with different types of turbines, although this is usually due for reasons other than noise. For noise constraints, the developer could try using a different noise setting, e.g. lower revolutions leading to lower noise and a little less power output.
There is a disadvantage in mixing the turbines in that the wind farm will have to have two spare parts inventories for each of the machines. Some of the parts are inter-changeable for particular models of various sizes (e.g. rotor components and blades), but not other big ticket items like gearboxes and generators because of the speed variations between the two models.