University of Southern Queensland
Faculty of Health, Engineering and Sciences

ISOLATED GRID SOLAR-BATTERY SUPPORT FOR SWER

A technical feasibility study submitted by

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for the degree of

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Abstract

The small town of Windorah in outback Western Queensland has its own, isolated distribution mini-grid. Both the power station and the local, isolated distribution network are owned and operated by Ergon Energy, Queensland's primary rural electricity distributor. The power station at Windorah has 3 base-load diesel prime power generating sets, but it also has five, 26 kW Photo Voltaic (PV) concentrating dishes. The town also has distributed customer PV generation.

Only 16 km to the East of Windorah's network, the end of a grid-connected, Single Wire Earth Return (SWER) feeder stretches 200 km from the town of Quilpie to the South-East. With increasing and sporadic loads, much of Queensland's rural and regional SWER feeders are under consideration for upgrade. Augmentation systems such as reactive power injection, energy storage or routing of new supply backbones have been investigated and implemented as alternatives to re-stringing some of the suffering SWER network.

This thesis aims to technically analyse the load and generation data from the two independent systems (SWER and Mini-grid) to determine if an opportunity exists for connection of the two through a battery storage system. The intent was two-fold;

- Place load on the SWER line to assist with voltage issues and to provide for diesel offsetting in the town of Windorah and;
- Provide power injection to the SWER to compensate for reactive power and to supply energy when required.
- Make use of the abundance of Solar Generation in Windorah

A literature review was conducted, examining the current research and options already available and employed for SWER replacement mitigation. The review also looked at the issues common to long line feeders, in particular regional Queensland's SWER lines.

The analysis concluded that the SWER out of Quilpie presents a unique opportunity to use the extra solar generation spill in the town of Windorah to both extend the life of the current SWER installation, as well as significantly reduce the consumption of diesel fuel through offsetting the requirement for spinning reserve.

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Certification of Dissertation

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

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

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Contents

List of Figures

List of Tables

List of Acronyms

ARENA – Australian Renewable Energy Agency

AVR – Automatic Voltage Regulation

BOM – Bureau of Meteorology

CPV – Concentrated Photo Voltaic

CT – Current Transformer

CSIRO – Commonwealth Scientific and Industrial Research Organisation

CSO – Community Service Obligation

HMI – Human Machine Interface

Hz - Hertz

kW - Kilowatt

kWe – Kilowatt Electrical

kWm – Kilowatt Mechanical

kVA – Kilo Volt Ampere

PV – Photo Voltaic

PLC – Programmable Logic Controller

RTU – Remote Terminal Unit

SCADA – Supervisory Control and Data Aquisition

Chapter 1 Introduction

Due to competitive pricing, high insolation and a burgeoning ethical stance, solar Photo Voltaic (PV) generation installations have become attractive and viable to mainstream and domestic electricity consumers in Australia.

Windorah has a unique, concentrated solar farm owned and operated by Queensland's rural electricity distributor, Ergon Energy. The farm was installed and commissioned in 2008, with some federal financial assistance. It has an array of five mirrored dishes, each with a generating capacity of 26 kW (Ergon Energy, 2015) and each equipped with solar tracking technology to trace the path of the sun as it crosses the sky. The solar component of the station is equipped with a battery storage system to aid in smoothing of the output under incidences of cloud cover or other sudden reductions in solar generation output.

Windorah also has a 'high' (Ergon, 2015) penetration of domestic PV installations. With no control over the injection from this generation, the power station must maintain high inertia spinning reserve to be able to ride through the fluctuations inherently common to PV generation. In addition, the low day time load, together with the specifics of the diesel sets results in a high proportion of solar generation from both the dishes and the distributed solar being spilled.

Ergon's vast (Ergon, 2014) rural and regional SWER networks extend to close to the isolated town of Windorah, but a substantial river system known as Cooper Creek has in the past presented a significant hurdle in the connection of Windorah to the national grid. The river system floods yearly (Tolcher, 1986) and with the storm activity in the area, would almost certainly guarantee loss of supply on a yearly basis, with the potential for an outage lasting for weeks until subsidence of the river system.

New pole base infrastructure (Cavanagh, 2011) supports the idea that the potential for loss of distribution pole due to flood, together with contemporary lightning protection systems means the river crossing may now be a viable option.

This thesis seeks to examine the technical feasibility of connecting the SWER to Windorah's Isolated network through use of a battery storage system.

1.1 Motivation

Ergon Energy owns and operates a total of 33 remote, off grid, or 'mini-grid' power stations spread throughout regional Queensland and the Torres Strait, Figure 1.1.

Figure 1.1 - Ergon Energy's Isolated Generation Sites (Ergon Energy, 2015)

The majority (30) of these stations are diesel powered. The remote nature of these sites poses significant logistics costs in transporting and supplying fuel. As a result,

and in combination with environmental responsibilities and commitments, opportunities for fuel savings are weighted and considered heavily.
The following questions provide motivation for this thesis;

- What if we connected Windorah to the SWER network and used the network to charge a battery overnight and discharge during the day. How much diesel would this save?
- What if we used the extra solar generated during the day to charge the batteries, as well as prop up the nearby SWER line?

1.2 Aim and Objectives

To conduct a feasibility study into a battery storage system for maintaining capacity for peak load to the end of a known Single Wire Earth Return (SWER) feeder to outback western Queensland (near Windorah).

The principal aim for this thesis is to prove or disprove the technical feasibility of interconnecting an energy storage system between the mini-grid of Windorah and the Single Wire Earth Return feeder which extends North-West from the grid-connected town of Quilpie.
The principal objective is to demonstrate the possibility of reducing Diesel consumption (by any amount) by further harnessing the solar generation from within Windorah.
The secondary objective is to aid the capacity of the SWER feeder by supplying additional load during light loading periods, and by supplying additional power during high load periods.
The economic intricacies are too great and varied to be considered within the scope of this thesis.

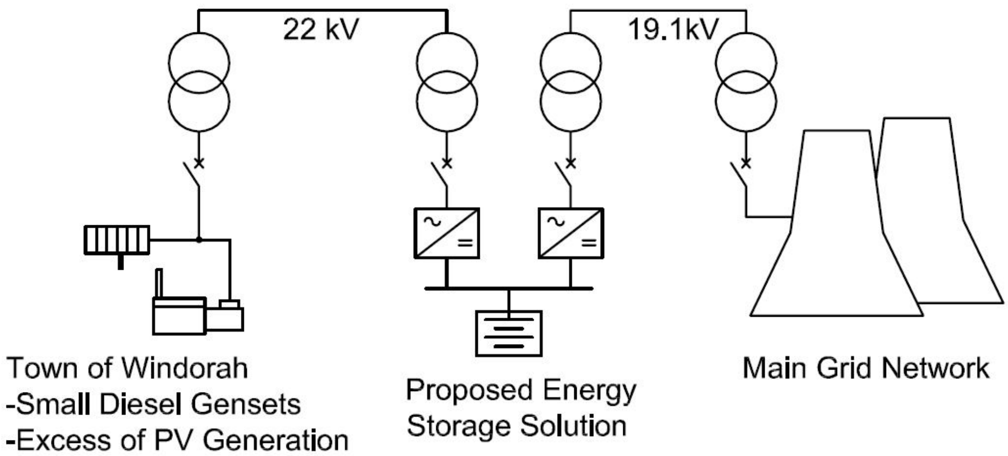

Figure 1.2 - Simple single line diagram of proposed solution

The objective of this research proposal is to investigate the utilisation of an over-abundance of solar power generation at Windorah, in South West Queensland, to prop up/augment a nearby Single Wire Earth Return (SWER) line. Due to Ergon's limitation of 20% penetration of solar into mini-grids for stability reasons, the grid's ability to absorb PV generation is already over and above capacity by a 'large factor'. (Ergon). There therefore exists an opportunity to store the excess energy generated for use later in either smoothing of the load in Windorah, or for feeding back into the SWER line. As well, the SWER may be used to charge this same storage, for use at peak loading time in Windorah which is inherently outside of the peak solar generating times.

The primary aim of this project is to investigate the technical sides of the integration of a Battery Storage Energy System (BESS), and limit it to the optimum size of the battery storage, the relative load of the battery storage on the isolated grid network, and the impact of the additional load on the isolated network.

In order to achieve the project aim, it is the intention of the project to achieve certain objectives;

- Measure, estimate, or otherwise observe the power and power quality at the end of the SWER, given the length of the line as well as the reactive demands of the transformer and consumer.
- Measure, estimate or otherwise observe the total installed solar capacity on the grid at Windorah. Both inclusive and exclusive of the solar farm.
- Design and model a battery storage solution aimed at being mutually beneficial for both the SWER feeder and the Windorah micro-grid in terms of fuel savings, power quality and infrastructure spending reductions.

1.3 Project Exemptions

Costings can be made for the individual components, but this project will not attempt to cost labour, or other overheads. Nor will it apply NPV or other financial analysis.

This project will only estimate the required electrical generation required in order to facilitate a beneficial programme of integration.

Chapter 2 Background

Currently there exists a Single Wire Earth Return (SWER) feeder extending from the town of Quilpie, to just outside of Windorah in South West Queensland. Towards the end of the SWER, the line comes within 16 km of Windorah's mini-grid (Google Earth, 2015) as shown in Figure 2.1.

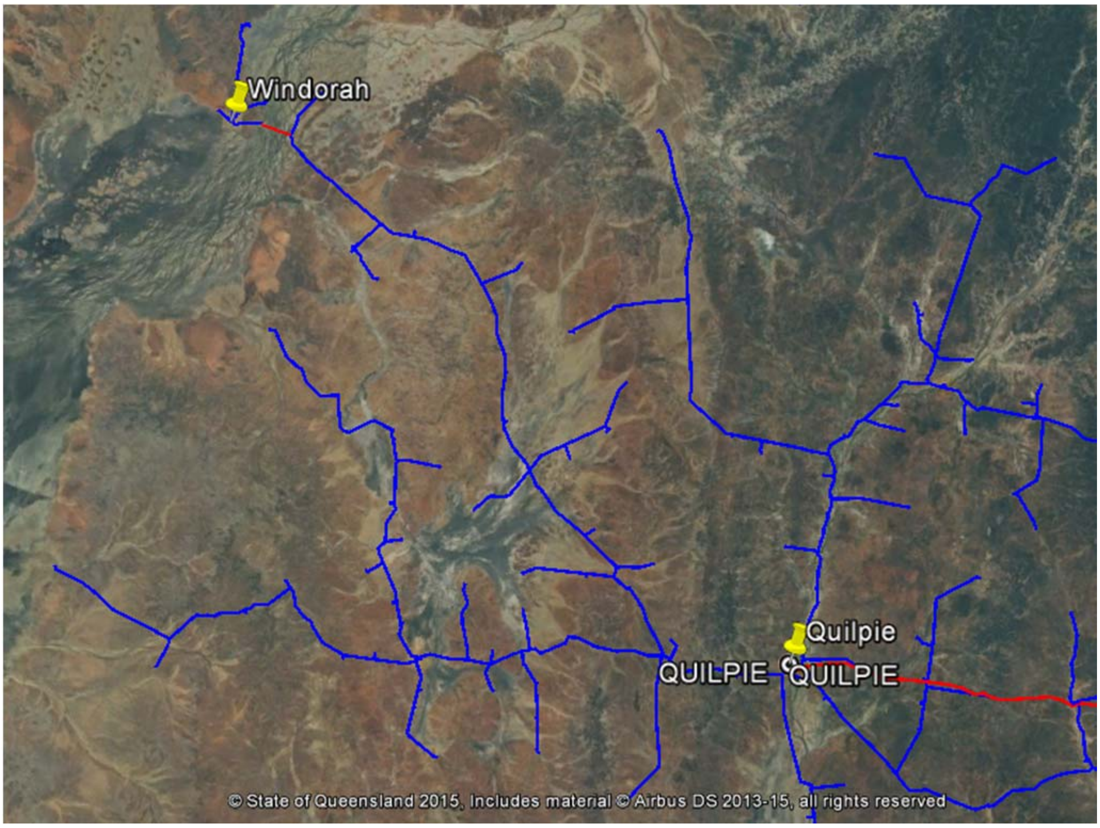

Figure 2.1 Google Earth Image of Quilpie SWER and proposed link to Windorah mini-grid

The town of Windorah is supplied electricity from three synchronous diesel 250 kW gensets. The gensets currently have a Deif (brand) Generator Paralleling Controller (GPC) architecture which integrates both the synchronising and load sharing functions. A Programmable Logic Controller (PLC) system is used to handle the priority settings of the generators, the control of discrete alarms and relays, as well as Supervisory Control And Data Acquisition (SCADA) communications through a Remote Telemetry Unit (RTU).

A significant obstacle for connecting the battery system to the SWER is the quality of power that may be supplied from the DC/AC converter. Since converters use IGBT technology, depending on the quality of the system implemented, the power may either be reasonably clean, or full of harmonics. Another identified issue is the ability for power converters to supply reactive power. Given that this point of the

SWER is towards the end of the line, the amount of line capacitance is likely to be high, and the Ferranti effect has been reported as effecting this line.

The solar farm is unable to supply reactive power, as well as being unable to respond/supply large changes/swings in load (supply) and as such must always have at least one base load generator remaining on. Since the diesel power station is built to have N+1 (Ergon refer to it as N-1) redundancy, the existence of 3 generators is a result of a peak load only ever calling for two generators to be in operation to supply load. From this, it can be taken that the load does not ever exceed 90% (Ergon's de-rating factor) of 500 kW.

Chapter 3 Review

As part of a push to allow for the development of off-grid mini-grids, a vast amount of research has been, and is currently being conducted into the development of infrastructure designed to cope with the intermittent nature of renewable energy systems.

A recent stocktake report compiled for the Australian Renewable Energy Agency (ARENA) (Australian Renewable Energy Agency, 2015), listed 51 large-scale projects designed directly to ‘Establish control over, or otherwise influence, intermittent generation sources’.

The effects of high PV penetration on micro-grids pose their own unique problems – in particular, high generation fluctuations which are generally, highly divergent from peak loading profiles (Teitzel, Haque, & Inwood, 2015). Because of this, utility companies are forced to limit, or otherwise control, the amount of PV penetration that they can accommodate on a micro-grid system. Various philosophies may be employed such as Loss of Power Supply Probability (LPSP) – a technique of sizing the base load generation based on the risk of PV generation loss (Villafafila & Mrabet Bellaaj, 2015).

Queensland’s rural electricity distributor, Ergon Energy has developed its own proprietary algorithm to determine the capacity of its micro-grids for further PV penetration. The algorithm factors the load trend for each isolated system, and considers the available capacity of its (primarily) diesel generation, and hence the stability of the system in the event of a loss of PV generation.

PV generation can be smoothed by different methods including inverter smoothing, predictive technologies like cloud sensing, and by using Energy Storage Systems (ESS). Types of storage systems vary widely, and include hydrogen storage (Tesfahunegn, Ulleberg, Vie, & Undeland, 2011), ultracapacitors and flywheels. As a leader in the solution to energy fluctuations by way of storage, Battery Energy Storage Systems (BESSs) are a popular and scalable alternative. Further solutions for controlling the intermittency using BESSs range from the employment of distributed BESSs (Zillman, Yan, & Saha, 2011) to regulating the PV export by means of increasing the grid frequency to signal a full battery system (Urtasun, Sanchis, Barricarte, & Marroyo, 2014). In addition, methods for sizing micro-grid energy storage systems are well researched. Recently, a journal describing an algorithm based method for determining the desired battery capacity was published (Fossati, Galarza, Martin-Villate, & Fontan, 2014).

In various locations throughout Queensland, there exists long, Single Wire Earth Return (SWER) feeders which are suffering from voltage sag. A lot of work has been done on battery support for the end of SWER lines. In 2013, USQ’s Tony Ahfock and Andreas Helwig completed and presented a study into the functionality and economics of using nickel-iron Edison batteries for use in active power injection to prevent voltage sag in long SWER lines (Helwig & Ahfock, 2013). Ergon Energy's own Grid Utility Support System (GUSS) (Ergon, 2015) has been designed and trialled to support sections of SWER by charging its batteries during periods of light loading, then reinjecting during periods of high loading.

3.1 ARENA

The Australian Renewable Energy Agency was established in 2012 to help pioneering renewable energy projects. According to ARENA's website, the agency has two objectives;

- Improve the competitiveness of renewable energy technologies
- Increase the supply of renewable energy in Australia. (Australian Government)

ARENA offers funding grants to unique renewable energy projects to aid viability and feasibility and all projects are carefully assessed to ensure they meet requirements. Stipulations made under an ARENA funding agreement include caveats for knowledge sharing in a bid to aid the national renewable energy industry

3.2 Existing Battery Systems

One of the inherent and obvious problems with solar generation and supply is the undesirable effect of the sun clouding over the panels and thus blocking the generation. This problem can occur in a matter of seconds (Mammoli, Barsun, Nurett, & Hawkins, 2012), especially over relatively centralised generation such as that which Windorah presents, being a geographically centralised town. As well, the concentrated solar dishes are in close proximity to each other. To counter this at the solar farm, 3 banks of 80, 12V AGM batteries have been installed to serve two purposes:

- Uninterrupted Power Supply (UPS) for the Solar Power Station
- Cloud Smoothing.

3.3 UPS Systems

The UPS function is called upon the tripping off of the diesel generation. In this instance, the solar farm breaker also opens. The primary purpose of the battery supply is to turn the solar dishes 'off-Sun'. Because of the concentrating of the solar rays by the mirrored dish, allowing the dishes to concentrate the Sun in any direction other than intended can be extremely dangerous particularly to surrounding infrastructure. The battery system is thus used to drive the dishes down into a 'park' position, which eliminates the chance of the mirrors catching the Sun. The secondary purpose of this function is to keep the Solar Station control and switchboards alive. Communications are also maintained through this battery system in the event of loss of mains supply.

3.4 Different Types of Batteries

Generally, Absorbed Glass Mat (AGM) lead acid batteries are the preferred type of cell to use in industrial applications and have been employed at the current Solar Farm.

3.5 Maintenance of Battery Systems

Due to the remote location, any proposed system with maintenance concerns will cause logistical problems with the ability to attend, supply, or otherwise maintain any battery system. Battery monitoring equipment would thus be essential.

3.6 Battery Capacity Monitoring

A method of monitoring the batteries would be required for two reasons

- To control battery charge level
- To monitor the condition of individual cells.

3.7 Timing of Charging/Discharging

It is anticipated that the charging of the system would switch immediately from one source to another based on a voltage signal. When the solar power is producing excess power (more than can be absorbed by Windorah without passing a stability threshold) then the charger will automatically be powered from the Windorah side. If the batteries are full, then the excess should ‘spill’ onto the SWER, or else switch the chargers off. In this case, the voltage will automatically rise on the Windorah side, independently switching any PV systems off. Conversely, if there is substantial load on the Windorah side, and the batteries are at a suitable charge state and/or there is little to no load on the SWER, then the SWER side chargers will activate.

Battery charging would need to operate mutually exclusively from each source, and a system of isolators to prevent both charging at once would have to be investigated.

3.8 Cloud Smoothing

The Cloud Smoothing function is designed to detect a rapid reduction in DC current to the inverters. In this event, the batteries are used to continue supply to the station bus, and ramp the generation down more slowly. According to Mr Ryan Cramp, Technical Officer of Ergon Energy’s Operations Department, the cloud smoothing function has actually been disconnected on the basis of conserving the batteries. Due to the low loads generally observed in Windorah, Ergon is of the as-yet, un-proven notion that any dumping of load on the station bus due to the solar generation failing or coming off (for any reason) is capable of being absorbed by the running diesel gen-set. A quick calculation shows that at worst case, this can be disproved;

Solar Generating output full capacity = 130 kW
Diesel Generation supplying 90% of its capacity (limit before a second set is called online) =
225 kW
Maximum Power supplied before PLC trips breaker on overload = 320 kW
Load on Generator if immediate and total loss of solar = 225 + 130 = 355 kW
Excess demand = 355 – 320 = 35 kW overload

In this event, all breakers would open and a dead bus event would occur.
This is clearly a worst case scenario, for several reasons including

- The Solar farm is unlikely to experience complete, immediate loss of generation
- The diesel generation is unlikely to be sitting at exactly 225 kW

The original intention for this trial was to limit it to certain times of the year when there is less chance of cloud intervention, as well as less load being catered for by the solar. However, Ergon informs that the trial has so far run for 18 months straight, and there is no intention of turning the cloud smoothing function back on in the foreseeable future. It is clearly a risk that they are, at this stage, prepared to absorb.

This battery system and solar generation have a limited, maximum fault current sustain, primarily because of the inverter system power electronics. This is likely to be an issue when considering fault current protection of any battery installation. Due to this issue alone, if the system is to be proposed using a battery storage solution, then it will likely not permit the removal of the diesel generation from the grid, for any period of time.

3.9 DC Conversion Systems

To provide grid AC supply, a suitable converter would be necessary to convert the battery DC supply to 50 Hz for both the SWER feeder and the Windorah network. Power quality would need to be assured for both. The SWER system is of course only single phase, while the Windorah system is 3 phase. A substation yard would need to be employed for the battery to 22 kV and from battery to 19.1 kV.
It is acknowledged that converting the AC from Windorah into DC, then chemical energy, then back to electrical AC, involving at least two converters and two transformers, does not appear to be the most efficient of processes, however it must be remembered that the idea is for the energy to be stored for use at peak times coinciding with each of the two networks.

3.10 The Town of Windorah

Windorah is a small town with a population of 158 (2006 census), 1000 km East-North-East of Brisbane, Queensland. The town is named after the Aboriginal word for Big Fish (Outback Now) which is a nod to the nearby Cooper's Creek. The town of Windorah's electricity consumption can be nearly completely attributed to the seasonal temperature variations. It is one of only a few towns in South West Queensland and as such the major share of its income stems not from industrial infrastructure but tourism.

3.11 Ergon Energy – CSO

Ergon Energy operates under a Community Service Obligation (CSO). The CSO is funded by the Queensland Government and is a subsidy designed to bridge the gap between the cost to supply electricity to rural and remote communities, and the revenue recuperated from its customers. The intention of the CSO is to provide for parity of pricing for Ergon's electricity customers across Queensland. In general, due to economies of scale, the cost of electricity supply to customers living outside of south east Queensland is more expensive than the uniform tariff scheme (Ergon Energy, 2013-2014). To ensure affordable living, the CSO offsets the difference created by this cost.

3.12 SWER Networks

A Single Wire Earth Return (SWER) network is a system of electrical distribution using a single wire conductor for supply and the earth as the return current path. It is used in place of the more common 3 phase, 3 wire and single phase, 2 wire distribution systems. It is employed in sparsely populated areas due its cost advantage over 3 phase systems, especially in New South Wales' and Queensland's rural areas (Chapman, 2001).

Typically, Ergon's SWER network operates at voltage levels of either 12.7 kV or 19.1 kV; a result of the phase to ground voltage of 33 kV and 22 kV systems respectively.

3.13 Nature of long lines and capacitive voltage rises.

Long, lightly loaded SWER lines can be subject to the Ferranti effect, which can cause voltages to rise, especially during periods of low load (World, 2015).

3.14 Nature of long lines and voltage drops.

Due to a combination of factors, voltage regulation can be a problem with SWER lines. Due to the nature of SWER, they are generally at the end of already heavily regulated networks and this can be compounded by high impedance isolators and conductors (World, 2015).

3.15 Gapped Band System

Due to the protrusion of distribution poles in remote areas from their immediate landscape, the frequency of lightning strikes can be higher than in built up or urban areas. The inconvenience to a customer of a lost pole can be exacerbated on a single supply line such as that generally found on a SWER lines where there is not an alternative source of supply. This, in turn, can be compounded by the delay in restoration of supply due to access difficulties.

Ergon Energy employs a lightning arrestor system known as “Gapped Bands” to protect distribution poles located in remote areas from lightning. The system uses an earthed conductor tail, run external to the pole, to connect to the lower band as seen in Figure 3.1. Another conductor then runs from the upper band to a lightning conductor placed atop the pole.

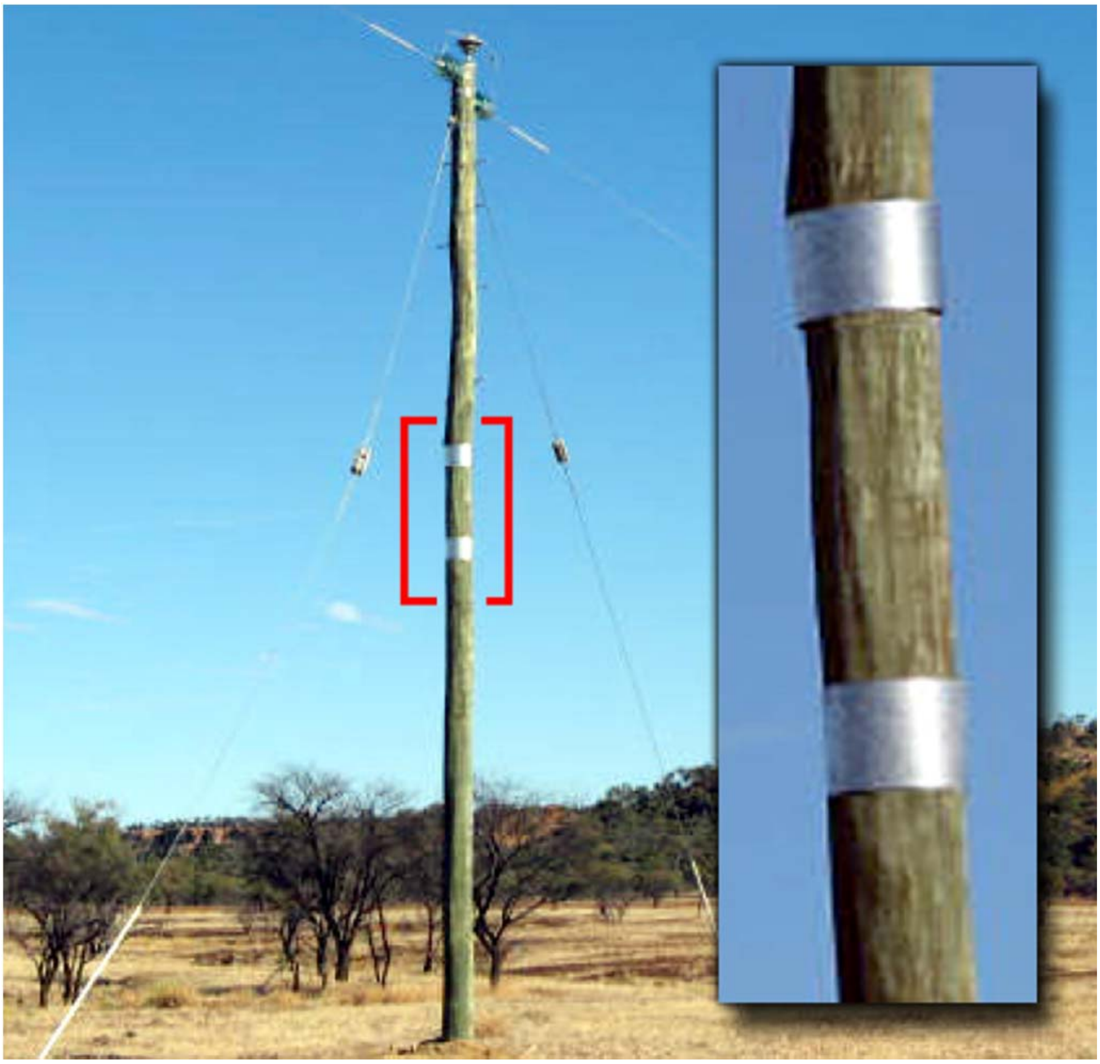

Figure 3.1 - Gapped Band System on a SWER pole

The installation of Gapped Bands on, for example, the Yallambie SWER has, to date, eliminated lightning related outages. On other SWER networks, the system has also had anecdotally high success rates, having been installed on a total of 1,248 poles (Ergon Energy, 2014).

When a lightning strike occurs on a pole fitted with a Gapped Band system, the arcing is reduced across the distance between the two bands, causing only superficial damage to the pole and hence saving the infrastructure from failure.

An example of the surface splintering between the gapped bands can be seen in Figure 3.2.

Figure 3.2 - Example of splintering between the Gapped Bands

3.16 Solar to Diesel Integration

At the moment, the load on the station bus determines the amount of penetration available for the solar at Windorah. This limit is set to 10% of the capacity of the operating diesel generator(s). This is for two reasons;

- To limit the instability to the generator
- To minimise the under-loading of the generator, which can cause long term carbon build up and damage to the engines' combustion chambers

Decentralised inverter energy systems have their output regulated by limit setting the voltage control on the inverter. In contrast, the solar farm is fed a set point via PLC as to the current load and, in response, the number of solar dishes turned on-Sun is adjusted to accommodate this.

It is envisaged that the mini-grid would see an additional battery storage as a load and thus the decentralised PV system would respond to the voltage accordingly. This would allow the decentralised units to have a ‘priority’ over the solar farm. Being a utility-owned asset, this would meet social obligations.

3.17 PV Output

Generally, the output of the distributed PV systems are fixed at the maximum generation available from the current insolation.

3.18 Spinning Reserve

In order for the system to be able to ride through fluctuations in load, an amount of reserve energy capacity is required. In the case of diesel gensets, much of this reserve is stored in the rotating inertia of the combination of flywheel, alternator and engine parts. In addition, the engine has the capacity to increase output in response to the additional load by increasing its speed reference (increasing fuel injection). In addition to absorbing load fluctuations, this is of particular importance in being able to supply fault current, and hence activating trip protection in the event of a network fault. Generally, PV inverter systems are unable to supply this reserve (much less fault current). To an extent, and dependent on the installation size, BESS’s are able to provide the energy required for load fluctuations, however the fault current is still limited to the inverter system’s power electronics.

3.19 Capacity

PV integration carries with it the undesirable characteristics of rapid and total fluctuations in generation due to cloud cover. A diesel generation based micro-grid must be capable of ramping up its power output swiftly enough to cover these fluctuations. In comparison to other sources of generation, diesel generators are reasonably quick to start, synchronise and take load. In the case of Windorah’s Scania DC12’s, this start-up time is in the order of 15 seconds. However, cloud coverage of Windorah’s 5 concentrator dishes can occur in a matter of 20 seconds, leaving a deficit of 5 seconds.

3.20 Existing Solar Penetration

The actual level of penetration from the existing roof top solar generation is already in excess. Information regarding the exact number and capacity of registered solar installations in the community is currently being pursued by Ergon Energy’s remote Asset Engineering Department. Information is hoped to be forthcoming on this in the near future, but the sensitivity of this information will have to be assessed. Currently it is listed as a ‘large factor’, according to Inverter Energy applications. Schematics of the Concentrated Solar farm show that while the solar farm itself has a fairly complex control system to monitor its own generation, no indication of this is communicated to the diesel power station. It seems that the diesel station simply sees a reduction in load on the main bus. The generation is however recorded via an RTU connection, both back to an HMI present in the diesel station, as well as via the SCADA system, back to Ergon’s office in Cairns. Whilst the solar generation from the dishes is simply a reduction in load, it should be remembered that the solar station is equipped with battery smoothing.

Chapter 4 Windorah's Diesel Station

Windorah's current diesel power station configuration was commissioned in 2010 with the installation of 3 diesel Scania DC12 prime power generating engines. The engines have the following fuel characteristics in Table 4-1;

Scania DC12-60A	
Rating:	Prime Power
Speed (rpm):	1500
Power (kWm)	399
Specific Fuel Consumption (g/kWh)	
full load:	190
3/4 load:	193
1/2 load:	199

Table 4-1 - Scania Fuel Ratings (Scania, 2009)

The gross power rating of 399 kW is de-rated to give an installed electrical supply capacity of 312 kVA/250 kW. These engines have special capacity due the manufacturer's warranty that they were capable of low load running for periods of continuous use as long as a periodic ramp up is instigated to allow burn off of any deposits and clearance of injectors.

4.1 Operational Philosophy

Ergon Energy designs its mini-grid power stations so that in the event of a generating set failure, the station still has enough capacity to meet demand.

4.2 Scania DC12 Engine

The installed generating engines are Scania DC12 – 60A engines, rated at prime power to 399 kW or 451 kVA. Ergon Energy de-rates the engines in an effort to conserve engine longevity and reliability. The maximum output from the engines is designed to provide prime input power to the alternator for a maximum power of 250 kW electrical at 0.8 power factor (312 kVA).

Chapter 5 Windorah's Solar Station

Windorah has 5 solar concentrating dishes. Commissioned in 2009, the installation was centred around becoming a pilot for future solar installation schemes, in an effort to offset diesel consumption.

Windorah's location is seen as an ideal location for solar generation with high average daily insolation levels and relatively few cloudy days, as seen in Figure 5.1.

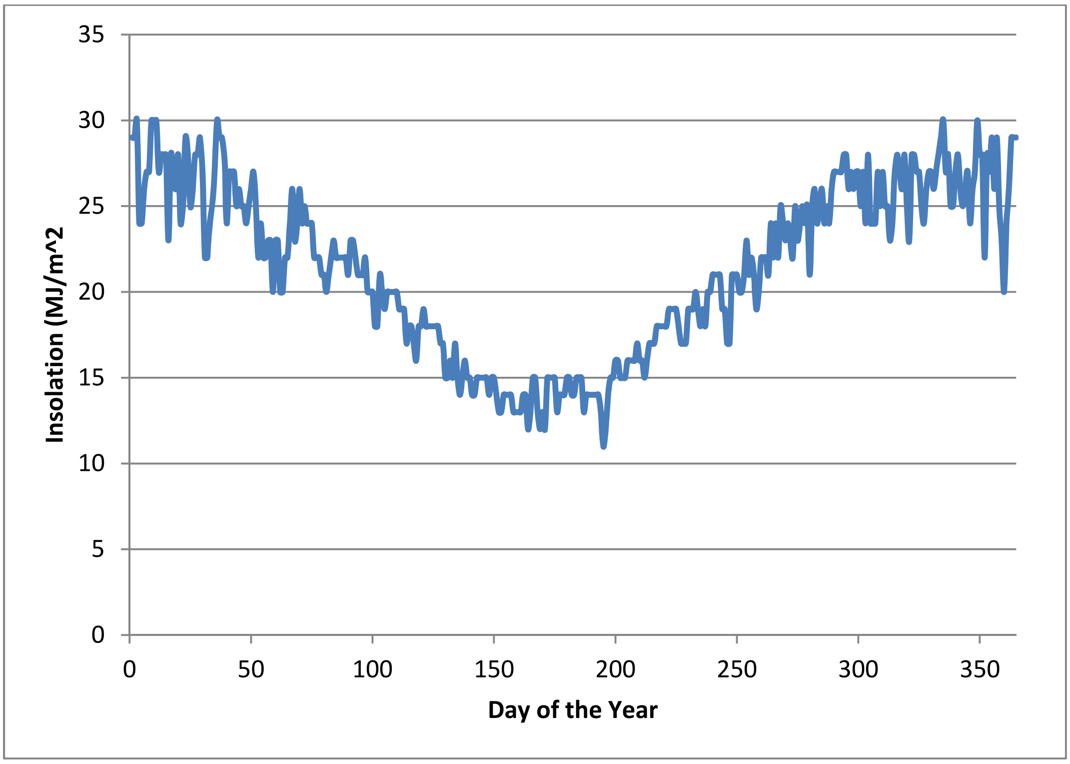

Figure 5.1 - 10 Year Average Insolation Readings (BOM, 2015)

Chapter 6 Methodology

In order to fully evaluate the feasibility of the proposed solution to the current problem of solar abundance mixed with capacity shortage on the SWER, data was taken to find the typical load on the station bus.

An understanding of the solar insolation availability in Windorah was also required, as well as the current PV generation capacity.

The project methodology was;

- Completion of the literature review of both private and public sources, including all available data regarding solar generation capacities and load profiles of Windorah and the SWER.
- Formation of a high level single line diagram of the proposed system.
- Determination of excess generation

6.1 HOMER Energy Mini-grid Software

Hybrid Optimization of Multiple Energy Resources (HOMER) is a software modelling package developed by the National Renewable Energy Lab division of the US Department of Energy. The software is designed specifically to model the optimisation and feasibility of integration of renewable energy sources with traditional sources, as well as to model load management and storage.

The package has a powerful suite of tools which includes the ability to model photo voltaic exposure using geographical grid references. For this thesis, HOMER was used to model the expected generation from the concentrated solar dishes.

The following settings were entered into HOMER for the Windorah Solar Station generation;

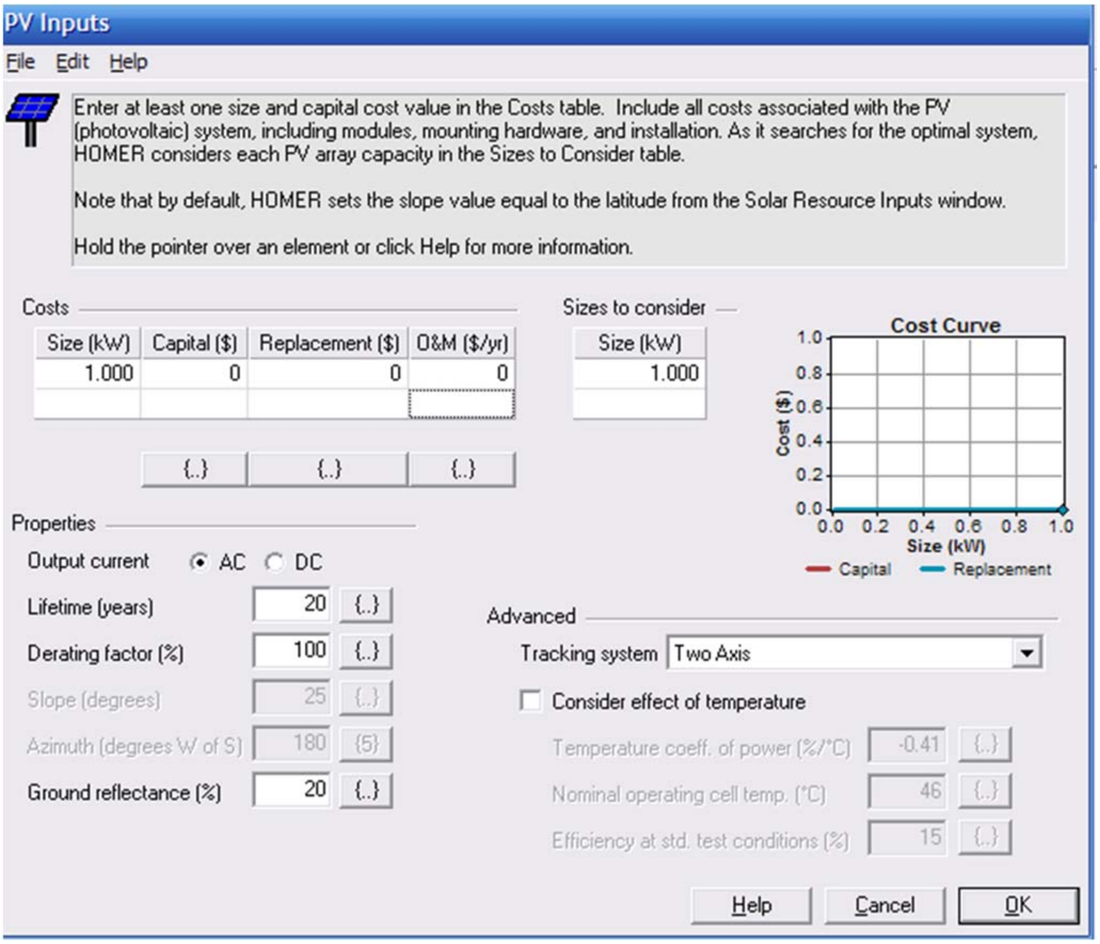

Figure 6.1 - HOMER software inputs used to generate output for solar tracking

A power output capacity of 1 kW was used for the modelling of the concentrator dishes. This allowed the results to be scaled up according to the potential total capacity and to allow future modelling of individual dish contribution scenarios. For example, if all dishes were online, multiplying the output by 5 x 26 kW would result in the total penetration available. However to enable reduced load or maintenance scenarios, the figure need only be multiplied by the appropriate number of dishes available.

The results returned from the HOMER model for PV generation from the concentrator dishes can be seen in Chapter 8, pg 30;

Chapter 7 Theoretical Analysis

7.1 Data Used

According to the GAM spreadsheet, Int_Gen_Isolated - Version 2.xlsx, there's currently 177 kW of installed PV capacity at Windorah.

Windorah's existing diesel generation plant consists of 3 diesel generators with capacity as follows;

Generator	Capacity
1	250 kWe
2	250 kWe
3	250 kWe

Table 7-1- Windorah Generator Rated Capacities

7.2 Windorah Mini-grid

Load recordings were taken using Ergon Energy's SCADA, to be used for each season (4) over a year of load data for each feeder, and the station bus. The loads are inclusive of any PV generation offset on the mini-grid, as there is no way of measuring the actual contribution of these installations.

The load measurements were combined to form an average, and then plotted to determine a typical load profile for the mini-grid.

7.3 Safe Operating Capacity

In addition, Windorah's Concentrated Solar Farm has capacity as follows

PV Concentrator	Capacity
1	26 kWe
2	26 kWe
3	26 kWe
4	26 kWe
5	26 kWe

7.4 Load data Profile

Windorah power station has three separate feeders. Load data was retrieved from each feeder over the course of a 2014 using Ergon's SCADA system. Each feeder has a metering CT for each phase which is connected to summation CTs and finally connected to a power transducer. The transducer monitors the instantaneous voltage on the station bus to calculate the load power. This figure is recorded at a half hourly resolution on the station PC and sent back to the server PC using the RTU.

Averages were taken over a 10 day period to reduce any significant effect from day to day anomalies that might be recorded, across each of four season periods.

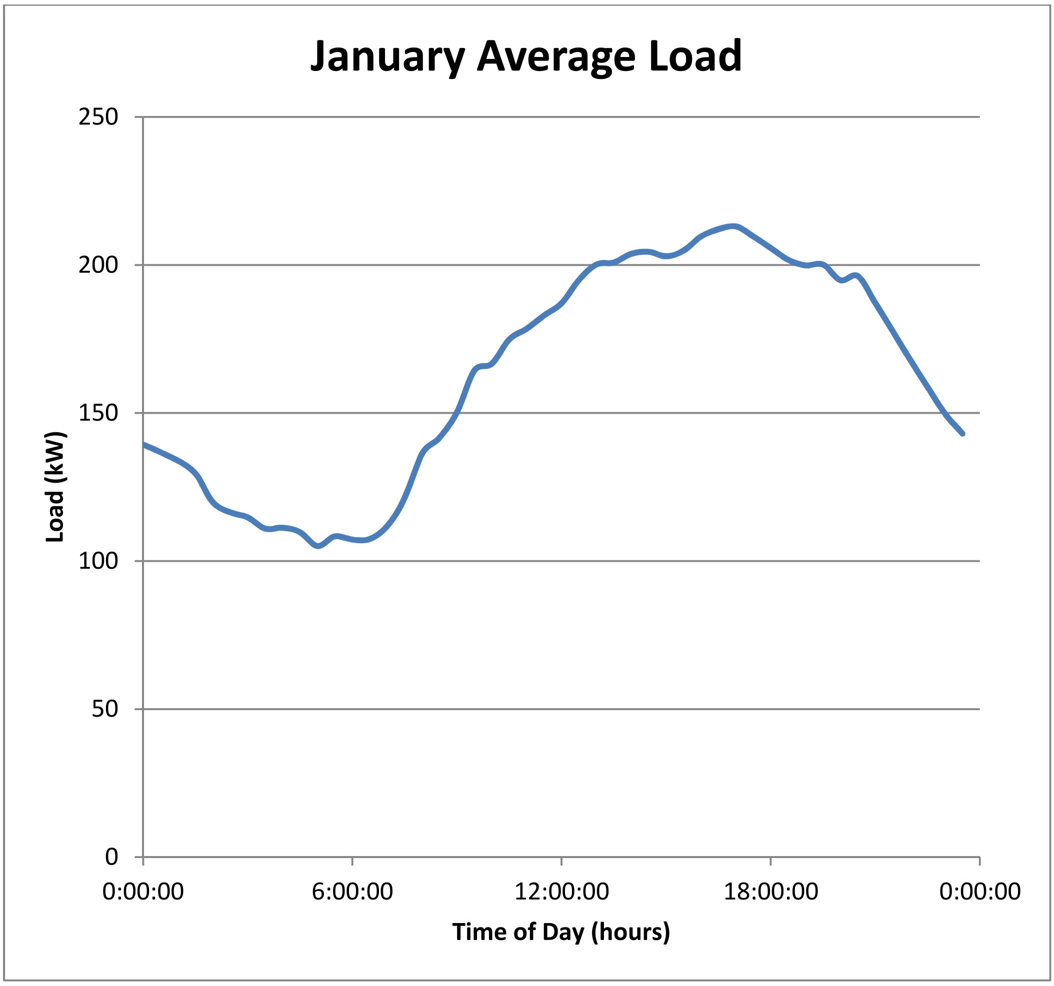

Figure 7.1 - Windorah Average Load (January 01-10, 2014)

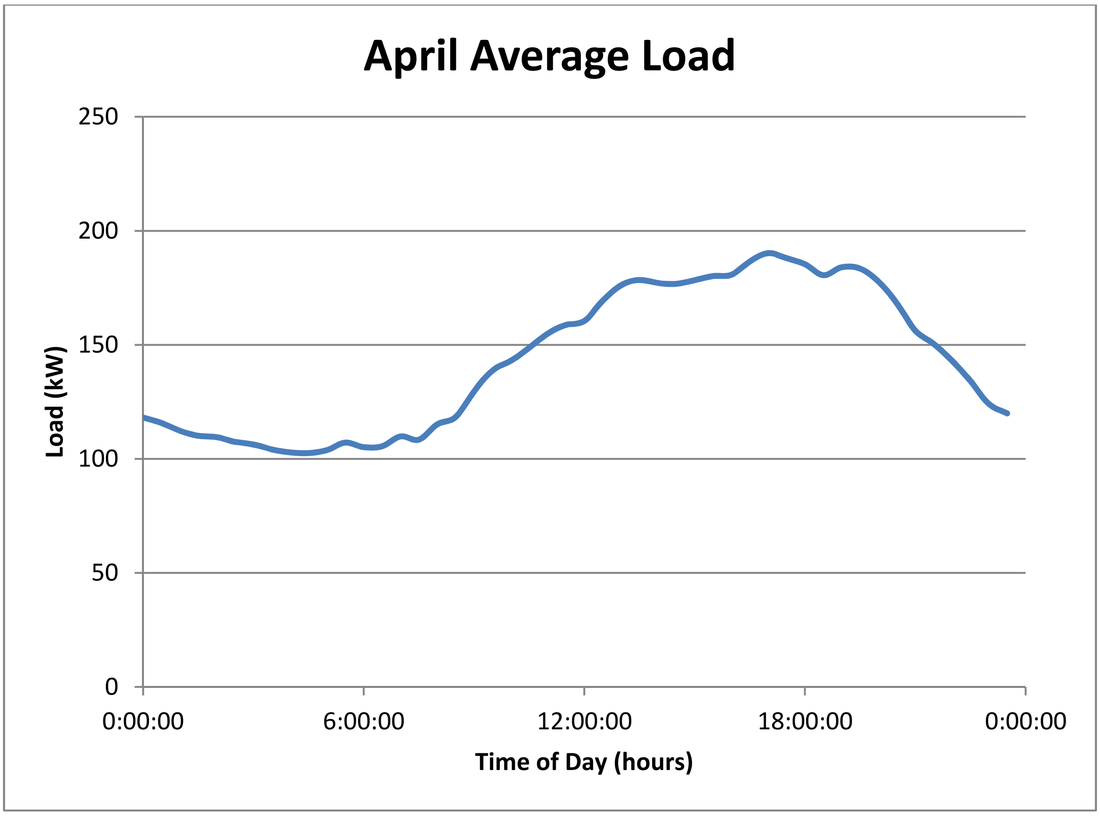

Figure 7.2 - Windorah Average Load (April 01-10, 2014)

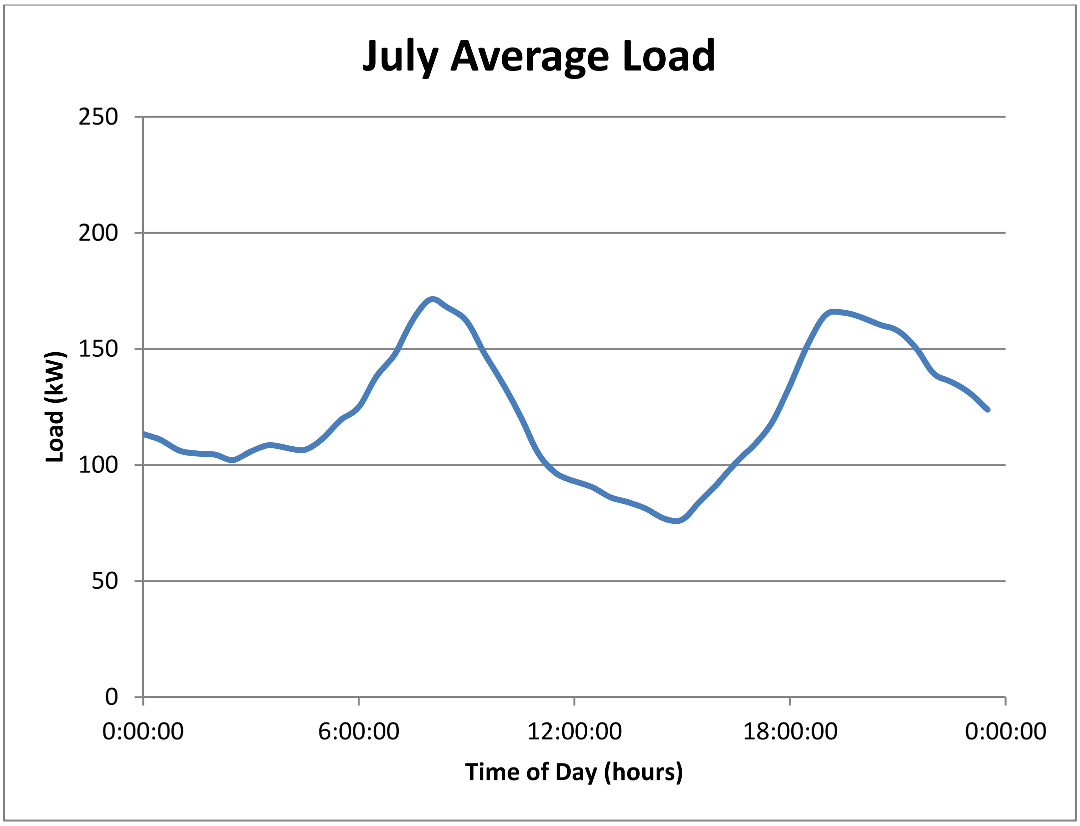

Figure 7.3 - Windorah Average Load (July 03-12, 2014)

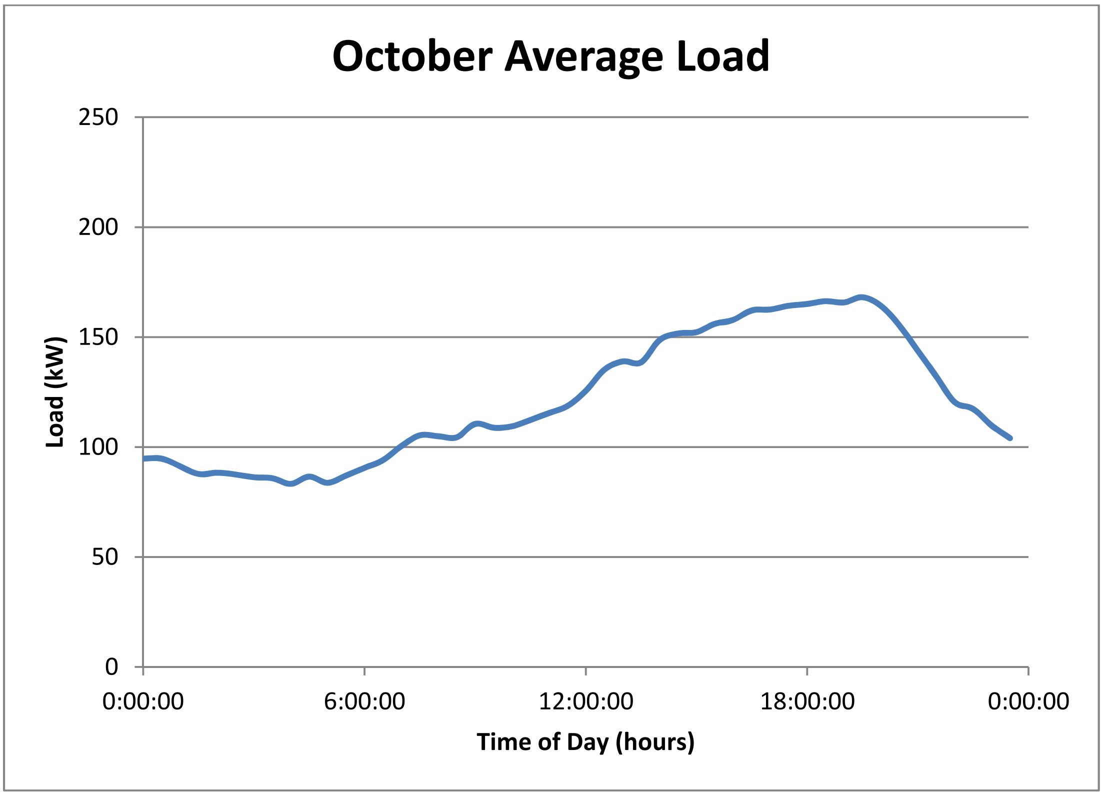

Figure 7.4 - Windorah Average Load (October 03-12, 2014)

The July and October readings were taken starting from the 3rd day of the month rather than the first or second due to missing entries on those days for both months.

7.5 Measuring of Insolation

Model done for estimation of total flat panel generation using Homer, with an efficiency rating of 75% to account for the panel, inverter, and transmission inefficiencies, as well as the non-perfect alignment of the panels to an angle of 25 degrees towards North.

Chapter 8 Results

The HOMER model for the potential maximum solar generation is shown in total for the Concentrator Dish Generation

8.1 HOMER Solar Dishes Model

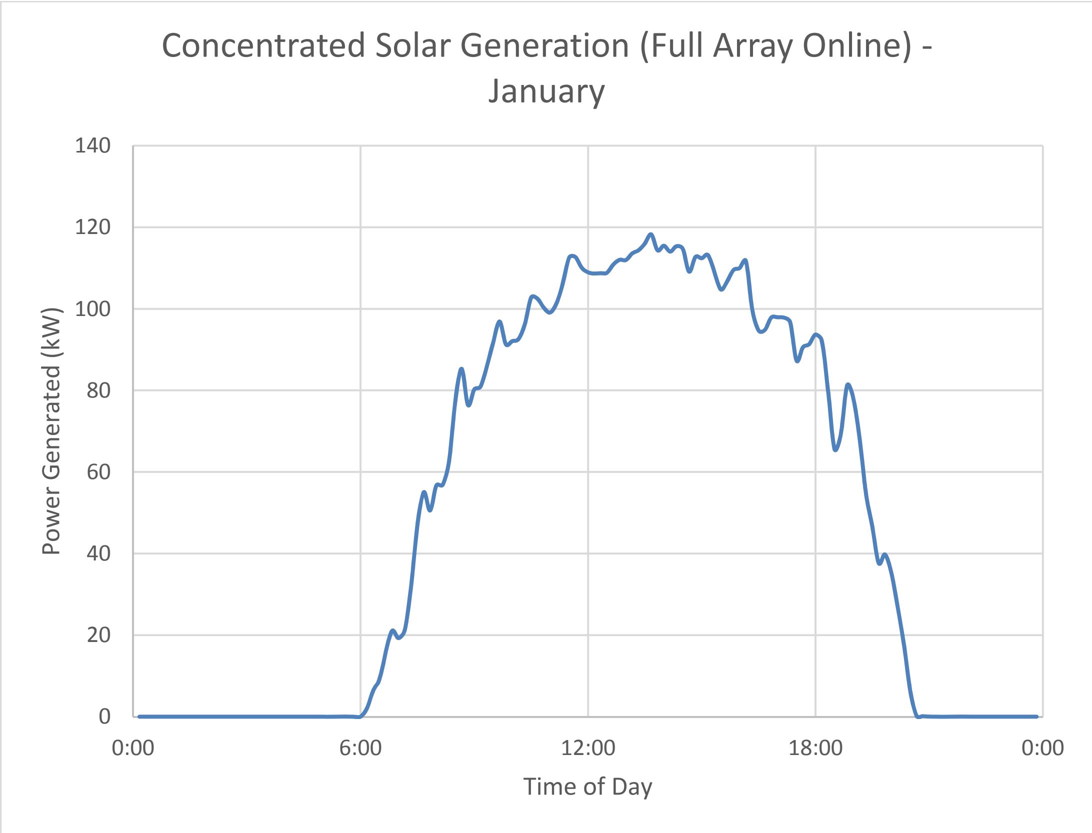

Figure 8.1 - Concentrated Solar Generation for all 5 dishes

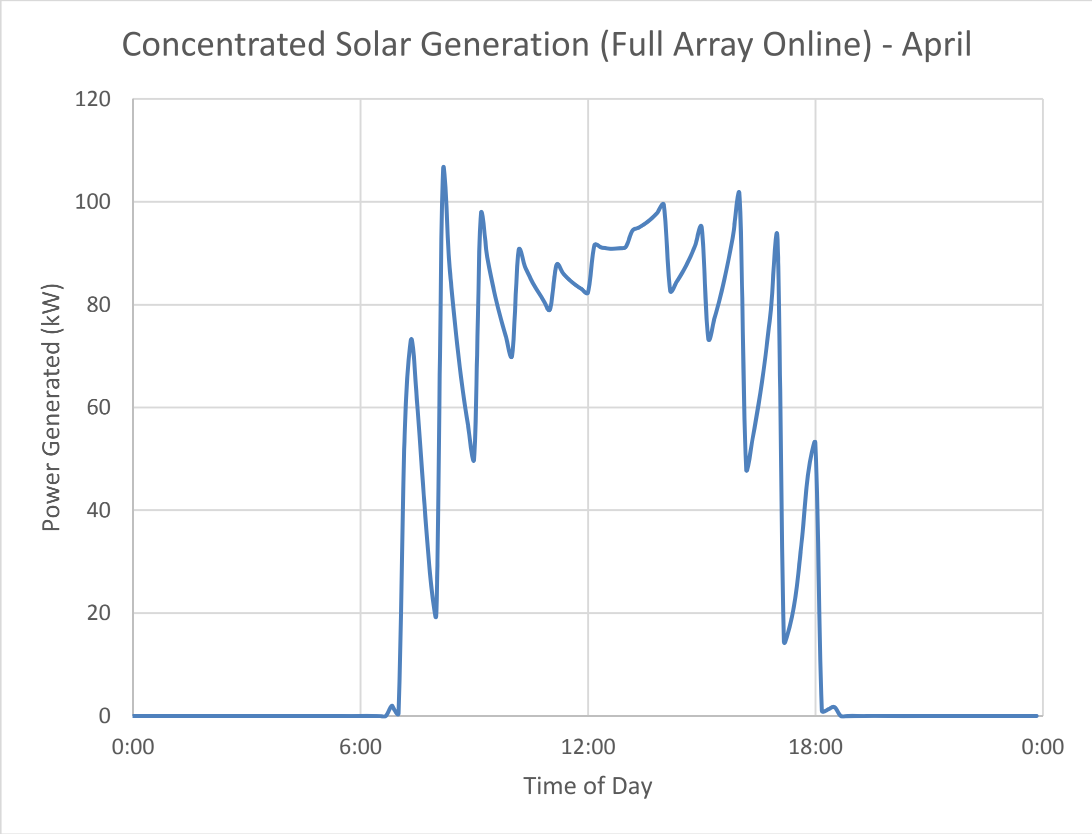

Figure 8.2 - Concentrated Solar Generation for all 5 dishes

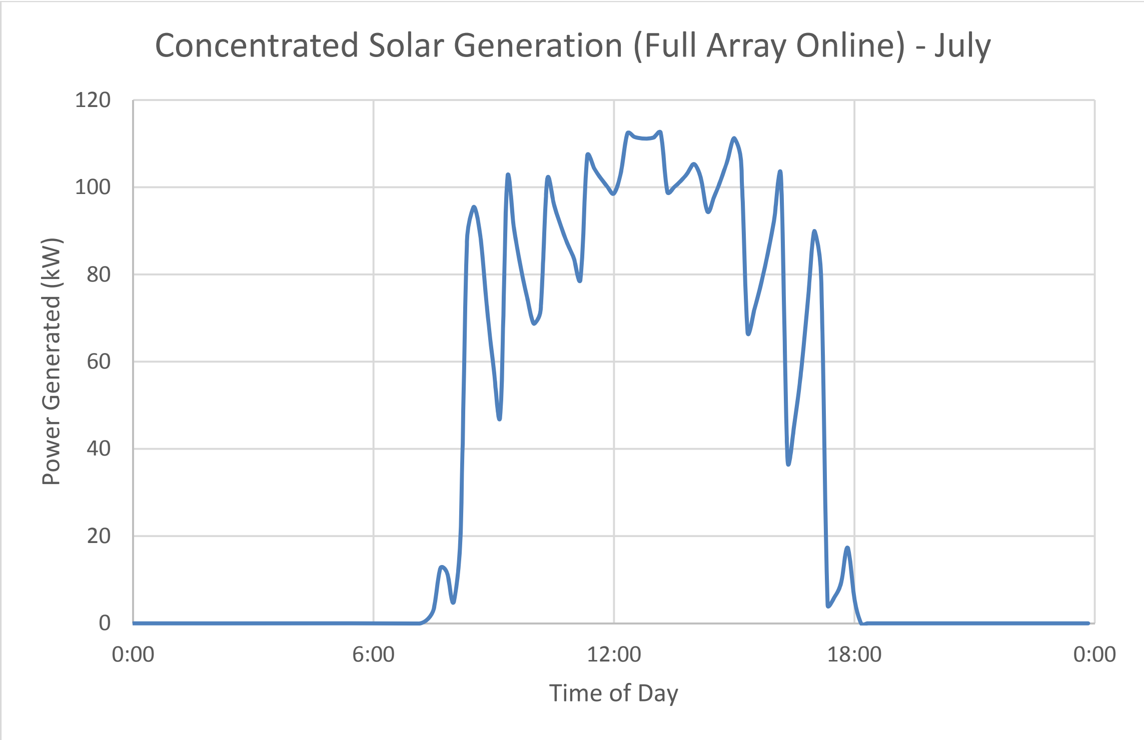

Figure 8.3 - Concentrated Solar Generation for all 5 dishes

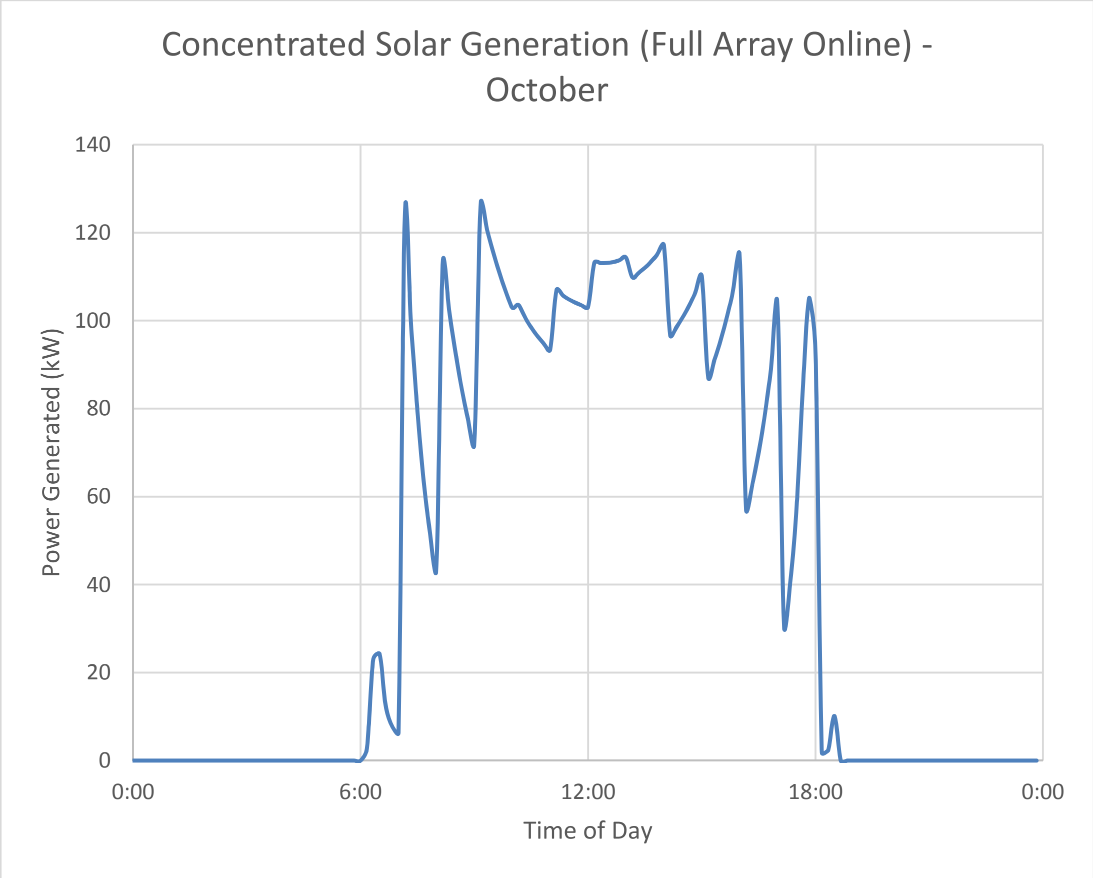

Figure 8.4 - Concentrated Solar Generation for all 5 dishes

8.2 HOMER Distributed Flat Plate Model

HOMER model of distributed flat panel Generation

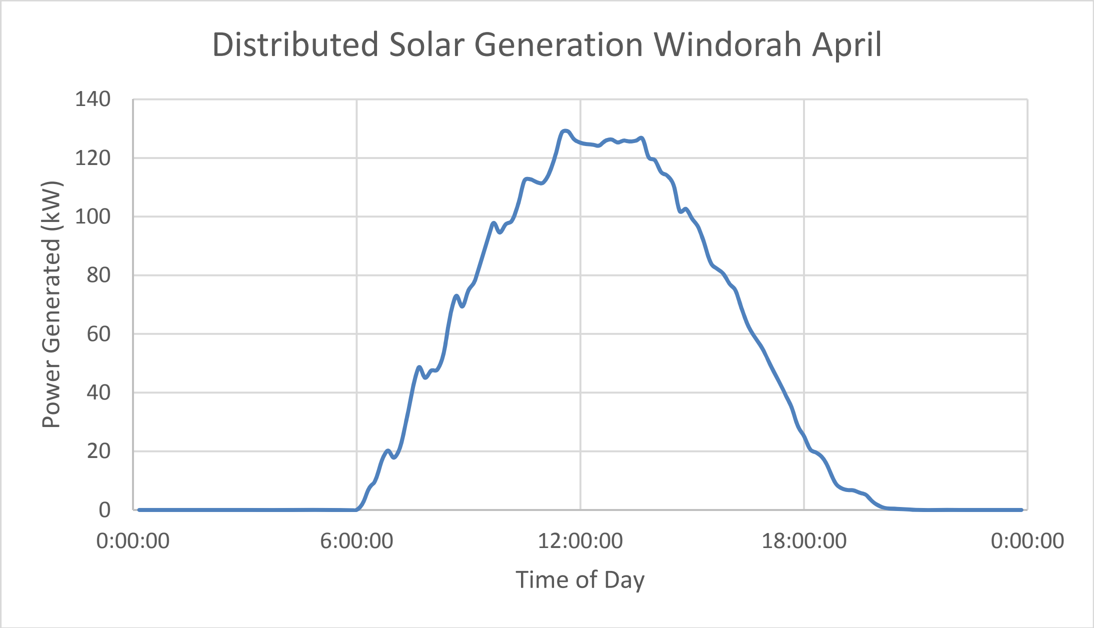

Figure 8.5 - Flat Panel Solar Generation Town of Windorah

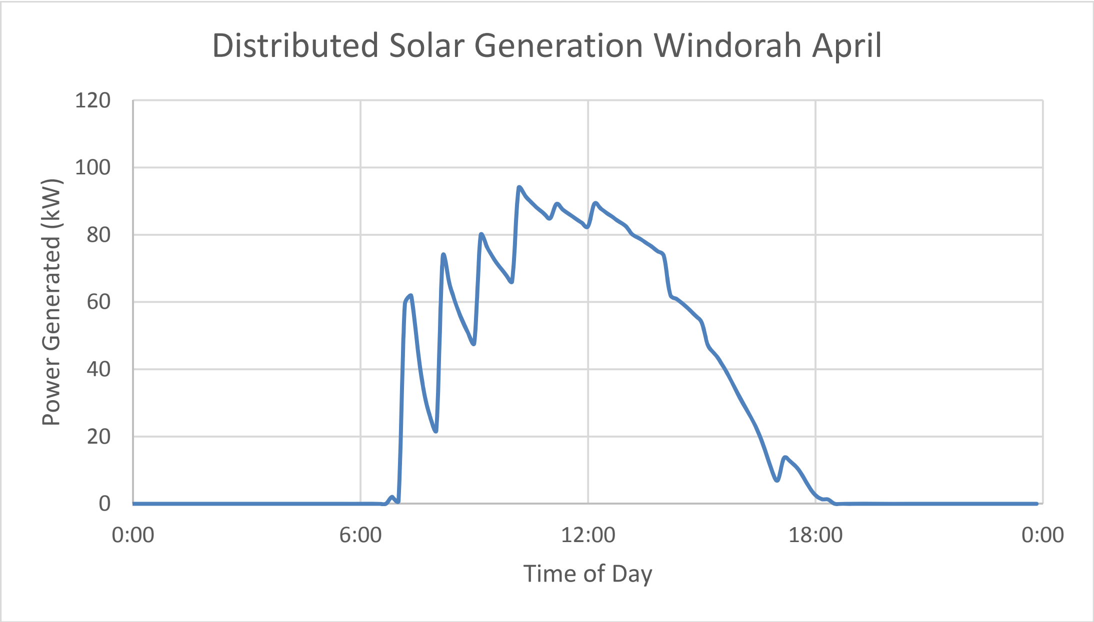

Figure 8.6 - Flat Panel Solar Generation Town of Windorah

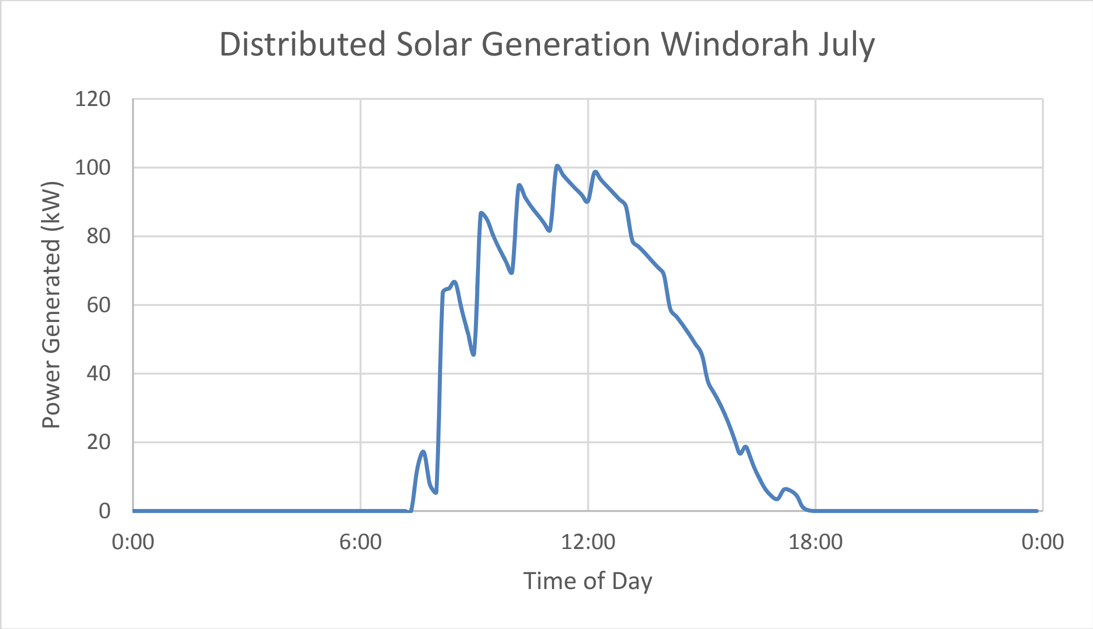

Figure 8.7 - Flat Panel Solar Generation Town of Windorah

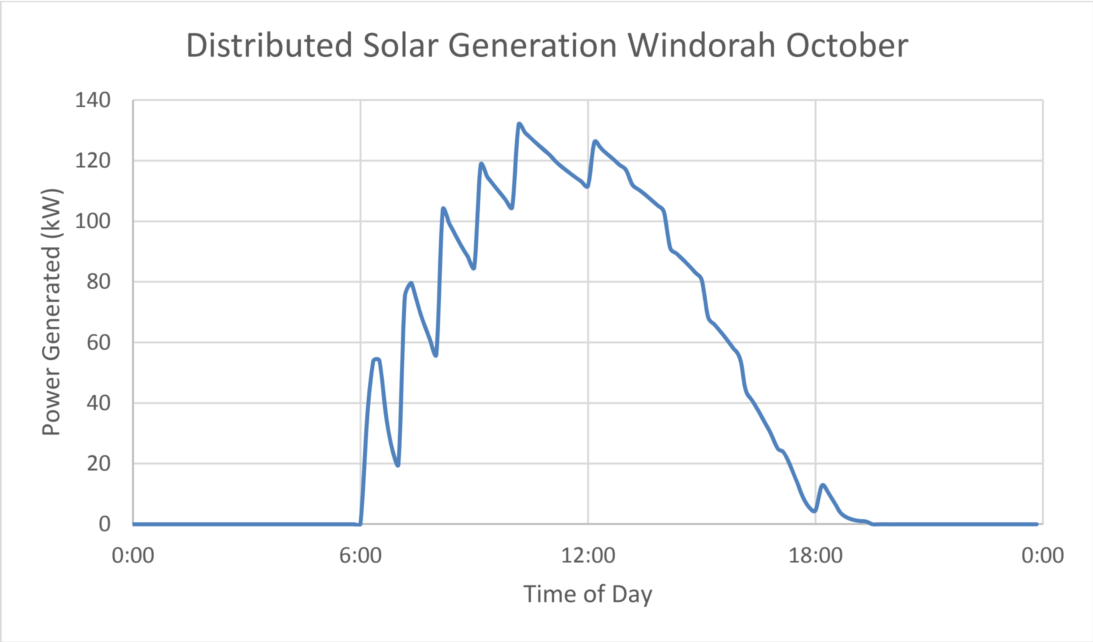

Figure 8.8 - Flat Panel Solar Generation Town of Windorah

Chapter 9 Data Analysis

The below plots (Figure 9.1, Figure 9.3, Figure 9.5, Figure 9.7) give a graphical indication of the total daily average solar generation against the daily average load in Windorah for January. The subsequent plots show the excess solar, taking into account the minimum diesel operating set points of 10 %, or 25 kW.

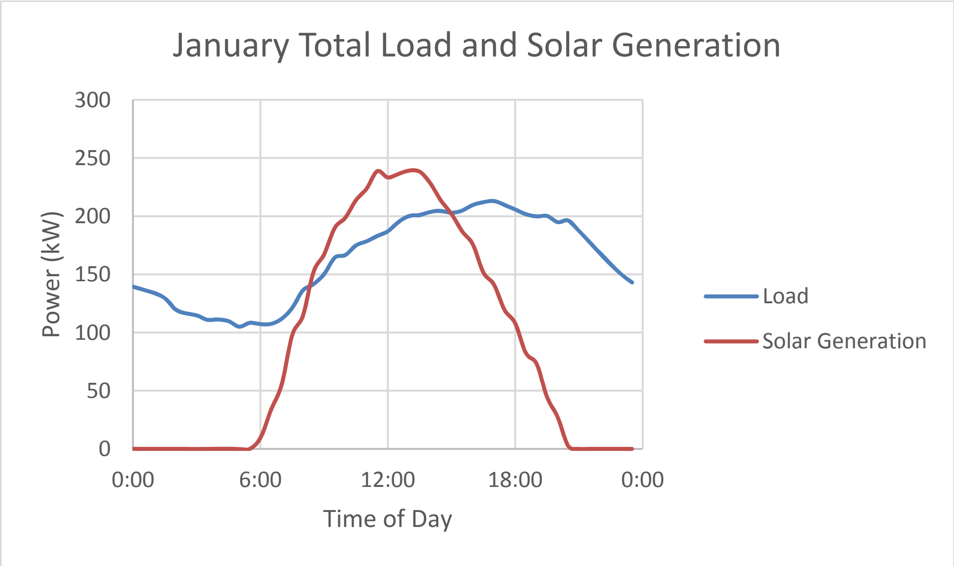

Figure 9.1 - Total Solar Generation Overlaid with Load, January Average

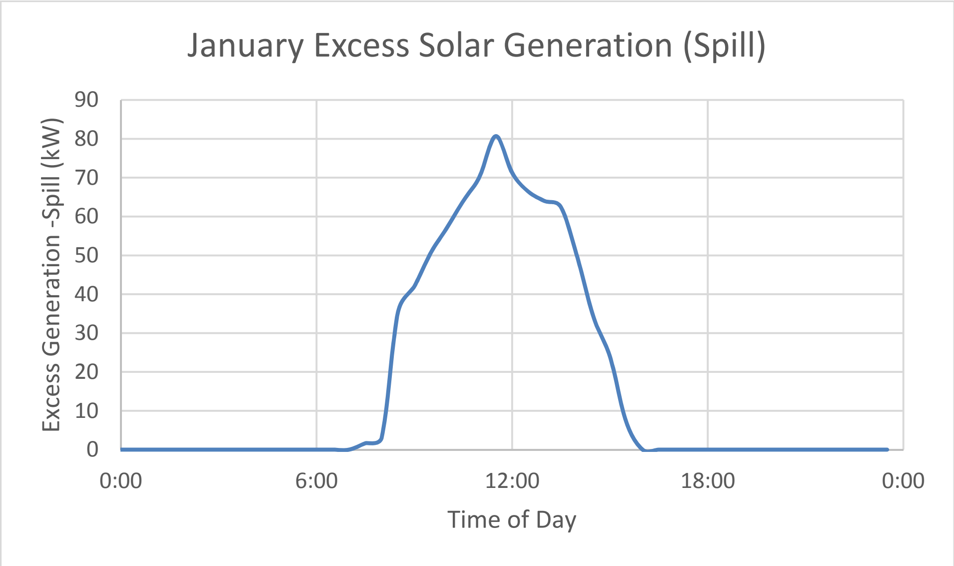

Figure 9.2 - Excess Solar Generation, January Daily Average

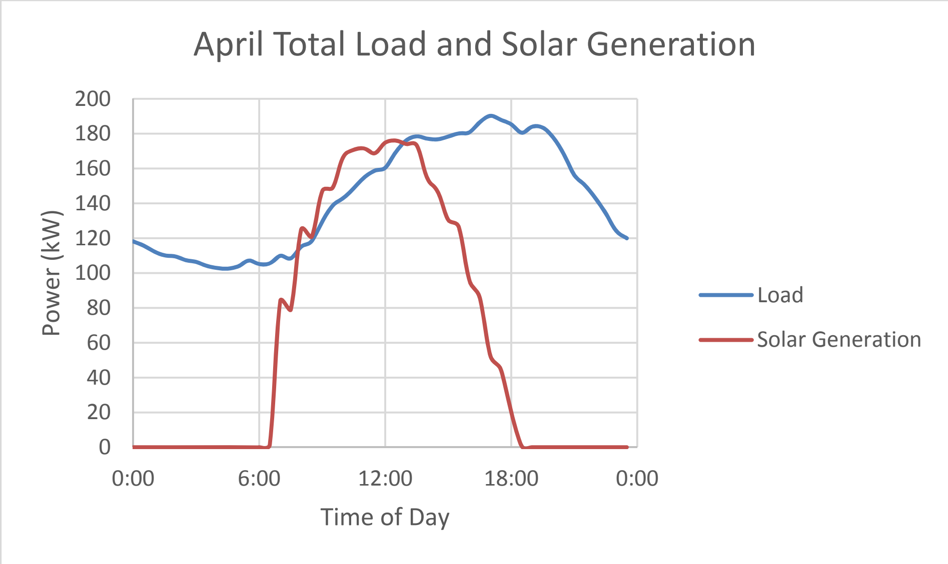

Figure 9.3 - Total Solar Generation Overlaid with Load, April Average

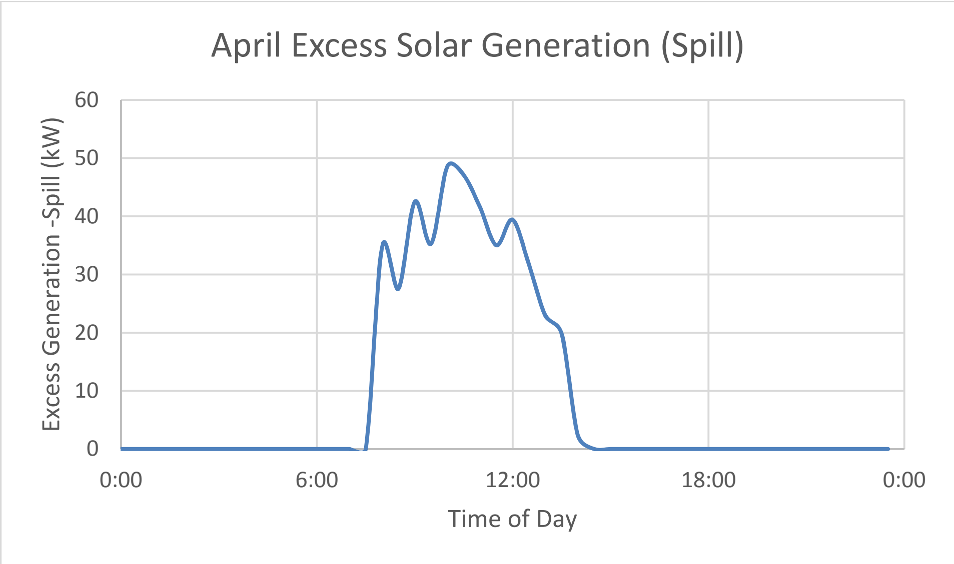

Figure 9.4 - Excess Solar Generation, April Daily Average

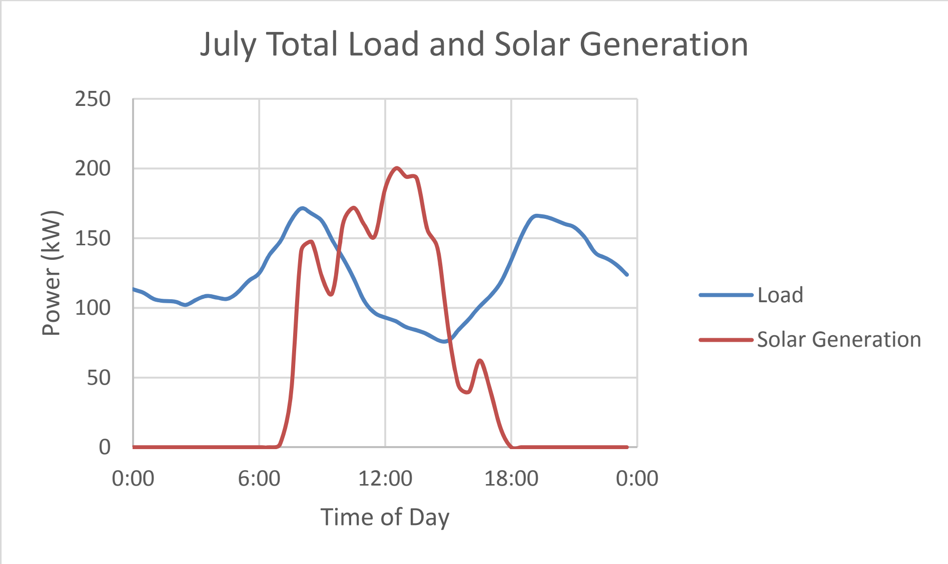

Figure 9.5 - Total Solar Generation Overlaid with Load, July Average

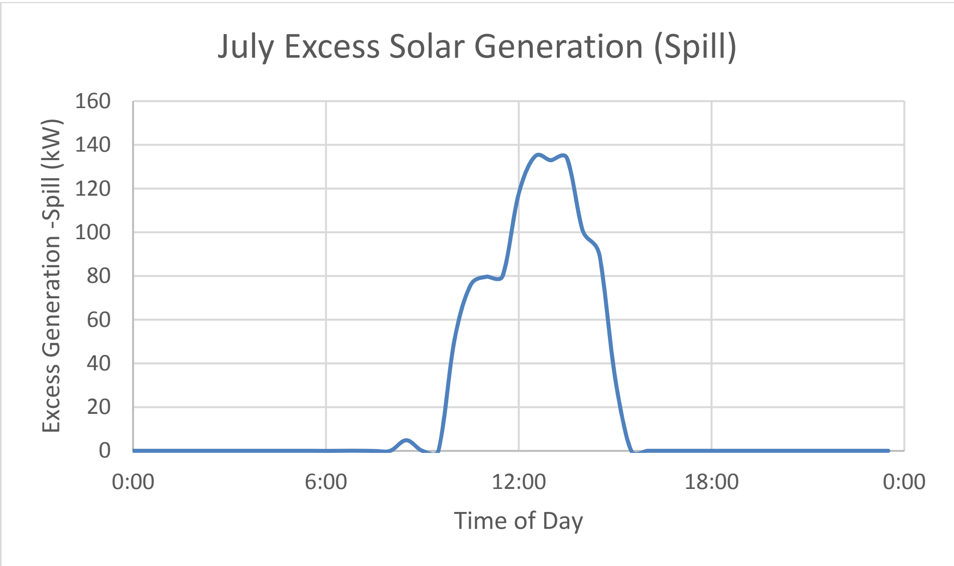

Figure 9.6 - Excess Solar Generation, July Daily Average

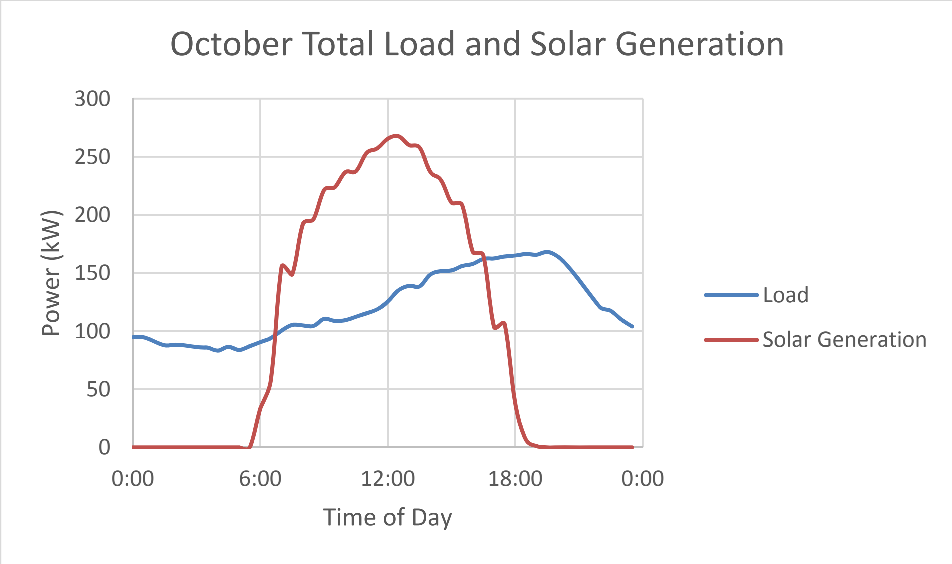

Figure 9.7 - Total Solar Generation Overlaid with Load, October Average

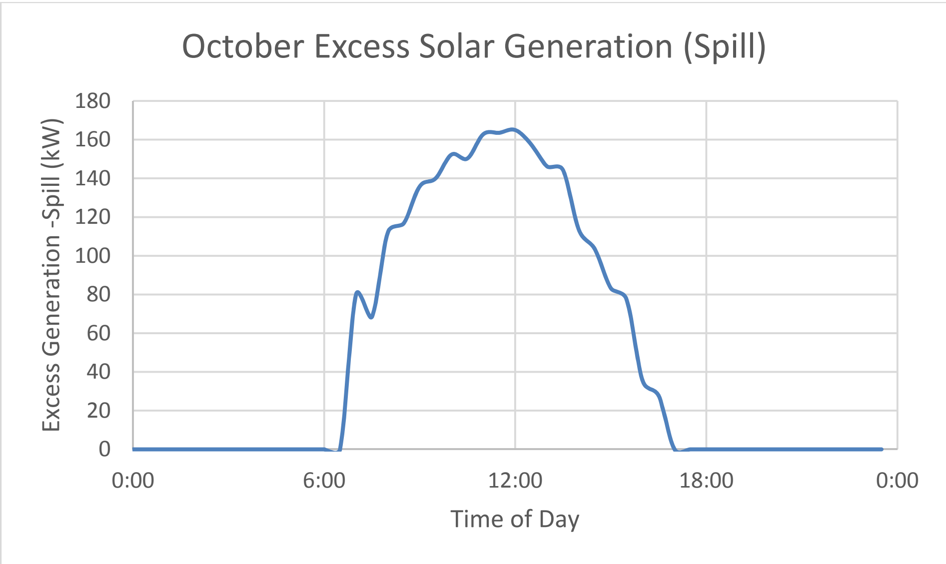

Figure 9.8 - Excess Solar Generation, October Daily Average

Different configurations of gensets on and number of dishes on

9.1 Difference between Flat Plate and Concentrator Dishes

Due to the twin axis tracking system of the power station's concentrator dishes, the generation curves from the dishes resemble very closely the insolation data retrieved from the Bureau Of Meterology. For this same reason, the generation curves from the distributed flat panel PV shows a much sharper rise and fall in generation throughout the day, as the insolation levels not only rise and fall as the Sun moves across the sky, but are also affected by the angle of incidence.

Chapter 10 Conclusion

The objective of this thesis was to investigate the technical feasibility of a battery storage system for maintaining capacity for peak load to the end of a Single Wire Earth Return feeder. The driving factor for investigative development of any sort of electrical generation in typical mini-grids, is the reduction in operating costs. In the case of Ergon Energy’s Isolated Systems, this is primarily through savings in diesel consumption. The abundance of solar insolation and the relative modern-day simplification of PV installations in Australia’s drier, remote regions present excellent opportunities to investigate reductions in diesel consumption.

The stability and fluctuations surrounding PV penetration pose a ceiling to the amount of diesel offset possible. With this study of Windorah, and its current PV generation levels, an alternative solution is proposed with exciting prospects for further development and warrants further investigation into the financial viability of such a scheme. The study concludes that the extra energy supply required to provide injection into the SWER should be readily available, and in fact already installed.

Of the 4 seasonal periods studied, peak, excess power generation is at its lowest in the month of April with a figure of just below 50 kW, demonstrating that the abundance of solar should be reliably produced throughout the year.

Chapter 11 Safety

Although it was never the intention of this research project to enact any physical applications, it is a very real possibility that flow on work based on this research may be used. To that end, a duty of care begun with the initialising of this project and as such, current best practice was applied to every step of the project. A risk assessment was developed and maintained as a dynamic, evolving document.

For future work, if the solution were to be implemented, it would be required that any potential hazards be identified. These may include, but are not limited to;

1. Appropriate fault protection levels not ascertained
2. Manual Handling of components, especially batteries
3. Maintaining clearance zones and barriers
4. Explosions from batteries

The above identified hazards can then be used against a typical Risk Assessment Matrix, as below;

	Consequence				
Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Extremely Likely	HIGH	HIGH	EXTREME	EXTREME	EXTREME
Likely	MODERATE	HIGH	HIGH	EXTREME	EXTREME
Moderate	LOW	MODERATE	HIGH	EXTREME	EXTREME
Unlikely	LOW	LOW	MODERATE	HIGH	EXTREME
Extremely Unlikely	LOW	LOW	MODERATE	HIGH	HIGH

For each of the suggested hazards, the risk is then assigned as;

1. (fault protection) Extremely Unlikely + Moderate = Moderate
2. (Manual Handling) Moderate + Moderate = High
3. (Clearance Zones) Unlikely + Moderate = Moderate
4. (Battery Explosions) Unlikely + Moderate = Moderate

Control measures must thus be applied to all four identified hazards to reduce the risk to low, and these must be designed into the project work.

Chapter 12 Future Work

Further analysis in HOMER may be used to better clarify and predict the behaviour and interaction of the two independent systems.

Better determination of the actual load profile of the SWER may also be gained through installation of a site specific power quality meter.

The reduction in load seen on the station bus could be mapped against the fuel consumption curves of the diesel generating engines, for financial feasibility.

Chapter 13 Thesis Timeline

The following table shows the estimated dates for completion of the major milestones of the project.

Item	Description	Anticipated Completion
1	Preliminary Report	10/06/2015
2	Literature Review	10/07/2015
3	Obtain all SWER data	22/07/2015
4	Obtain all Solar data	22/07/2015
5	Complete SLD for storage system	27/08/2015
6	Model Design	28/08/2015
7	Examine Control Gear	18/08/2015
8	Make Recommendation for appropriate control methodology	23/08/2015
9	Complete Draft Dissertation	4/09/2015
10	Complete Presentation	11/09/2015
11	Complete Dissertation	31/10/2015

Table 13-1 - Researh Project Schedule

A Gantt chart for the project, as mapped for the project's Preliminary Report, is shown in Figure 13.1

Figure 13.1 - Project Gantt Chart

Figure 13.1

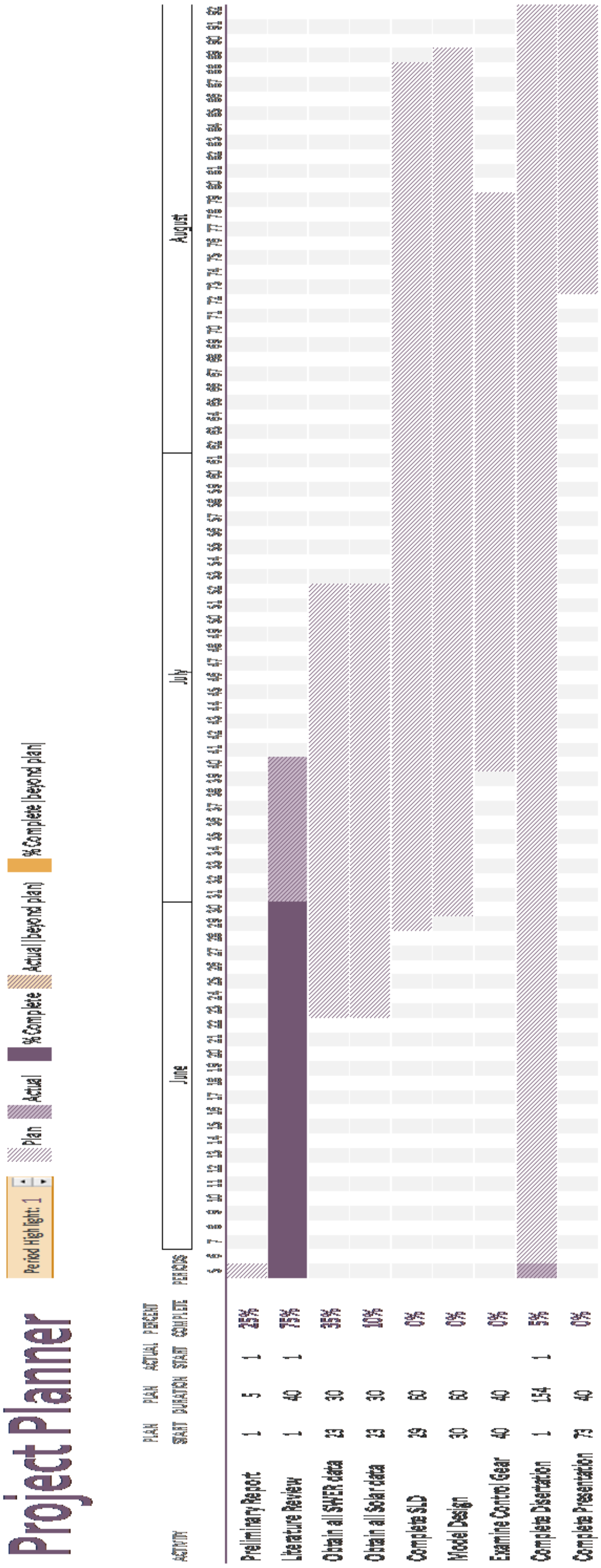

Figure 13.1 - Project Gantt Chart

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Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/ENG4112 Research Project

PROJECT SPECIFICATION

FOR:	**PHILIP TIMINGS**
TOPIC:	ISOLATED GRID SOLAR-BATTERY SUPPORT FOR SWER FEEDER
SUPERVISORS:	Dr. Narottam Das
SPONSORSHIP:	Ergon Energy
PROJECT AIM:	Conduct a feasibility study into a battery storage system for maintaining capacity for peak load to the end of a known Single Wire Earth Return (SWER) feeder to outback western Queensland (near Windorah).

PROGRAMME:

1. Investigate and document the current generation capacities and demand load of both Windorah's grid and the nearby SWER feeder.
2. Investigate spinning reserve of Windorah's current diesel power station
3. Determine stability concerns of solar penetration
4. Investigate market for energy storage options and pricing
5. Select modelling software
6. Predict impact of storage on both SWER feeder and Windorah's isolated grid.
7. Prepare dissertation

As time permits and pending viability:

8. Design and implement storage system

AGREED ________ (student) ________ (supervisor)

Date: 02 / 04 /2015 Date: 02 / 04 /2015

Examiner/Co-examiner ________________

Appendix B – Scania DC12 Technical Data Sheet

Page 12/36 of Scania DC12 technical data sheet, *Engine data Engines for power generation 12 – series*

Latest modification date: 060701

Technical data and cooling equipment recommendation

DC12 60A, order ref 10-20A

		1500 r/min	
		PRP	ESP
Gross power	kW	399	437
	kVA*	451	501
Specific fuel consumption	g/kWh		
full load		194	197
3/4 load		190	191
1/2 load		193	192
Heat rejection	kW		
to cooling water		154	170
to exhaust gas		263	292
to charge air		73	84
to surrounding air		35	39
Air consumption	kg/min	30	31
Air temperature before charge air cooler	°C	192	211
Air temperature after charge air cooler	°C	50	54
Fall of pressure, charge air cooler	Bar	0.10	0.12
Exhaust flow	kg/min	31	33
Exhaust temperature	°C	543	567

*The kVA range is calculated with the recommended fan for +35 °C air-on temperature to cooling system including the fan power losses at a generator efficiency common to the market.
For further information see "General, sect. 2".

		1500 r/min			
		PRP		ESP	
		Air-on temp.		Air-on temp.	
		35 °C	50 °C	35 °C	50 °C
Radiator					
front area	m^2	1.2	1.3	1.3	1.3
Coolant pump flow	dm^3/min	300	300	300	300
Fan					
type		Pusher	Pusher	Pusher	Pusher
Ø	mm	912	912	912	912
power losses	kW	11	11	11	11
speed ratio		1:1	1:1	1:1	1:1
Air flow					
free air flow	m^3/s	8.0	8.0	8.0	8.0
pressure reserve	mm Wc	24	30	26	20