# University of Southern Queensland

# Faculty of Engineering and Surveying

# Smart Grid for Tomorrow's Electricity Distribution

A dissertation submitted by

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towards the degree of

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# Abstract

Smart Grid promises to increase the reliability and efficiency of the current electricity grid through greater measurement and control. This project discusses the benefits of Smart Grid, and evaluates the performance of a Smart Grid in South East Queensland through the use of computer software simulations.

Smart Grid is not a specific technology, but rather a concept, which enhances current electricity grid infrastructure. It is typically described as a dynamic power transmission and distribution network which is characterized by the use of two-way communications technologies. Much research has been performed regarding Smart Grid concepts in recent years, with significant implementation in some European countries and the United States. While some of these concepts apply to Australia, there is a need for specific investigation to be carried out in order to achieve maximum effectiveness in integrating Smart Grid locally.

To build A Smart Grid model, first data regarding weather, electricity prices and electricity loads was gathered with the assistance of Energex, the Australian Energy Market Operator (AEMO) and the Bureau of Meteorology. The analysis of this data provided information regarding electricity usage patterns, as well as system attributes such as peak demands and load factors.

A South East residence was chosen for a case study and a Home Area Network (HAN) model was constructed which determined the operation as well as system components. On this basis, multiple simulations were performed using Matlab software, to determine the effects of the Smart Grid.

The results demonstrate the economical benefits for residential customers. As well as this, comparison with current electrical load trends estimates the real benefits in terms of system performance and economy for the entire SE Queensland electricity grid when using Smart Grid. The results from this study show that using Smart Grid, and particularly demand-side response in residential applications, will lower the peak demand of the overall electricity network and improve system load factors. This in turn would create a more efficient and economically viable electricity network for the future.

The use of Smart Grid in Australia is inevitable, but it is vital that consideration be given to the protocols and designs used so that its application is most effective. It is hoped that the outcomes of this project will stimulate greater implementation of Smart Grid, and provide reference for future work in this area of study.

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**Limitations of Use**

**Professor Frank Bullen**
Dean
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# CERTIFICATION

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

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

**Student Name**
**Student Number:**

_____
Signature

_____
Date

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# Acronyms

AEMO          Australian Energy Market Operator

BOM            Bureau of Meteorology

HAN            Home Area Network

HVAC          Heating, Ventilation and Air Conditioning

LF               Load Factor

NAN            Neighbourhood Area Network

PRT             Plantation Rise Transformer

PV               Photo-Voltaic

SG               Smart Grid

SSN             Small Scale Network

TOU            Time of Use

WAN            Wide Area Network

# Chapter 1    Introduction

## 1.1   Background and Problem Statement

There is no disputing the importance of electricity in all aspects of human activity in this, the 21$^{st}$ century. At home, in commercial environments or in major industry, human society has an utter dependence on electricity to maintain our way of life. This dependence on electricity requires that a reliable supply is always available. As mankind continues to advance and expand, there is also a greater need for more efficient generation and transportation of electricity to help maintain the desired economic, environmental and societal standards we enjoy.

In recent years, efforts have been made to enhance the methods of electricity supply and distribution in order to increase efficiency, but full utilisation of available technology has not yet been realised.

Smart Grid, a concept which involves greater measurement and control of electricity, is beginning to be implemented in different forms within various electrical networks all over the world. It does however still exist as an extremely broad and diverse concept and while some aspects of Smart Grid (such as standards) will ideally remain universal, unique applications need to be adapted to meet the needs of specific networks. These needs may arise due to economical, governmental and logistical restraints imposed upon the electricity grid in which the Smart Grid will operate.

Being a relatively highly developed country, Australia shares similar infrastructure and access to technology as other countries such as the USA and Great Britain. Due to this fact, many SG concepts developed overseas can be applied to Australia's electricity network; however, to achieve maximum effectiveness in integrating SG, specific investigation must be performed.

While there is considerable research being performed by various companies, government bodies and financial institutions within Australia (Wolfs & Islam 2009), the problem is that there is minimal quantifiable data available to justify the effectiveness of SG in Australia.

To summarise, the problems with current electricity grids are that:

- There are too many power outages in electrical networks.
- Systems are not as efficient as they could be.
- There is not enough control of electrical loads by consumers and utilities.
- New technologies such as Smart Grid are not being applied widely or quickly enough, partly due to lack of research.

## 1.2  Objectives, Contributions and Outcomes

This study focuses on the application of Smart Grid in electricity generation, transmission and distribution in South East Queensland, and endeavours to obtain quantitative and relevant data which will aid in the assessment of the feasibility of implementing Smart Grid in this area.

Through gathering current information regarding electricity usage and prices in Queensland, as well as other data which may affect electricity usage behaviour, patterns can be seen which will identify deficiencies in the existing grid. Additionally, real data will be found through the means of a case study on a typical household located in Woombye, Sunshine Coast, SE Qld.  This will be in the form of obtaining electrical load data from the residence as well as other parts of the local network.

This project will focus primarily on evaluating the performance of a smart grid network in a residential setting, and as such, a model for a smart grid Home Area Network (HAN) will be developed, which will be based on significant and credible prior research.

It is supposed that by simulating the electricity use of the same household, but with integration of SG concepts, real benefits will be demonstrated that will not only profit the end-user, but will improve key aspects of the entire electricity grid such as lowering peak demand.

To summarise, the aim of this study is to provide evidence of the usefulness of SG in Australia, and make suggestions on how it may most effectively be utilised.  It is hoped that an outcome of this effort will be a greater consideration and accelerated implementation of Smart Grid from governing bodies and major players in the Electricity Industry in Australia.

# Chapter 2    Literature Review

## 2.1  Current Electricity Networks

### 2.1.1            Electricity Generation, Transmission and Distribution

From a consumer's point of view, electricity is readily and instantly available.  From a system wide point of view however, there are many key processes which take place from the point of generation to the point of consumption.   There are also many different types of consumers and various ways in which electricity is used.
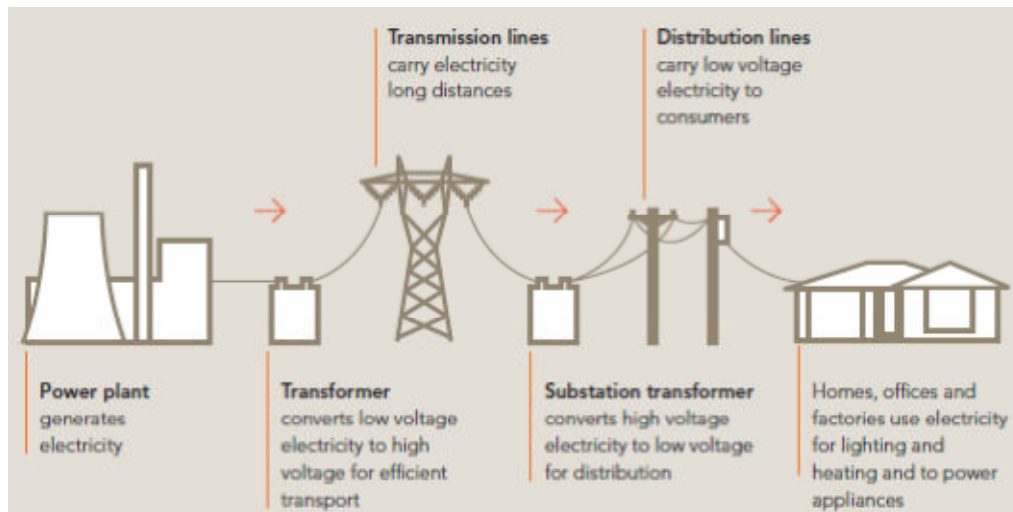


(1)  **Figure 2.1.1.1 – Simplified view of the Electricity network (AEMO 2010, p. 3)**

Electricity can be produced in various ways – Nuclear, Solar, Hydro, Wind, Thermal or burning of fossil fuels.  The AEMO (2010) states that more than 90 per cent of Australia's electricity production relies on the burning of fossil fuels - coal, gas and oil.  These beginnings for electricity occur at power plants, which are usually located at or near fuel sources.   In Australia, these power plants generate three-phase alternating-current electricity at 50Hz with common voltage levels being 13.8kV (Ramakrishnan et al. 2010, p. 1.11).  Adjacent to the points of generation are power transformers which step-up the voltage to higher voltages such as 275kV in Queensland.  These higher voltages are used so that at a given level of power, the line current is reduced which means a reduction in required conductor size and line losses, according to the equation:

$$S = \left(\sqrt{3}\right) \times V_L \times I_L$$

Where,            S = Apparent Power

$V_L$ = Line Voltage

$I_L$ = Line Current

From the power plants, the electricity is then sent at 275kV over primary transmission lines - which are usually overhead conductors attached to steel towers - to substations known as 'bulk supply substations' which are closer to the actual load centres. As an intermediate point between generation and consumption, the substation steps the voltage down to typical sub-transmission levels of 132kV and also provides the ability for switching and directing loads. As such, substations at this level contain equipment such as transformers, circuit breakers, surge arrestors and busbars. The electricity is then sent at this sub-transmission level either by overhead or underground conductors to further substations which transform the voltage level down to 33kV. They feed other substations called 'zone substations' where the voltage is stepped down again to 11kV. The high-voltage (HV) distribution lines operating at these voltages each supply a number of final step-down transformer substations which reduce the voltage to a line voltage of 415V. These final 11kV/415V substations are usually in the form of pole mounted or pad mounted transformers with associated protective equipment.
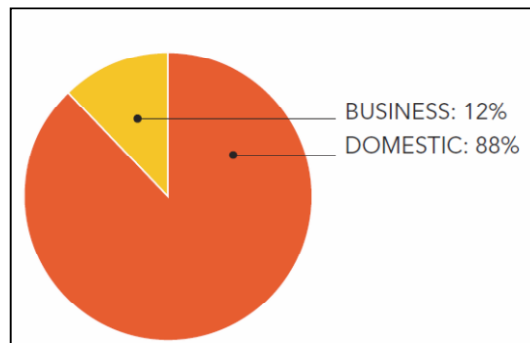


**(2) Figure 2.1.1.2 – Number of Customers by Sector (Electricity Gas Australia, 2010)**
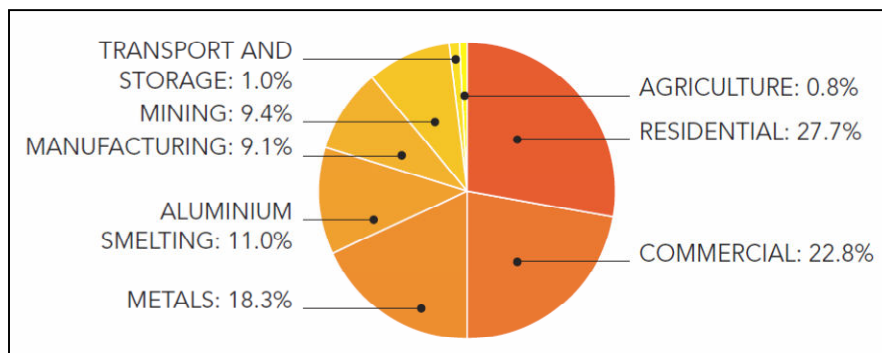


**(3) Figure 2.1.1.3 – Electricity consumption by Sector (Electricity Gas Australia, 2010)**

These transformers then feed consumers via a low voltage (LV) reticulation system where they receive a 415V three phase or 240V single phase supply. Regarding the use of electricity, it can be seen in figure 2.1.1.2 that there are a higher number of domestic consumers than business related consumers, although in figure 2.1.1.3 it is

shown that residential customers consume less than a third of the total electricity generated in Australia. Further deduction shows that by percentage, the average business related customer (commercial, industrial, etc) consumes approximately 20 times more electricity than that of the average domestic customer.


## 2.1.2 Electricity Market Dynamics

There are many organisations both governmental and private which are involved in the electricity industry which influence the way in which electricity is managed and the price for which it is provided. There are bodies which govern and regulate such as the Australian Energy Regulator (AER), bodies which co-ordinate supply and demand such as the Australian Energy Market Operator (AEMO), retailers such as Origin Energy, and organisations that manage the physical grid assets such as Energex in south-east Queensland.

The Ministerial Council on Energy (MCE) is the national policy and governance body for the Australian energy market and provides national oversight and coordination of policy development to address the challenges facing Australia's energy (MCE, n.d.). The Australian Energy Market Commission (AEMC) is the rule maker and developer for the nation's energy markets. Part of their role is to provide strategic and operational advice to the MCE. The Australian Energy Regulator (AER) is a constituent part of the Australian Competition and Consumer Commission (ACCC) and its main role is to regulate the wholesale electricity market (AER, n.d.). The combined effort of these governing bodies ensure that the energy market is fair and secure, standards for transmission and distribution networks are developed and maintained, and that the national electricity law is enforced.

The wholesale electricity market for eastern and southern Australia is known as the National Electricity Market (NEM) and is a wholesale market through which generators and customers trade electricity. As the name suggests, generators represent power plants which are typically privately owned companies who sell electricity to retailers, who buy this wholesale electricity and package it with transmission and distribution services for sale to residential, commercial and industrial customers. The NEM is managed by the Australian Energy Market Operator (AEMO) who among other duties determines the spot price of electricity according to the available electricity reserves. In this role, the AEMO dispatch the generation necessary to meet demand. The role of the AEMO is important as electricity is a volatile commodity in that it cannot be stored for future use, and that it can be generated from many different locations in the grid, meaning that accurate co-ordination is essential. (AEMO 2010, p. 4)

In terms of the actual physical delivery of electricity, it has been mentioned that generation is provided by individual private entities; however the remaining links of transmission and distribution in SE Queensland are covered by large organizations - namely Powerlink and Energex.

Powerlink is a government-owned corporation and are known as a Transmission Network Service Provider (TNSP). As Powerlink are a regulated monopoly business, their revenues are set by the (AER). Powerlink is responsible for the transportation of electricity from power stations through the high-voltage transmission network. This covers from when electricity leaves the power stations right down to where it is reduced to a lower voltage of 132kV at Powerlink's high-voltage substations, although in some cases, Powerlink transports electricity directly to some very large customers, such as aluminium smelters. Their role is to maintain this part of the network infrastructure and thus reliably and securely provide electricity to the distribution networks (Powerlink 2009).
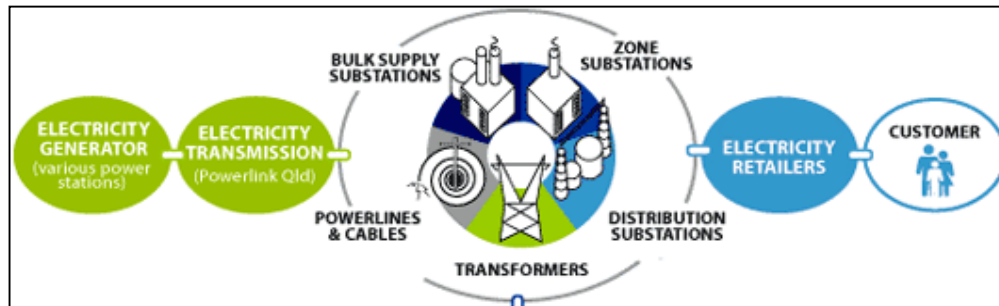


**(4) Figure 2.1.2.1 – Relationship between Energex, Powerlink & Customers (Energex 2011)**

In south-east Queensland, Energex owns and operates the electricity distribution network, and as such maintain all components such as overhead and underground conductors, transformers etc. from the 132kV Powerlink substations right down to the point of supply for customers. Like Powerlink, Energex's economic regulation is governed by the Australian Energy Regulator (Energex 2011).

From a customer's point of view, access to the electricity grid is provided through the means of electricity retailer who makes the appropriate arrangements for connection and bill the customer for the electricity used. Unlike the wholesale electricity prices at which the retailers purchase electricity; customers tend to pay 'flat-rate' type prices for the electricity they consume. In Queensland, for all households and small business consumers on standard customer contracts these prices are dictated by the Queensland Competition Authority (QCA), Queensland's independent economic regulator, and set on an annual basis. Some current tariffs listed by QCA (2010) that apply to domestic and commercial applications from 1st July 2010 till 30th June 2011 are as follows:

TARIFF 11 – DOMESTIC (LIGHTING, POWER AND CONTINUOUS WATER HEATING)

This flat-rate tariff is applicable to domestic premises.

CONSUMPTION                    19.41 cents per kWh

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METERING SERVICE FEE     $7.47 per month

TARIFF 31 – NIGHT RATE (SUPER ECONOMY)

This tariff is applicable to permanently connected apparatus (particularly electric water heaters) within certain restraints.  Supply is available for a minimum of 8 hours per day, but the times when supply is available are subject to variation at the absolute discretion of the distribution entity. In general, this supply is between the hours of 10.00 pm and 7.00 am.

CONSUMPTION            7.92 cents per kWh
MINIMUM PAYMENT        $5.20 per month

TARIFF 33 – CONTROLLED SUPPLY (ECONOMY)

This tariff is applicable to permanently connected apparatus (particularly electric water heaters) within certain restraints.  Supply is available for a minimum of 18 hours per day, but the times when supply is available are subject to variation at the absolute discretion of the distribution entity. In general, this supply is between the hours of 10.00 pm and 7.00 am.

CONSUMPTION            11.66 cents per kWh
MINIMUM PAYMENT        $5.20 per month

TARIFF 22 – GENERAL SUPPLY – TIME OF USE

This tariff is applicable for commercial use and allows lower rates for set off-peak times.

CONSUMPTION (7am – 9pm, Monday – Friday)            26.43 cents per kWh
CONSUMPTION (All other times)                       9.31 cents per kWh
METERING SERVICE FEE                                $29.82 per month

For greater detail of tariff criteria, and for the full list of Queensland electricity tariffs, refer to:
<http://www.dme.qld.gov.au/zone_files/Electricity/2010-11_gazette_notice.pdf>

## 2.1.3     Electricity Grid Design Principles

In order to supply customers with electricity of high quality it is important that continuity of supply is maintained at a constant frequency and that voltages are within

appropriate limits; as many electrical appliances in use throughout society are essentially constant voltage rated devices. In order to achieve this, certain principles and technologies are employed, such as voltage regulation, power factor correction and switching.

Loss of power at any point in the network is a result of either intentional load shedding due to overloading, or faults in the system. Most faults are related to momentary excess voltages and currents which are caused by lightning strikes, switching, and short circuits between conductors and earth, or between two conductors. Other common faults include open circuits, which can be created by physical damage to conductors or equipment. Faults on the 11kV network and up have the most widespread effects on customers as Berende et al. (2008, p. 2) state that supply lost due to medium voltage faults is 3 times that of supply lost due to low voltage faults. When there is a loss of power in any part of the network, action can be taken to isolate the fault and restore power where possible; thus impacting the least amount of customers. Key factors in the effectiveness of this action are network topologies and switching.
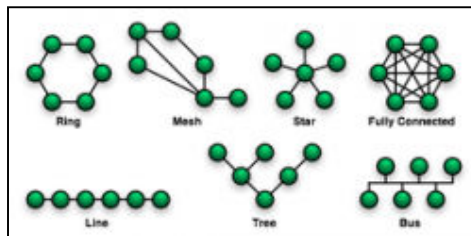


(5) Figure 2.1.3.1 – Diagram showing various topologies

As shown in figure 2.1.3.1, there are many types of topologies possible within a given electrical network, and the nodes shown may represent substations, transformers or customer's points of supply, depending on the network. In terms of reliability, a mesh or fully connected network is preferable, as when a fault occurs on one branch, there are many other possible routes for flow of electricity. Of course, due to cost restraints, this is not always possible, particularly in less densely populated areas. A common topology used on sunshine coast networks is a star/tree network with feeders running out radially and branching off at various points.

The actual redirecting of electricity flow is done by circuit breakers / isolators strategically placed at various points of the grid. They are commonly placed at mid-points on long stretches of feeder, or at intersections of parallel feeders, to allow restoration of power following a fault. These switches can be remotely and automatically operated, but are most commonly manually operated. In assistance with isolating faults and restoring power are fault indicators which are often mounted in conjunction with overhead powerlines to give a visual indication of where a fault has occurred for maintenance crews.

Queensland legislation requires that Distribution Network Service Providers such as Energex maintain a steady state voltage of 240V ± 6% at customer premises (Quinn et al. 2010, p. 1). Problems may arise due to excessive voltage drop when the demand is high, however consumer voltage can be maintained at the correct level by using voltage control methods. Additionally, good practice requires that voltage drop in the consumers mains does not exceed about 15V from transformers at the end of the 11kV feeder, which is achieved by selecting appropriate lengths and properties of the conductors used in distribution networks; (Ramakrishnan et al. 2010, p. 12.6). To achieve permissible voltage levels, voltage regulating apparatus is necessary such as On-Load-Tap-Changing (OLTC) which is typically applied at 33/11kV transformers and higher. These OLTC transformers are capable of varying the voltage a range of say 33kV +/- 5% in discrete 1.25% increments. To instigate tap changes, these transformers have automatic voltage regulating (*AVR*) equipment and associated line drop compensating (LDC) equipment (Ramakrishnan et al. 2010, p. 12.3).
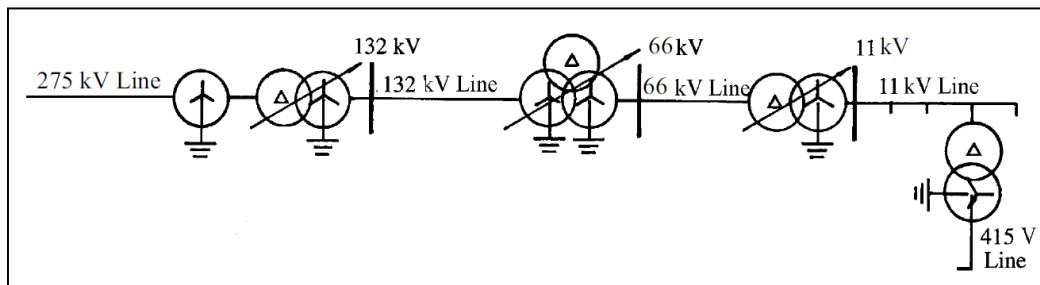


**(6) Figure 2.1.3.2 – Diagram showing inter-network connection and voltage control**

The AVC makes an estimate of the voltage at the load using a model of the line and applies Line Drop Compensation. The AVR initiates a tap change when the network voltage on the load side floats outside the voltage bandwidth for a given time delay. In effect, the AVR increases the bus voltage at heavy load and decreases the bus voltage at light load. The loads on a transformer tend to be distributed at different distances (electrically) from the transformer, so the LDC is set to maintain a constant voltage at the electrical midpoint of the network, thus achieving a minimum overall variation between the no load and full-load conditions. According to Quinn et al. (2010, p. 1), concerns regarding AVR/LDC are that it can be difficult to set and maintain accurate LDC settings with load growth and feeder expansion, and that LDC is less effective if there are differing load profiles on adjacent feeders from the one transformer. Tap changing is also used at distribution level transformers (i.e. 11kV/415V), however it is normally manually-operated, and can only be done off-load (Ramakrishnan et al. 2010, p. 12.9).

Another significant influence on the quality of system supply is that of the active/reactive power conditions in the system. Ramakrishnan et al. (2010, p. 12.9) state that a mismatch between the active power (W) generated and the active power demand will tend to cause variations in the frequency, but a mismatch between the reactive power (VAr) generated and demanded will cause the system voltage to vary.

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An example is when a circuit load has a lagging power factor, the receiving-end voltage is lower than the sending-end voltage. Reactive power is both generated and absorbed at different points in the system and most elements have both a series inductive reactance component and a shunt capacitive reactance component.

For overhead lines and cables the shunt impedance is capacitive, leading to VAr generation, which is proportional to voltage squared, and consequently is greater at higher voltages. While cables generate VAr for all creditable loading conditions, the net effect of inductance and capacitance on overhead lines is that they generate MVAr when lightly loaded but absorb MVAr when heavily loaded. Shunt impedance is inductive for transformers, and their magnetising inductance creates VAr losses which, if experiencing core saturation may increase rapidly with voltage. Other influences on reactive power are the alternating magnetic fields of equipment such as motors and lighting ballasts which create a reactive load. Overall, when the system is heavily loaded the result is a lagging power factor and VAr absorbs ion within the system, but when it is lightly loaded the result is a leading power factor and VAr generation.

These variances in reactive power are able to be balanced with the use of devices such as synchronous capacitors, series capacitor banks or static VAR compensators which are generally applied at 11kV levels or higher. Capacitor banks, which are often located at substations, can be switched in when the system is heavily loaded to generate VAr's and hence counteract the lagging power factor of an overly inductive system. Static VAR compensators are capable of both generating VArs (using capacitors) and consuming VArs (using thyristor-controlled reactors) depending upon system requirements.

The remaining balancing of the VAr load is handled by generators and is limited by the particular generator's ability to absorb or supply VArs to the system. A typical generator at full MW output can operate with power factors ranging from 0.95 lead to 0.85 lag (Ramakrishnan et al. 2010, p. 12.12). In times of light loading, generators absorb VArs which causes them to operate in an under-excited state, and this can increase the risk of issues such as pole slipping. During times of heavy load, generators are required to operate in an over-excited state in order to produce VArs, which causes an increase in rotor field currents.

In the aid of maintaining healthy grid components, there are also various forms of protection used, such as circuit breakers and surge arrestors, however they are not related to the scope of this work.


## 2.1.4    Current Load Trends

The Queensland electricity grid, as with any electricity grid, demonstrates particular load trends which are cyclic over a daily period, a weekly period and an annual period. The data used to construct the figures in this section are taken from the

AEMO website <http://www.aemo.com.au/data/price_demand.html> and the Matlab codes used to produce these graphs are found in appendix F1.



QLD LOAD - DAILY CYCLE
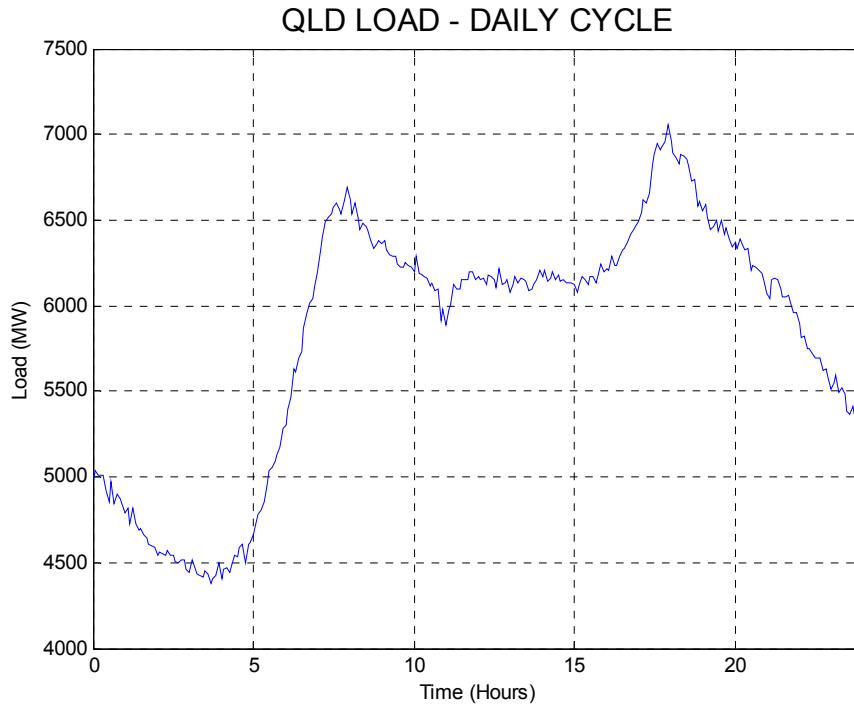
**(7) Figure 2.1.4.1 – QLD Load Cycle Monday 16th May 2011**

For a daily cycle, energy use tends to be low during the night and early morning, with a major peak at around 8-9am and sustained high energy use throughout the daytime hours (coinciding with business hours). There is also another major peak at around 6-7pm which is related to daylight hours and people returning to their homes (Kamel 2009, p. 2).

**QLD LOAD - WEEKLY CYCLE**
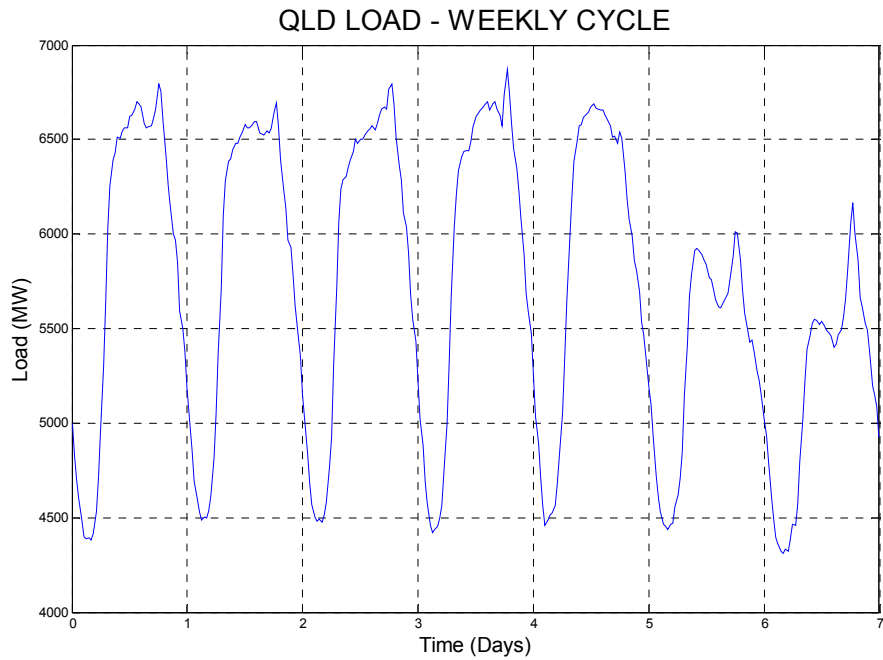
**(8) Figure 2.1.4.2 – QLD Load Cycle Monday 11th April – Sunday 17th April 2011**

Over the course of a week, it can be seen in figure 2.1.4.2 that the load across each weekday is quite similar, whereas on the weekend, less electricity is used and peak demand is lower. This is due to commercial and industrial operations being greater during weekdays.

QLD LOAD - YEARLY CYCLE
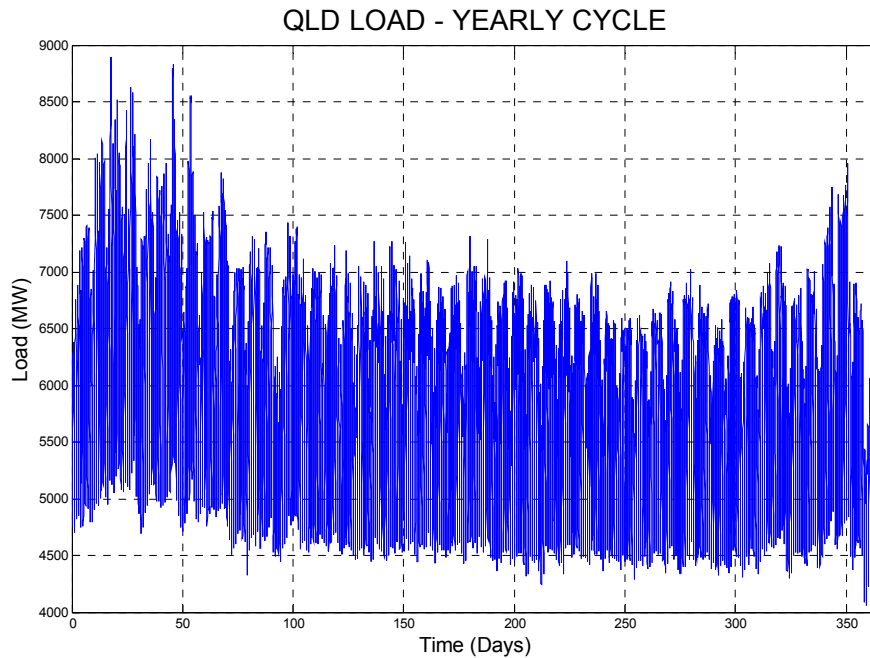
**(9)  Figure 2.1.4.3 – QLD Load Cycle January 2010 – December 2010**

The trend over a year is heavily impacted by seasonal variations, and as such daytime loads and peak demand tends to be higher in the warmer months due to the use of air-conditioning (Ramakrishnan et al. 2010, p. 11.9).

Obviously these load trends have an impact on system efficiency and economics and can be assessed with appropriate formulae.  Appropriate factors which apply are Load factor and Plant factor.  The load factor (LF) is the ratio of the average load over the peak load, for a designated period of time and is defined as:

$$Load\ Factor = \frac{AL}{PL}$$

Where,                        AL  = Average load over a given period
                                   PL = Peak load over the same period

In practical terms of electricity generation the base load is the constant load and is the lowest load in a given period, which in the example of figure 2.1.4.1 is 4379MW. This load is supplied by base load generating plants which typically run 24 hours a day, 7 days a week.   Anything above this load must be supplied by peak load plants (PLP).   Therefore, a lower value of system LF indicates that the peak load is comparably much higher than the average load, and therefore there is a greater dependence on peak load plants to meet load requirements.  It is important to note that base load plants can produce electricity at a lower cost per kWh.

Another similar relationship is the Plant Factor (PF), which is the ratio of the average load on a generating plant over the rated capacity of the plant for a designated period of time and is defined as:

$$Plant\ Factor = \frac{ALP}{RCP}$$

Where,  ALP = Average load output by the plant over a given period
RCP = Total rated capacity of the plant

This indicates that if a plant is rarely run close to its capacity, it will have a lower PF. For generating plant, the cost of fuel required to send out each kWh consists of the delivered cost of fuel plus the handling cost in the station. The average cost per unit sent out is lowest for a station if it is operating continuously on full load, and hence has a high PF (ELE2704 p.4.4).

For a simplified example, again using data from fig 2.1.4.1 on the 16$^{th}$ May 2011, it can be found that the Load Factor of the Queensland network on this particular day is 0.825.  Earlier, it was shown that the base load is 4379MW, and the peak load is 7057MW, meaning that PLP peak load would be 2678MW.  Further analysis shows that the average load on the PLP is 1443MW, and hence the plant factor of the PLP is 0.5388.  Considering that maximum efficiency is achieved when LF and PF are both unity (theoretically), it shows that the Queensland electricity network has much room for improvement in terms of load management.
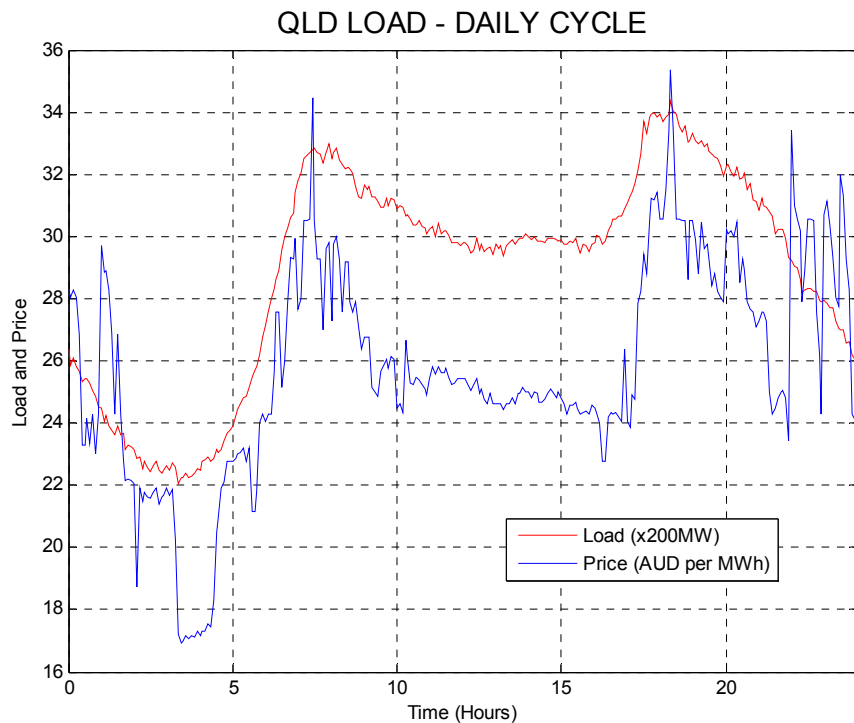


**(10)  Figure 2.1.4.4 – QLD Load and Price Cycle  Thursday 12$^{th}$ May 2011**

Another important trend which is greatly influenced by load on the network is that of electricity prices. The Regional Reference Price (RRP) is the price that retailers pay for electricity in the national electricity market. This price generally follows the same trend as the total electrical load or demand. This is clearly demonstrated in figure 2.1.4.4 where it can be seen that the price profile has a similar shape to that of the load profile. It can be deduced therefore that price follows demand over the different times of the day, week and year. It is necessary to note that other factors can influence the RRP, such as faults or potential faults in the network, as well as the uncertainty of future loads – as the price is partly dictated by the prediction of future demand. As was mentioned in section 2.1.2, the actual price a customer pays is dictated by 'flat-rate' type electricity tariffs does not appear to be directly related to the system load. However, in reality, electricity providers must bear the cost for managing the potentially extreme and often unpredictable fluctuations in the RRP, and as such flat-rate premiums are affected accordingly (Fraser, n.d.). In short, if load profiles were smoother and more predictable, the cost to generate and manage electricity would decrease, and the price consumers pay would reflect this.

## 2.2 The Smart Grid

### 2.2.1 Introduction

As mentioned, Smart Grid is an extremely broad subject; however most sources unanimously describe SG as a truly dynamic power transmission and distribution network which is characterised by the use of two-way communications technologies (Roncero 2008, Wei, 2010). Smart grid is not necessarily a new way of producing or distributing electricity, or a new electrical network topology, but rather an enhancement upon the existing network which allows communications between all critical points in the system. Indeed SG proposes a comprehensive communications link which encompasses electricity production, transmission, distribution and consumption. The three essential and defining attributes of the Smart Grid are:

1. Sensing and Measurement
2. Advanced Control Methods
3. Integrated Communications

The overall purpose of SG is to improve the efficiency and the quality of electricity at all points in the system, and to secure a reliable supply to all users.

In order to achieve two-way communications, there are obviously both data inputs and outputs generated within the SG. The outputs are generated through the means of sensing, metering and measurement. Common outputs at a given point in the system include real time power consumption data and power quality data such as power factor and efficiency information. Inputs to the system consist mainly of signals to control different functions in the grid such as switching, and may be a result of data that has been received and analysed, or preferences and manual commands which have been issued. Inputs may be in the form of pricing and tariff signals, and curtailment instructions which trigger actions such as redirecting or eliminating loads (Roncero 2008, p. 2). In a practical sense, the smart grid involves having many 'smart devices' located throughout the entire electricity grid which are capable of interaction with one another. Most of these devices would be capable of making measurements and issuing both inputs and outputs, or performing functions themselves.

There are several key capabilities of SG, which offer significant benefits over conventional electricity grids:

- Improved Quality of Power. Again, due to the presence of sensors and controllers, the direction and balancing of power flow can be altered to achieve maximum efficiency. This includes more effective use of grid assets.
- Self Healing. Through data acquisition and control, the SG can avert possible disruption of service, meaning greater reliability.
- Integration of Distributed Generation (DG). Due to SG communications allowing greater awareness of power flows in the network and by the means of

automated switching, different sources of DG (solar, wind etc) can be integrated without disrupting the system balance in any way.

- Allows Demand Side Response (DSR). As consumers are able to receive greater information regarding load and price data, they are able to modify their electricity use to suit, saving money and improving overall system performance. Refer section 2.2.4.

There are also many more benefits as a result of the above characteristics, such as reduction in maintenance, reduction in congestion, reduction in peak demand, higher capacity utilisation, increased capital investment efficiency, and consequently a reduction in negative environmental impacts (Roncero 2008, p. 2).


## 2.2.2        Early use of Communications in Distribution Control

The idea of integrating communications with electrical networks is not new, and several technologies exist which allow some control and monitoring of power grids. The current systems that have been employed are similar in concept to Smart Grid. For instance, distribution automation (DA) technologies are presently being integrated with measurement and control systems to provide rapid reconfiguration of specific sections of the distribution system (Advanced Control Methods 2007, p. 4). Common concepts and devices include closed loop voltage control (CLVC), supervisory control and data acquisition (SCADA), energy management system (EMS), remote terminal unit (RTU), phasor measurement unit (PMU), and intelligent electronic devices (IED).

Due to the use of these modern devices, high-voltage sub-stations today measure and gather large amounts of data. The main data obtained is the status of any switch (open or closed), and measured analog currents and voltages which can be sampled up to 100 times a second synchronized to an absolute time standard. The latter measurements are usually obtained by PMUs. Local use of this data at substations is mainly for protection and control within the station itself, such as voltage control (BOSE p.1). In fact, one of the major flaws in the current control and measurement techniques used is that many of these control algorithms act autonomously at a local substation level and hence do not benefit from a system-wide perspective (Advanced Control Methods 2007, p. 4). The PMUs and other IEDs (such as switches and transformer tap changers) within the substation are usually connected via a LAN, and data flow is controlled by an RTU (Chikuni & Dondo 2007, p. 1).

The primary functions of the RTU are to execute tasks within a substation, and to make substation data available to the system control via communications channels. The amount of data being gathered at a substation today is so voluminous that with current architecture, most of it cannot be transmitted out of the substation at the rates at which they are gathered, and in actuality very little is transmitted using current SCADA technology (Bose 2010, p. 1).

As mentioned, all the RTUs within the communications network will have some kind of overall system control. SCADA is used prominently throughout the world, and along with an accompanying EMS is able to manage the network through analyzing the data and allowing an operator to take manual actions, or providing autonomous control. The SCADA gathers the data by polling the remote terminal units (RTUs) at all the substations about every 2–10 seconds (Bose 2010, p. 4). The only closed-loop control typically done at the control center itself is automatic generation control (AGC), although some systems have now incorporated automatic voltage control (Bose 2010, p. 4).

Another primary role of the SCADA-EMS, and located at the control centre is the system database. Information within the database is in the form of real-time (measurement) data, and static data which describes the characteristics of the system, such as line impedances and other component attributes. This real-time and static data allows the SCADA-EMS to make calculations and issue commands accordingly. Additionally, the data can be stored in a historical database to assist in fault evaluation. One of the restrictions of the SCADA system is that as the static database resides in the SCADA-EMS control center, it has no relationship with the data models being used at the substations themselves (Bose 2010, p. 4).

In accommodating for SCADA and other measurement and control systems, a variety of communications media are used in today's electricity grid, including copper wiring, optical fiber, power line carrier technologies, and wireless technologies such as slow microwave (Integrated Communications 2007, p. 5). There are also standards developed for such systems such as the IEEE standard C37.1-1994 which specifies the communication topologies which can be used in SCADA (Chikuni & Dondo 2007, p.2).

As an example of communications in distribution control in Australia, in recent years, Ergon Energy had six independent power control systems replaced with a single SCADA system which comprised of two control centres and six regional front end locations for data acquisition. Under Ergon Energy's SCADA system design, there is a single database, a single historical database, standard naming conventions for all points, improved monitoring tools and security, and maintenance is now managed from one location (ABB Australia 2008).

Current communications and control technologies used in the electrical grid such as SCADA provide a good framework for a smart grid, in that the principles and concepts employed have proven successful in some areas. Some of these current technologies such as PMUs may even be integrated with a true smart grid. There are however, several key weaknesses in current methods that necessitate the need for a real smart grid:

- On a low and medium voltage level, today's grid lacks many of the smart sensors and control devices that need to be deployed to provide the control mechanisms to manage the entire electrical system.

- In some ways, the communications systems utilized in the power industry today are too localized, where RTUs take actions without knowledge of the whole system.
- In other ways, the current systems are too centralized to facilitate full peer-to-peer interaction between all 'nodes' in the network.
- With the current communication infrastructure, the amount of relevant data which is transmitted is too limited, and the speed of transmission too slow to allow real time, optimum system control.
- The current communications architecture does not support true "plug and play" interoperability between different devices.
- There is a lack of universally accepted standards for communications defined and agreed upon in the industry.
- In general, there need to be a much greater number of nodes in the network that are capable of measurement and control.

## 2.2.3 Smart Grid in Large Scale Networks

A large scale network refers to the electricity grid as a whole, from generation through to the customer's point of supply, and focuses mainly on transmission and distribution. The benefits achievable on this level have been briefly mentioned already, and include improved quality of power, self healing and better integration of distributed generation (DG). In discussion of the way in which SG enhances large scale networks it is necessary to acknowledge again that all nodes in the network are capable of either taking measurements, transmitting data, receiving data, analysing data, issuing commands, acting on commands or some combination of the aforementioned functions. When referring to large scale networks, the nodes, or 'smart devices' are located at points of generation such as at power plants; points of voltage transformation such as at substations; points of switching, and any major feeders . In general, the sheer amount and availability of near real-time data as well as comprehensive static data will enable diagnostics to identify solutions for existing, emerging, and potential problems and inefficiencies at the system, subsystem, and component levels (Advanced Control Methods 2007, p.12).

In terms of creating a self healing network, in the case of the loss of part of the network such as a section of transmission line, smart devices located throughout the network can sense the loss of power, then devices located at substations or other critical switching points are capable of analysing possible solutions and diverting power flows accordingly, without causing cascading failures. It is also possible to avoid disasters caused by overloading as the SG is able to monitor power levels across the whole grid, thus allowing for intervention before large scale load shedding is necessary. This can be achieved by sending out an 'emergency' signal to devices on the critical sections of the grid which in turn deactivate all non-essential users of power, thus allowing continuous power to essential users. Additionally, for problems that are too large and too fast for human intervention, the smart grid can automatically

restore grid components or network sections after abnormal events. Other possible self healing methods involve using historical data to make probabilistic risk assessments based on equipment, power plants and lines most likely to fail (Wei 2010, p.3).

Distributed generation (DG) is becoming increasingly important due to the benefits it offers in terms of reduced environmental impact, ease of installation and high efficiency (Chiradeja 2005, p. 1). Typically, DG is used at low voltage, distribution levels, and commonly takes advantage of renewable energy sources which are often irregular. Examples of DG include wind turbines, which are used at EHV, HV, MV and LV levels; hydro generation (wave, tidal, non-storage) which is used at HV and MV levels; photo-voltaic (solar), which is used mainly at LV levels; and, micro-CHP which is used at LV levels. At a residential level, there is also the potential for electric vehicles to be connected to the grid, which can also provide power input to the grid. Douglas et al. (2008, p. 1) proposes that use of the above mentioned types of distributed generation in Great Britain will increase from 9.6% of total power generation in 2004 to as much as 42.3% of total power generation in 2020. The increase in use of DG poses serious problems for the current electricity grid as it is transformed from a centralized infrastructure with one-way power flow to a distributed infrastructure with two-way power flows (Chen et al. 2010, p. 1). These problems mainly consist of issues regarding balancing power flow and frequency, due to fluctuating levels of power being generated, and the fact that much of it would be produced in a highly distributed fashion at LV levels, and mostly in single phase (Douglas et al. 2008, p. 1). By effectively combining DG with SG, it is clear that these problems can be solved as all nodes in the system can be aware of power surpluses and deficits in the network, and power can be directed, generated or disconnected appropriately.

On a large scale network, SG also has a dramatic, positive impact on efficiency and the quality of power being delivered. Firstly, by optimising the use of existing grid infrastructure, there is effectively a reduction in the rate at which additional electric utility infrastructure needs to be produced (Chen et al. 2010, p. 1). Also, due to the use of more localized control, and when used in conjunction with DG as mentioned above, loads are served more locally leading to less power flows within the grid, and hence less line losses (Bell et al. 2008, p. 1). As well as insuring supply is available at all points in the network at all times, the presence of distributed communications and control allows for the use of power factor correction (such as capacitor banks) and voltage regulation to be used not only at medium and high voltages, but also on a more local level; dispersed throughout the network and controlled remotely. By the use of static and real-time data, devices in the smart grid can select the optimal route by which power is delivered, depending upon current conditions in the grid, thus, again reducing system losses. Additionally, the large amounts of information extracted from the smart grid can help determine and even preempt the need to activate, or deactivate power plants, which improves plant efficiencies and costs.

### 2.2.4  Smart Grid in Small Scale (Residential) Networks

In this study, a small scale network (SSN) is referring to an electrical network starting from a customer's point of supply, and encompassing all electrical equipment within that network.  The customer may be industrial such as an entire car manufacturing plant; commercial such as a 10 storey office building; or residential such as an apartment building, or home area network (HAN) (Fadlullah et al. 2011, p. 2).  Although perhaps described as a network within a network, smart SSNs are in fact fully integrated with the entire smart grid, and are able to communicate with other components on the grid via a controller/gateway.

At the core of any SSN is a central 'smart' controller, which performs two primary functions.  Firstly, it serves as a gateway to the wider smart grid, and thus receives data from 'higher' level devices on the grid, which would greatly consist of control signals and commands.  In this gateway role, the controller also transmits data concerning the state of the SSN, such as current power consumption (Huq & Islam 2010, p. 1).  Secondly, the central controller communicates with smart devices within its SSN and controls some or all of these devices according to the information received from the smart grid, and according to preferences input by the customers themselves (Fadlullah et al. 2011, p. 3).  These smart controllers also perform the functions of, or work in conjunction with what is termed in Australia today as a 'smart meter'.  These current smart meters allow remote meter reading by utilities and inform consumers of their power consumption.  Within the SSN itself can be any number of electrical devices, which may be electrical equipment controlled by 'smart devices', or electrical equipment which are 'smart' themselves and as such can directly interact with the SSN.

Another aspect of the SSN would be the integration of LV distributed generation into the smart grid.  The study conducted by (Douglas et al. 2008, p. 1) proposes that use of LV distributed generation in Great Britain will increase from 0.5% of total power generation in 2004 to as much as 15.4% of total power generation in 2020.  This increase in LV DG at consumer's premises will necessitate the use of an SSN controller which would be responsible for directing the usage of the additional energy (Mauri et al. 2008, p. 3) - whether it is used within the SSN, or exported to the larger grid - and would help tackle the issues discussed in section 2.2.3.  A related benefit of SSN is the ability to integrate and manage energy storage.  Energy produced by DG can be stored using large batteries, which can also collect electricity produced by mains power at off-peak times.  This electricity can then be used in times of emergency, or to reduce load on the grid during peak times (Mauri et al. 2008, p. 3), and energy flows would again be controlled by the SSN controller.

One of the most valuable capabilities of the smart grid when coupled with SSNs is the opportunity for implementation of demand side response (DSR); also known as demand side management (DSM). This is where consumers - due to the access of information provided by the smart grid - are able to control their power consumption according to electricity prices and availability.  As mentioned in section 2.1.3 load trends show that the load factor of the current QLD network is far from optimal,

which alludes to the tremendous improvements which could be achieved with greater load management.  A consumer's SSN controller (whether industrial, commercial or residential) can receive information regarding live load levels on the network.  There is then the opportunity to curtail electricity consumption during times of peak demand and to defer certain electrical applications to times of low demand.  Similarly, live information of electricity prices (which tend to follow load trends), can allow consumers to disallow certain electricity usage when prices exceed a certain limit.

 By reducing peak demand and thus transferring the load equally across an entire day, much greater system efficiency and economy can be achieved.  This occurs as power plants run at higher capacity factor - reducing running costs - and as the need for construction of new power plants is deferred due to more efficient use of current installations - reducing capital costs (Marwan & Kamel 2010, p. 2).  Also new system components to be installed such as feeders, busbars, transformers etc. would not require such high power/current ratings meaning a reduction in cost.   As a consequence of this greater efficiency, electricity prices for consumers would potentially reduce, particularly with the correct economic models in place involving principles such as time of use (TOU) tariffs.


# 2.3   Smart Grid Implementation and Topology

Smart Grid is essentially a communications based technology, and as such there are different ways in which it can be instigated in both large scale (WANs and NANs) and small scale networks.

Large scale networks can potentially use many types of media similarly to existing SCADA technologies; however two popular methods of transmitting data are via powerlines and via wireless networks, which both allow the high bandwidth and low latency required for Smart Grid communications.

Data sent and received by smart grid devices can be transferred using power line communication (PLC), which enables modulated carrier signals to be sent over existing electrical conductors.  This technology has been used to some extent for many years by utilities such as Energex, who employ ripple control (RC) to switch off particular electrical devices at times of high load.  The greatest advantage of this method is the available infrastructure which allows signals to be sent wherever power is available (Haidine et al. 2011, p. 3).  This limits the topology options as the communications network follows the electrical network directly.
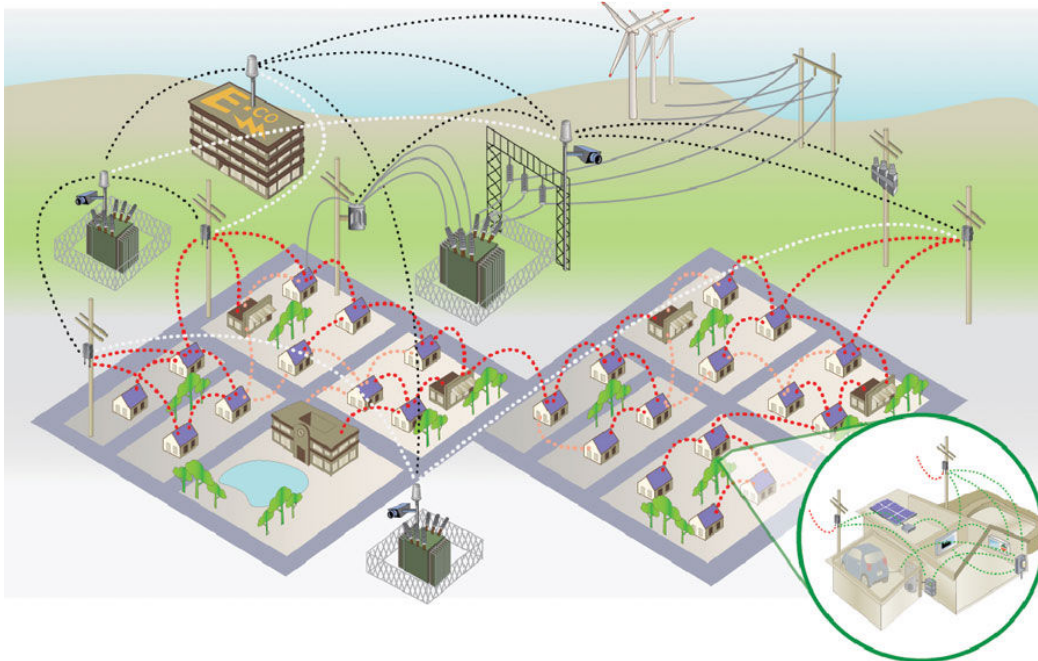
**(11)  Figure 2.3.1 – Wireless Smart Grid (http://www.trilliantinc.com/library-files/kit/system_architecture.jpg)**

Wireless networks for smart grid applications are used by such companies as Trilliant who are a specialist smart grid communications company (Trilliant 2010). Using wireless technology, data can be transferred using radio frequency (RF) signals via the GSM or 3G framework, or even on private networks. The main benefit of wireless networks is the possibility of extensive mesh topologies meaning that many devices can be directly interconnected and can easily interact with each other within the capabilities/range of the transmitters. The main risk of this medium is that of data security, which requires adequate authentication and encryption to protect critical information such as control signals.

Small Scale networks generally have a smaller area in which to cover in order to effectively communicate between the 'controller' and the smart devices within the network. This reflects on the common communications options used in small scale networks, as wireless technologies take precedence. WiFi (IEEE 802.11) is the most widely used protocol for wireless in-home communications (Fadlullah et al. 2011, p. 4), and is capable of ample data rates for smart grid applications; however devices using WiFi consume comparatively high amounts of power. Conversely Bluetooth (IEEE 802.15.1), which is another popular protocol, features low power consumption but suffers from data transfer rates which may not be adequate for SG, and is inflexible in the ability to incorporate many devices on one network. Bluetooth networks range can also only perform over a range of 10m which limits application in industrial and commercial situations. The ZigBee (IEEE 802.15.4) protocol enables low power consumption and a long range, but data rates are much lower than that of Wifi. Another network option is Ethernet, however flexibility is restricted to some degree as physical cabling is required.

40

Small scale network topology is generally dictated by the protocol/method being used, with common topologies being star or mesh networks. Although mesh networks afford high flexibility, star networks are adequate as long as all devices are within range of the central controller/gateway.

## 2.4 Smart Grid Devices

As displayed in sections 2.2, Smart Grid can be considered to have a multi-level structure, and can be broken down more specifically into:
- Wide Area Networks (WAN) which cover entire or large branches of the electricity grid.
- Neighbourhood Area Networks (NAN) which may for example cover an 11kV branch of the grid.
- Home Area Network (HAN, or small scale network) which covers a customer's premises.

There are many devices and functions in an electrical network, and the smart grid consists of different devices to allow the improvements aforementioned. It is also important to note, that depending upon requirements, some existing devices such as PMUs can be incorporated into the Smart Grid. The following is an example of a smart grid and associated devices:

### 2.4.1 Central Control

Although SG enables decentralised 'peer to peer' communications, there is still the need for central control to monitor the health of the entire network. Additionally, major points on the network such as 275/132kV substations and Power Plants require more capable controllers than say a 415V transformer, due to the large volume of data they need to process. An example of a central controller is the 'LMM700 load control centre' offered by Elster, which enables continuous load monitoring and dynamic generation of switching commands as well as complete system control (Elster Metering n.d.).

### 2.4.2 WAN / NAN Controllers

As part of the Smart Grid, all substations will have a Smart Controller/Gateway. These controllers - such as the Itron 'Data Concentrator Mark3'- are able to take measurements and transmit data to upper level controllers in push and pull mode (scheduled and requested data) as well as receiving control instructions. They also send commands to, and harvest data from lower level controllers within their sub-network (Itron 2011).

**(12)  Figure 2.4.2.1 – Itron Data Concentrator Mark3**

An example of this interaction would be where a smart controller located at an 11kV/415V substation informs the HAN controllers on its network that load must be quickly reduced due to some fault within the grid wherein the HAN controllers then turn off all non-essential devices within their networks, thus avoiding system failure due to overloading.

## 2.4.3        WAN / NAN Devices

Devices such as voltage regulators and VAR compensators are typically located at substations and are automatically controlled by local smart controllers according to system requirements.  Other devices such as isolators and 'measuring points' are interspersed throughout the transmission and distribution sections of the grid.

Measuring points can be located at any position of interest in the grid such as at intersecting points on a feeder, or at mid-points on long stretches of transmission line. Their task is to take measurements and transmit the data back to WAN/NAN smart controllers to facilitate monitoring of system health and to assist in the locating of faults.  Measuring points can be in the form of 'power quality meters' such as the GE PQMII (GE Digital Energy 2010).  Measuring capabilities may also be combined with any device on the grid or at a substation, such as circuit breakers, isolators and surge arrestors.

Isolating switches are always located at substations for various applications, but are also located at different points in the grid to allow isolation of sections of feeder, or to allow connection of parallel feeders to facilitate changes in power flow.  When coupled with SG technology, WAN/NAN controllers can automatically and remotely control the opening and closing of isolators according to data received from measuring points.  An example of this is the Radius NME 200 produced by AK Power Solutions, which provides electric motor driven operation of load break switches via remote operation (AK Power Solutions n.d.).

### 2.4.4       SSN / HAN Controllers

The functions of a SSN/HAN controller were mentioned in section 2.2.4, and can be simplified as being the role of receiving data (control signals) from upper level controllers, sending load data back to upper level controllers, and controlling electrical devices within its SSN. Available HAN controllers include the Itron ACE 400 or the Control4 EC-100 (Control4 n.d.), however because of the maturity level of these products, at this point there still lacks a total solution with respect to supporting utility demand response signals as well as giving full user control.



**(13) Figure 2.4.4.1 – Control4 Ec-100**

### 2.4.5       SSN / HAN Devices

Depending on whether the SSN/HAN is a hard-wired or a wireless network, there are different devices available. There are devices such as the Develco ZHDR201 DIN Meter Relay, which allows control of whole circuits such as lighting or clusters of appliances connected to the relay located in the distribution board. For controlling singular appliances, there are devices such as the Develco ZHWR201 which monitors power as well as allowing on/off control via the HAN controller (Develco Products n.d.).

  

**(14) Figure 2.4.5.1 – Develco ZHDR201**        **(15) Figure 2.4.5.2 – Develco ZHWR201**

There are also devices which can be directly controlled by utilities such as the Elster LCR120 - which allows PLC relay control (see section 2.5) - and the Trilliant Pioneer

Thermostat which allows control of HVAC equipment during load control events (Elster Metering n.d.; Trilliant 2010).



**(16) Figure 2.4.5.3 – Elster LCR120**
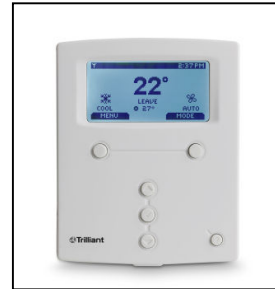


**(17) Figure 2.4.5.4 – Trilliant Pioneer Thermostat**

## 2.4.6        Auxiliary Devices

There are also other devices necessary to enable communications within the smart grid. In the case of PLC communications, as well as the need for transmitters and receivers, it is also necessary for couplers to be used to allow injection of audio frequency signals into the high voltage network; an example of which being the Elster RAP (Elster Metering n.d.) .



**(18) Figure 2.4.6.1 – Elster RAP**



**(19) Figure 2.4.6.2 – Trilliant SecureMesh Connector**

With wireless networks, depending on the capabilities of WAN/NAN/SSN controllers and devices, there can be the need for separate gateways or connectors, which transmit and receive the data which is produced by controllers. An example of this is the Trilliant SecureMesh Connector (Trilliant 2010).

# 2.5 Smart Grid Standards

The development of appropriate standards is essential in the successful integration of Smart Grid technology into countries the world over, as well as ensuring an efficient, reliable and secure grid. Two major international bodies which focus on electrical and electronic technologies are the Institute of Electrical and Electronics Engineers (IEEE) and the International Electrotechnical Commission (IEC). Smart Grid Australia (2010) have stated that the Commonwealth Government should actively monitor international standardisation efforts and, in conjunction with industry groups, align as closely as possible with them to avoid isolation.

IEEE (2011) states that they currently have over 100 approved and proposed standards relating to Smart Grid, and the IEC (2011) claim that over 100 IEC Standards have been identified as relevant to the Smart Grid. Some key standards include:

- IEC 61970 and IEC 61968: Providing a Common Information Model (CIM) necessary for exchanges of data between devices and networks, primarily in the transmission (IEC 61970) and distribution (IEC 61968) domains.
- IEC 61850: Facilitating substation automation and communication as well as interoperability through a common data format.
- IEEE 1615-2007: Recommended Practice for Network Communication in Electric Power Substations
- IEC 60870-6: Facilitating exchanges of information between control centers.
- IEC 62351: Addressing the cyber security of the communication protocols defined by the preceding IEC standards.
- IEEE 1547.2-2008 Application Guide for IEEE Std 1547, IEEE: Standard for Interconnecting Distributed Resources with Electric Power Systems.
- IEEE 1159.3-2003: Recommended Practice for the Transfer of Power Quality Data in a vendor independent manner.
- IEEE 802.15.1-2005 Standard for Information Technology - telecommunications and information exchange Systems between systems - Local and metropolitan area networks-Specific requirements - Part 15.1a: Wireless Medium Access Control (MAC) and Physical Layer

It is preferable that open standards be used to allow interoperability and easy integration of new systems and products and thus avoid the risk of stranded asset investments by parts of the smart grid market.

## 2.6  Conclusion

This literature review has aided in understanding the current state of electricity distribution, consumption and economics. A general overview of how electricity gets from generation to consumption has been given as well as insight into the way in which the grid operates. Discussion of current methods of maintaining quality of

supply and also current load trends has aided in identifying ways in which the smart grid can not only enhance the grid, but overcome its deficiencies.

Significant focus has also been given to the way in which Smart Grid improves the electricity network on all levels, as well as explanation as to how it is actually implemented and the devices which are used.

To summarise, the weaknesses in the current electricity grid are:

- Lack of adequate autonomous control in distribution and transmission networks
- Lack of control of consumer's power consumption

The general product of these weaknesses is that reliability, efficiency and costs to customers are far worse than they potentially could be. This report has shown how smart grid can specifically address these weaknesses.

In conclusion, it is clear that there is a need to introduce the smart grid into south east Queensland, and this report will seek to quantify some of the benefits in doing so. Due to the availability of data, and the scope of this project, the body of this report will focus on improving control of customer's power usage through the use of Smart Grid Home Area Networks (HANs).

# Chapter 3   Data Acquisition and Analysis

## 3.1   Location and Setting

The residence used for this study is located on Plantation Rise Drive in Woombye, and is approximately 100 km north of the Brisbane CBD and lies directly 14km from the coast (see figure 1.1).  The climate pattern is described as typically having wet summers and dry winters.  Information on the Bureau of Meteorology shows that the mean summer temperatures in 2010/11 ranged from 20.1-29.1 degrees Celsius and the winter temperatures in 2010 ranged from 5-18 degrees Celsius (BOM 2011).  On the Summer solstice (December 22) 2010, the sunrise and sunset times were 4:52am and 6:41pm respectively, and on the winter solstice (June 22) 2010, the sunrise and sunset times were 6:36am and 5:04pm respectively.
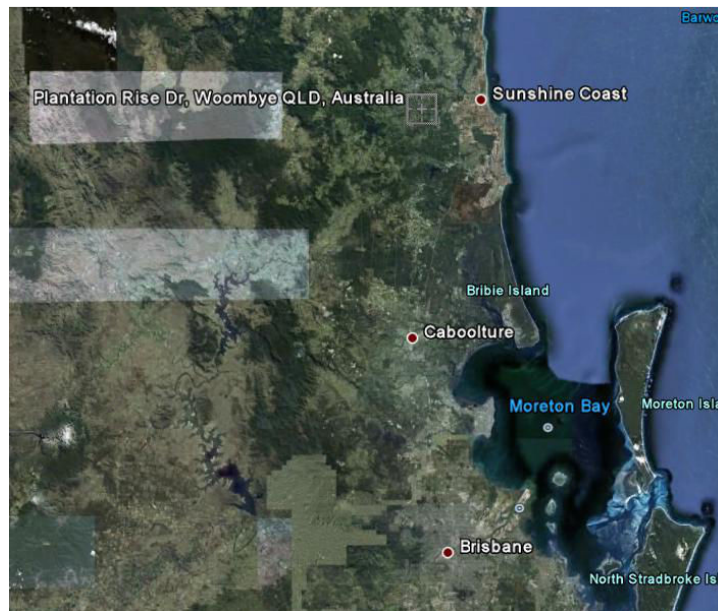


**(20)  Figure 3.1.1– Location of Woombye with respect to Brisbane (taken from Google Earth)**

In terms of it position in the electricity grid, the Sunshine coast receives an EHV supply of 275kV at a major substation (SSPWD) in Palmwoods.  In order to reach Plantation Rise Drive, electricity is first distributed from SSPWD at a voltage of 132kV to a substation at Nambour (SST16).  At SST16, the voltage is transformed to 33kV and distributed to the Palmwoods Central substation (SSPWC), another substation located at Palmwoods.  Here the voltage is transformed to 11kV and sent via feeder PWC2 to one of the pad-mount transformers located at Plantation Rise Drive (SC1494340).  The voltage is transformed to 240V single phase and distributed to the consumers on that branch including the residence in focus.  Refer to figure 3.1.2 for a simplified line diagram of electricity flow.
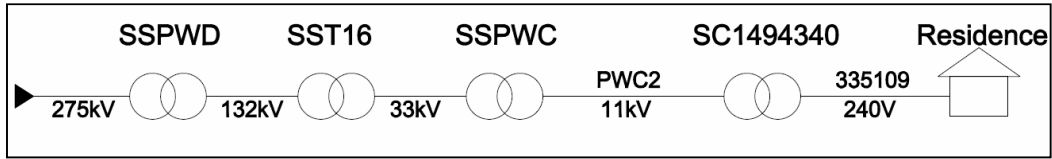
**(21) Figure 3.1.2– Line Diagram – SSPWD to Residence**

In this study, load data of for Queensland will be taken from the Australian Energy Market Operator (AEMO) and includes loads covered by the National Electricity Market (NEM) as shown in figure 3.1.3.
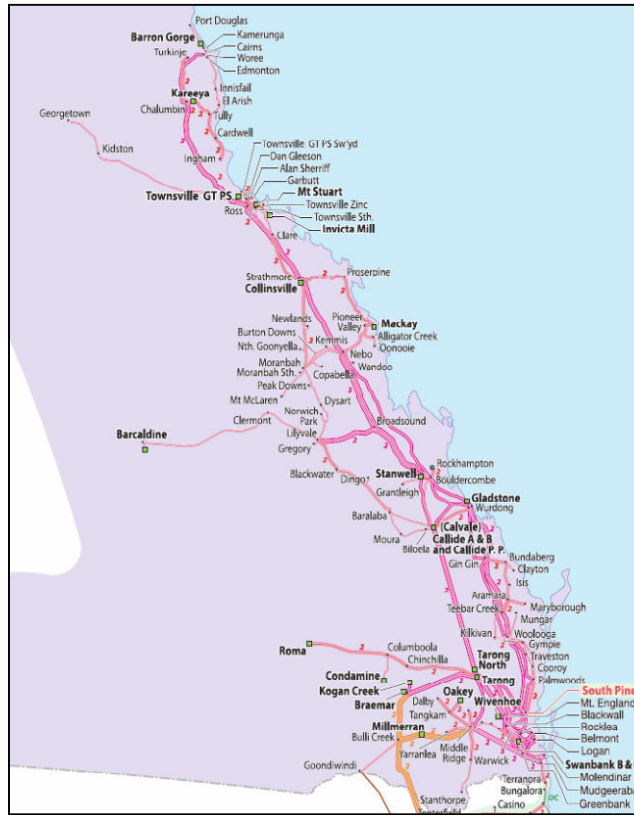


**(22) Figure 3.1.3– Queensland Boundaries of the NEM (AEMO 2010b, p. 184)**

Load data will also be taken at SST16, SSPWC, transformer SC1494340 (PRT), and at the residence on Plantation Rise Drive with assistance from Energex. For more detailed diagrams of the network, see Appendix E1 to E5. Data was obtained from different sources and in different ways. This data was used firstly to identify characteristics of the existing load profiles at many different levels of the grid. Other key purposes for obtaining this data were to assist in the creation of smart grid models and also to calculate the benefits of using Smart Grid.

## 3.2  Data Acquisition

As mentioned, data was obtained in different ways, and for different purposes. This section will detail the sources of data, and the purpose of the data. A complete data log showing data obtained from Energex, the AEMO and the BOM is shown in Appendix B2.

### 3.2.1  Energex Data

Energex field staff took measurements at the residence and at the adjacent Plantation Rise Transformer (PRT) simultaneously using current transformers and data loggers. The data was captured at 30 second intervals, and was converted to 5 minute intervals for use in models and simulations employed in this project.

Energex also provided load information for the 11kV feeder (PWC2) as well as at the 33kV and 132kV (SSPWC & SST16) substations which feed the area. This data was captured using the Energex SCADA system at 30 minute intervals. Similarly, this data needed to be converted to 5 minute intervals, and this was done by loading the data into Matlab, and using the *interp1* function, which uses linear interpolation to generate data between the known data points. An example of raw data obtained from the AEMO is shown in Appendix H3.

### 3.2.2  AEMO Data

Data was obtained from the Australian Energy Market Operator (AEMO) regarding Qld loads and wholesale electricity prices. As mentioned, the data obtained only represents loads and prices associated with the NEM network in Qld, as shown in figure 3.1.3. This data was available at 5 minute intervals and was therefore used directly in Matlab simulations. An example of raw data obtained from the AEMO is shown in Appendix H4.

### 3.2.3  Residence Data

An assessment of all devices using electricity in the residence was performed along with manual measurements being taken of the power usage of all these devices. Measurements were only taken of devices which are commonly used on a regular basis i.e. at least 3 times per week. These measurements were obtained using an Extech MA640 True RMS Clamp Meter, which was capable of measuring current with a resolution of 0.01A and accuracy of +/-(2.8% + 8 digits) at currents below 60A AC.

The method used to take these measurements was as follows:

- Turn off all electrical devices in the home.
- With the assistance of a licensed electrician, the clamp meter is clamped around the main conductor in the distribution board of the residence.
- All electrical devices are tested individually to achieve an accurate current reading and hence power consumption of the device.
- For devices such as the dishwasher and washing machine which have cycles, readings were taken over the course of the cycle and averaged over 5 minute intervals.

Not all devices which were possible to assess using this method. Some devices such as the Air Conditioner required calculations, and therefore a completed table can be found in section 3.3.5.

In addition to the measurements, information was obtained from the occupants regarding electricity usage habits. This included producing a table with all electrical devices including lighting; and time slots were filled in during which the devices were in use. This was done for a typical winter's day and a typical summer's day. There were also two scenarios considered – one where people are home during the day (current situation), and one where no one is home from 9am to 4pm, which is common for many households.

The occupants reported that due to their lifestyle, most electrical devices are used similarly throughout the entire year, with some exceptions being air conditioning, ceiling fans and lighting. The measurements, combined with this information from the occupants, provided an assessed power usage model, which will be compared with the measured power usage model, and will subsequently be used in future calculations.
For comprehensive data regarding electricity usage habits, see Appendix D1 and D2, and for the layout of all electrical devices in the home, see Appendix C1 and C2.


## 3.2.4 BOM Data

Data from the Bureau of Meteorology was also provided to identify critical days to assess, based on extreme weather conditions. The data of particular interest was temperature data, as this directly influences the use of heating in winter and cooling in summer.

This data was available in 30 minute intervals, and had to be interpolated using Matlab similarly to the Energex SCADA data. Days of particular interest were the 12th May and the 9th June 2011 which were particularly cold days; and the 17th December 2010 and the 18th January 2011 which were particularly hot days. An example of raw data obtained from the AEMO is shown in Appendix H2.

# 3.3 Calculating Other Load Data

Some loads such as the fridge, freezer, hot water unit and air conditioner were unable to be assessed fully by measurement. These loads vary with seasonal changes, and the electrical load is dependant heavily on climatic variation. As measurements were taken from June to July 2011, only cooler weather data was obtainable, and therefore usage in warmer months must be calculated.

### 3.3.1 Fridge Loads

The refrigerator at the residence was found to have an operating current of 0.8A or 192VA. Due to time and equipment limitations, a full load profile for 24 hours was unobtainable. Because of this, information was taken from other studies to estimate the daily load profile for the fridge both in winter, and in summer.

To assist in constructing a 24hr load profile, data was used from Energy Efficient Strategies, a company in Melbourne which consisted of a month of data from February for an electronic control automatic defrost 520 L Group 5B refrigerator in a home. Data included power consumed as average watts per minute and room temperature and a sample of this data is shown in Appendix H1. Also, in helping to modify this load profile to match the required load profile for summer and winter, information found in Harrington 2000, p.13 was used. The relevant graph is shown in figure 3.2.1.1 below.
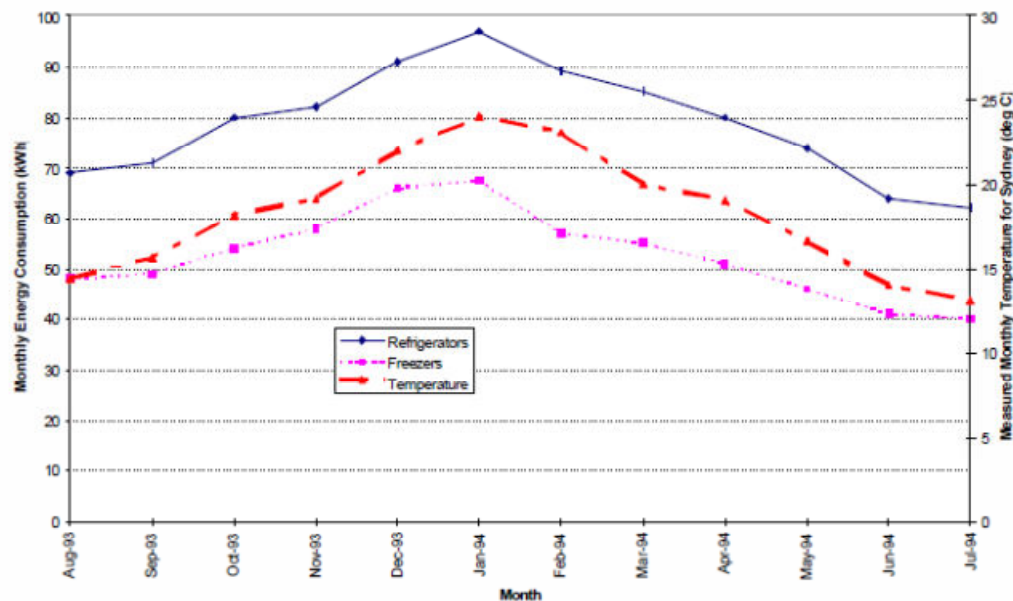


**(23) Figure 3.3.1.1 – Monthly Variation in Refrigerator and Freezer Energy Consumption (Harrington 2000, p13)**

First, the fridge load profile is estimated for the 9$^{th}$ June 2011. From the test data, the load profile for the 23$^{rd}$ February 2011 was chosen for comparison. The typical load of the test fridge was approximately 127W, whereas the residence fridge has an aforementioned load of 192VA, so first, the test data was modified so that the 127W became 192VA, whilst maintaining the duty cycle (load profile) of the fridge. The average temperature on the 23$^{rd}$ February test data was 20.5°C, and the average temperature on the 9$^{th}$ June at the residence was 12.16°C. It was found through interpolation of the information in figure 3.2.1.1 that energy consumption is around 87kWh with average temperatures of 20.5°C, and around 62kWh with temperatures of 12.16°C. As the average power consumed on the modified 23$^{rd}$ February data was 74.42W, it was calculated that the average power on 9$^{th}$ June would be 62kWh / 87kWh * 74.42W = 53W.

As the fridge is either on or off (not variable speed), achieving the load profile for 9$^{th}$ June was done by modifying the 23$^{rd}$ February load profile through shortening the duration of the operation of the fridge (manipulation of the duty cycle). With consideration of things such as the times of frequent use of the fridge (breakfast, lunch dinner etc), the modified load came to an average of 50.1W which is within 6% of the desired 53W. This estimated load profile was used for all simulations for winter months. For complete results, see Appendix B.2.

Summer Loads

The same method was used to find an estimated load profile for 18$^{th}$ January 2011, when the average temperature inside the residence was 24.03°C, taking air conditioning into account. Again, using the information in figure 3.2.1.1, the estimated average power consumed on the 18$^{th}$ January would be 97.5kWh / 87kWh * 74.42 = 83.35W.

Through modifying the 23$^{rd}$ February load profile, the 18$^{th}$ January load came to an average of 85.28W which is within 3% of the desired 83.35W. This estimated load profile was used for all simulations for summer months. For complete results, see Appendix B.2.

### 3.3.2        Freezer Loads

As similar information to that of the fridge (load profiles, temperatures, and average energy consumption) was available for the freezer, a similar method was used to calculate estimated winter and summer load profiles. This time, the measured load for the chest freezer at the residence was 88.56VA, and the load of the test freezer was 93W. It is also important to note that the freezer is located in the garage, which is

subject to higher temperatures in summer when compared with the air conditioned interior of the residence.

Winter & Summer Loads

Due to the similar method used to find freezer loads, and for the sake of brevity, the results are shown in table 3.3.2 below.

| | 23rd February 2011 (Test Data) | 9th June 2011 (Winter) | 18th January 2011 (Summer) |
| --- | --- | --- | --- |
| Avg. Temperature (°C) | 20.5 | 12.16 | 26.6 |
| Desired Avg. Load (VA) | 49.63 | 33.96 | 62.53 |
| Actual Average Load (VA) | 49.63 | 34.91 | 62.51 |
| Error (%) | 0 | 2.7 | 0.07 |

(1) **Table 3.3.2.1 – Estimated Typical Freezer Loads for Summer and Winter**

For complete results, see Appendix B.2.

### 3.3.3 Hot Water Unit (HWU) Loads

The hot water unit at the residence is a Rheem 5513/007 heat-pump type with an electrical booster element. The heat pump is rated at 1300W and the booster is rated at 3600W. During the course of the data collection phase of the project, there was a fault with the HWU in that the heat pump was not working, and as such heating of the water was solely performed by the electric booster element.
This is not an accurate representation of the realistic operation of the HWU, and therefore estimates need to be made to model its function. From the Energex measurements in June 2011, it was easy to identify the times when the HWU was operating from the load profile. To see the operation times of the HWU, see appendix D.2.

Winter Loads

According to the Australian Government's Department of Climate Change and Energy Efficiency website, heat pump hot water systems use approximately 1/3 of the amount of power of electric element type systems with ambient temperatures of 15°C. As this was the approximate temperature during testing, this figure will be used as estimation.

On the 9 June, 2011, the electricity used by the HWU was equal to 11.136kWh. As this was supplied solely by the booster element, the estimated energy used if the heat pump were in operation would be approximately 11.136kWh / 3 = 3.79kWh. This is confirmed when comparing the ratio of the booster element over the heat pump, 1300/3600 * 11.136kWh = 4.02kWh. From this, a plausible solution was to modify the HWU load profile by directly replacing the load of 3600W with 1300W.

Summer Loads

No data existed as to the summer loads for the HWU however heat pumps inherently operate more efficiently when ambient temperatures are higher. The Department of Climate Change and Energy Efficiency website again states that when the ambient temperature is 30°C, heat pump hot water systems use approximately 1/5 of the amount of power of electric element type systems. This means that in summer, heat pump HWUs use approximately 0.6 times the power they use in winter.

Again, as the HWU uses 4.02kWh on the 9 June 2011, the approximate usage in summer would be 4.02kWh * 0.6 = 2.4kWh each day. As the HWU is either on or off (not variable speed), achieving a summer load profile was done by modifying the winter load profile through shortening the duration of the operation of the HWU. For complete results, again see Appendix B.2

### 3.3.4 Air Conditioning (AC) Loads

As no measurements were able to be taken at the residence in summer, a simple thermodynamics model will be used to calculate the electrical power used by the air conditioning system. The air conditioner used at the residence is a Fujitsu AOT54LJBYL condensing unit with 14.5kW cooling capacity at 5.57kW electrical load.

First, information given by the residents revealed which areas of the house are cooled by the AC and at what times of the day. With reference to Appendix C.3, usage of the AC on a hot summer day is as follows:

- AC thermostat is typically set at 24°C.
- AC is used in zones 1, 3 and 4 (shown as red shaded area) when the temperature hits around 28°C to 30°C or at lunch time until 6:30pm.
- From 6:30 till 9:00pm, zones 1, 2, 3, 4, 5 and the bottom right hand corner room of zone 6 use AC.

The total load on the air conditioning is affected by heat gain on the residence which is caused by:

- Heat transfer by convection through the roof, windows, external walls and internal walls
- Heat transfer caused by direct solar radiation.

- Internal heat gains due to occupants, lighting, electrical equipment and cooking.
- Ventilation and infiltration through door gaps etc.

Heat Transfer

The basic formula relating to heat transfer used is:
$$Q = A \times U \times \Delta T$$

Where,  $Q$ = Energy used (Watts)
$A$ = Surface area of adjoining surfaces ($m^2$)
$U$ = Heat transfer coefficient (depends on materials used)
$\Delta T$ = Difference between the two temperatures

This equation is performed for each surface of the zones that are being air conditioned, with the area for each surface ($A$) being calculated from measurements taken at the residence. The value for $\Delta T$ is calculated assuming that the air conditioned areas are at 24°C, and using outside air temperatures acquired from the Bureau of Meteorology.

The different values for U are as follows:

- Roof, $U_R$ = 0.384. Assuming metal deck, ceiling air space, R2 insulation, 13mm plasterboard ceilings.
- External Walls, $U_{EW}$ = 0.51. Assuming outside wall 110mm brick, air gap, R1.5 insulation, 10mm plasterboard wall sheeting.
- Internal Walls, $U_{IW}$ = 1.78. Assuming no insulation, 10mm plasterboard wall sheeting.
- Windows, $U_W$ = 5.5.

As mentioned, $\Delta T$ will be ($T_{OUT} - T_{AC}$), where $T_{OUT}$ is the outside air temperature, and $T_{AC}$ is the air temperature in the air conditioned areas. This applies to the roof, external walls and windows, but for the internal walls, $\Delta T$ will be ($T_{INT} - T_{AC}$) where $T_{INT} = ((T_{OUT} + T_{AC}) / 2)$. This means that it is assumed that the temperature of the areas in-between the air-conditioned areas and the external areas is half way between the two.

Solar Heat Transfer

Solar heat transfer occurs as a result of direct solar radiation on the outside surface of the house including the roof, walls and windows. Calculating the heating effects of direct solar radiation requires data relating to the position of the sun at all times in the day, as well as data relating to shading etc. As this is overly complex with respect to the scope of this project, this factor was initially disregarded, but due to errors was given a constant value of 1800W during daytime hours (see errors and corrections section below).

<u>Internal Heat Gains</u>

According to CAMEL which is one of Australia's leading air conditioning load estimation programs, developed by ACADS-BSG Building Services Software, a reasonable value for the heat load of occupants is 130W per occupant.

It is difficult to represent the exact heat load caused by lighting, power and cooking. These values will be calculated as a proportion of 0.8 * lighting electrical load, 0.6 *general appliance electrical load and 1.0 * cooking appliance electrical load.

<u>Ventilation and Infiltration</u>

Exact calculations of these variables is highly complex and beyond the scope of this project. As such, this factor was initially ignored, but due to errors, a constant value of 1500W was assigned.

<u>Overall Load on Air Conditioner</u>

Combining all the factors above gives an equation which calculates the total load on the AC.

$$Q = (A_R \times U_R \times \Delta T) + (A_{EW} \times U_{EW} \times \Delta T) + (A_{IW} \times U_{IW} \times \Delta T) + (A_W \times U_W \times \Delta T) + L_S + L_L + L_P + L_O + L_{VI}$$

Where,     $Q$ = Energy used (Watts)
 $A_R$ = Total surface area of roof (m$^2$)
$U_R$ = Heat transfer coefficient of roof (0.384)
$A_{EW}$ = Total surface area of external walls (m$^2$)
$U_{EW}$ = Heat transfer coefficient of external walls (0.51)
$A_{IW}$ = Total surface area of internal walls (m$^2$)
$U_{IW}$ = Heat transfer coefficient of internal walls (1.78)
$A_W$ = Total surface area of windows (varies over time)
$U_W$ = Heat transfer coefficient of windows (5.5)
$L_S$ = Heat load caused by solar radiation (varies over time)
$L_L$ = Heat load caused by lighting (varies over time)
$L_P$ = Heat load caused by power, including cooking (varies over time)
$L_O$ = Heat load caused by occupants (varies over time)
$L_{VI}$ = Heat load caused by ventilation and infiltration (varies over time)
$\Delta T$ = Difference between the two temperatures (varies over time)

The following are areas which differ throughout the day due to different AC zones being used:

| FOR TIMES BEFORE 6:30pm | FOR TIMES AFTER 6:30pm |
|---|---|
| $A_R$ = 87.19 m$^2$ | $A_R$ = 140.46 m$^2$ |

$$A_{EW}= 71.34 \text{ m}^2 \qquad\qquad A_{EW}= 125.42 \text{ m}^2$$

$$A_{IW}= 58.46 \text{ m}^2 \qquad\qquad A_{IW}= 75.73 \text{ m}^2$$

$$A_{W}= 14.32 \text{ m}^2 \qquad\qquad A_{W}= 19.32 \text{ m}^2$$

The actual electrical load of the AC is found by the following equation:

$$Q_E = Q_A \times \frac{Q_{Emax}}{Q_{Amax}}$$

Where,    $Q_E$ = Electrical Energy used (Watts)
$Q_A$ = Cooling Energy used (Watts)
$Q_{Emax}$ = Electrical Capacity of AC (Watts)
$Q_{Amax}$ = Cooling Capacity of AC (Watts)

It is important to note that these calculations are designed for steady state temperatures, and do not take into account the higher load required on start up used to reduce temperatures to the desired levels.  Calculation of these loads is too in depth for the scope of this project.

Calculation Errors and Corrections

When testing the formula and ignoring the solar heat gain and ventilation/infiltration factors, some irrational results were found.  For example, at 10:00am on 18th January 2011, the outside air temperature was found to be 32.62°C.  Using the initial formula, the cooling load on the air conditioner was found to be approximately 4570.65W.  According to the Australian Institute of Refrigeration, Air Conditioning and Heating Handbook, a check value for cooling loads in a residence is 120W/m$^2$.  Using this estimate, the maximum reasonable cooling load on the residence should be in the order of 87.16 m$^2$ x 120W/m$^2$ = 10459.2W.

This indicates that the model used is underestimating the cooling load required to maintain the residence at 24°C.  To rectify this, some reasonable values for solar heat transfer and ventilation/infiltration need to be added.

 If the cooling load of 10459.2W is achieved at a reasonable maximum outside air temperature of 35°C, and it is assumed that with an outside air temperature of 24°C, the cooling load would be 0W ($\Delta T =0$), then at 32.62°C, the cooling load should be close to:

$$\frac{(32.62 - 24)}{(35 - 24)} \times 10459.2 = 8196.209 \ W$$

This means that there is an additional heat load of (8196.209 – 4570.65) = 3625.559W due to solar heat transfer and ventilation, and other errors.  As has been mentioned,

the exact calculation of these factors is beyond the scope of this project, and as the value of 3625.209W is only a guide it is therefore proposed that the following values be used:

<div style="text-align:center">

FOR DAYTIME HOURS      ALL OTHER TIMES

$L_{VI} = 1500W$          $L_{VI} = 1500W$

$L_S = 1800W$          $L_S = 0$

</div>

These assumptions are made, as although the position of the sun changes over the course of a day, the net effect in terms of heating the house will be roughly equal at all times with the effect tapering around sunrise and sunset. Also the effect of filtration/ventilation (cool air escaping and warm air entering) is considered to be constant.

Results

Calculations are performed using Matlab and integrated into the simulation, with an example being shown in figure 3.3.4.1 below.
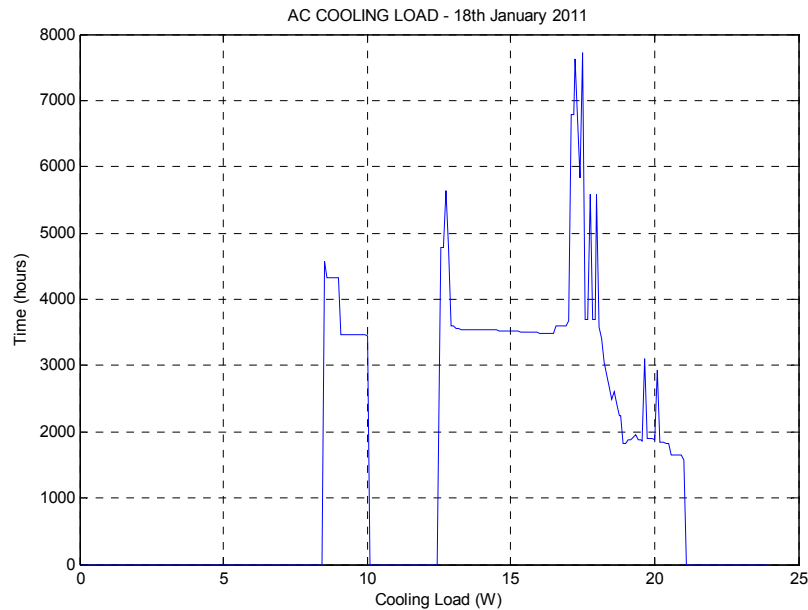


**(24) Figure 3.3.4.1 –Estimated AC Cooling load profile for the 18<sup>th</sup> January 2011**

The load profile shows the variations in cooling load over the course of the day. With no other influence other than outside air temperature, the load would be fairly smooth and follow the same shape as ambient air temperatures during the day. It is clear

however from spikes in the profile that the use of cooking appliances have a large impact on the amount of work the AC has to perform to maintain temperatures at 24°C. The gap in the middle of the day coincides with when there is no one at home and the AC is switched off.

### 3.3.5 Completed Electrical Device Inventory

Table 3.3.5.1 shows the completed electrical device inventory which gives an overview of the electrical loads of all the devices used at the residence. Refer to Appendix C.1 and C.2 for identification and location of all electrical devices.

**(2) Table 3.3.5.1 – Electrical Device Inventory**

| ITEM | STAND-BY | ON | DETAILS |
|---|---|---|---|
| AC | N.M | 2969.50 VA | Peak load is shown. Load varies over time |
| CPU | 14.70 VA | 98.40 VA | Includes printer and monitor |
| DRYER | N.M | 1678.25 VA | |
| DISHWASHER | N.M | 2084.95 VA | On 'Eco' setting. Peak load is shown. Load varies over time |
| DVD1 | See TV1 | 15.68 VA | Average load is shown |
| DVD2 | See TV2 | 15.68 VA | Average load is shown |
| FRIDGE | 2.6 VA | 192 VA | Average loads are shown |
| FREEZER | 0.3 VA | 88.56 VA | Average loads are shown |
| HWU (Booster) | N.M | 3817.92 VA | |
| HWU (Heat Pump) | N.M | 1378.27 VA | |
| IRON | N/A | 2045.75 VA | Peak load is shown. Load varies over time |
| MICROWAVE | N.M | 1421.88 VA | On 'High' setting. |
| OVEN | N.M | 1931.10 VA | Set at 180°C. Peak load is shown. Load varies over time |
| RANGE HOOD | N.M | 95.94 VA | Set at medium setting |
| STOVE (1 plate) | N/A | 1175.88 VA | Set at 4/5 setting. Peak load is shown. Load varies over time |
| STOVE (2 plates) | N/A | 2135.28 VA | Set at 4/5 setting. Peak load is shown. Load varies over time |
| TV1 | 22.14 VA | 253.38 VA | Average loads are shown |
| TV2 | 22.14 VA | 212.43 VA | Average loads are shown |
| TOASTER | N/A | 772.44 VA | |

| | | 1132.09 | Peak load shown. Average cycle. Temperature set to |
|---|---|---|---|
| WASH. MACH. | N.M | VA | 30°C |
| VACUUM | N/A | 1180.80 VA | |
| LIGHTS 3 (L3) | N/A | 100.86 VA | Also applies to L7, L9, L10, L16, L18 |
| LIGHTS 4 (L4) | N/A | 174.66 VA | |
| LIGHTS 5 (L5) | N/A | 201.72 VA | |
| LIGHTS 11 (L11) | N/A | 151.29 VA | |
| LIGHTS 31 (L31) | N/A | 41.82 VA | |
| EXHAUST FAN | N/A | 54.12 VA | Applies to both exhaust fans (EF1 & EF2) |
| CEILING FAN | N/A | 36.90 VA | Peak load is shown. Applies to all ceiling fans (F1, F2 etc.) |

Notes:        N.M denotes 'not measurable' with clamp meter (i.e. insignificant amount)
             N/A denotes 'not applicable'

## 3.4  Load Profile Analysis

One of the main goals of this project is to be able to predict what the impact on the electricity grid as a whole would be if all residential settings used smart-grid HANs. This is a difficult task, as residential loads obviously differ greatly from one house or residence to the next. For this reason, estimation needs to be made based on the results found in the data gathering stage of this project. Also, as there are different types of loads (see section 2.1.1), it is hard to know what part of the total QLD load consists of residential loads. It is helpful to know that particular patterns exist in residential, commercial and industrial loads which can help in the prediction of the effects of large scale implementation of smart grid (Berende et al., p. 3).
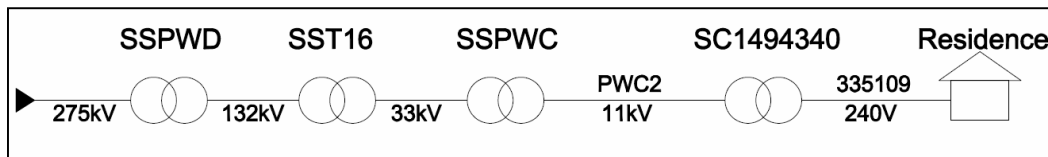


(25)  **Figure 3.4.1– Line Diagram – SSPWD to Residence**

Data was acquired at the residence itself as per section 3.1.3; at the PRT Transformer (SC1494340); at the PWC2 Feeder; at SSPWC Substation; at SST16 Substation; and as the total Queensland NEM load.

The purpose of this section is to analyse the load measurements and compare them in order to better predict the effects of smart grid use on a large scale.

### 3.4.1  Residence Load and Comparison with Plantation Rise Transformer (SC1494340)

<u>RESIDENCE LOADS</u>

As has been mentioned, the residence chosen was considered to be a fairly typical modern house.  An example of the load profile is shown in figure 3.4.1.1.
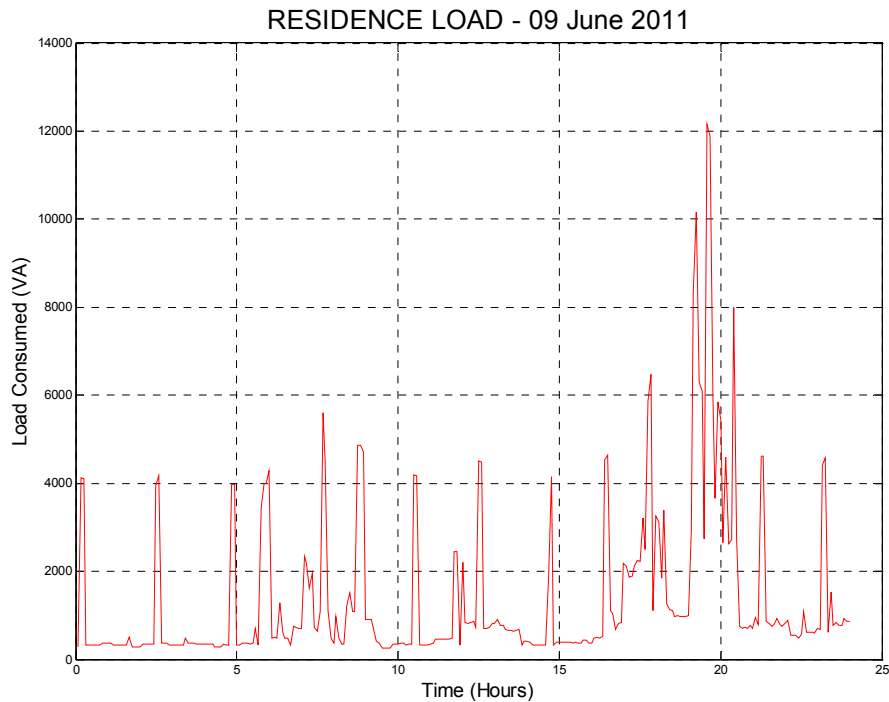


**(26)  Figure 3.4.1.1 – Residence Load Cycle Thursday 9<sup>th</sup> June 2011**

This figure shows the load profile for a cold winter day with the temperature varying from 12.5 to 14.1°C, however, it is important to note that no heating was used during this period.  Apart from the almost periodic spikes, which are caused by the booster on the heat-pump type hot water system, this displays a typical residential load profile.  There is a slight general peak around the hours of 5:30 to 9:30am, and a major general peak around the hours of 4:00 to 10pm.
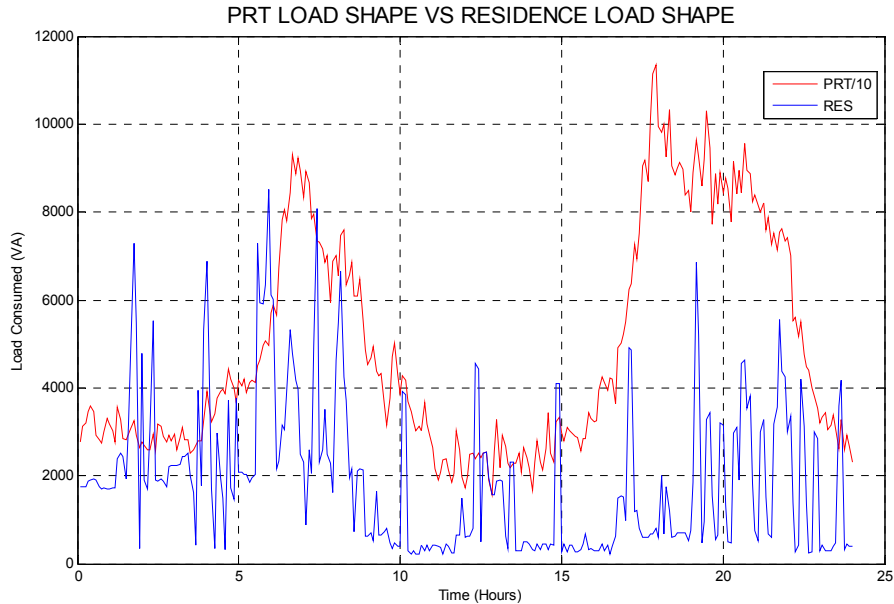
**(27)  Figure 3.4.1.2 – Residence and PRT Load Cycle Thursday 14<sup>th</sup> July 2011**

Figure 3.4.1.2 shows the load profile for both the Plantation Rise Transformer (PRT) and the residence on a cold winter day with the temperature varying from 8.7 to 22.9°C. On this day, heating was used, and this is particularly demonstrated at the period ranging from 7pm till midnight.  Again, throughout the entire 24hour period, there are periodic spikes which are caused by the booster on the heat-pump type hot water system.  This data shows the impact that home heating systems have on electrical load profiles.

Several observations and conclusions can be made from this data that influence the prediction or 'scaling' of loads.  Firstly, it is shown that it is very difficult to identify relationships or patterns between these two load data sets.  A very important point to identify is that the Plantation Rise Transformer solely feeds residential loads (i.e. No commercial or industrial loads), and as such can be considered purely as a representation of an average of residential loads.  Furthermore, from visual inspection and from data obtained from Energex (see appendix E1), it can be shown that at the time of measurement there were a total of 65 residences being fed by the transformer. A further discussion of these factors will be addressed and a relationship will be found in the section 3.5.

## 3.4.2        Plantation Rise Transformer (SC1494340) Compared with Upper Wakefield Street Transformer (SC1427301)

In the interest of finding a relationship between residential loads, the Plantation Rise Transformer (PRT) loads have been compared with that of the Upper Wakefield Street Transformer (UWT) loads.   The location of these two transformers is

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demonstrated again in diagrams provided by Energex (see appendix E1 & E2). An example of the PRT and UWT loads is shown in figure 3.4.2.1.
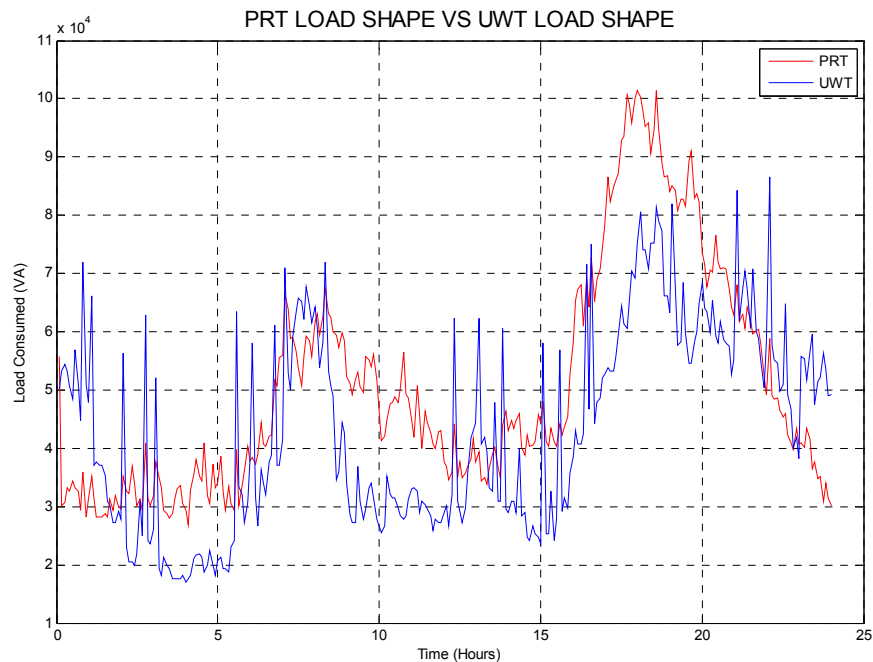


**(28)  Figure 3.4.2.1 – PRT and UWT Load Cycle Thursday 19th May 2011**

It is important to note that the exact composition of the UWT transformer is unknown (due to a lack of data), but it is primarily a residential transformer.  The somewhat random spikes in the UWT load in figure 3.4.2.1 show that there is obviously some kind of industrial and/or commercial load contributing to the overall load, as it is extremely unlikely that an increase in load would increase at many different residences simultaneously.  Results show that:

- The PRT load factor = 0.5;
- The UWT load factor = 0.5;
- The Average Ratio (PRT/UWT) = 1.24;
- The Minimum Ratio (PRT/UWT) = 0.5 and occurs at 12:50am;
- The Maximum Ratio (PRT/UWT) = 4.58 and occurs at 4:35am.

These ratios are displayed in figure 3.4.2.2.
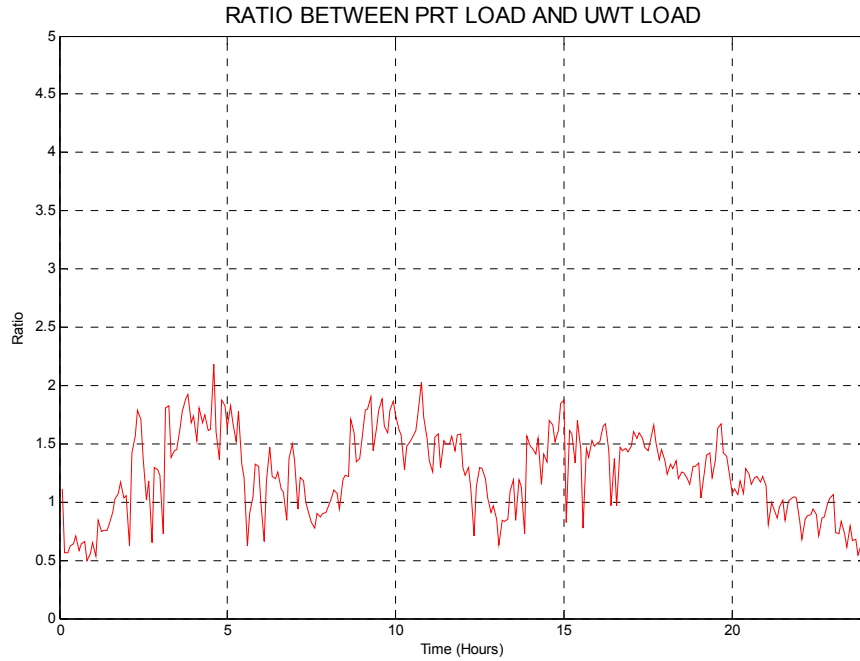
**(29)  Figure 3.4.2.2 – Ratio between PRT and UWT Loads - Thursday 19th May 2011**

With smoothing of the UWT load, which is performed by removing the spikes that are caused by apparent non-residential loads, the load shapes are shown in figure 3.4.2.3.
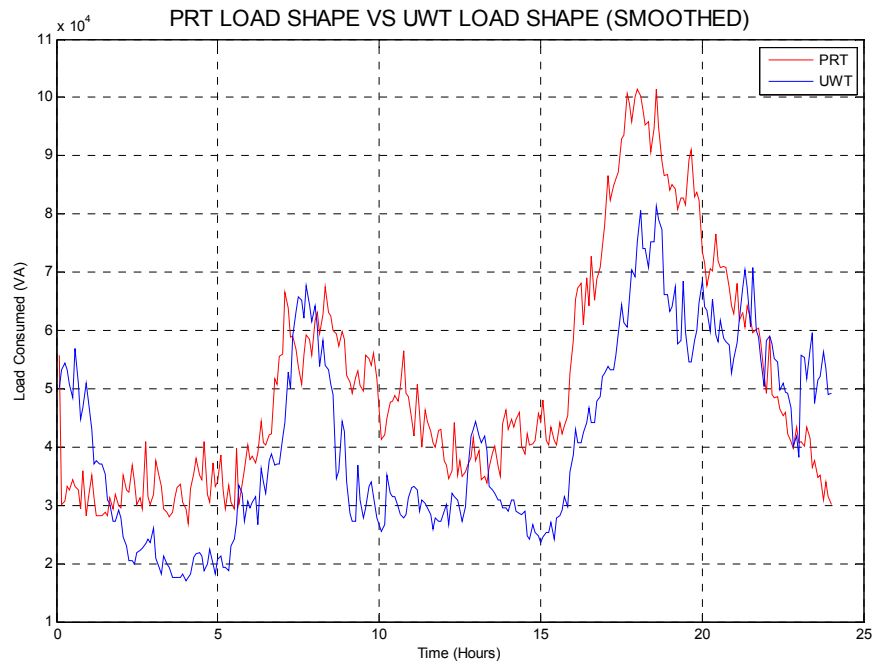


**(30)  Figure 3.4.2.3 – PRT and (smoothed) UWT Load Cycle Thursday 19th May 2011**

With the UWT data being smoothed, the UWT load factor = 0.51, the Average Ratio (PRT/UWT) = 1.3, the Minimum Ratio (PRT/UWT) = 0.55 and occurs at 11:45pm, and the Maximum Ratio (PRT/UWT) = 4.58 and occurs at 4:35am. More importantly, it is now visually evident that the UWT load has a very similar profile to that of the PRT load. There is still an influence by non-residential loads which is particularly notable from around 8pm till midnight.
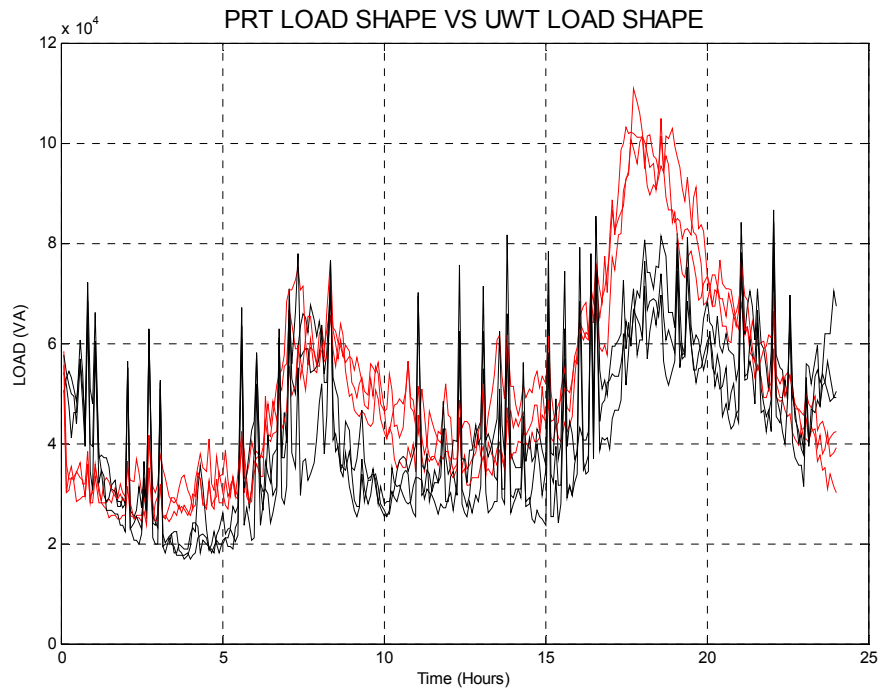


**(31) Figure 3.4.2.4 –PRT and UWT Load Cycles - Thursday 19th May till Saturday 21st 2011**

Data has also shown that the relationship between PRT and UWT is consistent over multiple days. The above figure 3.4.2.4 shows the load profiles for PRT (in red) and UWT (in black) of the 19th, 20th and 21st superimposed over each other.

As has been mentioned in section 3.4.1, it is a fact that the PRT solely supplies residential loads. Comparison of load data of PRT with UWT confirms this fact, and also confirms the fact that the UWT load must primarily consists of residential loads, but also consists partially of industrial / commercial loads. This further validates the use of PRT loads to represent typical residential loads.

### 3.4.3    Plantation Rise Transformer (PRT) Load, Comparison with PWC2 Feeder and Estimation of PRT Summer Loads

Much has already been discussed about the nature of the Plantation Rise transformer and its indication of an average residential load profile. No load data exists for PRT in summer months, so an estimation of warm-weather loads must be found.

In this section, analysis will be made of PRT loads including finding an average winter load profile. Comparisons will then be made with PWC2 loads in order to estimate an average summer load profile for PRT.

PRT LOADS
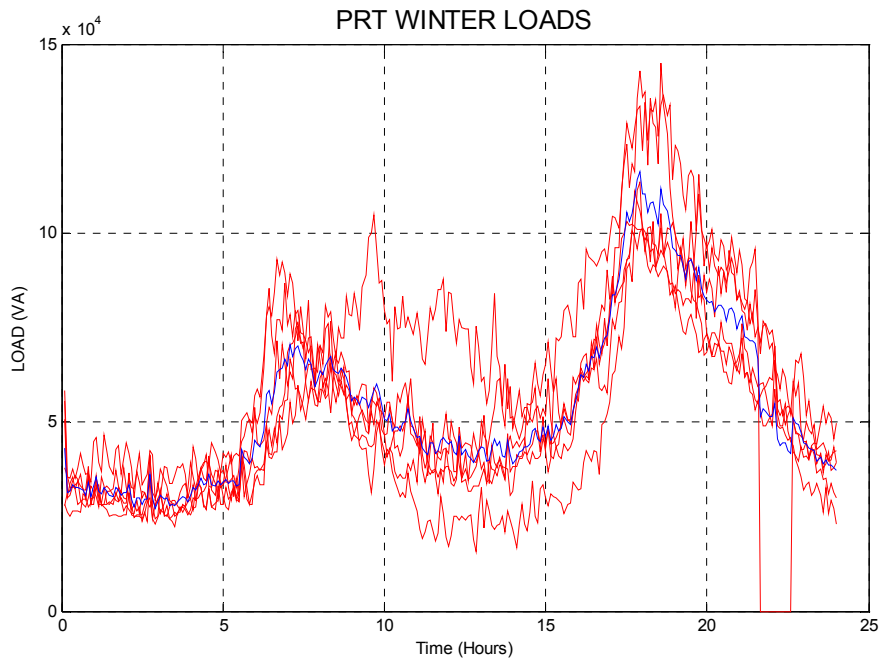


**(32) Figure 3.4.3.1 –PRT Winter Load Cycles - Thursday 19th – Saturday 21st May 2011 & Thursday 14th – Saturday 16th July 2011**

Figure 3.4.3.1 above shows the loads and the average in blue. Note the loss of power on the Saturday 15th July from 9:40 till 10:40 pm.

The high load during the middle of the day was Saturday 16th July which was a cold and rainy day that had 29.6mm of rain and temperatures ranged from 12.8 to 15.9°C. This higher load is probably due to the fact that more people are home on a Saturday, and particularly when it's cold and rainy, and presumably heating would have been used.

An average load for winter weekday is shown in figure 3.4.3.2 below, which also smooths out the fault.

PRT WINTER WEEKDAY LOADS (Fault Removed)
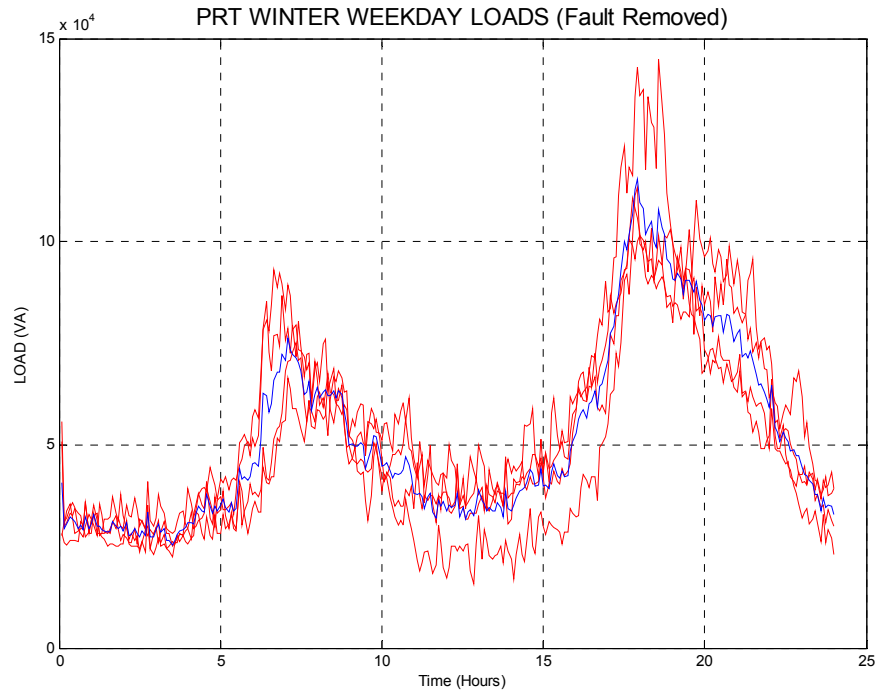
**(33) Figure 3.4.3.2 –PRT Winter Weekday Load Cycles - Thursday 19th – Friday 20th May 2011 & Thursday 14th – Friday 15th July 2011**

This shows that the average from this data set is a fairly accurate representation of the daily weekday winter load on PRT, and will be used to help in scaling of residential loads.

PWC2 LOADS
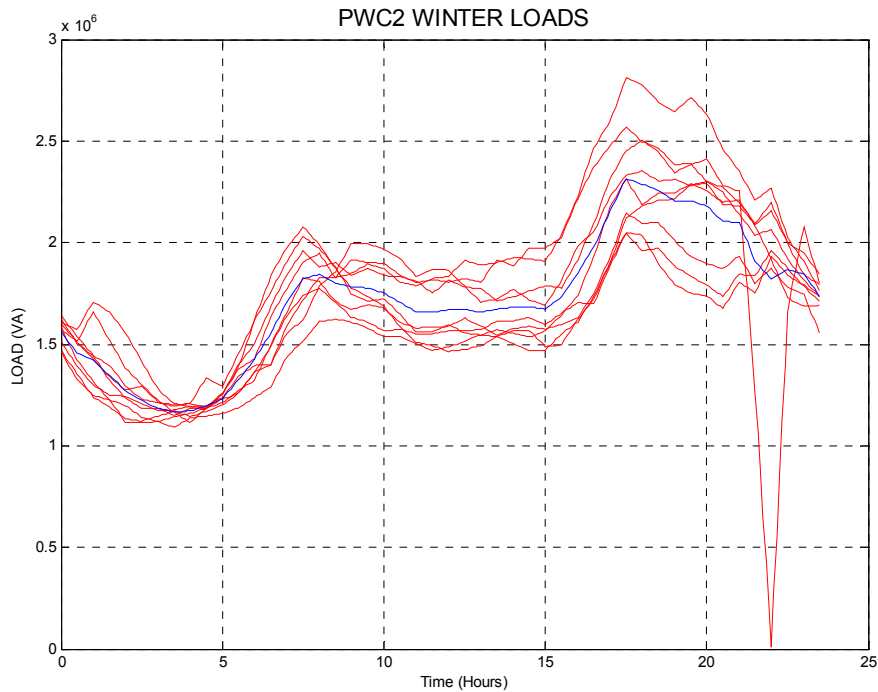


PWC2 WINTER LOADS

**(34) Figure 3.4.3.3 – PWC2 Winter Load Cycles - Thursday 19th – Saturday 21st May 2011, Thursday 9th – Saturday 11th June 2011 & Thursday 14th – Saturday 16th July 2011**

Figure 3.4.3.3 above shows the loads and the average in blue. Note the near loss of power on the Saturday 15th July at 10:00pm.

The significantly higher loads during the period from about Midday to 10:00pm are from cooler days such as Thursday the 9th of June and Saturday 16th July; with June 6th being the coldest maximum temperature of 2011 at 14.1°C. Again, these higher loads are related to low temperatures and hence greater usage of heating in homes between 4:00pm and 5:00am, and all day in commercial settings.

To make an accurate comparison with the average winter load for PRT, figure 3.4.3.4 shows the PWC2 winter weekday load cycles just for Thursday 19th to Friday 20th May 2011 and Thursday 14th to Friday 15th July 2011, as information exists for both PRT and PWC2 for these dates.
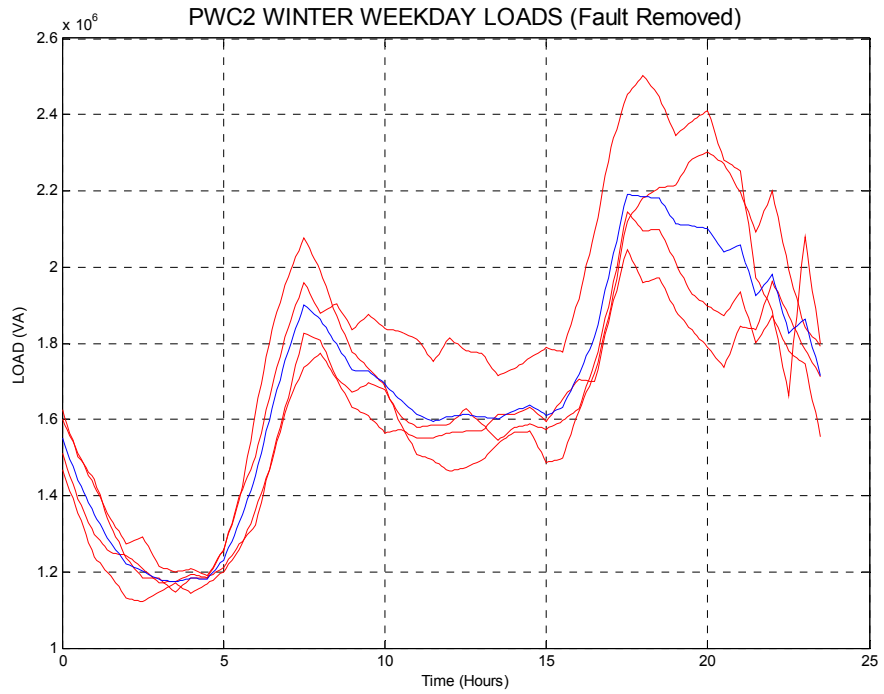
**(35)  Figure 3.4.3.4 –PWC2 Winter Weekday Load Cycles - Thursday 19th – Friday 20th May 2011 & Thursday 14th – Friday 15th July 2011**

Although there is greater variance than that found in the PRT average loads, there is still a recognisable pattern which is highly recurrent from day to day.
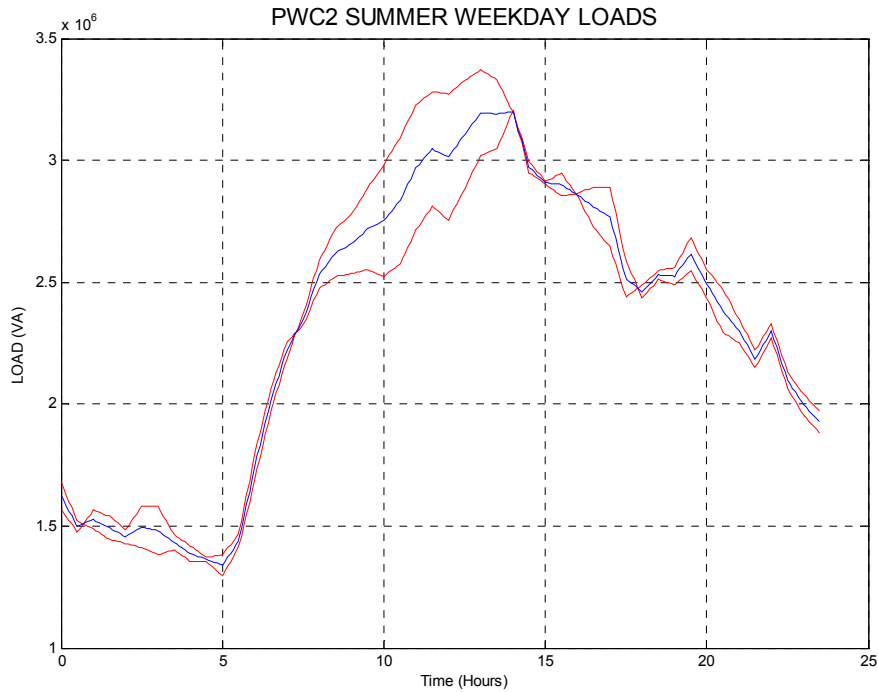
**(36) Figure 3.4.3.5 –PWC2 Summer Weekday Load Cycles - Friday 17th December 2010 & Tuesday 18th January 2011**

Figure 3.4.3.5 above shows the loads from two hot days in summer, with the average in blue. The similarities in the load cycles from the two days are significant even though they are different days of the week, and one month apart. It can be seen that on the 18th of January, the load begins increasing at a higher rate at about 8:00am when compared to the load for the 17th of December. This is probably due to the warmer weather at that time on that day, with a temperatures being 31.7°C at 9:00am on the 18/01/11 and 28.5°C on the 17/12/11.
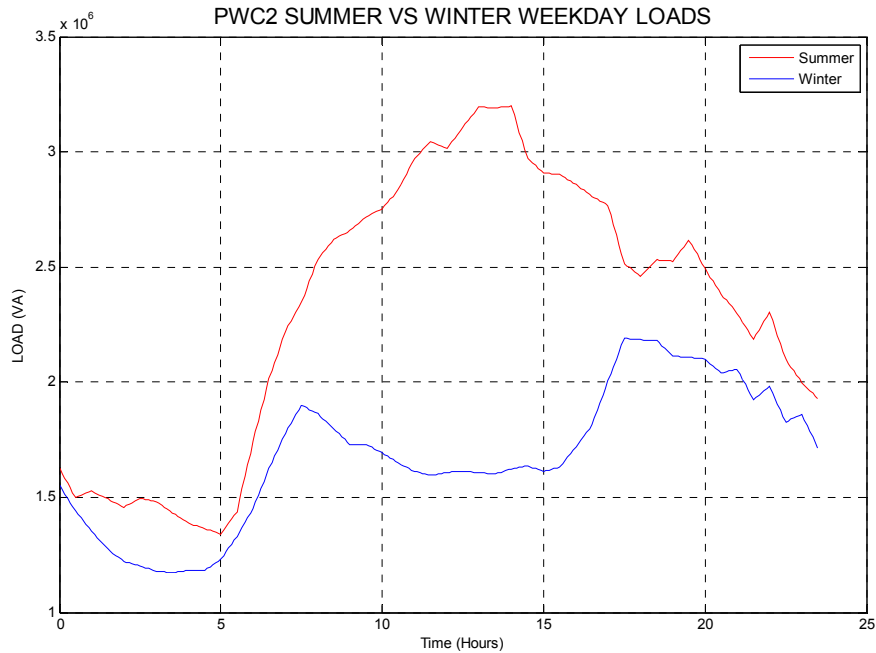
**(37)  Figure 3.4.3.6 –PWC2 Average Summer Weekday Load and Average Winter Weekday Load**

Figure 3.4.3.6 above shows the average hot summer load cycle and the average winter load cycle.

- The Summer load factor = 0.727;
- The Winter load factor = 0.766;
- The Average Ratio (Summer/Winter) = 1.39;
- The Minimum Ratio (Summer/Winter) = 1.04 and occurs at 12:30am;
- The Maximum Ratio (Summer/Winter) = 1.99 and occurs at 1:30pm

## PRT LOADS VERSUS PWC2 LOADS
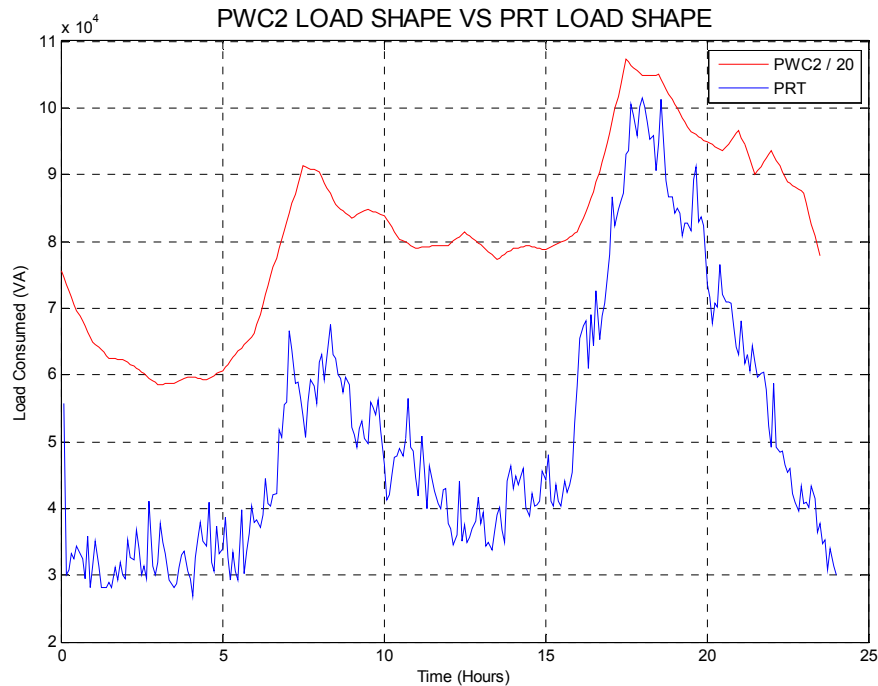


**(38) Figure 3.4.3.7 – PRT and PWC2 Load Cycle - Thursday 19th May 2011**

In terms of comparisons with the PWC2 Feeder, Figure 3.4.3.7 shows the load profile for both the Plantation Rise Transformer (PRT) and the PWC2 Feeder on a mild winters day with the temperature varying from 15.6 to 23.7°C. Upon visual inspection, similarities can be seen in terms of peak loads which are evident at around 7:30am and again at 6:00pm.

Calculations show that:

- The PRT load factor = 0.5;
- The PWC2 load factor = 0.75;
- The Average Ratio (PWC2/PRT) = 33.96;
- The Minimum Ratio (PWC2/PRT) = 20.56 and occurs at 6:40pm;
- The Maximum Ratio (PWC2/PRT) = 48.9 and occurs at 12:10am.

The higher P.F. of PWC2 (0.75) immediately indicates the presence of commercial and/or industrial loads on PWC2. Figure 3.4.3.8 shows the ratios for the same day.

RATIO BETWEEN PRT LOAD and PWC2 LOAD
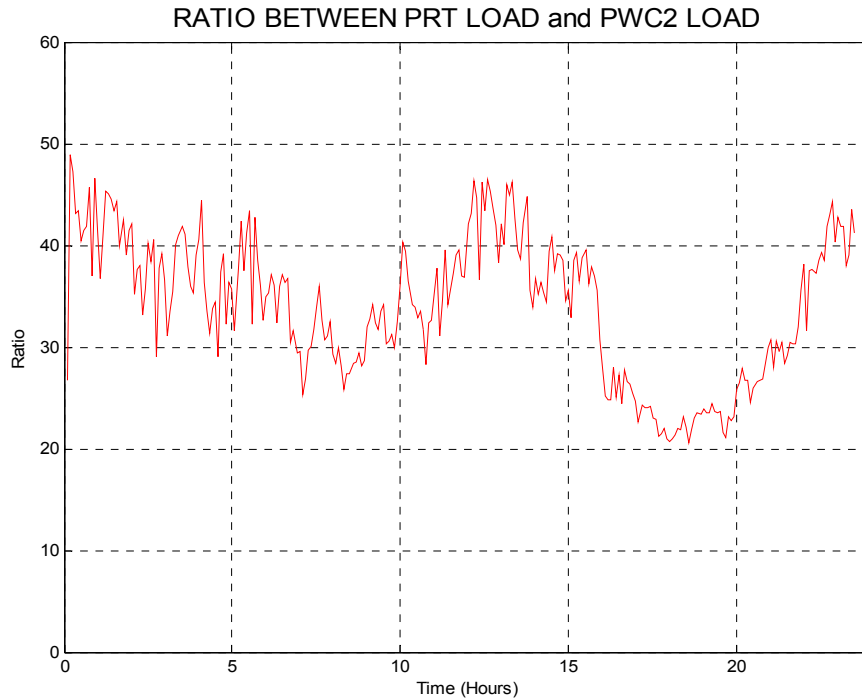
**(39)  Figure 3.4.3.8 – Ratio Between PRT and PWC2 Loads - Thursday 19th May 2011**

This figure reveals much about the relationship between PRT and PWC2 loads.  First of all, the ratio is lower around the hours of 6:30am – 10:00am and more noticeably at 3:30pm – 10:00pm, meaning that the PRT and PWC2 loads are 'closer'.  This means that during these periods, the PRT load constitutes a greater percentage of the total PWC2 load.  These periods of time coincide with the peaks in the purely residential PRT load, and when most people are at home.

Conversely, when the ratio is higher, at 10:00pm till 6:00am and at 10:00am till 3:30pm, the PWC2 load must consist mainly of commercial and industrial loads.

AVERAGE WINTER LOADS
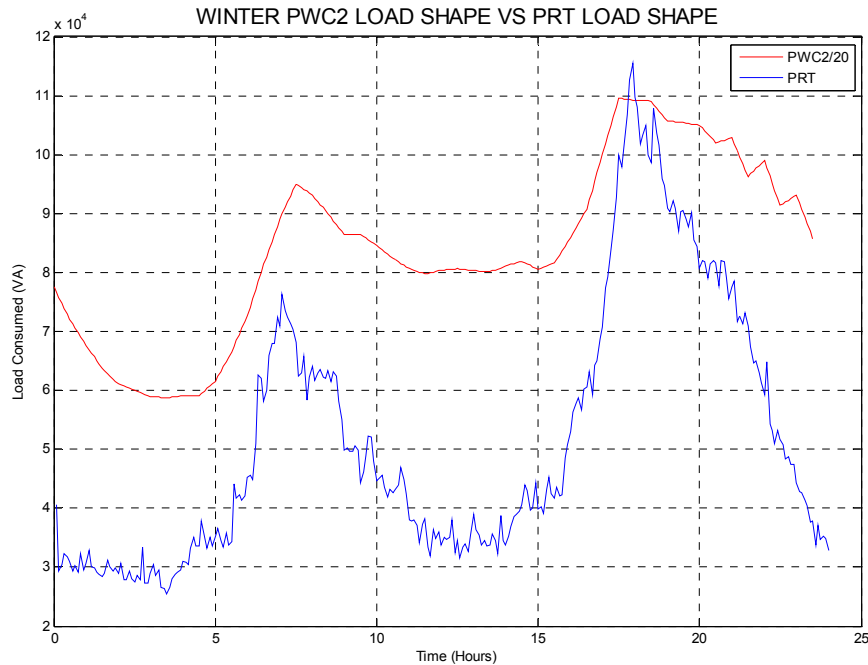


**(40)  Figure 3.4.3.9 – PRT and PWC2 Load Cycle – Winter Weekday Average 2011**

This is of course similar to that shown on 19th May 2011.

Calculations show that:

- The PRT load factor = 0.45;
- The PWC2 load factor = 0.766;
- The Average Ratio (PWC2/PRT) = 35.25;
- The Minimum Ratio (PWC2/PRT) = 18.92 and occurs at 5:55pm;
- The Maximum Ratio (PWC2/PRT) = 51.53 and occurs at 12:10am.

By using the ratio of (average PWC2 winter weekday load) / (average PRT winter weekday load) calculated at each 5 minute interval, missing load data for PRT can now be estimated for the 9th and 10th of June 2011.

AVERAGE SUMMER LOADS

In order to estimate some data for PRT in summer, the ratios found thus far regarding PRT and PWC2 will be used.  To find the average summer weekday load for PRT, perform:

(PWC2 average summer weekday load)  /  ((PWC2 average winter weekday load)/ (PRT average winter weekday load))
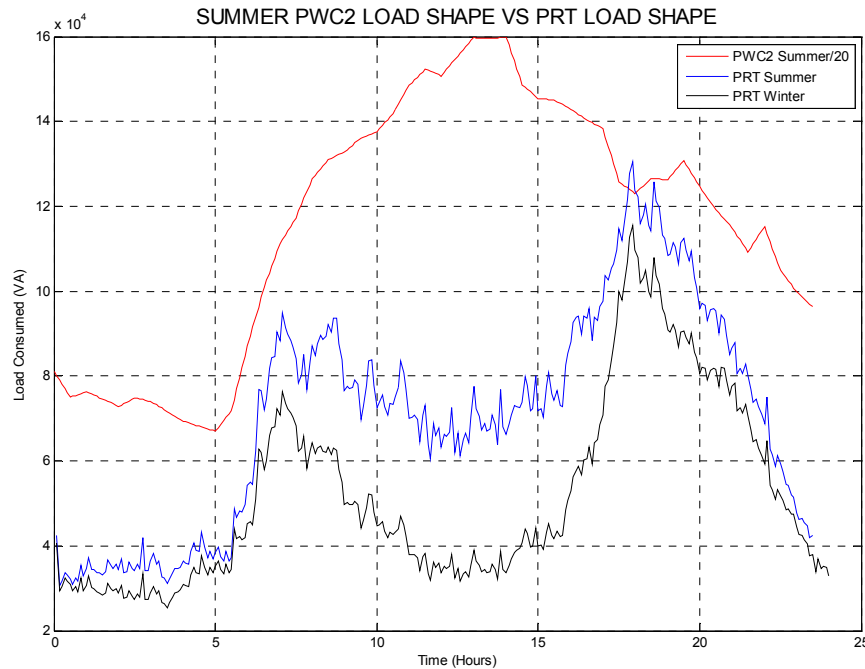


**(41)  Figure 3.4.3.10 – PRT and PWC2 Load Cycle – Summer Weekday Average 2011**

The figure above shows the estimated PRT average summer load as well as the measured PRT and PWC2 average winter loads.  This method assumes that the ratio between the PRT summer and winter loads is the same for that of the PWC2 loads.  Upon visual inspection of the PRT summer load profile, it seems likely that inaccuracies exist, particularly during the periods of about 7am to 3pm.  However, due to the absence of measured data for summer months, this will provide a reasonable estimation for this study.

## 3.4.4        Estimated Residential Component of PWC2

It is important to estimate the total component of residential load on PWC2 in order to aid in the projection of smart grid results to higher levels.  As well as the above ratio data, and previously mentioned information, assistance in formulating this estimation can be found in the following facts and educated assumptions:

- Again, PRT entirely consists of residential load
- PWC2 mainly feeds residential loads, but also contains both commercial and industrial loads (evidenced by its load profile).
- The commercial loads on PWC2 consist of schools and other private businesses which do not generally operate after 5:00pm, with the possible exception of refrigeration and security loads.

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- No information exists on the specific industrial loads on PWC2, and in the absence of exact data, an assumption is made that the industrial load is constant over the 24hour period.
- Residential load profiles will be the same at all levels of the electricity grid in the same general geographical area, on the same day.

On this basis, it can be concluded that the total load on PWC2 after, say 5pm consists of industrial load (assumed as constant) and residential load. To find out what the 'constant' industrial load is, we need to subtract the constant or base Residential load.

EXAMPLE – 19 May 2011

Note that prior to these calculations, smoothing of the PRT load is performed by a method of moving averages. The following calculations will demonstrate this method, showing the first 4 data points in a set:

$Ysmooth(1) = \textbf{\textit{y(1)}}$
$Ysmooth(2) = (y(1) + \textbf{\textit{y(2)}} + y(3)) / 3$
$Ysmooth(3) = (y(1) + y(2) + \textbf{\textit{y(3)}} + y(4) + y(5)) / 5$
$Ysmooth(4) = (y(2) + y(3) + \textbf{\textit{y(4)}} + y(5) + y(6)) / 5$

The example shown is using a 'smoothing factor' of 5.

On the 19$^{th}$ May 2011 the base load for PRT occurs at 4:05am and is 26.86kVA, and the PWC2 base load occurs at 3:00am and is 1.170318.31 MVA.

We do not know how many transformers have exactly the same base load as PRT, so to calculate a total 'residential base load', we perform (AVERAGE RATIO of PWC2/PRT) X (PRT BASE LOAD) = 33.9591 X 26.86kVA = 912.251kVA.
Therefore the constant industrial load = 1.170318.31 MVA - 912.251kVA = 258.067kVA

So, if we now subtract a constant load of 258.067kVA from the PWC2 load, the remainder consists of Residential and Commercial loads.

At around 5:30pm to 6:30pm, peak loads are achieved for both PRT and PWC2 and with the constant industrial load subtracted, the PWC2 load must consist entirely of residential loads. By finding the ratio of PWC2/PRT at this time, we can find an estimate of the residential component of PWC2.

The average ratio at this time was found to be 19.8642, and is known as the key ratio. The estimate of the residential component of PWC2 is now found by multiplying PRT by the key ratio. The results are shown in figure 3.4.4.1 below.

**APPROXIMATE RESIDENTIAL COMPONENT OF PWC2**
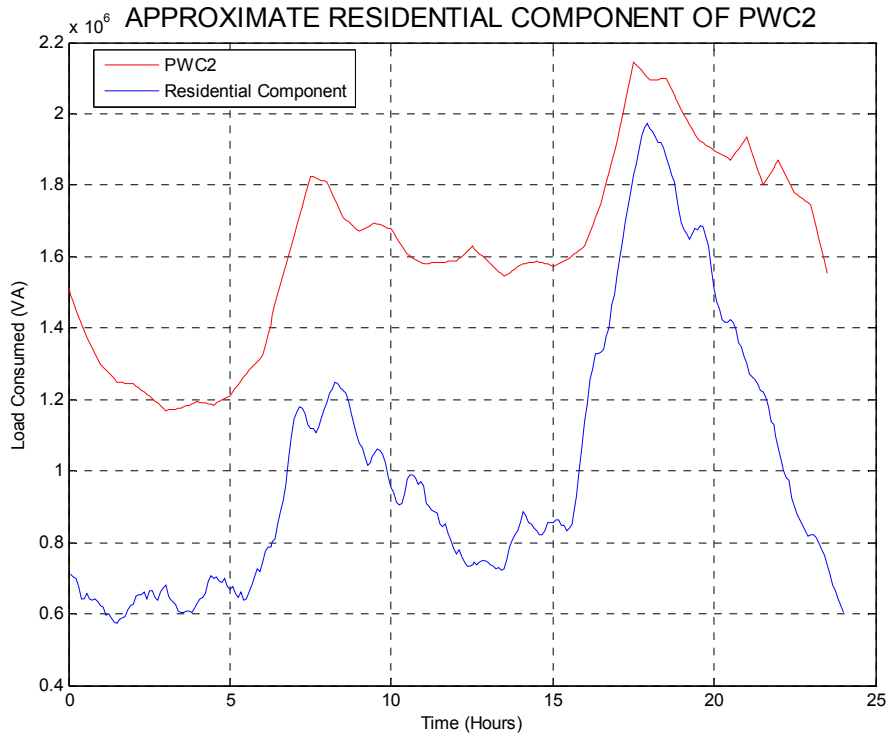
**(42) Figure 3.4.4.1 – Estimated Residential Component of PWC2 – 19<sup>th</sup> May 2011**

The process above shows some flaws, and this would be improved if exact information of all loads on PWC2 was known. As this is beyond the scope of this project, the assumptions made provide a reasonable estimation. This method was used to calculate the residential component of PWC2 for all days assessed in this project.

## 3.4.5    SSPWC Substation Load and Comparison with PWC2 Feeder

SSPWC LOADS

The following figure shows examples of SSPWC loads in winter and summer.
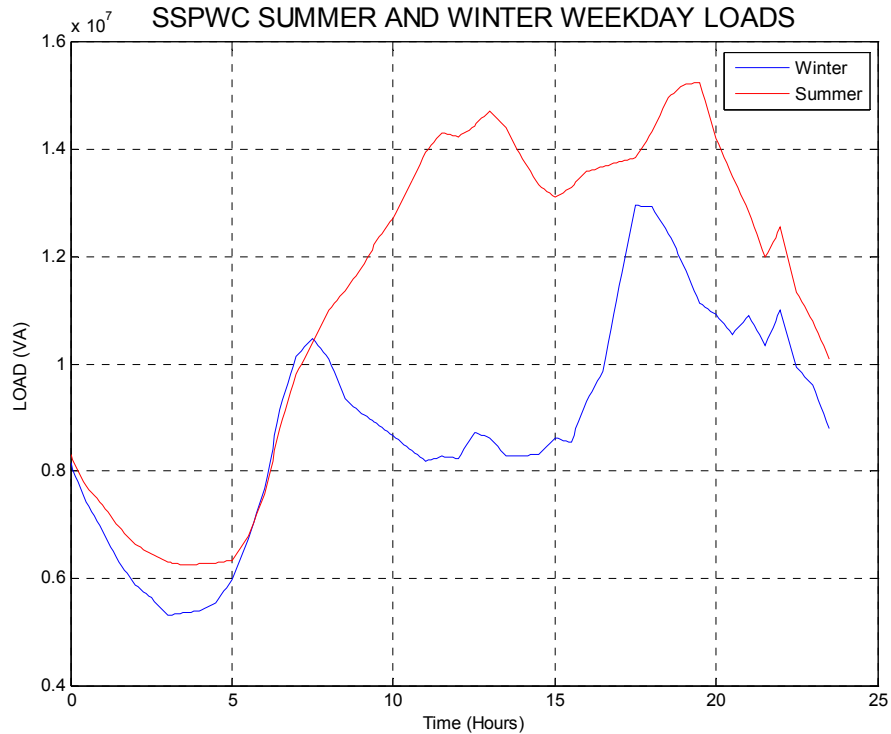
**(43) Figure 3.4.5.1 –SSPWC Winter and Summer Loads - Thursday 19th May 2011 & Tuesday 18th January 2011**

The results are as follows:

- The Summer load factor = 0.743;
- The Winter load factor = 0.683;
- The Average Ratio (Summer/Winter) = 1.28;
- The Minimum Ratio (Summer/Winter) = 0.96 and occurs at 6:30am;
- The Maximum Ratio (Summer/Winter) = 1.74 and occurs at 1:30pm

There are some notable differences between this figure and the equivalent for PWC2 seen in section 3.4.4. The main differences are:

- The slight load increase in the winter load profile at around 12:00 to 2:00pm (lunch).
- A lower maximum ratio, meaning that the summer load is 'closer' to the winter load.
- A higher secondary pm peak in the summer load profile at around 7pm.

These observations all point to the fact that SSPWC must have a higher overall residential load component percentage than that of PWC2.

PWC2 LOADS VERSUS SSPWC LOADS

To make exact comparisons between PWC2 and SSPWC, load profiles for 19th May 2011 will again be used. Figure 3.4.5.2 shows the load profiles for this day.
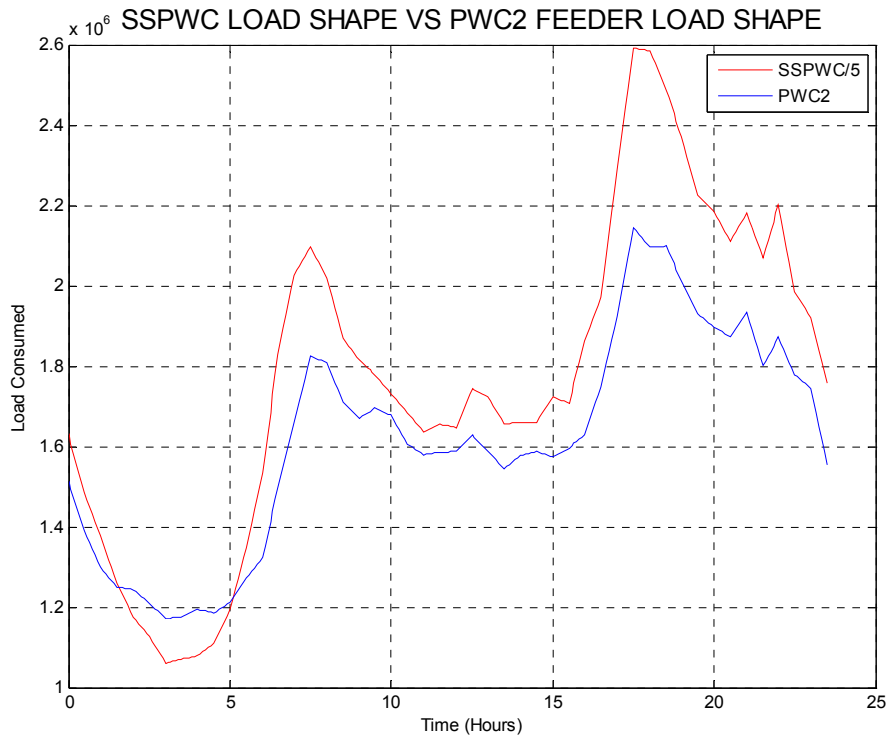
**(44)  Figure 3.4.5.2 – PWC2 and SSPWC Load Cycle - Thursday 19th May 2011**

Upon visual inspection, there are very clear similarities seen in terms of peak loads which are evident at around 7:30am and again at 6:00pm.
Calculations show that:

- The PWC2 load factor = 0.75;
- The SSPWC load factor = 0.68;
- The Average Ratio (SSPWC / PWC2) = 5.42;
- The Minimum Ratio (SSPWC / PWC2) = 4.51 and occurs at 4:00am;
- The Maximum Ratio (SSPWC / PWC2) = 6.17 and occurs at 6:00pm.

The lower load factor of SSPWC (0.68) confirms that although commercial and industrial loads exist, there is a greater proportion of residential load on SSPWC than on PWC2. The fact that the ratio peaks at 6:00pm also confirms this. Figure 3.4.5.3 shows the ratios for the same day.

RATIO BETWEEN PWC2 LOAD and SSPWC LOAD
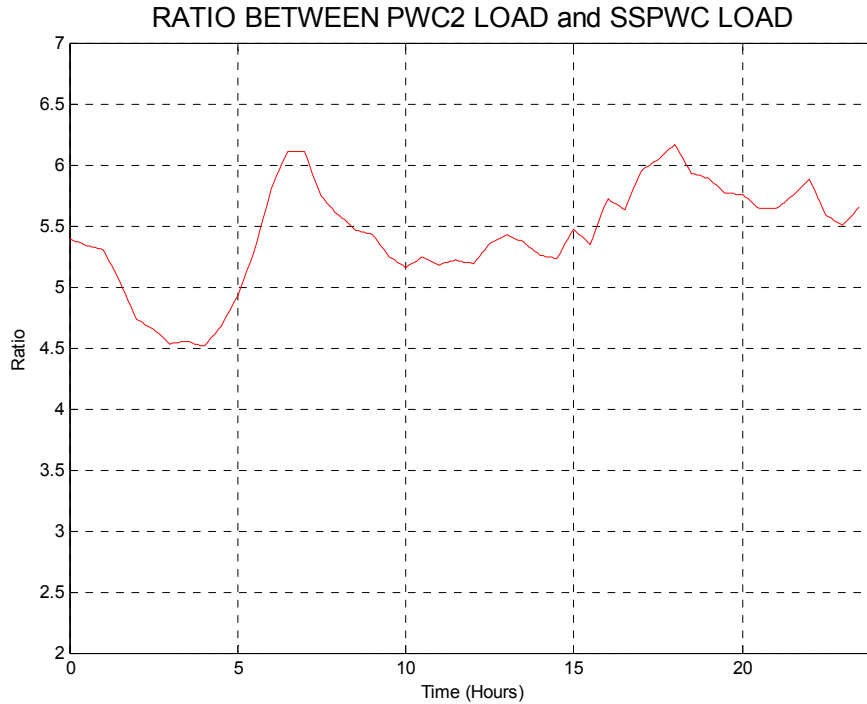
**(45) Figure 3.4.5.3 – Ratio Between PWC2 and SSPWC Loads - Thursday 19th May 2011**

This figure confirms again that SSPWC is a more 'residential load' than PWC2. This means that other feeders running off SSPWC, such as perhaps PWC3 or PWC4 must consist of more residential loads than PWC2 (see diagram appendix E4).

### 3.4.6    Estimated Residential Component of SSPWC

The load profiles of SSPWC appear to lie somewhere between the load profiles of PRT and PWC2. This is also indicated by the respective load factors of 0.75 (PWC2), 0.68 (SSPWC) and 0.45 (PRT) shown on the 19th May 2011. As PRT is a purely residential load, it will be used again for this comparison, and although the load profile is very similar between SSPWC and PRT, a direct ratio cannot be used, due to the presence of commercial and industrial loads on SSPWC.

A similar method will be used to that employed to find the residential component of SSPWC. Due to a general (but non-specific) knowledge of the loads on SSPWC it can be assumed:

- Again, PRT entirely consists of residential load
- SSPWC mainly feeds residential loads, but also contains both commercial and industrial loads (evidenced by its load profile).
- Most commercial loads on SSPWC consist of schools and other private businesses which do not generally operate after 5:00pm, although an small,

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unknown quantity would. There would still be commercial constant loads due to refrigeration and security systems.

- No information exists on the specific industrial loads on SSPWC, and in the absence of exact data, an assumption is made that the industrial load is constant over the 24hour period.
- Residential load profiles will be generally the same at all levels of the electricity grid in the same general geographical area, on the same day.

On this basis, it can be concluded that most of the load on SSPWC after, say 5pm consists of industrial load (assumed as constant) and residential load. To find out what the 'constant' industrial load is, we need to calculate and then subtract the constant or base Residential load from the base SSPWC load.

EXAMPLE – 19 May 2011

Note that prior to these calculations, smoothing of the PRT load is performed in the same manner as it was in section 3.4.4, but with some additional smoothing.
On the 19th May 2011 the base load for PRT occurs at 4:05am and is 29.37kVA, and the SSPWC base load occurs at 3:00am and is 5.30MVA.

(AVERAGE RATIO of PWC2/PRT) X (PRT BASE LOAD) = 181.82 X 28.89kVA = 5.25MVA.

Therefore the constant industrial load = 5.30 MVA – 5.25MVA= 53.76kVA

This is unreasonable, as the constant industrial load on PWC2 was estimated to be 258.067kVA. According to the minimum ratio between SSPWC/PWC2, which occurs around the time of the base loads, the constant industrial load on SSPWC should be approximately 4.51*258.067kVA = 1.163882 MVA.

So, if we now subtract a constant load of 1.163882 MVA from the SSPWC load, the remainder consists of Residential and Commercial loads.

At around 5:30pm to 7:00pm, peak loads are achieved for both PRT and SSPWC and with the constant industrial load (all non-residential constant loads) subtracted, the SSPWC load must consist almost entirely (around 99%) of residential loads. By finding the average ratio of (SSPWC*0.99)/PRT at this time, we can find an estimate of the residential component of SSPWC.

The average ratio at this time was found to be 120.046, and is known as the key ratio. The estimate of the residential component of SSPWC is now found by multiplying PRT by the key ratio. The results are shown in figure 3.4.6.1 below.

**APPROXIMATE RESIDENTIAL COMPONENT OF SSPWC**
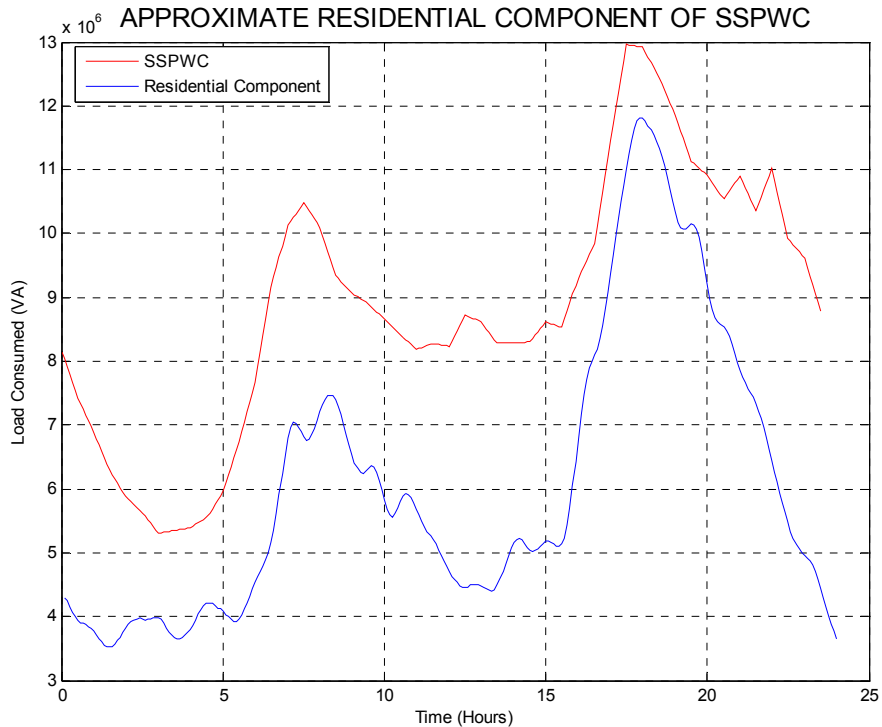
**(46) Figure 3.4.6.1 – Estimated Residential Component of SSPWC – 19th May 2011**

Despite the assumptions made, this appears to be a realistic approximation of the residential load component of the total SSPWC load. An interesting observation here is the slight rise in load on SSPWC at around 12:00 to 2:00pm, which indicative of a residential lunchtime load, but is not present in the residential component profile. This may be due to the residential load profile being modelled on the PRT load profile, which may, in that particular area have less people at home during the middle of the day than average. This reveals some inaccuracy in the estimation.

### 3.4.7      SST16 Substation Load and Comparison with SSPWC Substation and PWC2 Feeder

SST16 LOADS

The following figure shows examples of SST16 loads in winter and summer.

**SST16 SUMMER AND WINTER WEEKDAY LOADS**
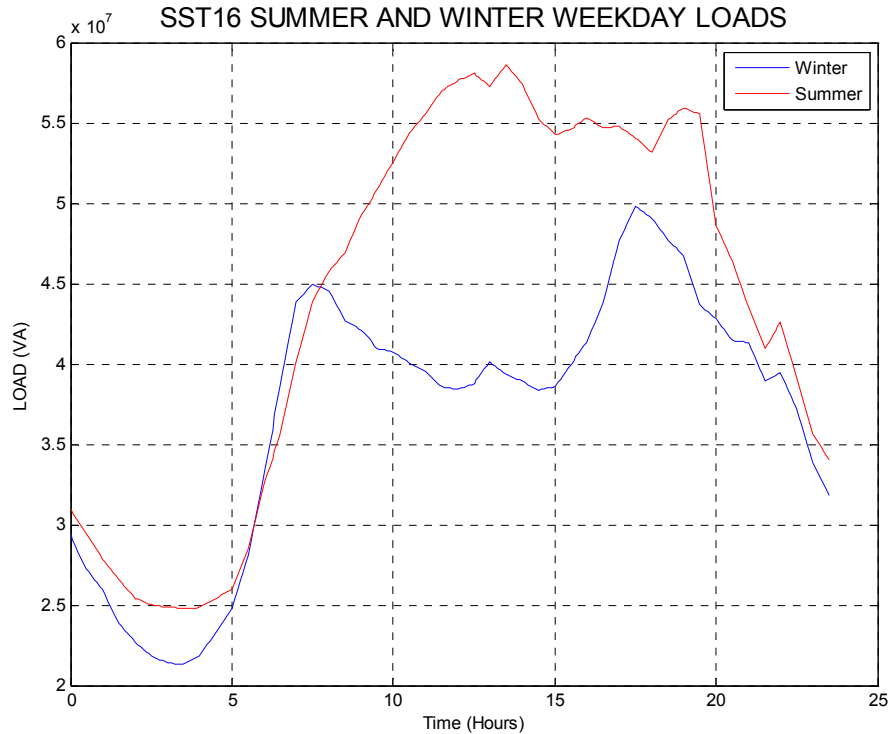
**(47) Figure 3.4.7.1 –SST16 Winter and Summer Loads - Thursday 19th May 2011 & Tuesday 18th January 2011**

The results are as follows:

- The Summer load factor = 0.752;
- The Winter load factor = 0.743;
- The Average Ratio (Summer/Winter) = 1.18;
- The Minimum Ratio (Summer/Winter) = 0.91 and occurs at 7:00am;
- The Maximum Ratio (Summer/Winter) = 1.5 and occurs at 12:00 noon

With reference to load profiles for SSPWC and PWC2 (seen in sections 3.4.3 and 3.4.5), similar comments could be made, with the SST16 load profile lying between the SSPWC shape and the PWC2 shape. It is hard to see any patterns that give explicit insight into the nature of the load; however it is clearly similar to that of PWC2 and SSPWC.

SST16 LOADS VERSUS SSPWC & PWC2 LOADS

For comparable results, comparisons between PWC2, SSPWC and SST16 were also performed for the 19th May 2011. Figure 3.4.7.2 shows the load profiles for this day.
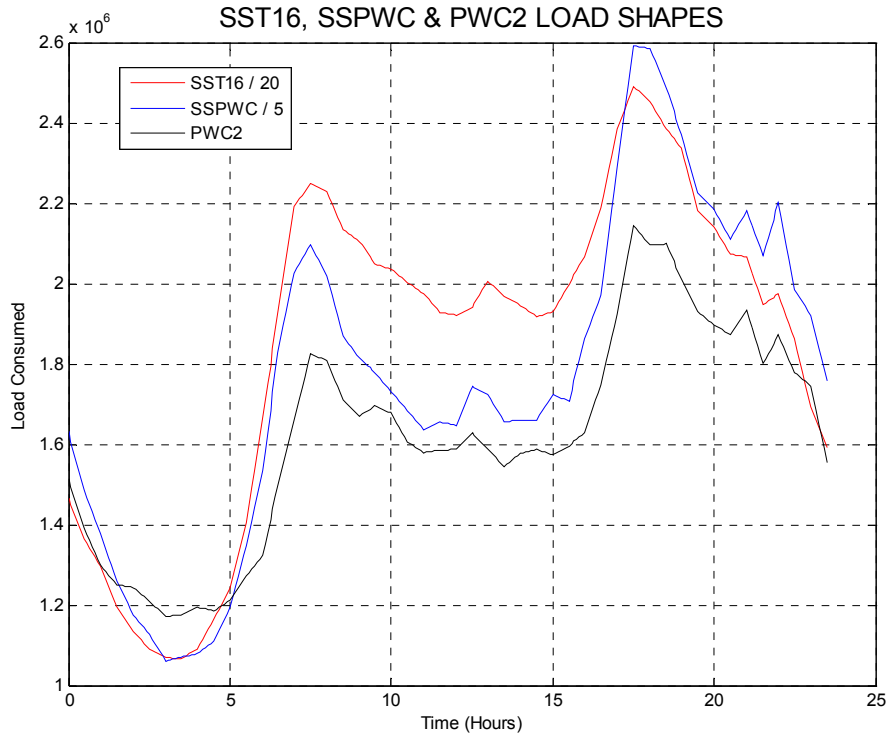
**(48)  Figure 3.4.7.2 – SST16, SSPWC and PWC2 Load Cycle - Thursday 19<sup>th</sup> May 2011**

As expected, there are very clear similarities again in terms of peak loads which are evident at around 7:30am and again at 6:00pm.
Calculations show that:

- The PWC2 load factor = 0.75;
- The SSPWC load factor = 0.68;
- The SST16 load factor = 0.74;
- The Average Ratio (SST16 / SSPWC) = 4.19;
- The Minimum Ratio (SST16 / SSPWC) = 3.52 and occurs at 11:00pm;
- The Maximum Ratio (SST16 / SSPWC) = 4.82 and occurs at 11:00am.
- The Average Ratio (SST16 / PWC2) = 22.71;
- The Minimum Ratio (SST16 / PWC2) = 18.03 and occurs at 4:00am;
- The Maximum Ratio (SST16 / PWC2) = 26.45 and occurs at 7:00am.

In order to give a more comprehensive analysis of the SST16 load, an examination of the ratio plots is needed.

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RATIO BETWEEN SST16 LOAD and SSPWC LOAD
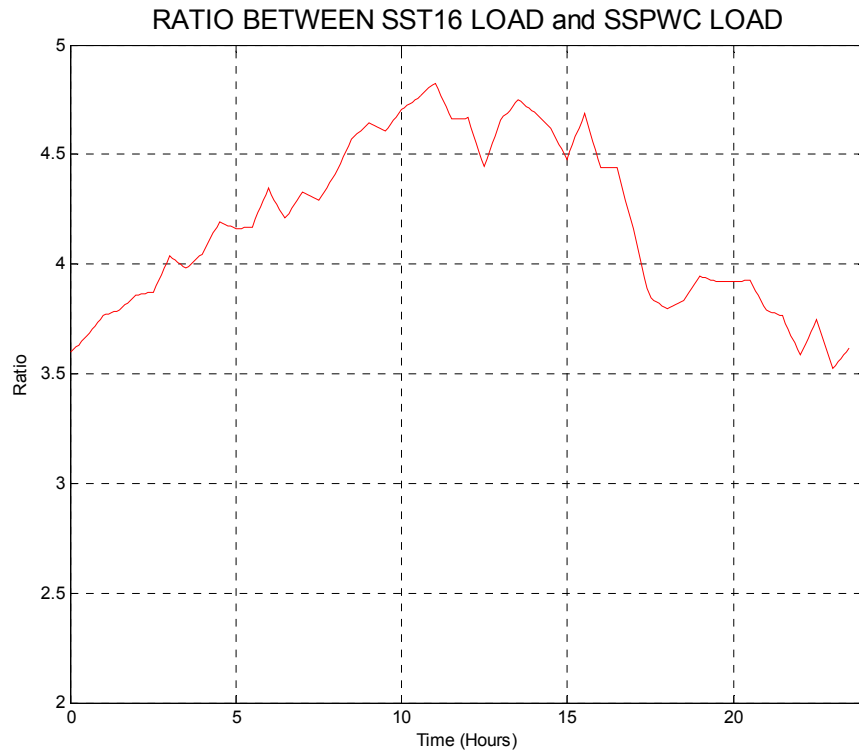
**(49) Figure 3.4.7.3 – Ratio Between SST16 and SSPWC Loads - Thursday 19th May 2011**

**RATIO BETWEEN SST16 LOAD and PWC2 LOAD**
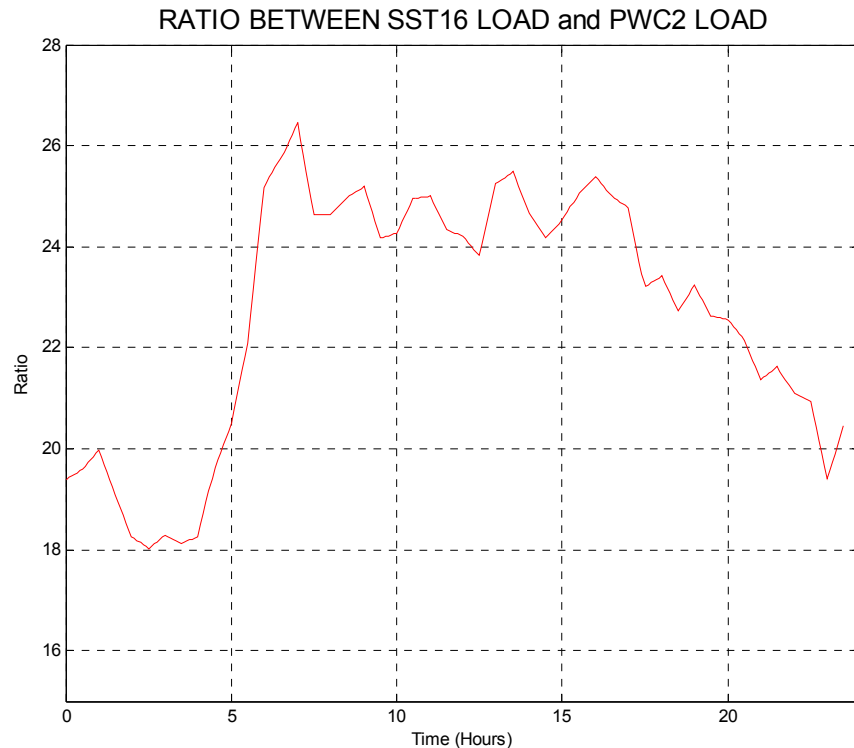
**(50) Figure 3.4.7.4 – Ratio Between SST16 and PWC2 Loads - Thursday 19ᵗʰ May 2011**

Both the calculations and the ratio plots show that SST16 has a higher comparable load between the hours of around 6am to 4:30pm, which indicates a greater commercial or daytime industrial load component.

## 3.4.8 Estimated Residential Component of SST16

Other information gleaned from the load profile comparisons show that the load profiles of SST16 appear to lie somewhere between the load profiles of SSPWC and PWC2. Although SST16 has proven to have a significantly higher influence from daytime commercial and industrial loads, The PRT load profile can still be applied, as certain patterns still align with the SST16 load profile.

There is more uncertainty about the exact composition of the SST16 load, but due to broad (but non-specific) knowledge of the areas that are serviced by SST16 (see appendix E5) it can be assumed:

- Again, PRT entirely consists of residential loads
- SST16 mainly feeds residential loads, but also contains both commercial and industrial loads (evidenced by its load profile).
- The load profile indicates that most commercial loads on SST16 consist of daytime loads which do not appear to operate after 5:00pm. After this time the non-residential load on SST16 seems to match that of PWC2 and SSPWC.

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There would still be commercial constant loads due to refrigeration and security systems.

- No information exists on the specific industrial loads on SST16, and in the absence of exact data, an assumption is made that the industrial load is constant over the 24hour period.
- Residential load profiles will be generally the same at all levels of the electricity grid in the same general geographical area, on the same day.

On this basis, it can be concluded that the total load on PWC2 after, say 5pm consists of industrial load (assumed as constant) and residential load. To find out what the 'constant' industrial load is, we need to subtract the constant or base Residential load.

EXAMPLE – 19 May 2011

Note that prior to these calculations, smoothing of the PRT load is performed in the same manner as it was in section 3.4.4. Additional smoothing was also required to provide a more realistic residential component of SST16, as erratic fluctuations in the PRT load are exaggerated as the load is scaled higher.

On the 19th May 2011 the base load for PRT occurs at 4:05am and is 29.74kVA, and the SST16 base load occurs at 3:30am and is 21.30MVA.

Due to similarities within the load profiles of SST16 and SSPWC in the early hours of the morning when base loads occur (see figure 3.4.7.2), the ratio at this time can be exploited to estimate the constant industrial load. According to this ratio, the constant industrial load on SSPWC should be approximately
3.98*(Base load of SSPWC) = 3.98*(1.163882MVA) = 4.63225036 MVA

So, if we now subtract a constant load of 4.632 MVA from the SST16 load, the remainder consists of Residential and varying Commercial loads.

At around 5:30pm to 7:00pm, peak loads are achieved for both PRT and SST16 and with the constant industrial load (all non-residential constant loads) subtracted, the SST16 load must consist almost entirely (around 99%) of residential loads. By finding the average ratio of (SSPWC*0.99)/PRT at this time, we can find an estimate of the residential component of SSPWC.

The average ratio at this time was found to be 461.6931, and is known as the key ratio. The estimate of the residential component of PWC2 is now found by multiplying PRT by the key ratio. The results are shown in figure 3.4.8.1 below.

**APPROXIMATE RESIDENTIAL COMPONENT OF SST16**
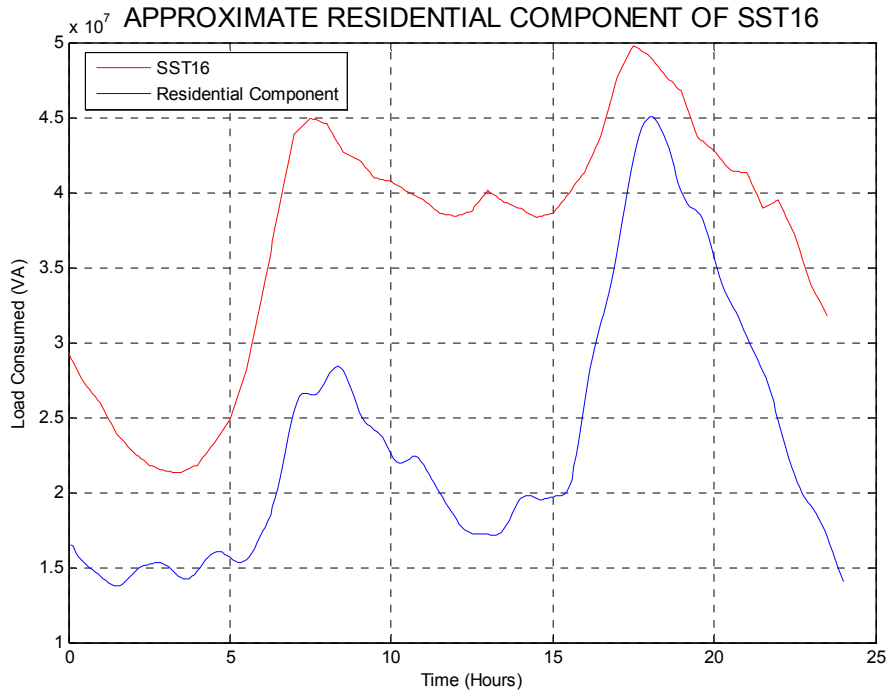
**(51) Figure 3.4.8.1 – Estimated Residential Component of SST16 – 19<sup>th</sup> May 2011**

This approximation reflects the relatively higher levels of daytime commercial and industrial loads on SST16, which is quite evident when compared to equivalent loads for SSPWC and PWC2 (see sections 3.4.4 and 3.4.6). This appears to be a good estimation for the residential component of SST16.

## 3.4.9    NEM Queensland Load and Comparison with SST16 Substation

QLD LOADS

The following figure shows examples of Qld loads on the National Electricity Market (NEM) network in winter and summer.
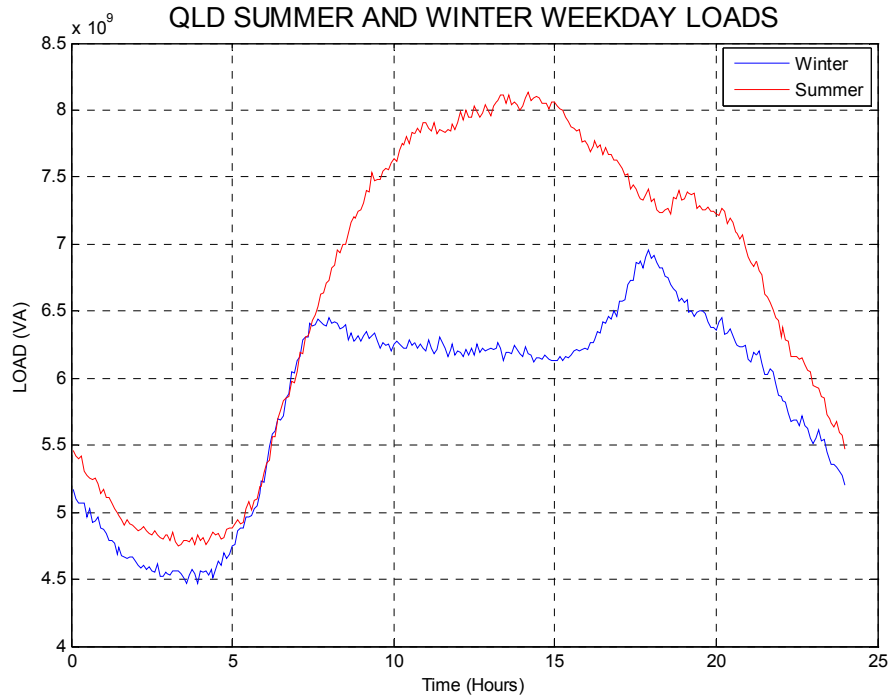
**(52) Figure 3.4.9.1 –QLD Winter and Summer Loads - Thursday 19<sup>th</sup> May 2011 & Tuesday 18<sup>th</sup> January 2011**

The results are as follows:

- The Summer load factor = 0.817;
- The Winter load factor = 0.84;
- The Average Ratio (Summer/Winter) = 1.132;
- The Minimum Ratio (Summer/Winter) = 0.98 and occurs at 6:10am;
- The Maximum Ratio (Summer/Winter) = 1.324 and occurs at 1:25pm

The load profile shows obvious similarities to SST16, SSPWC and PWC2, with minimum and maximum ratios occurring at similar times of the day. The most notable difference is that the load factor for both winter and summer are higher than those of SST16, SSPWC and PWC2. This is almost certainly due to the higher percentage of industrial load on the Qld wide network. Indeed on SST16 and below, there are no major industrial centres that need to be serviced, when compared to the mining and other heavy industries that are present on the Queensland branch of the NEM.

SST16 LOADS VERSUS QLD LOADS

Load profile comparisons for QLD and SST16 were performed for the 19<sup>th</sup> May 2011. Figure 3.4.9.2 shows the load profiles for this day.
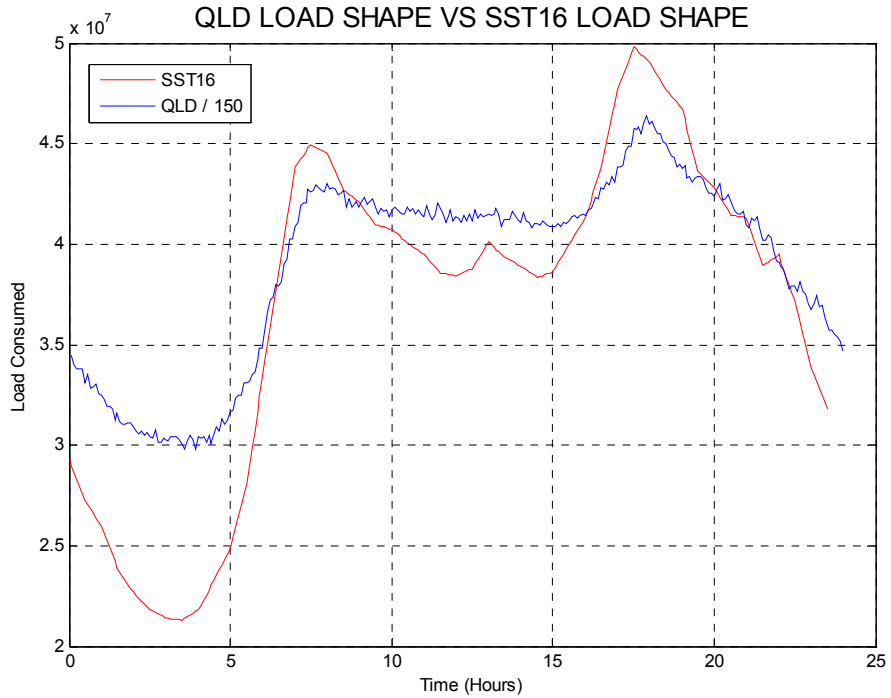
**(53) Figure 3.4.9.2 – QLD and SST16 Load Cycle - Thursday 19<sup>th</sup> May 2011**

Localised peak loads occur on both profiles again at around 7:30am and 6:00pm; however the QLD load is noticeably 'flatter'.
Calculations show that:

- The SSPWC load factor = 0.743;
- The QLD load factor = 0.84;
- The Average Ratio (QLD / SST16) = 162.67;
- The Minimum Ratio (QLD / SST16) = 136.044 and occurs at 5:25pm;
- The Maximum Ratio (QLD / SST16) = 213.953 and occurs at 3:20am.

To aid in analysis, the ratio plot for (QLD/SST16) is shown in figure 3.4.9.3.

RATIO BETWEEN QLD LOAD and SST16 LOAD
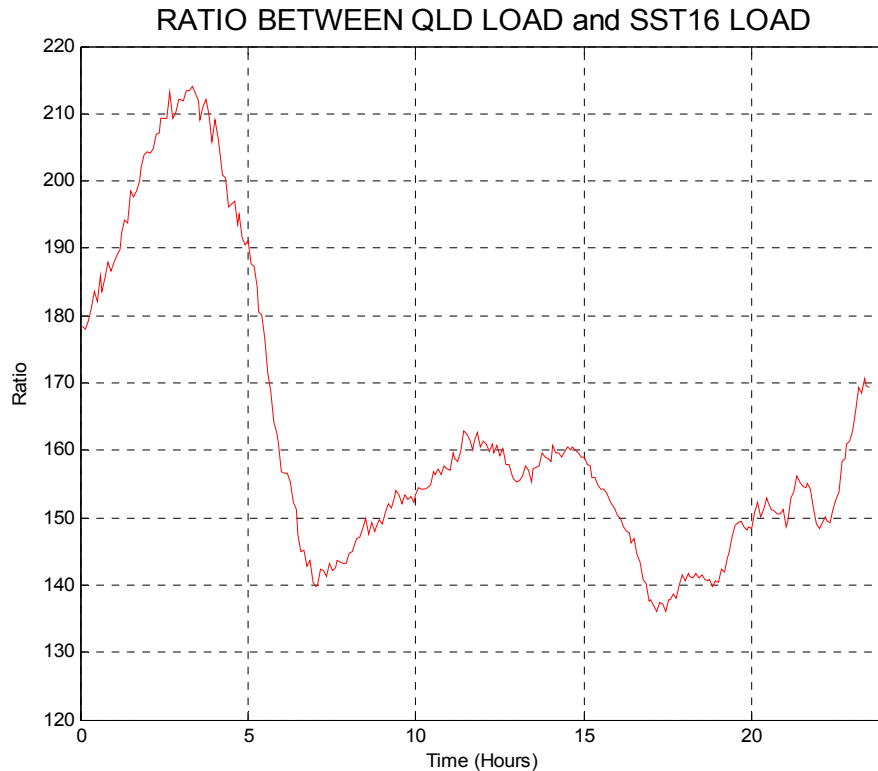
**(54) Figure 3.4.9.3 – Ratio Between QLD and SST16 Loads - Thursday 19<sup>th</sup> May 2011**

The load factor and ratio data confirm that the total QLD load has a higher 'non-residential' component than SST16 and below.  This is shown both by the higher load factor, and the fact that ratios are at a minimum at the peak residential load times.
Interestingly, the ratio plot shows that the QLD load is comparatively much higher than the SST16 load from about midnight till 6am in the morning.  As has been shown previously, SST16 has a significant daytime commercial / industrial load component, but this ratio plot shows that the QLD 24hour base load or constant industrial load is much higher.

### 3.4.10        Estimated Residential Component of QLD Load

Obviously, the QLD load is highly complex in the nature of all contributing loads. This means that calculation of the residential component of the total load is very difficult to perform accurately, however some assumptions can be made to achieve a rough estimation.  As PRT is a known purely residential load, its load profile will again be used.  Assumptions for the calculation are:

- Again, PRT entirely consists of residential loads

- There is a constant load over the 24hour period which represents industrial loads and constant commercial loads such as refrigeration.
- After 5-6pm, commercial loads consist of loads such as supermarkets, restaurants etc, which constitute a minimal percentage of the total load at that time
- Residential load profiles will be generally the same throughout the QLD network. This will actually vary slightly due to possible different weather conditions in different parts of Queensland, however taking account of this is too complex for this project.
- According to current data, the total residential component should consist in the order of 27.7% of the total QLD electricity consumption (REFERENCE NEEDED). This is assuming that QLD loads follow the trends of Australia wide loads.

On this basis, it can be concluded that the total QLD load after, say 5pm consists of assumed constant loads, residential loads and a small amount of commercial loads.

EXAMPLE – 19 May 2011

First, using the information that residential loads make up around 27.7% of total loads, estimation can be made by finding total QLD electricity consumed in QLD on $19^{th}$ May 2011.

This was found to equal 140.211395 GWh.

27.7% of this equals 38.838556415 GWh.

On the same day, the electricity consumed by PRT was found to equal 1.21555335714 MWh.

Therefore the QLD residential load = (38.838556415GWh / 1.21555335714MWh) * PRT Load   = 31951.33820063662 * PRT Load

An estimate will also be made in a similar manner to section 3.4.7, with additional smoothing to provide a more realistic residential component of QLD, as erratic fluctuations in the PRT load are exaggerated as the load is scaled higher.

On the $19^{th}$ May 2011 the base load for PRT occurs at 4:05am and is 29.74kVA, and the QLD base load occurs at 3:30am and is 21.30MVA.

Due to similarities within the load profiles of QLD and SST16 in the early hours of the morning when base loads occur (see figure 3.4.9.2), the ratio at this time can be exploited to estimate the constant industrial load. According to this ratio, the constant industrial load on QLD should be approximately
212*(Base load of SST16) = 212*(4.63225036MVA) = 982.037076 MVA

So, if we now subtract a constant load of 982.037 MVA from the QLD load, the remainder consists of Residential and varying Commercial loads.

At around 5:30pm to 7:00pm, peak loads are achieved for both PRT and QLD and with the constant industrial load (all non-residential constant loads) subtracted, the SST16 load must consist almost entirely (around 97%) of residential loads. By finding the average ratio of (SSPWC*0.99)/PRT at this time, we can find an estimate of the residential component of SSPWC.

The average ratio at this time was found to be 60017.7, and is known as the key ratio. The estimate of the residential component of PWC2 is now found by multiplying PRT by the key ratio. The results are shown in figure 3.4.10.1 below.
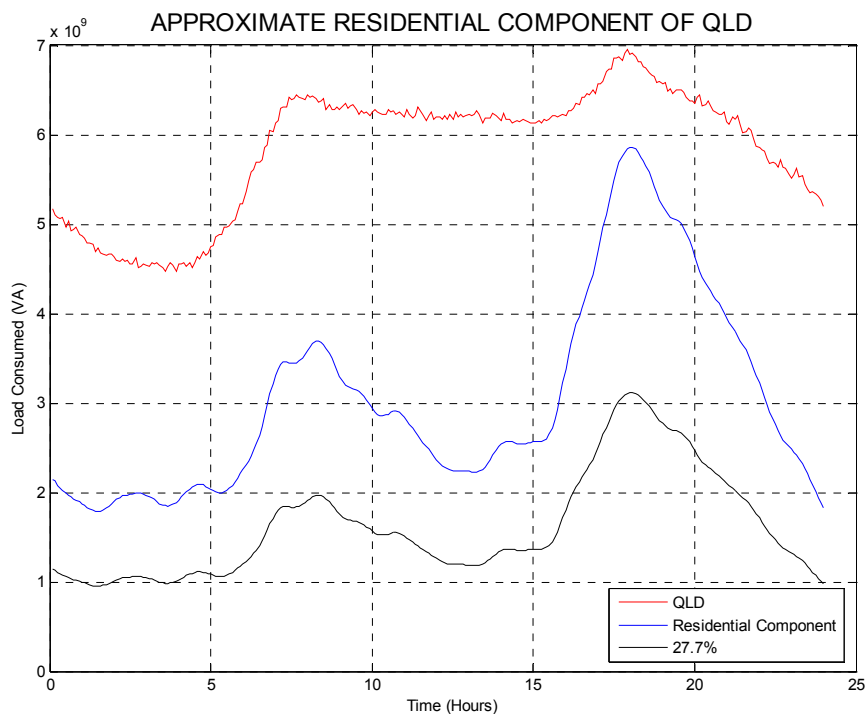


**(55)  Figure 3.4.10.1 – Estimated Residential Component of QLD – 19th May 2011**

This figure shows that there is some uncertainty in the model used. The estimated residential component is found to equal 52.56% of the total load, which is nearly 2 times greater than the 27.7% estimate. This is probably due to a poor estimation of the constant industrial load, which should be much greater than 982.037076 MVA.

In this case, it appears that the 27.7% estimation would be more accurate; however both scenarios can be used to propose the possible impact of smart grid HANs being used.

### 3.4.11      Residential Component Results for Key Dates

Using the methods previously described, results for other key days which will be assessed are shown in table 3.4.11.1 below.

|  | 9/6/2011 | 18/1/2011 |
|---|---|---|
| PWC2 CONSTANT INDUSTRIAL LOAD | 349.23kVA | 382.43kVA |
| PWC2 KEY RATIO | 18.268 | 17.69 |
| SSPWC CONSTANT INDUSTRIAL LOAD | 1.638MVA | 1.778MVA |
| SSPWC KEY RATIO | 121.161 | 107.521 |
| SST16 CONSTANT INDUSTRIAL LOAD | 6.535MVA | 7.131MVA |
| SST16 KEY RATIO | 417.231 | 397.067 |
| QLD CONSTANT INDUSTRIAL LOAD | 1367.158MVA | 1391.967MVA |
| QLD KEY RATIO | 47472.8 | 48714.2 |
| QLD 27.7% RATIO | 29333.5 | 25873.3 |

**(3)  Figure 3.4.10.1 – Residential Component Results for Key Dates**

# 3.5  Finding Normalized / Average Residential Loads

As shown in section 3.4.1, an exact comparison of the residential load with PRT load shows little similarities.  An attempt will be made to find a relationship in this section.  Using the example of the 9th of June 2011, measured and assessed data from the Residence and estimated data from PRT will be compared.  As the aim of this study is to identify direct improvements through using smart grid, and as the smart grid simulations will involve assessed data, it is first important to find the validity of the assessed data.

Another method to estimate the load of an individual residence was to count the number of residences that were fed by PRT on that date.  Through using LV Geographic diagrams supplied by Energex (see Appendix E1), and by visual assessment of which blocks of land actually were occupied by functioning homes, it was found that approximately 65 residences were fed by PRT on that date.  Therefore, another estimate of an individual residence load can be represented as PRT/65.

Figure 3.5.1 shows a comparison of the assessed load, the measured load and the PRT/65 load on the 9th June 2011. The assessed and measured loads have been smoothed by a factor of 20, and the PRT load has been smoothed by a factor of 5 to allow easier comparison.
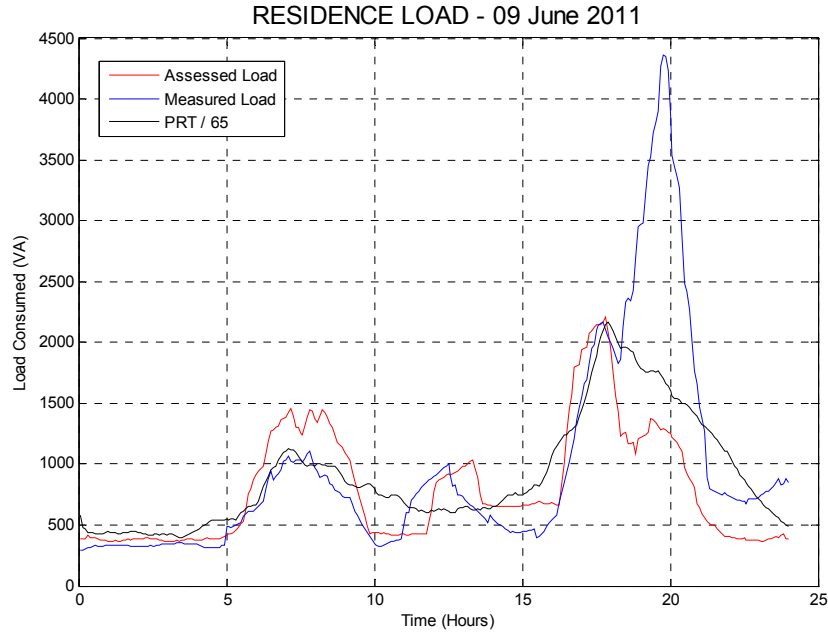


**(56) Figure 3.5.1 – Assessed & Measured Load – 9th June 2011**

It is clear that the general shape of all three load profiles is similar. In order to find a more direct relationship between the purely residential PRT load and the residence, it is important to understand that there will be obvious disparity in the use of electricity from one residence to another.

With a lack of information regarding the electricity usage habits of all residences on PRT, the following method will be used to translate the impact of smart grid from one residence to the overall representation of residential loads:

1. Simulation will be run to find changes using smart grid HAN.
2. The 'smart-grid' load profile will be directly compared to the initial assessed load.
3. At each 5 minute interval, the power saved/gained will be expressed as a percentage of the initial assessed load at that point.
4. The percentages of power saved/gained will be averaged over pre-determined intervals, and applied to the PRT load. This averaging is done to avoid inaccurate 'spikes' in the results.

This is deemed as the most appropriate method, given the information available.

## 3.6 Analysis of Electricity Prices

One of the proposed methods to control switching of electrical devices using the HAN is the use of price variation information.  If true time of use tariffs were put into place, the price that end-users pay for electricity would be a factor of the wholesale electricity price.  This section will more closely analyse electricity price trends, and derive smart grid control information based on this.

### 3.6.1 Wholesale Price Trends

As mentioned in section 2.1.4, wholesale electricity prices tend to follow the same trends as the electrical load.  However, also mentioned is the volatile nature of electricity market which can at times lead to extreme peaks and troughs in the electricity prices.  One such example is the $18^{th}$ January 2011, where although the normal average price hovers around \$0.40/MWh, a peak of \$3778.10/MWh occurs at 11am, and a trough of \$-999.92/MWh occurs at 1:00pm.  These high fluctuations are due to corrections being made following faults or errors occurring in the dispatch of electricity.

Figure 3.6.1.1 gives an example of the average daily prices for January and June, with any extreme fluctuations removed.

PRICE COMPARISON - JAN 2011 & JUNE 2011
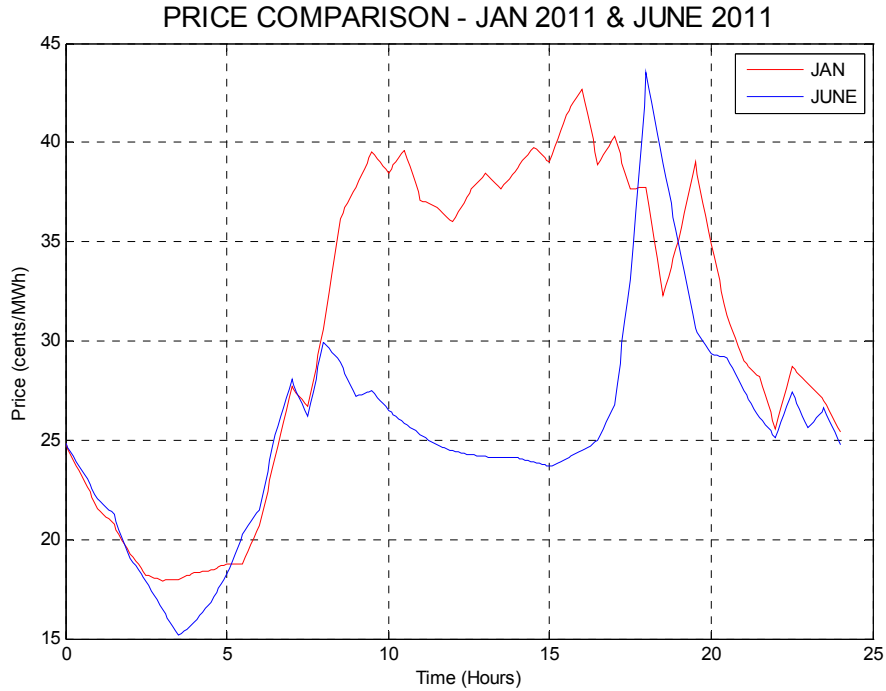
**(57)  Figure 3.6.1.1 – Average Daily Prices January and June 2011**

Currently, the wholesale prices do not translate directly to prices that residential consumers pay.  The current domestic tariff as of August 2011 is $0.2069/kWh.

### 3.6.2    Queensland Electricity Generation Costs

One of the foreseen benefits of using smart grid is reducing peak loads and improving the load factor of the electricity grid as a whole.  Part of this study will involve predicting the possible reduction in electricity generation costs that will result from better system performance allowed by smart grid implementation.  In order to do this, a model must be used to calculate the current costs, as well as the potential costs when using smart grid.  According to (Kamel et al. 2009, p. 5) a general formula used for energy generation costs of any particular generating plant is:

$$C_E = \frac{C_{TR} \times FCR}{T_O \times PCF} + COP$$

Where,          $C_E$ = Cost of energy generated ($/Wh)
                     $C_{TR}$ = Cost of the installed power ($/W)
                     FCR = fixed charge rate of the capital (%)
                     $T_O$ = Time span e.g. 24 hours (1 day) or 8760 hours (1 year)
                     PCF = Plant Capacity Factor

COP = Operation and maintenance cost of the plant ($/W)

The PCF is defined as the relationship between the actual energy generated by the plant and the energy that would be generated if the plant operated at its rated power. For a simple example, if the plant was rated at 1kW and produced 12kWh over a 24 hour period, the PCF would be 12kWh/24kWh = 0.5.

As mentioned in section 2.1.4, the base load is the constant load and is the minimum load in a given period. This load is supplied by base load generating plants which typically run 24 hours a day, 7 days a week. Anything above this load must be supplied by peak load plants.

In calculation of overall generation costs, the base load and peak load will be assessed separately, and then the overall cost will be considered. This is done as it is anticipated that the base load will increase and the peak load decrease when smart grid is used. The following values will be used to calculate the base load and peak load generating costs and are dependent on the method used to generate electricity:

|  | Base Load Generating Plant | Peak Load Generating Plant |
|---|---|---|
| $C_{TR}$ | $1000/kW | $1200/kW |
| FCR | 16% | 16% |
| COP | $0.05/kW | $0.04/kW |

These values are used as it is assumed that nearly all base load power plants in Queensland use coal powered steam turbine generators which tend to have a lower cost of installed power per kW and a higher operating cost than some methods of generation such as hydro. As well as a vast majority being fossil fuel powered, Peak load plants also consist of thermal, solar and commonly hydro powered generators which are able to 'make up the difference' during times of peak load. Base load plants have a PCF of 1, whereas peak load plants obviously have a much lower PCF, which means that costs to generate electricity per kWh are much higher for peak load plants.

To see the full implementation of this model and results, refer to section 6.2 and the Matlab code in Appendix F4.

# 3.7 Conclusion

To conclude, this chapter has described the nature of and the amount of data that was acquired to be used in developing a Smart Grid model and analysing the results. Measured electrical data was provided by Energex and the AEMO for the residence and adjacent transformer (PRT), the 11kV feeder (PWC2), the 33kV and 132kV substations (SSPWC & SST16), as well as QLD NEM loads.

Additionally, an inventory of devices within the home was taken along with manual load measurements using a digital clamp meter. Also of high importance was the weather data obtained from the Bureau of Meteorology and the wholesale electricity price data obtained from the AEMO.

It was also necessary to calculate some other loads that could not be realistically measured during the period of this study. This included the Air Conditioning and the hot water unit, and these calculations were performed using known data and applicable mathematical models.

All this data was then used to compare loads and estimate the residential component of loads at the various levels of the grid. Again, calculations were made to analyse these loads such that the effect of Smart Grid being used in residential settings on a large scale can be predicted (see section 5.2). Also in aid of finding the effects of the Smart Grid, wholesale prices were analysed to develop Smart Grid control techniques, and a model to estimate the QLD electricity generation costs was used.

# Chapter 4  Smart Grid Home Area Network Model

## 4.1  Introduction

An appropriate home area network (HAN) design must be formed in order to model a residential smart grid.  This design has taken into account all existing electrical equipment at the residence, and will propose in what manner the HAN will operate.  It will involve:

- Designating devices to circuits (eg. essential and non-essential)
- Designating switching conditions(eg. according to electricity prices)
- Proposing enhancements to the existing network (eg. solar panels)

Other aspects of design that can be specified are the actual communications topology and functioning of the HAN, as well as the 'smart devices' which may be used in the HAN network.

To aid in network design, other smart grid and associated studies will be taken into account, such as that found in Chapter 2.

The main aim of the network model design is to reduce loads at peak times where possible, while minimising impact on the lifestyle of the occupants.

## 4.2  Device Designation

The actual functioning of the HAN is flexible, and depending on the way in which smart grid is implemented, could be defined by governing bodies or by the individual consumer's preferences.  In this study, this functioning is defined by consulting with the occupants of the residence in focus, and with consideration to the goals of smart grid.  As such, real-life implementation may vary, with this study providing a basis for analysis.

This section will explain some of the considerations when determining the designation of devices and give details on these designations. The general logic used is that devices are placed in order of most important to least important and as a 'request for power' is made, the HAN controller determines if power can flow to the device based on the power available (see section 4.3).  To observe the location of all devices within the residence, see Appendix C1 and C2.

### 4.2.1 Essential Devices

Essential devices are any electrical device that will preferably run at anytime they are needed. These are devices that will still need to operate in the case of a power failure, or if power allocation is reduced (see section 4.3.2).

Devices that fall into this category are some internal lights, fridges and freezers.

### 4.2.2 Important Devices

The definition of an 'important device' is very subjective, however in this study an important device is defined as a device necessary for the practical functioning of the home.

Devices that fall into this category are generally all internal lights, and cooking appliances. These devices are required at very specific times and for specific purposes.

### 4.2.3 Less Important Devices

These devices are those which have a less important role in the functioning of the home, or are not required at a specific time.

On the higher end of this classification are devices such as the hot water unit, washing machine, dishwasher vacuum cleaner, iron and dryer. In the middle section of this classification are devices for entertainment such as a television, DVD player or computer. On the lower end are devices such as air conditioning and fans.

### 4.2.4 Un-Interruptible Devices and Delay of Operation

Of the categories mentioned above, some of the devices may be deemed as uninterruptible. This means that although they may be of low priority, once they have started, they must not be interrupted (if possible). This may include devices such as the washing machine or the oven if specified by the consumer, and this action is again performed by the HAN controller.

Another feature that has been used is delay of operation. This means that if a low priority device such as the dishwasher is in operation, and then power is reduced due to HAN switching conditions, then its operation can be delayed rather than terminated. This is particularly helpful in the case of the washing machine, dishwasher, hot water unit and dryer. This can also apply to cooking appliances if interruption is absolutely necessary.

### 4.2.5　　　Special Designation

In some instances, it was found necessary to allow some appliances exemption from certain switching conditions of the HAN.

For example, in some simulations when using price variation (TOU) control (section 4.3.3.1), it was found that high disruption occurred in the operation of cooking appliances around dinner time (5-7pm). This is due to the relatively high electrical load of cooking appliances. To allow for realistic operation of the home, it was therefore necessary to make all cooking appliances exempt from TOU control, but still subject to other control by the HAN.

In circumstances such as this, special note will be made regarding the particular simulations results.

### 4.2.6 Device Designation Overview

Although different simulations use slightly different device designations, table 4.2.6.1 below shows a typical device designation. It shows all devices in order of importance and any special control used.

| Designation Number | Electrical Device | Classification | Control |
|---|---|---|---|
| 1 | L9 | Essential | |
| 2 | Fridge | Essential | |
| 3 | Freezer | Essential | |
| 4 | L3 | Important | |
| 5 | Stove | Important | Delay of Operation |
| 6 | Microwave | Important | Delay of Operation |
| 7 | Oven | Important | Delay of Operation |
| 8 | Toaster | Important | Delay of Operation |
| 9 | L18 | Important | |
| 10 | L31 | Important | |
| 11 | L16 | Important | |
| 12 | L11 | Important | |
| 13 | L5 | Important | |
| 14 | L4 | Important | |
| 15 | L7 | Important | |
| 16 | TV1 | Less Important | |
| 17 | DVD1 | Less Important | |
| 18 | TV2 | Less Important | |
| 19 | Computer | Less Important | |
| 20 | HWU | Less Important | Delay of Operation |
| 21 | Vacuum | Less Important | Delay of Operation |
| 22 | Range Hood | Less Important | |
| 23 | Exhaust Fan 1 | Less Important | |
| 24 | Fan 7 | Less Important | |
| 25 | Fan 1 | Less Important | |
| 26 | Fan 4 | Less Important | |
| 27 | Dishwasher | Less Important | Delay of Operation / Un-interruptible |
| 28 | Washing Machine | Less Important | Delay of Operation / Un-interruptible |
| 29 | Dryer | Less Important | Delay of Operation |
| 30 | AC | Less Important | |

(3) **Table 4.2.6.1 – Device Designation**

# 4.3 Control and Switching Conditions

Ideally, the HAN would operate in the same way as a normal house-hold electricity network would operate – that is, when an appliance or device is switched on, electricity flows to the device, and it will operate. It is important at this point to reiterate that the purpose of a smart grid HAN is to allow demand side management, which involves controlling electricity flows according to available information.

The identified key events that will trigger smart-grid intervention in the HAN are:

- Reduction of available power
- Loss of available power
- Price Variations

There are two ways in which this control may be instigated, and that may be either by the user, who desires to reduce their electricity bill, or by the utility (such as Energex), who desires to improve load profiles and maintain a reliable electricity supply for all. In this project, a combination of the two will be considered, and following the simulations, a conclusion on these control methods will be offered.

With current tariffs in place, there is little more that smart grid can do to allow money savings for customers, however there is a push towards TOU tariffs as mentioned in Literature review. Regardless of savings to consumers, there is currently a great need to make systems more efficient (reduce peak load).

## 4.3.1 General Control

The two basic values important in HAN control are the power required or requested, the power available, and the power used. The power required or requested is the total power being used at the residence at any given time without smart grid intervention. This is a combination of the power being used by all electrical devices in the home.

The power available is determined by the HAN controller, and depending on the type of control being used is influenced by the current electricity prices/tariffs or the state of the electricity grid. The power used is the actual electricity consumed in the home following intervention by the HAN controller
.
For a simple example, suppose that at 7pm at night, the power required is 1800W and the power available is 2500W. This means that currently, all desired electrical devices are operating with 700W spare. At this moment, the hot water unit switches on, or makes a 'request for power'. The load of the hot water unit is 1300W, meaning that the total power required is now 3100W. The HAN controller senses that the power required is higher than the power available, and postpones the operation of the hot water unit until there is sufficient power available. This means that although the

power required/requested is 3100W, the actual power used remains at 1800W. This is shown below:

| Power Required = 1800W | → | Power Required = 3100W |

| Power Available = 2500W | → | Power Available = 2500W |

| Power Used = 1800W | → | Power Used = 1800W |
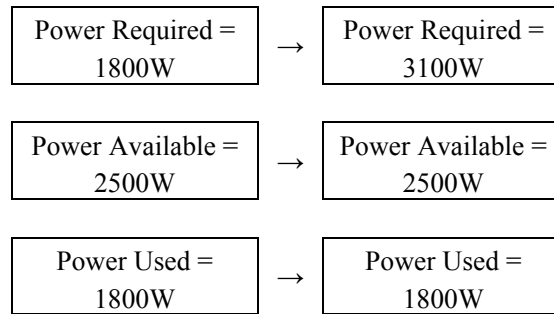
**(58)  Figure 4.3.1.1 – Simple Example of HAN Control**

## 4.3.2          Power Loss

This condition is not instigated by the electricity utility or the consumer, but is the result of a fault occurring on the network meaning that no power is available to some portion of the grid.  This may occur due to lightning strike or a fallen branch, or may be due to failure of some component of the grid.

In this instance, the HAN controller senses the loss of power and in the case where distributed generation is being used (see section 4.4), takes action. The HAN controller first senses the power required to power all devices with a 'request for power' status.  If the PV system is generating energy, the HAN controller senses the amount being generated.  As well as this, the HAN controller may trigger the batteries to operate/discharge if necessary, with the rate of discharge being set at a predetermined level.   The HAN controller then allocates the available power to devices, according to device designation.

## 4.3.3          Power Reduction

This condition would most likely be instigated by the electricity utility as part of a controlled load shedding incident which may be related to failure of part of the grid, or in response to an error in the dispatching of electricity.  Essentially a signal is sent out to all relevant HAN controllers in the network via the smart grid, which causes them to reduce loads to a pre-set level determined by the utility.

For example, a fault may occur on a 33kV feeder meaning that hundreds of homes would lose power.  A Wide Area Network (WAN) controller could redirect electricity flows through a different route, but to avoid overloading cables and transformers, a load shed signal is sent which commands all HAN controllers in that branch of the network to limit loads to say 1kW in their sub-network.  In doing this, continuity of supply is maintained while the fault is identified and rectified.

As with the 'Power Loss' scenario (section 4.3.2), the HAN controller could utilise PV and batteries to increase the amount of power available at the residence during this time.

### 4.3.4 Load Variation

To achieve the goal of reducing peak demand and improving the load factor of the electricity grid, the HAN needs regular day-to-day control in normal operating conditions. As much is known about electricity load profiles and trends, it is possible to have set loads allocated to residential customers based on this knowledge. This scheme would involve setting load limits for different times of the day, and perhaps for different seasons.

For example, in January in Queensland, all residential consumers may be allowed:

- 5kW maximum load from 12:00am till 6am
- 2.5kW maximum load from 6am till 9am
- 3.5kW maximum load from 9am till 5pm
- 2.5kW maximum load from 5pm till 9pm
- 5kW maximum load from 9pm till 12:00am

This control would be mandated by the government and implemented by being preset into the HAN controller in the form of static data.

### 4.3.5 Price Variation

Another proposal for day-to-day control is that of price variation which would be related to wholesale electricity prices. While there are many ways to instigate this, in this study the HAN controller will use real-time prices to calculate power available to be used. The main advantages of this type of control are:

1. As has been shown, wholesale electricity prices follow load trends.
2. It encourages consumers to use less power at peak times by using financial incentives.
3. It minimises governing legislation.
4. As it uses real time data, more accurate and effective control can be achieved.

A smoothened version of the current wholesale electricity price profile can be used to accurately represent a realistic tariff scheme for end-users (consumers). This will be taken as the average daily prices for each month which is calculated from data obtained from the AEMO. Figure 4.3.5.1 gives an example of the average daily prices for January and June, with any extreme fluctuations removed.

PRICE COMPARISON - JAN 2011 & JUNE 2011
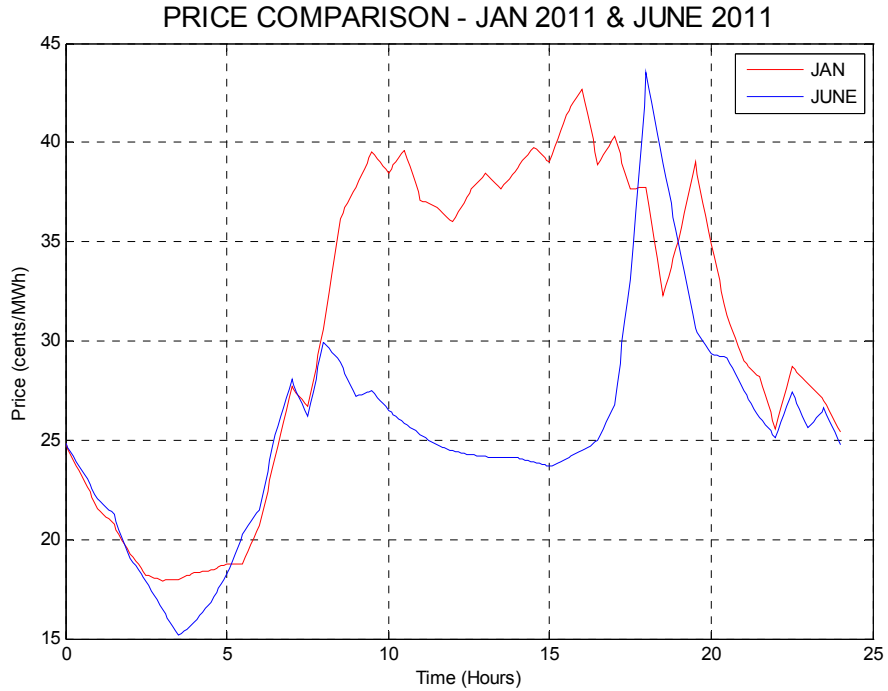
**(59) Figure 4.3.5.1 – Average Daily Prices January and June 2011**

As previously mentioned, the current domestic tariff as of August 2011 is $0.2069/kWh. The true time-of-use (TOU) tariff scheme constructed for this study will simply calculated by:

$$Domestic\ Consumer\ Price(k)$$
$$= \frac{Current\ Domestic\ tariff}{Average\ Wholesale\ price} \times Wholesale\ Price(k)$$

Where,                    k = any instant in the day

An example given in figure 4.3.5.2 shows the January domestic consumer price using the TOU tariff suggested.
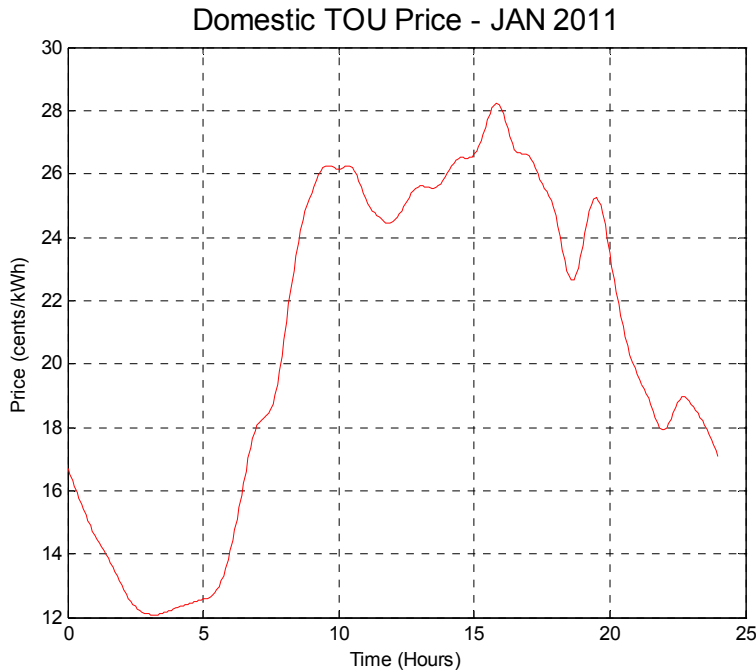
**(60) Figure 4.3.5.2 – Proposed TOU price for Domestic Consumers in January**

Price Variation Control (TOU Tariff Control)

From the average monthly prices, monthly price variation control can be formulated with comparison to typical residential loads. The basis of this control will be represented as 'power available' to the HAN controller, and will be inversely proportional to the price profiles as follows:

$$Power\ Available(kW) = \frac{1}{Price(cents/kWh)} \times Price\ Limit(cents/h)$$

The price limit can be set by the individual customer, with a higher price limit meaning more power is available, but overall cost of electricity will be higher, and a lower price limit being the inverse. This can be performed over any interval. For an example, on any day in January (see above), if your price limit is set to 18cents/hour, then for a 5 minute interval starting at 9am, you can consume an average of 18/25.5 = 706W during that period.

## 4.3.6       Conclusion

It has been shown that there are a number of ways in which smart grid control can be implemented, and how the methods used would reflect on the functioning of the HAN.

The simulations in this project will use a combination of these methods as follows:

- Day-to-day control will be using the price variation technique.
- When necessary, the utilities will command the HAN controllers to reduce load in order to avoid loss of power.

This combination means that consumers still maintain control over their electricity usage, and that the load control reflects the real-time situation of the overall load on the grid. It also gives the utilities the ability to improve reliability of the network through emergency intervention.

# 4.4   Enhancements / Distributed Generation

Although some simulations will be performed solely using smart-grid technology, it is of value to design a network that also incorporates distributed generation. A model will be produced to calculate the amount of energy that can be used at the residence, fed back into the grid, or stored for later use.

### 4.4.1          Photo-Voltaic (PV) Cells and Inverter

Some of the simulations will involve the use of Photo-voltaic solar cells which convert solar radiation into direct current (DC) electricity. This will reduce the load on the electricity grid during daytime hours, and can be economically beneficial for the consumer. The overall size of the proposed system will be 3.64kW at 48VDC, and will involve solar cells, an inverter and deep cycle batteries.

System Components

For the purposes of the simulation, selection of the particular system components has an impact upon the efficiency of all processes in the conversion from solar energy right down to AC power. The components chosen and their relevant specs are:

1. **Ulica (or similar) Monocrystalline Solar Modules**
   UL-260D solar modules are rated at 260W, have an efficiency of 15.3% and a temperature coefficient of -0.40/ °C. This means that the modules 15.3% of the solar energy received into electrical energy, and that there is a loss of 0.4% of the maximum power output for each degree the effective cell temperature rises above 0°C (see AS 4509.2 equations 3.4.3.9(1) and 3.3.4.7). As the actual solar cell dimensions for each module is 1.5 m$^2$, and as the total system is 3.64kW, it means that there are a total of 14 modules, giving a total surface area of 21 m$^2$.

## 2. Aurora (or similar) Inverter

PVI-3600 inverters are rated at a nominal DC power of 3.6kW. The only applicable characteristic of this inverter is the conversion efficiency which is rated at a maximum of 96%.

## 4.4.2    Energy Storage

As well as a PV system, the use of deep cycle batteries will also be considered. A major benefit of using energy storage in conjunction with PV is that the batteries can be charged during the day when residential loads are low and PV output is high, and this energy can be used during peak residential load times which typically occur outside of daytime hours. This can theoretically reduce residential peak demand.

Another key benefit of energy storage becomes obvious with consideration of the proposed smart grid control in this study where available loads can be drastically reduced for short periods of time. In these circumstances, the HAN can use energy from the batteries to supplement the power available from the grid. This means that there would be less interference into the electricity usage of the consumer. With deep cycle batteries, there is also an 'emergency' power supply available in the case of total loss of power.

<u>System Components</u>

Battery cells were chosen to match the size of the PV system as well as the likely charging and discharging times available to avoid the battery falling below 50% charge over a typical 24 hour period.

### 1. Sonnenschein (or similar) Deep Cycle Gel Batteries
A600 4OPzV200 are 2V, 200Ah batteries. This rating is with a 100% discharge of 20A over 10 hours. Actual power output varies, with a 100% discharge over 1 hour yielding 149A DC current (refer Appendix G2). As the PV system voltage is 48V, 24 cells will be required.

Internal Resistance is rated at 0.49mΩ per cell, and using the equation for power:

$$P = V \times I = I^2 \times R$$

Where,      P  = Power (W)
            V = Voltage across battery terminals (V)
            I = Current flowing (A)
            R = Resistance (Ω)

With the example of 20A discharge,

$$P = I^2 \times R = 20^2 \times (0.00049 \times 24) = 4.704W$$

Charging and Discharging Rates

As mentioned, to achieve optimal results, the batteries must fit the application. The cycle or use of the batteries must be sustainable during successive daily use. This is dependent on the ability of the PV system to recharge the cells, but also determined by the actual use or discharging of the cells. For simplicity, discrete values for charging and discharging will be used for the simulations, and data is taken from the Sonnenschein data sheet with relevant extracts shown in appendix G2. Discharge times are taken directly from the data sheet and extrapolation of data shows that there is an almost linear (assumed linear for simulations) relationship between the depth (level) of discharge and the time taken to charge the cells.

For an example of determining the limitations of the system, with the charging current of 20A (meaning 960W), it was found that the best case scenario was in January when the PV system can supply around 6.8 hours of charging per day, and the worst scenario was in June when the PV system can supply around 5.3 hours of charging per day.

After investigation, the following charging and discharging levels were selected to potentially be used in the simulations:

| CHARGING LEVEL | CHARGING LEVELS | | |
|---|---|---|---|
| | Power Used | Time to charge from 50% to 100% | Charge increase over 5 minutes |
| 20A | 960W | 20 hours | 0.20% |
| 30A | 1440W | 13 hours | 0.32% |

| DISCHARGING LEVEL | DISCHARGING LEVELS | |
|---|---|---|
| | Power Supplied | Charge decrease over 5 minutes |
| 20A | 960W for 10 hours | 0.83% |
| 34A | 1632W for 5 hours | 1.67% |

**(5) Table 4.4.2.1 – Battery Charging and Discharging Levels**

From these values, two possible scenarios, based on both PV and battery characteristics are:

1. Charging at 20A and discharging at 20A.
2. Charging at 20A and discharging at 20A, but charging at a higher 30A where possible, and discharging at a higher 34A where needed.

The second scenario would better utilize the energy generated for use at a time of greater demand. This would likely result in less financial gains for the customer (see section 4.4.4), but greater gains for the electricity grid as a whole such as lower peak demand and a higher load factor.

Emergency Considerations

In addition to normal operation, the use of batteries is also beneficial in power loss and power reduction situations (see section 4.3.2 and 4.3.3).

In the case of a power reduction, this can be expected to last shorter periods of time with a maximum of 2 hours. In this instance, the battery will still function normally, but will be allowed to discharge below 50%. In the case of a power loss, this could last for several hours, and therefore the battery will be set to a discharge 20A, and will be allowed to discharge below 50%.

### 4.4.3        Overall DG Model

The output of electrical power produced from the Solar system is basically a factor of the available radiation energy levels minus all losses. The radiation levels are obtained from Australian Solar Radiation Data Handbook which provides the average irradiation levels in south east Queensland at hourly intervals for each month of the year (see Appendix G3). This takes into account known trends such as cloud cover etc. and the units are in $W/m^2$. The losses or, de-rating factors are mainly due to the characteristics of the components listed above. As well as any assumptions listed above, it is assumed that the solar panels are mounted at 22° which is considered to be optimal in SE Queensland. The overall formula derived to determine the instantaneous AC power available to the residence is:

$$Power = (Energy\ Produced\ by\ PV\ Cells - Energy\ Used\ to\ Charge\ Batteries + Battery\ Output) \times (Inverter\ Efficiency)$$

To expand,

$$P_a = \left( \left( \left( (IL \times M_F \times A \times PV_E) - (\Delta T \times T_C \times P_{max}) \right) \right) - \left( (C_C \times V_{DC}) - (C_C{}^2 \times R_B) \right) + \left( (C_D \times V_{DC}) - (C_D{}^2 \times R_B) \right) \right) \times I_E$$

Where,      $P_A$ = AC Power available to residence (W)
                IL = Irradiation Level ($W/m^2$)
                $M_F$ = Mounting factor due to angle of solar panels and global position (0.9)
                A = Area of PV cells ($21m^2$)
                $PV_E$ = Efficiency of PV cells (0.153)

ΔT = Present ambient temperature
$T_C$ = PV Cell Temperature coefficient (-0.004/ °C)
$P_{max}$ = Maximum power output of PV modules (3.64kW)
$C_C$ = Charging current of batteries (80A)
$V_{DC}$ = System DC voltage (48V)
$R_B$ = Battery internal resistance (0.49mΩ X No. of cells (24) = 11.76mΩ)
$C_D$ = Discharging current of batteries - dependent on power required (A)
$I_E$ = Efficiency of inverter (0.96)


Results


Comprehensive results including battery usage can only be shown when running a full smart grid simulation (see section 6.2), but figure 4.4.3.1 below shows the AC power available to the residence without taking the battery usage into account.



**(61)  Figure 4.4.3.1 –Solar Power Available to the Residence 18th January 2011**


## 4.4.4        Feed-In Tariff

Feed-in tariffs are currently used throughout Australia and provide income to the consumer based on the amount of energy they can export back to the electricity grid. Simulations used will take into account the energy fed back to the grid which will consist of any energy produced by the PV system that is not used by charging the

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batteries or powering the residence. The current minimum feed-in tariff in Queensland is 44cents per kWh (Solar Bonus Scheme, 2011), and will be used to calculate income generated as a result of exporting electricity to the grid in the simulations.

There is of course a trade-off between using PV output to charge the batteries or to feed back into the grid. Obviously the more energy that is used to charge the batteries means that there is less energy to export to the grid, and these factors must be considered.


## 4.4.5　　　　Application and Operation of DG

As part of the Smart Grid network, the solar and battery system will be controlled by the HAN controller. This would require a 'power flow controller' which can monitor power flows as well as control the charging and discharging of the batteries. The layout of all components is shown in figure 4.4.5.1.
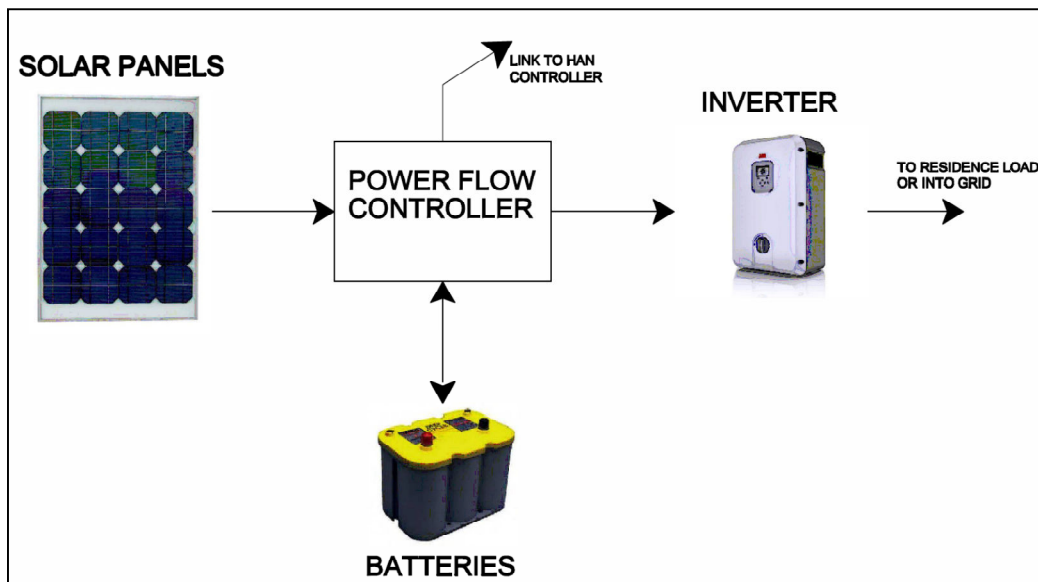


**(62)  Figure 4.4.5.1 –Layout of Distributed Generation System**


As mentioned, there are different simulations that will be run using distributed generation, with different use of the battery to obtain optimal results. The general flow of the DG operation is shown in a flow chart in figure 4.4.5.2. In the simulation, this process occurs at intervals of 5 minutes; however practical application would require a higher resolution. In this example, charging is at 20A and discharging at 20A; but charging is at a higher 30A where possible, and discharging at a higher 34A where needed.

READ
PV_OUT, Bc, Pa, Pr, T

IF
PV_OUT>1440W

IF
(Pa + PV_OUT - 1440W) > Pr

Bc = (Bc + 0.16Pr)
PV_SYS_OUT = (PV_OUT - 1440W)
B_OUT = 0W
O_SYS_OUT = PV_SYS_OUT + B_OUT
O_SYS_OUT

Bc = (Bc + 0)
PV_SYS_OUT = PV_OUT
B_OUT = 0W
O_SYS_OUT = PV_SYS_OUT + B_OUT
O_SYS_OUT

IF
PV_OUT>960W

IF
(Pa + PV_OUT - 960W) > Pr

Bc = (Bc + 0.24Pr)
PV_SYS_OUT = (PV_OUT - 960W)
B_OUT = 0W
O_SYS_OUT = PV_SYS_OUT + B_OUT
O_SYS_OUT

Bc = (Bc + 0)
PV_SYS_OUT = PV_OUT
B_OUT = 0W
O_SYS_OUT = PV_SYS_OUT + B_OUT
O_SYS_OUT

IF
Bc > 80%

IF
5pm<T<5am OR
8pm<T<5pm

IF
Pr > (Pa + 960W)

Bc = (Bc - 1.67Pr)
PV_SYS_OUT = PV_OUT
B_OUT = 1920W
O_SYS_OUT = PV_SYS_OUT + B_OUT
B_OUT = 0W

IF
Pr > Pa

Bc = (Bc - 0.83Pr)
PV_SYS_OUT = PV_OUT
B_OUT = 960W
O_SYS_OUT = PV_SYS_OUT + B_OUT
B_OUT = 0W

Bc = (Bc + 0)
PV_SYS_OUT = PV_OUT
B_OUT = 0W
O_SYS_OUT = PV_SYS_OUT + B_OUT
O_SYS_OUT

ABBREVIATIONS
PV_OUT = OUTPUT OF PV
PV_SYS_OUT = PV OUTPUT TO SYSTEM
Bc = CHARGE OF BATTERY
B_OUT = BATTERY OUTPUT TO SYSTEM
Pa = POWER AVAILABLE
Pr = POWER REQUIRED
T = TIME
O_SYS_OUT = OVERALL SYSTEM OUTPUT

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**Figure 4.4.5.2 –Distributed Generation Flow Chart**

For full detail of the distributed generation control, see the Matlab file in Appendix F2.

# 4.5   HAN Model Overview

A simplified example of the operation of the HAN is shown if figures 4.5.1, 4.5.2 and 4.5.3. These flow charts show the operations that take place for each iteration control – which are performed at intervals determined by the computing power of the HAN controller.

**ABBREVIATIONS**
Pa = POWER AVAILABLE
Pr = POWER REQUIRED
DG_OUT = DG SYSTEM OUTPUT
E_LOAD = Load of essential devices
UI_LOAD = Load of already running
non-interruptible devices
Price = Current wholesale price
(obtained via the smart grid)

**READ** Commands from Smart Grid

**IS** there a power failure?
— YES → (see figure 4.5.2)
— NO →

**IS** there a power reduction?
— YES → (see figure 4.5.2)
— NO →

**READ** Price, Pr

**CALCULATE** Pa (Based on Price)

**CALCULATE OUTPUT OF DG** (see figure 4.4.5.2)

Pa = Pa + DG_OUT

**IS** Pa > E_LOAD
— NO → Pa = Pa - 0
— YES → Pa = Pa - E_LOAD

**READ** Status of Uninterruptible devices

**ARE** Uninterruptible devices on?
— NO → ② (see figure 4.5.3)
— YES → Pa = Pa - UI_LOAD → ② (see figure 4.5.3)

**READ** Status of Uninterruptible devices

**ARE** Uninterruptible devices on?
— NO → ③ (see figure 4.5.3)
— YES → Pa = Pa - UI_LOAD → ③ (see figure 4.5.3)
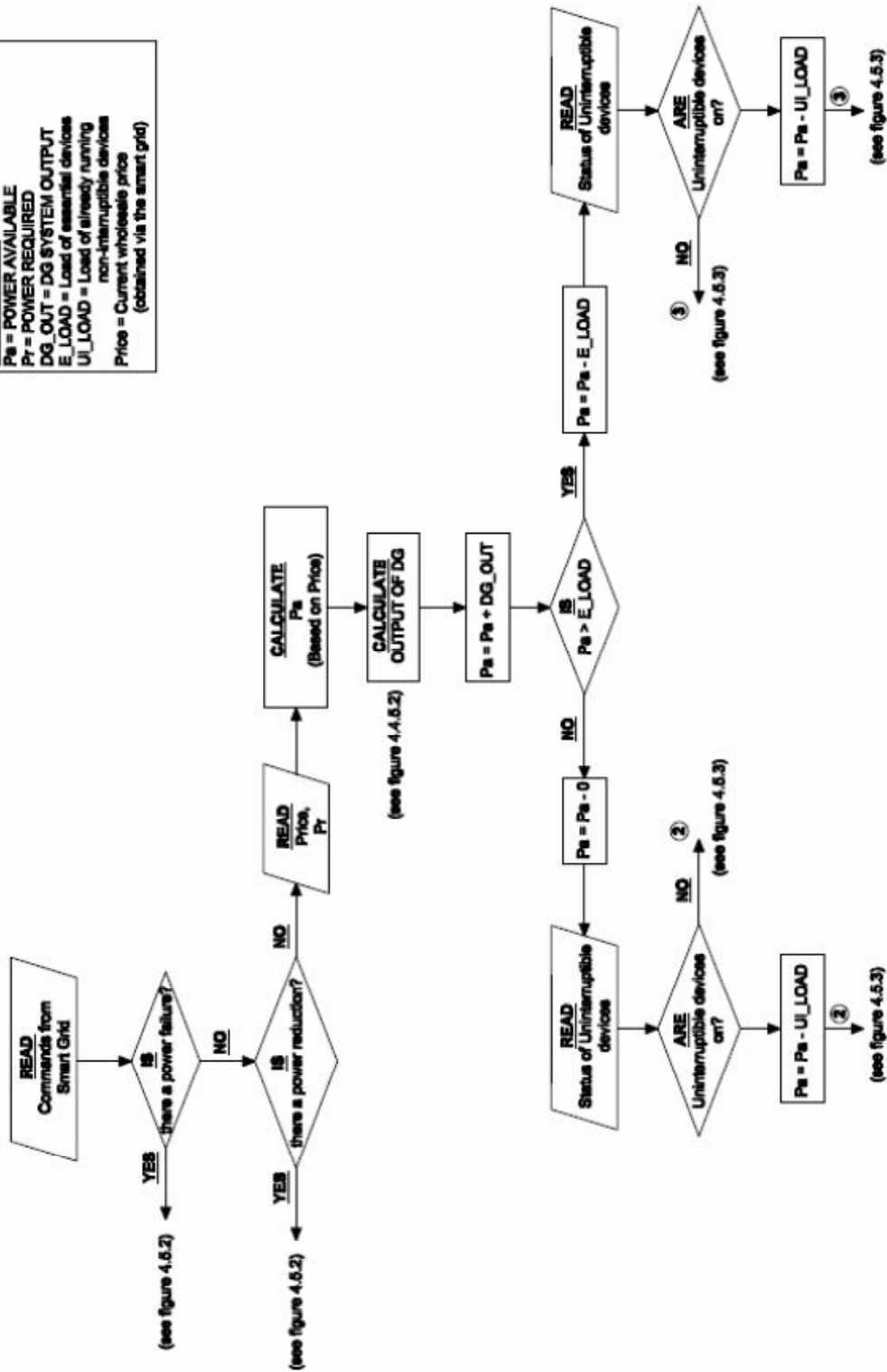
**(64)  Figure 4.5.1 –Initial stages of HAN flow chart – Normal Operation**

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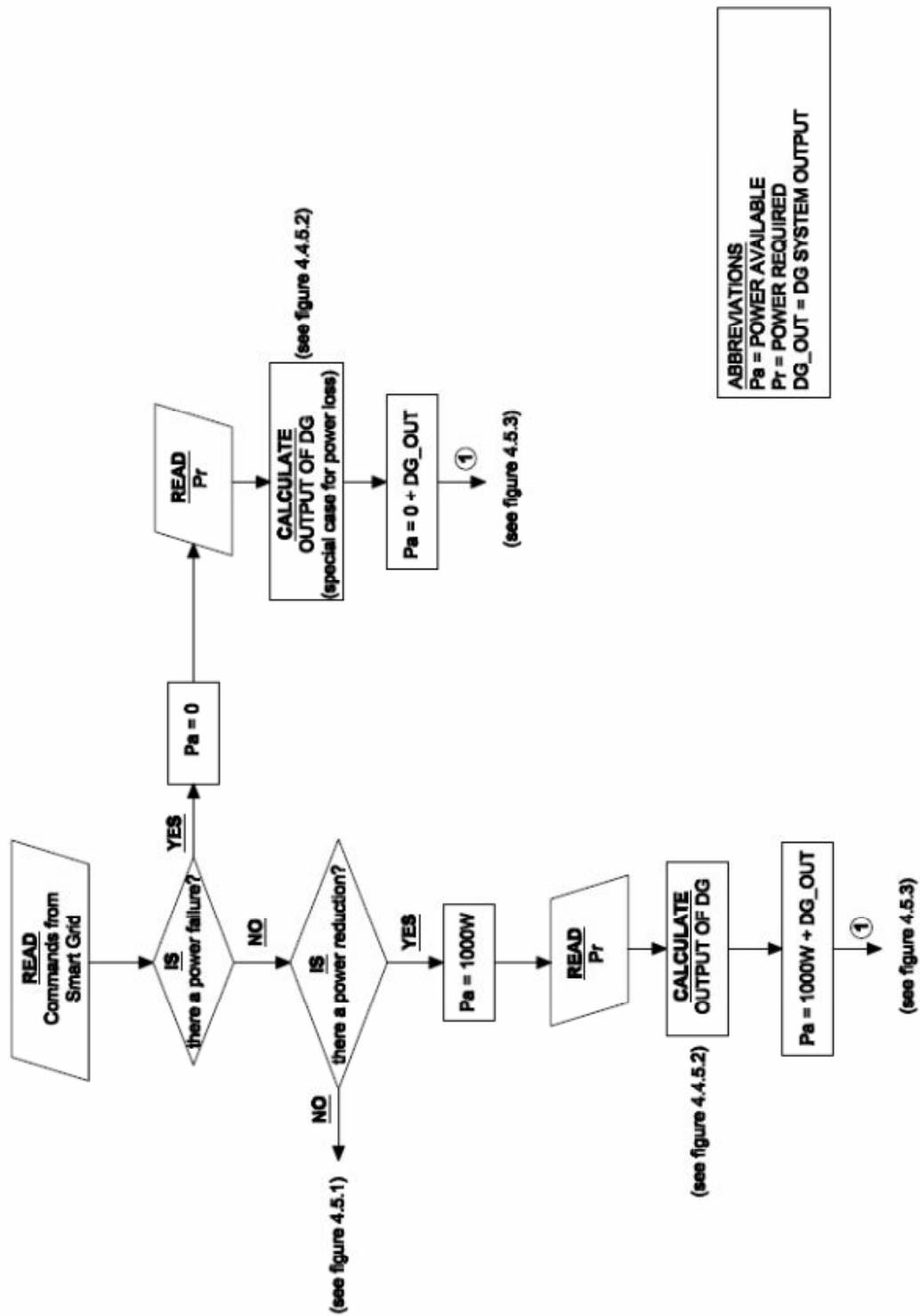
**(65)  Figure 4.5.2 –Initial stages of HAN flow chart – Power failure or Power Reduction**

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ABBREVIATIONS
Pa = POWER AVAILABLE
Pr = POWER REQUIRED
DG_OUT = DG SYSTEM OUTPUT
E_LOAD = Load of essential devices
UI_LOAD = Load of already running
non-interruptible devices
Price = Current wholesale price
(obtained via the smart grid)

READ
Commands from
Smart Grid

IS
there a power failure?

YES
(see figure 4.5.2)

NO

IS
there a power reduction?

YES
(see figure 4.5.2)

NO

READ
Price,
Pr

CALCULATE
Pa
(Based on Price)

CALCULATE
OUTPUT OF DG

(see figure 4.4.5.2)

Pa = Pa + DG_OUT

IS
Pa > E_LOAD

YES

Pa = Pa - E_LOAD

READ
Status of Uninterruptible
devices

ARE
Uninterruptible devices
on?

NO

③
(see figure 4.5.3)

YES

Pa = Pa - UI_LOAD

③
(see figure 4.5.3)

NO

Pa = Pa - 0

READ
Status of Uninterruptible
devices

ARE
Uninterruptible devices
on?

NO

②
(see figure 4.5.3)

Pa = Pa - UI_LOAD

②
(see figure 4.5.3)

123
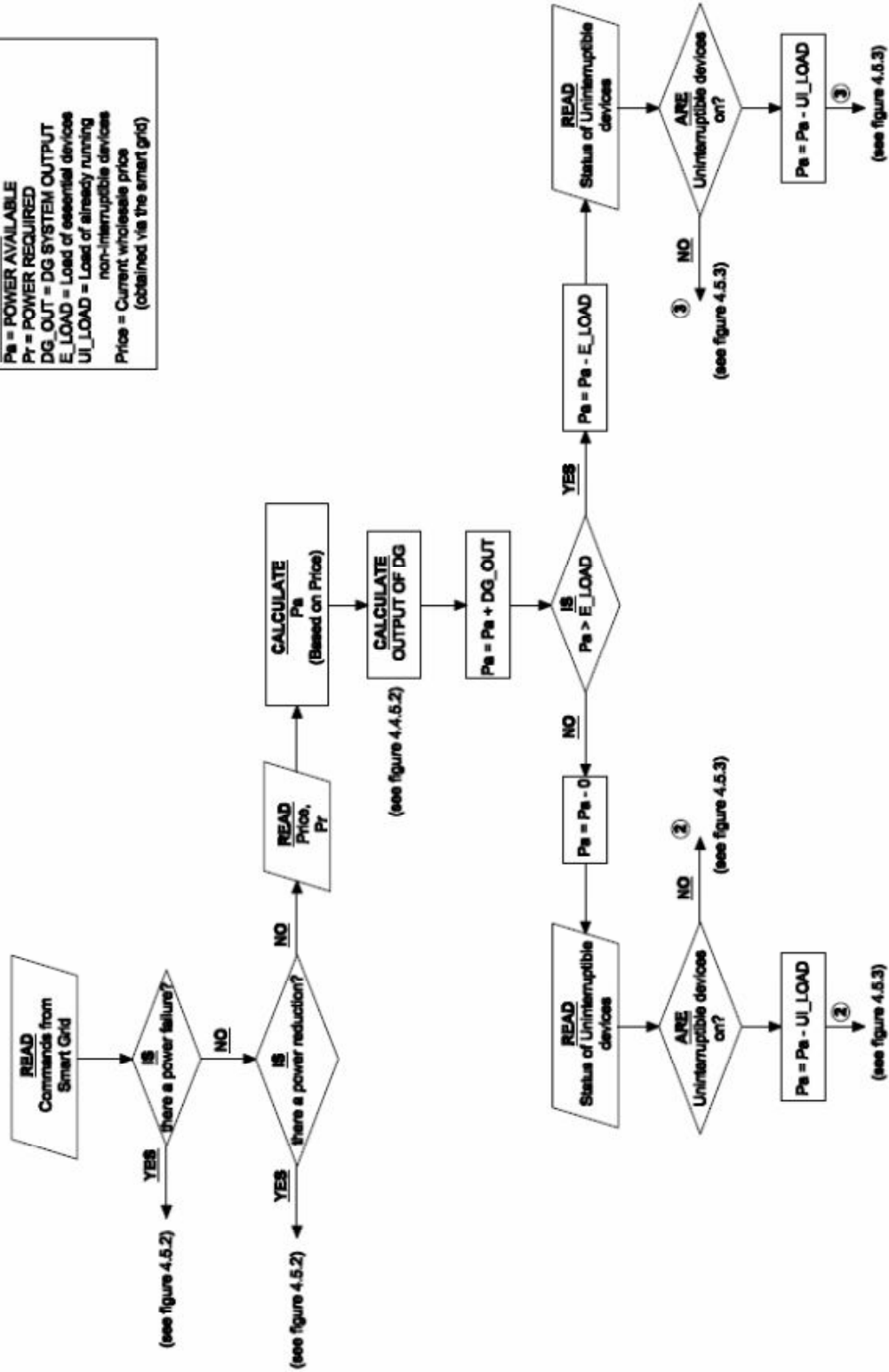
An important feature of the model is that regardless of the conditions (e.g. normal operation or power failure), the HAN controller will use all power available as efficiently as possible, thus minimising impact on the electricity use of the consumers within the given parameters.

For example, consider a scenario that occurs at 8pm when a fault occurs on the network and load to the house is limited to 1kW.  While the HAN controller is 'stepping through' the devices it comes to the TV and available power left is only 100W.  As the TV is currently consuming 191W, it exceeds the available power and is switched off.  That available power is then 'passed down' to any lower priority devices that require less than the 100W – for example the dishwasher at that time, which may only require 80W.

# 4.6  Designation of HAN Devices and Network Topology

A general discussion on the different Smart Grid topology options and the devices that may be used is given in section 2.3 and 2.4.  In accordance with the HAN model that has been proposed, the HAN must consist of:

- A HAN controller
- Devices that can measure and transmit load data as well as perform switching which may include:
    o  Switchboard Mounted relays
    o  Internal wall or ceiling mounted relays
    o  Power socket mounted relays
    o  Actual smart appliances
- Transmission medium such as Cat.5e cabling or wireless network

This section will cover the proposed devices and function of the HAN.

## 4.6.1          HAN Topology

First, it is proposed that a wireless network be used for HAN devices to communicate. This is due to ease of installation; particularly in retro-fitting existing buildings.  The WiFi (IEEE 802.11) and Zigbee (IEEE 802.15.4) protocols are both candidates due to the range of the networks (both over 30m), the presence of network security and the high adoption rates of these technologies (Huq P.6).  Zigbee uses less power to transmit and receive data (1-100mV) than that of WiFi (up to 780mW), which makes Zigbee a more attractive option.  ZigBee devices also may take only milliseconds to

exit their sleep states compared to Bluetooth or WiFi devices  FADLULLAH p.63).
Zigbee also supports star, tree and mesh topologies, whereas WiFi only functions as a
star topology, which can limit flexibility.  WiFi's real strength is the high data
transmission rates of 11Mbps (802.11.b) whereas Zigbee has data transfer rates of
only 250kbps, which is significantly lower.

To overcome the low data transfer rates of Zigbee, Fadlullah et. al. (PAGE 64)
suggest a method in which Zigbee HAN devices can transmit data in a more efficient
manner.  Instead of the devices constantly transmitting load data, these devices remain
in a 'sleep' mode unless their power requirements change, or if the HAN controller
makes a request for data.  Assuming that the data transmission rate is 10 packets per
second and a packet size of 90 bytes for each device, and that the devices transmit
data no more than once per second, then a Zigbee HAN with 100 devices will
maintain a packet delivery ratio of 88%.  Considering that most loads will not switch
at such high rates, it is likely that the Zigbee protocol has adequate data transmission
rates for the application at hand.

In summary, although other solutions may exist, it is proposed that a wireless Zigbee
network be used in a star topology configuration for this application.

## 4.6.2          HAN Controller

The role of the HAN controller is covered in detail in section 2.2.4 and 2.4.4, but to
summarise, it must receive messages from the grid, monitor power use in the home,
manage switching within the home and thus will perform the function of the Zigbee
network gateway.  The actual operations performed by the HAN controller are shown
in section 4.5.  As the HAN controller will have a Graphical User Interface (GUI) it
will display load information to the consumer as well as possibly having different
options for control which can be selected.  Due to this fact, it will be mounted in a
central location in the home.  In addition, electricity price information may be
obtained from an internet connection, which would require a typical router.
As has been previously mentioned, the Control4 EC-100 Energy Controller performs
many of the required functions in that it displays power use, allows control of
Heating/Cooling device thermostats and allows utility load management, but at
present, no device freely available in Australia appears to perform all the required
functions specified in this study.

## 4.6.3          Plug-In Relays / Power Monitors

Where possible, plug-in relays/power monitors will be used as they afford the easies
installation.  A perfect example of this is the Develco ZHWR201 wall plug meter
which monitors power as well as allowing on/off control via the HAN controller
(Develco Products n.d.).

**(67) Figure 4.6.3.1 – Develco ZHWR201**

This device will be used for the fridge, freezer, microwave, toaster (if necessary), TVs and DVD players. It can also be used for the washing machine, dishwasher and dryer depending on their ability to resume their cycle following a loss of power. In general, this device can be used for any stationary electrical appliance that uses a power socket.

### 4.6.4 Switchboard Mounted Relays / Power Monitors

For devices that are permanently connected and on a singular sub-circuit, a switchboard mounted relay can be used. A suitable solution is the Develco ZHDR201 DIN meter relay.



**(68) Figure 4.6.4.1 – Develco ZHDR201**

Appliances that will use this method will be the air conditioner, hot water unit, stove and oven.

### 4.6.5 Internal Wall / Ceiling Relays / Power Monitors

For all lighting, ceiling fans and exhaust fans, a logical solution is an in-wall or in-ceiling mounted relay/power monitor. An example of this is the SimpleHomeNet ZBMLC15 single metering relay.
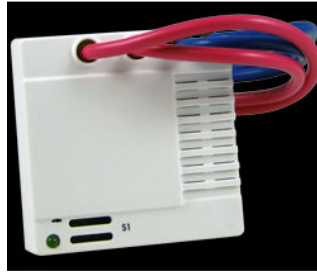
**(69) Figure 4.6.5.1 – SimpleHomeNet ZBMLC15**

Using this type of relay/meter, lights can be individually monitored and controlled (relay placed between the switch and the light fitting/s), or they can be controlled in groups such as 'external lights'. Similarly, all ceiling fans, or all exhaust fans may be placed on one relay.

### 4.6.6　　　　　Other Control & Monitoring

In integrating all electrical appliances into the HAN some special cases may exist. One such example is the computer, as this has an actual shut-down procedure and cannot be switched off abruptly. In this case, the HAN controller may communicate with the CPU via the Zigbee network or router to trigger a shut-down procedure if loads must be reduced.

Another issue is with electrical appliances that are mobile, with one such example being the vacuum cleaner. In this instance the use of 'smart appliances' is necessary, where the actual appliance itself is able to communicate with the HAN. This is an emerging technology and would not practically be available in Australia currently.

## 4.7　Conclusion

To conclude, it has been shown how the HAN model was developed, including justification of each aspect of the design. It has been shown how the HAN is actually controlled, which will generally be by the means of price variation control, and emergency interference from the utilities/electricity provider.

Devices are switched according to priority and other switching conditions, and this may vary depending on preferences of the user, which has been specified.

Enhancements such as distributed generation were considered and designed so as to be incorporated into some of the simulations. More specifically, a 3.64kW solar system and a 48V 200Ah battery have been matched to the residence.

The actual network topology and devices used have also been specified, utilising a Zigbee wireless network, a controller and various relays. An overview of the actual operation or functioning of the HAN has also been given, showing how all aspects fit together.

# Chapter 5    Simulations

## 5.1   Introduction

A key aim of this project is to establish the potential benefits of using smart grid in residential settings.  In order to do this, all of the load data that has been gathered, and the HAN model that has been developed is utilised to develop and perform simulations.

These simulations were designed and executed using Matlab version 7.7 software. The purpose of these simulations is to imitate the actual functioning of a HAN controller (monitor status of devices, control switching etc.) when used in a typical SE Queensland residential application.  Through running simulations for several realistic scenarios, it is possible to assess the potential impact if Smart Grid is to be used in Queensland.  As well as simulations, Matlab was also used to perform other complex computations such as calculating air conditioning loads, and also analysing results.

Each simulation had its own folder containing the corresponding Matlab files as well as any necessary input data, such as electrical loads and temperatures which were stored as text documents (.txt files).The Matlab files used this data as input information, and outputs were displayed on the Matlab Command Window.

## 5.2   Matlab Simulation and Analysis

As mentioned, simulation and analysis were both performed using Matlab.  For all of the different scenarios, the same general simulation was run using the different input information such as the temperatures for that day, the irradiation levels, the time of day that occupants were at home, etc.

Also, for each scenario, the same Matlab program was used to analyse the results and project outcomes to higher levels of the grid.  In this section, a basic explanation will be given of the Matlab files used.

### 5.2.1          Main Simulation

The main simulation was performed using a generic file with the name of "simulation_body.m" which is a Matlab-M file.  All simulations were performed from midnight till 4:30am the following morning (28.5 hours) at 5 minute intervals (342 data points in total).

The first part of the file loads all of the input data.  This input data includes:

- All device load data (approximately 30 .txt files) for that day and scenario (based on the gathered assessed load data)
- Wholesale electricity price for that day
- Irradiation levels for that day
- Ambient temperatures for that day

Next, all variables are defined such as the price limit used for the 'price variation control' (refer section 4.3.5).

Within the simulation, the output of the PV system is also calculated, which involves defining relevant variables such as the area of the solar panels and the panel efficiency; and calculating electrical output based on these variables and the irradiation levels.

Following these initial calculations, a large 'while' loop is run which contains many nested 'if' loops. Each of the 'if' loops basically determines the state of each device with respect to the 'power available' at that time. At the start of the 'while' loop, the output of the DG system is calculated, and then each electrical device is assessed in order of priority. Due to the constraints, the device is then either allowed 'on', turned 'off', or postponed according to the device designation and HAN model used (see sections 4.2.6 and 4.5).

For each step in this 'while' loop, various output information is calculated, and after the program is run, the results are displayed. The outputs include:

- The amount of electricity that is fed back into the grid
- The income generated from feed-back into the grid
- The net load on the grid
- The load on the grid if not using Smart Grid
- The cost of electricity to the residence
- The cost of electricity to the residence if not using Smart Grid
- The savings and savings percentage as a result of using Smart Grid
- The load factor using smart grid
- The load factor if not using Smart Grid
- A plot displaying the net power used, the actual load on the grid, and the load on the grid if not using smart grid.
- Notification if any devices were switched off or postponed, the time that it occurred and the duration.

The resultant load profile is then used in the next Matlab file to find a normalised residential load.

An example of a "simulation_body.m" simulation file is shown in Appendix F2.

### 5.2.2       Analysis – Normalised Residential Load

The results from the simulation show the outcome of Smart Grid application at one residence, however to find a realistic representation of overall average residential loads, a normalised load must be found. The generic filename used for this analysis is "NORMALISED_RES_LOAD" and is based on the model presented in section 3.5. Again, the first part of the file loads all input data. This input data includes:

- All device load data for that day and scenario (based on the gathered assessed load data).
- The load profile for the net load on the grid of the residence when using smart grid.
- The measured PRT load.

After the definition of some variables, calculations are then performed to formulate the normalised residential load. This is done by comparing the initial assessed load at the residence with the smart grid load of the residence, and applying the changes to the PRT load profile.

As mentioned in section 3.5, these improvements are averaged over pre-determined intervals to avoid unrealistic results. In all simulations, the intervals used were:

- Midnight to 5am – Night time off-peak
- 5am to 9am – Morning Peak
- 9am to 4pm – Daytime off-peak
- 4pm to 5pm – Early night peak
- 5pm to 8:45pm – Night peak
- 8:45 to Midnight – Night time off-peak

These intervals were chosen mostly in accordance with common residential load profile attributes, but also in response to the shape of the load profile of the residence used. These intervals generally produced the most realistic results across all simulations.

The outputs from this Matlab file include:

- The PRT peak load with and without smart grid being used.
- The PRT base load with and without smart grid being used.
- The PRT average load with and without smart grid being used.
- The PRT load factor with and without smart grid being used.
- A plot displaying the PRT load with and without smart grid being used.

The resultant load profile is then used in the next Matlab file to find the effects on higher levels of the grid.

An example of a "NORMALISED_RES_LOAD" simulation file is shown in Appendix F3.

### 5.2.3 Analysis – Projection Onto Higher Levels of the Grid

Now that the normalised residential load and the smart grid load of PRT is found, results can be projected onto higher levels of the grid. This is done using a generic file with the name of "SG_GRID_IMPROVEMENT.m", which is based on data found in section 3.4. This file was able to estimate results for the PWC2 feeder, the SSPWC substation, the SST16 substation and the QLD NEM levels.
Input data for this file includes:

- The QLD, SST16, SSPWC, PWC2 and PRT measured load data.
- The QLD NEM wholesale electricity prices.
- The PRT load when using smart grid.

A series of calculations are then performed finding the residential load components for PWC2, SSPWC, SST16 and QLD by multiplying the PRT smart grid load by the key ratios that are summarised in section 3.4.11. Then, the overall load profiles for PWC2, SSPWC, SST16 and QLD can be found by finding the difference between the residential load with smart grid and without smart grid being used.

Following these calculations, the program then estimates the QLD generation costs with and without using smart grid according to the method shown in section 3.6.2.
The outputs from this Matlab file include:

- Peak loads for PWC2, SSPWC, SST16 and QLD with and without using smart grid.
- Base loads for PWC2, SSPWC, SST16 and QLD with and without using smart grid.
- Average loads for PWC2, SSPWC, SST16 and QLD with and without using smart grid.
- Load factors for PWC2, SSPWC, SST16 and QLD with and without using smart grid.
- Percentage savings in QLD electricity generation costs.
- Plots of the loads for PWC2, SSPWC, SST16 and QLD with and without using smart grid.

An example of a "SG_GRID_IMPROVEMENT" simulation file is shown in Appendix F4.


## 5.3  List of Simulations Performed

Section 5.2 described the Matlab files that were used to find the effects of using Smart Grid.  To find a more holistic representation of the impact of smart grid, numerous simulations have been run with different scenarios, such as different times of the year and with different enhancements to the HAN.  The different simulations that have been run are shown in table 5.3.1 below.

| Scenario | Date | People at home 9am to 4am? | Using PV? | Using Battery? | Initial Battery Charge | Cooking Appliances exempt from Price variation Control? | Set Price Limit |
|---|---|---|---|---|---|---|---|
| 1 | 18/01/11 | YES | NO | NO | N/A | YES | $0.6 per kWh |
| | 18/01/11 | NO | NO | NO | N/A | YES | $0.6 per kWh |
| 2 | 9/6/2011 | YES | NO | NO | N/A | YES | $0.6 per kWh ($0.4 @ 5-10am & 3-11pm) |
| | 9/6/2011 | NO | NO | NO | N/A | YES | $0.6 per kWh ($0.4 @ 5-10am & 3-11pm) |
| 3 | 18/01/11 | YES | YES | NO | N/A | YES | $0.6 per kWh |
| | 18/01/11 | NO | YES | NO | N/A | YES | $0.6 per kWh |
| 4 | 9/6/2011 | YES | YES | NO | N/A | YES | $0.6 per kWh |
| | 9/6/2011 | NO | YES | NO | N/A | YES | $0.6 per kWh |
| 5 | 18/01/11 | YES | YES | YES | 60% | NO | $0.6 per kWh |
| | 18/01/11 | NO | YES | YES | 60% | NO | $0.6 per kWh |
| 6 | 9/6/2011 | YES | YES | YES | 60% | NO | $0.6 per kWh |
| | 9/6/2011 | NO | YES | YES | 60% | NO | $0.6 per kWh |
| 7 | 18/01/11 | YES | YES | HIGH* | 50% | NO | $0.6 per kWh |
| | 18/01/11 | NO | YES | HIGH* | 50% | NO | $0.6 per kWh |
| 8 | 9/6/2011 | YES | YES | HIGH* | 50% | NO | $0.6 per kWh |
| | 9/6/2011 | NO | YES | HIGH* | 50% | NO | $0.6 per kWh |

**‘**HIGH***’ *Denotes 30A Charging and 34A discharging where possible*
**(6)  Table 5.3.1 – List of Normal Simulations**

As can be seen, for each scenario (1-8) the simulation is performed with people at home during the day, and with people not home during the day.  In the results section, this will be averaged to give the overall effect, and thus it will be assumed that 50% of residencies have people home during the day.

It is also important to point out that some scenarios had different set price limits for the price variation control, and also, some scenarios had cooking appliances exempt from price variation control.  These differences occur to allow each scenario to have realistic outcomes.  For example, in scenario 1, if cooking appliances were not exempt from price variation control, it was found that at dinner time, there were delays of up

to 1.5 hours for some appliances such as the oven.  This is extremely undesirable and impractical.  For another example, in scenario 2, if the set price limit was not varied throughout the day, the HAN controller had very little intervention and thus no gains were found.

To see the effects of a loss of power or a power reduction command from the Smart Grid, the following simulations were also performed as shown in table 5.3.2.

| Scenario | Scenario Type | Based on Which Scenario? | Date | Description |
|----------|---------------|--------------------------|------|-------------|
| 9 | Load Reduction Incident | 1 | 18/01/11 | 'Power available' is limited to 600W at 7pm for 10 minutes due to a network fault |
| 10 | Power Loss Incident | 7 | 18/01/11 | Power is lost at 7pm for 2 hours due to a network fault |

**(7)  Table 5.3.2 – List of Additional Simulations**

# 5.4   Conclusion

In conclusion the simulations and analysis were designed and executed using Matlab version 7.7 software.  Simulations were performed for 10 different scenarios to find an optimal application of the Smart Grid.  Three different Matlab M-files were used for each scenario as follows:

1. "simulation_body.m" performed the simulation, replicating the actual functioning of a Smart Grid HAN.
2. "NORMALISED_RES_LOAD.m" created an average residential load based on the results of the single residence, and on information known about PRT.
3. "SG_GRID_IMPROVEMENT.m" analysed the data and estimated the effects of Smart Grid being used in all residential settings, on multiple levels of the grid.

Results from the simulations will be shown in Chapter 6.

# Chapter 6 Results and Further Analysis

## 6.1 Introduction

This section shows the results found running the various simulations. For each date, multiple simulations were run using different the scenarios mentioned, and results as well as explanations will be shown. Following this, results will be compared and analysed to determine the optimal HAN configuration.

## 6.2 Simulation Results

In this section, the daily results will be shown. Section 6.2.1 will give the full results of a successful simulation (Scenario 7) wherein peak loads were reduced and load factors were improved. It will demonstrate the alterations to normal electricity usage due to use of the Smart Grid HAN, show a table of key factors at various levels of the grid (PRT, PWC2, SSPWC, SST16, QLD), and show plots of the load profiles for the residence and the QLD loads. Due to the large amount of results data, the subsequent sections 6.2.2-6.2.10, which show the outcome of Scenarios 1-6 and 8-10, will only show the alterations to normal electricity use and the table of key factors.

### 6.2.1 Full Worked Example - Scenario 7 – 18th January - Price Variation Control, PV and Battery (High Battery Use)

This scenario is used as the example scenario, as it was proven to be the most effective of all the scenarios that were tried.
The following results are with:

- Time of Use control set at $0.60 per kWh
- Using Solar and batteries.
- Battery charge current at 20A or 30A DC.
- Battery discharge current at 20A or 34A DC.
- Initial battery charge at 50%
- Battery discharge limited to 5pm till 8pm

PEOPLE AT HOME DURING THE DAY

Note that due to the HAN controller intervention the following alterations to usage took place:

- Air Conditioner was turned off from 8:30am till 9:05am (35 minutes)
- Air Conditioner was turned off at 12:35pm for 5 minutes

- Air Conditioner was turned off at 12:45pm for 5 minutes
- TV 2 was turned off at 5:10pm for 5 minutes
- Range Hood was turned off at 5:10pm for 5 minutes
- Air Conditioner was turned off from 5:05pm till 5:45pm (40 minutes)
- Oven was postponed from 5:15pm till 5:40pm (25 minutes)
- Microwave was postponed from 5:20pm till 5:35pm (15 minutes)
- Air Conditioner was turned off from 5:25pm till 5:45pm (40 minutes)
- TV 1 was turned off at 5:55pm for 5 minutes
- Air Conditioner was turned off from 5:55pm till 6:05pm (10 minutes)
- Oven was postponed from 6:10pm till 6:20pm (10 minutes)
- TV 1 was turned off at 6:20pm for 5 minutes
- Air Conditioner was turned off at 6:20pm for 5 minutes
- TV 1 was turned off at 6:35pm for 5 minutes
- TV 2 was turned off at 6:35pm for 5 minutes
- Air Conditioner was turned off at 6:35pm for 5 minutes
- Exhaust Fan 1 was turned off at 6:35pm for 5 minutes
- Lights 4 was turned off at 6:35pm for 5 minutes
- Hot water unit was postponed from 7:20pm till 8:30pm (1 hour 10 minutes)
- Air Conditioner was turned off at 7:40pm for 5 minutes
- Air Conditioner was turned off from 8:20pm till 8:30pm (10 minutes)
- Air Conditioner was turned off at 8:50pm for 5 minutes
- Dishwasher was postponed from 7:40pm till 8:50pm (1 hour 10 minutes)

## PEOPLE NOT HOME DURING THE DAY (9am to 4pm)

Note that due to the HAN controller intervention the following alterations to usage took place:

- Air Conditioner was turned off at 8:50am for 5 minutes
- Air Conditioner was turned off at 4:30pm for 5 minutes
- TV 2 was turned off at 5:10pm for 5 minutes
- Range Hood was turned off at 5:10pm for 5 minutes
- Air Conditioner was turned off from 5:05pm till 5:45pm (40 minutes)
- Oven was postponed from 5:15pm till 5:40pm (25 minutes)
- Microwave was postponed from 5:20pm till 5:35pm (15 minutes)
- Air Conditioner was turned off from 5:50pm till 6:10pm (20 minutes)
- TV 1 was turned off at 5:55pm for 5 minutes
- Air Conditioner was turned off from 5:50pm till 6:10pm (20 minutes)
- Oven was postponed from 6:10pm till 6:20pm (10 minutes)
- TV 1 was turned off at 6:20pm for 5 minutes
- Air Conditioner was turned off at 6:20pm for 5 minutes
- TV 1 was turned off at 6:35pm for 5 minutes
- TV 2 was turned off at 6:35pm for 5 minutes
- Air Conditioner was turned off at 6:35pm for 5 minutes
- Exhaust Fan 1 was turned off at 6:35pm for 5 minutes

- Lights 4 was turned off at 6:35pm for 5 minutes
- Hot water unit was postponed from 7:15pm till 8:20pm (1 hour 5 minutes)
- Air Conditioner was turned off at 7:40pm for 5 minutes
- Air Conditioner was turned off from 8:20pm till 8:30pm (10 minutes)
- Air Conditioner was turned off at 8:55pm for 5 minutes
- Dishwasher was postponed from 7:40pm till 8:50pm (1 hour 10 minutes)

RESULTS

The following plots show results from the scenario when people are home during the day. Figure 6.2.1 shows the effect on the residential load, and figure 6.2.2 shows the overall effect on the QLD load profile.
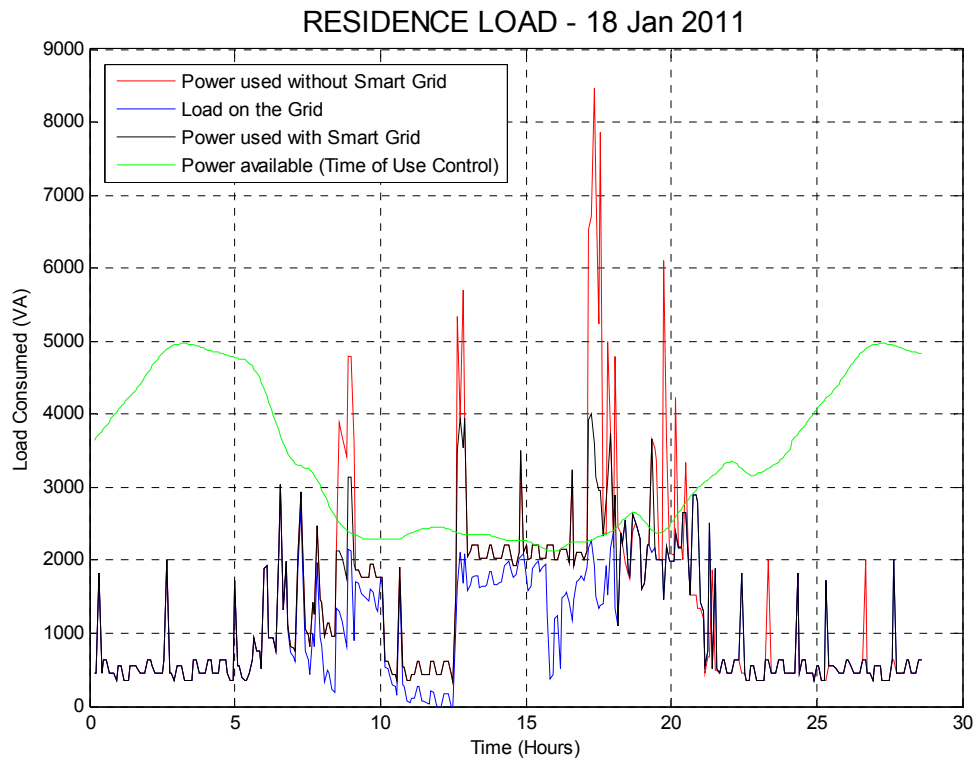


**(70) Figure 6.2.1.1 – Effect of Residential Smart Grid on Residential Load 18th January 2011**

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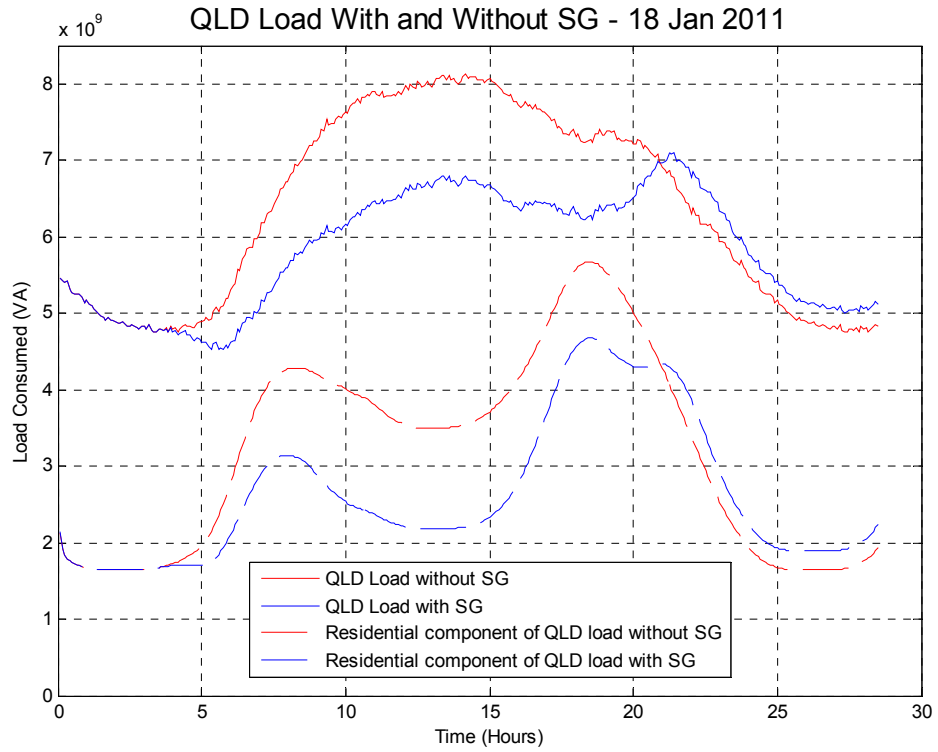
**(71) Figure 6.2.1.2 – Effect of Residential Smart Grid on QLD Load 18<sup>th</sup> January 2011**

The following table shows key factors for scenarios of not using smart grid, using smart grid with people at home during the day, and using smart grid with people not home during the day.

| KEY FACTOR | Not Using SG | Using SG (People Home 9-4) | Using SG (People NOT Home 9-4) | Using SG AVERAGE |
|---|---|---|---|---|
| Cost of Electricity to Residence | $8.91 | $6.28 | $4.63 | $5.46 |
| Savings Percentage | 0% | 29.65% | 33.92% | 31.79% |
| PRT Peak Load | 125.490kVA | 106.408kVA | 107.719kVA | 107.064kVA |
| PRT Average Load | 65.316kVA | 54.040kVA | 48.455kVA | 51.248kVA |
| PRT Load Factor (LF) | 0.52 | 0.508 | 0.45 | 0.479 |
| PWC2 Peak Load | 3.371MVA | 2.892MVA | 2.538MVA | 2.715MVA |
| PWC2 Average Load | 2.213MVA | 2.015 MVA | 1.917 MVA | 1.966MVA |
| PWC2 Load Factor (LF) | 0.656 | 0.697 | 0.755 | 0.726 |
| SSPWC Peak Load | 15.255MVA | 13.695MVA | 13.801MVA | 13.748MVA |
| SSPWC Average Load | 10.579MVA | 9.374MVA | 8.773MVA | 9.074MVA |
| SSPWC Load Factor (LF) | 0.693 | 0.684 | 0.636 | 0.660 |
| SST16 Peak Load | 58.606MVA | 47.909MVA | 47.328MVA | 47.619MVA |
| SST16 Average Load | 41.082MVA | 36.636MVA | 34.419MVA | 35.528MVA |
| SST16 Load Factor (LF) | 0.701 | 0.765 | 0.727 | 0.746 |
| QLD Peak Load | 8136.14MVA | 7105.54MVA | 7130.29MVA | 7117.92MVA |
| QLD Average Load | 6380.61MVA | 5831.71MVA | 5559.66MVA | 5695.69MVA |
| QLD Load Factor (LF) | 0.784 | 0.821 | 0.78 | 0.801 |
| Savings in QLD Electricity Generation Costs | 0.00% | 9.26% | 11.46% | 10.36% |
| QLD Peak Load (27.7%) | 8136.14MVA | 7424.55MVA | 7030.11MVA | 7227.33MVA |
| QLD Average Load (27.7%) | 6380.61MVA | 6089.07MVA | 5944.58MVA | 6016.83MVA |
| QLD Load Factor (LF) (27.7%) | 0.784 | 0.82 | 0.846 | 0.833 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | 5.69% | 8.79% | 7.24% |

**(8) Table 6.2.1 – Scenario 7 - Effect of Residential Smart Grid 18<sup>th</sup> January 2011**

## 6.2.2   SCENARIO 1 – 18<sup>th</sup> January - Price Variation Control Only

The following results are with:

- Time of Use control set at $0.60 per kWh all day
- All cooking appliances (stove, oven etc) are not switched off if prices get high (not subject to price variation control)

PEOPLE AT HOME DURING THE DAY

Note that due to the HAN controller intervention the following alterations to usage took place:

- Vacuum was postponed from 8:50am till 9:00am (10 minutes)
- Air Conditioner was turned off from 8:30am till 9:15am (45 minutes)
- Air Conditioner was turned off from 12:35pm till 12:55pm (20 minutes)
- Air Conditioner was turned off at 2:45pm for 5 minutes
- Air Conditioner was turned off at 3:20pm for 5 minutes
- Air Conditioner was turned off at 3:45pm for 10 minutes
- Air Conditioner was turned off at 4:05pm for 5 minutes
- Air Conditioner was turned off at 4:30pm for 5 minutes
- Air Conditioner was turned off from 5:05pm till 5:55pm (50 minutes)
- Air Conditioner was turned off at 6:00pm for 5 minutes
- Hot water unit was postponed from 7:15pm till 8:20pm (1 hour 5 minutes)
- Dishwasher was postponed from 7:40pm till 8:55pm (1 hour 15 minutes)
- Air Conditioner was turned off at 7:40pm for 5 minutes
- Air Conditioner was turned off from 8:20pm till 8:35pm (50 minutes)

PEOPLE NOT HOME DURING THE DAY (9am to 4pm)

Note that due to the HAN controller intervention the following alterations to usage took place:
- Air Conditioner was turned off from 8:30am till 8:45am (15 minutes)
- Air Conditioner was turned off at 8:55am for 5 minutes
- Vacuum was postponed at 4:30pm for 5 minutes
- Air Conditioner was turned off at 4:05pm to 4:45pm (40 minutes)
- Air Conditioner was turned off from 5:05pm till 5:35pm (30 minutes)
- Air Conditioner was turned off from 5:45pm till 5:55pm (10 minutes)
- Air Conditioner was turned off at 6:00pm for 5 minutes
- Hot water unit was postponed from 7:15pm till 8:20pm (1 hour 5 minutes)
- Dishwasher was postponed from 7:40pm till 8:55pm (1 hour 15 minutes)
- Air Conditioner was turned off at 7:40pm for 5 minutes
- Air Conditioner was turned off from 8:20pm till 8:35pm (50 minutes)
- Air Conditioner was turned off at 8:55pm for 5 minutes

## RESULTS

The following table shows key factors for scenarios of not using smart grid, using smart grid with people at home during the day, and using smart grid with people not home during the day.

| KEY FACTOR | Not Using SG | Using SG (People Home 9-4) | Using SG (People NOT Home 9-4) | Using SG AVERAGE |
|---|---|---|---|---|
| Cost of Electricity to Residence | $8.91 | $7.65 | $5.91 | $6.78 |
| Savings Percentage | 0% | 14.17% | 14.47% | 14.32% |
| PRT Peak Load | 125.490kVA | 120.798kVA | 120.801kVA | 120.8kVA |
| PRT Average Load | 65.316kVA | 64.364kVA | 65.098kVA | 64.731kVA |
| PRT Load Factor (LF) | 0.52 | 0.533 | 0.539 | 0.536 |
| PWC2 Peak Load | 3.371MVA | 3.333MVA | 3.333MVA | 3.333MVA |
| PWC2 Average Load | 2.213MVA | 2.198 MVA | 2.211 MVA | 2.205MVA |
| PWC2 Load Factor (LF) | 0.656 | 0.659 | 0.656 | 0.658 |
| SSPWC Peak Load | 15.255MVA | 14.815MVA | 14.815MVA | 14.815MVA |
| SSPWC Average Load | 10.579MVA | 10.484MVA | 10.563MVA | 10.524MVA |
| SSPWC Load Factor (LF) | 0.693 | 0.708 | 0.713 | 0.711 |
| SST16 Peak Load | 58.606MVA | 57.734MVA | 57.734MVA | 57.734MVA |
| SST16 Average Load | 41.082MVA | 40.736MVA | 41.027MVA | 40.882MVA |
| SST16 Load Factor (LF) | 0.701 | 0.706 | 0.7 | 0.703 |
| QLD Peak Load | 8136.14MVA | 8008.91MVA | 8008.91MVA | 8008.91MVA |
| QLD Average Load | 6380.61MVA | 6334.66MVA | 6370.41MVA | 6352.54MVA |
| QLD Load Factor (LF) | 0.784 | 0.791 | 0.785 | 0.788 |
| Savings in QLD Electricity Generation Costs | 0.00% | 0.61% | -0.20% | 0.21% |
| QLD Peak Load (27.7%) | 8136.14MVA | 8059.19MVA | 8059.19MVA | 8059.19MVA |
| QLD Average Load (27.7%) | 6380.61MVA | 6356.2MVA | 6375.19MVA | 6365.7 |
| QLD Load Factor (LF) (27.7%) | 0.784 | 0.789 | 0.785 | 0.787 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | 0.37% | -0.02% | 0.18% |

**(9) Table 6.2.2.1 – Scenario 1 - Effect of Residential Smart Grid 18<sup>th</sup> January 2011**

### 6.2.3 SCENARIO 2 – 9<sup>th</sup> June - Price Variation Control Only

The following results are with:
- Time of Use control set at $0.40 per kWh during peak times of 5am till 10am and 3pm till 11pm.
- Time of Use control set at $0.80 per kWh during all other off-peak times.
- All cooking appliances (stove, oven etc) are not switched off if prices get high
- 

PEOPLE AT HOME DURING THE DAY

Note that due to the HAN controller intervention the following alterations to usage took place:

- Washing machine was postponed at 6:40am for 5 minutes
- Hot water unit was postponed from 7:40am till 9:15am (1 hour 35 minutes)
- Vacuum was postponed at 8:25am till 8:45am (20 minutes)
- Fan 4 was turned off at 8:45am for 5 minutes
- Vacuum was postponed at 9:05am for 5 minutes
- Hot water unit was postponed from 4:15pm till 4:25pm (10 minutes)
- Hot water unit was postponed from 6:05pm till 9:15pm (3 hours 10 minutes)
- Exhaust Fan 1 was turned off at 6:35pm for 5 minutes
- TV 2 was turned off at 6:45pm for 10 minutes
- Dishwasher was postponed from 7:40pm till 11:00pm (3 hours 20 minutes)

PEOPLE NOT HOME DURING THE DAY (9am to 4pm)

Note that due to the HAN controller intervention the following alterations to usage took place:

- Washing machine was postponed at 6:40am for 5 minutes
- Hot water unit was postponed from 7:40am till 8:50am (1 hour 10 minutes)
- Vacuum was postponed at 4:15pm for 5 minutes
- Vacuum was postponed at 4:45pm till 4:55pm (10 minutes)
- Hot water unit was postponed from 5:40pm till 9:15pm (3 hours 35 minutes)
- Exhaust Fan 1 was turned off at 6:35pm for 5 minutes
- Exhaust Fan 1 was turned off at 6:45pm till 6:55pm (10 minutes)
- TV 2 was turned off at 6:35pm for 10 minutes
- TV 1 was turned off at 6:40pm for 5 minutes
- Dishwasher was postponed from 7:40pm till 11:00pm (3 hours 20 minutes)

RESULTS

The following table shows key factors for scenarios of not using smart grid, using smart grid with people at home during the day, and using smart grid with people not home during the day.

| KEY FACTOR | Not Using SG | Using SG (People Home 9-4) | Using SG (People NOT Home 9-4) | Using SG AVERAGE |
|---|---|---|---|---|
| Cost of Electricity to Residence | $5.56 | $5.34 | $5.06 | $5.20 |
| Savings Percentage | 0% | 4.03% | 4.26% | 4.15% |
| PRT Peak Load | 147.053kVA | 131.626kVA | 131.028kVA | 131.327kVA |
| PRT Average Load | 54.221kVA | 58.249kVA | 57.866kVA | 58.058kVA |
| PRT Load Factor (LF) | 0.369 | 0.443 | 0.442 | 0.443 |
| PWC2 Peak Load | 2.810MVA | 2.745MVA | 2.745MVA | 2.745MVA |
| PWC2 Average Load | 1.77MVA | 1.848MVA | 1.841MVA | 1.845MVA |
| PWC2 Load Factor (LF) | 0.631 | 0.673 | 0.671 | 0.672 |
| SSPWC Peak Load | 17.730MVA | 16.769MVA | 16.769MVA | 16.769MVA |
| SSPWC Average Load | 10.217MVA | 10.713MVA | 10.666MVA | 10.690MVA |
| SSPWC Load Factor (LF) | 0.576 | 0.638 | 0.635 | 0.637 |
| SST16 Peak Load | 61.789MVA | 57.213MVA | 57.213MVA | 57.213MVA |
| SST16 Average Load | 37.4MVA | 39.111MVA | 38.951MVA | 39.031MVA |
| SST16 Load Factor (LF) | 0.605 | 0.684 | 0.657 | 0.671 |
| QLD Peak Load | 7720.81MVA | 7693.81MVA | 7693.81MVA | 7693.81MVA |
| QLD Average Load | 6004.07MVA | 6196.57MVA | 6178.39MVA | 6187.48MVA |
| QLD Load Factor (LF) | 0.778 | 0.805 | 0.803 | 0.804 |
| Savings in QLD Electricity Generation Costs | 0.00% | -2.71% | -2.53% | -2.62% |
| QLD Peak Load (27.7%) | 7720.81MVA | 7374.85MVA | 7374.85MVA | 7374.85MVA |
| QLD Average Load (27.7%) | 6004.07MVA | 6123.01MVA | 6111.78MVA | 6117.40MVA |
| QLD Load Factor (LF) (27.7%) | 0.778 | 0.83 | 0.811 | 0.821 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | 0.71% | -0.75% | -0.02% |

**(10)  Table 6.2.3.1 – Scenario 2 - Effect of Residential Smart Grid 9th June 2011**

### 6.2.4   SCENARIO 3 – 18<sup>th</sup> January - Price Variation Control & PV

The following results are with:

- Time of Use control set at $0.60 per kWh.
- Using PV
- All cooking appliances (stove, oven etc) are not switched off if prices get high

PEOPLE AT HOME DURING THE DAY

Note that due to the HAN controller intervention the following alterations to usage took place:

- Air Conditioner was turned off from 8:30am till 9:00am (30 minutes)
- Air Conditioner was turned off from 5:05pm till 5:40pm (35 minutes)
- Air Conditioner was turned off at 5:45pm for 10 minutes
- Air Conditioner was turned off at 6:00pm for 5 minutes
- Hot water unit was postponed from 7:15pm till 8:20pm (1 hour 5 minutes)
- Dishwasher was postponed from 7:40pm till 8:55pm (1 hour 15 minutes)
- Air Conditioner was turned off at 7:40pm for 5 minutes
- Air Conditioner was turned off from 8:20pm till 8:35pm (15 minutes)
- Air Conditioner was turned off at 8:55pm for 5 minutes

PEOPLE NOT HOME DURING THE DAY (9am to 4pm)

Note that due to the HAN controller intervention the following alterations to usage took place:

- Air Conditioner was turned off at 8:50am for 5 minutes
- Vacuum was postponed at 4:30pm for 5 minutes
- Air Conditioner was turned off at 4:05pm to 4:45pm (40 minutes)
- Air Conditioner was turned off from 5:05pm till 5:55pm (50 minutes)
- Air Conditioner was turned off at 6:00pm for 5 minutes
- Hot water unit was postponed from 7:15pm till 8:20pm (1 hour 5 minutes)
- Dishwasher was postponed from 7:40pm till 8:55pm (1 hour 15 minutes)
- Air Conditioner was turned off at 7:40pm for 5 minutes
- Air Conditioner was turned off from 8:20pm till 8:35pm (15 minutes)
- Air Conditioner was turned off at 8:55pm for 5 minutes

RESULTS

The following table shows key factors for scenarios of not using smart grid, using smart grid with people at home during the day, and using smart grid with people not home during the day.

| KEY FACTOR | Not Using SG | Using SG (People Home 9-4) | Using SG (People NOT Home 9-4) | Using SG AVERAGE |
|---|---|---|---|---|
| Cost of Electricity to Residence | $8.91 | $5.59 | $4.61 | $5.10 |
| Savings Percentage | 0% | 51.72% | 78.29% | 65.01% |
| PRT Peak Load | 125.490kVA | 120.798kVA | 120.798kVA | 120.798kVA |
| PRT Average Load | 65.316kVA | 31.025kVA | 27.676kVA | 29.351kVA |
| PRT Load Factor (LF) | 0.52 | 0.279 | 0.025 | 0.152 |
| PWC2 Peak Load | 3.371MVA | 3.333MVA | 3.333MVA | 3.333MVA |
| PWC2 Average Load | 2.213MVA | 1.608 MVA | 1.108 MVA | 1.358MVA |
| PWC2 Load Factor (LF) | 0.656 | 0.633 | 0.437 | 0.535 |
| SSPWC Peak Load | 15.255MVA | 14.815MVA | 14.815MVA | 14.815MVA |
| SSPWC Average Load | 10.579MVA | 6.899MVA | 3.861MVA | 5.380MVA |
| SSPWC Load Factor (LF) | 0.693 | 0.496 | 0.278 | 0.387 |
| SST16 Peak Load | 58.606MVA | 57.734MVA | 57.734MVA | 57.734MVA |
| SST16 Average Load | 41.082MVA | 27.498MVA | 16.278MVA | 21.888MVA |
| SST16 Load Factor (LF) | 0.701 | 0.543 | 0.321 | 0.432 |
| QLD Peak Load | 8136.14MVA | 8008.91MVA | 8008.91MVA | 8008.91MVA |
| QLD Average Load | 6380.61MVA | 4710.56MVA | 3334.01MVA | 4022.285MVA |
| QLD Load Factor (LF) | 0.784 | 0.653 | 0.462 | 0.558 |
| Savings in QLD Electricity Generation Costs | 0.00% | 23.60% | 43.45% | 33.53% |
| QLD Peak Load (27.7%) | 8136.14MVA | 8059.19MVA | 8059.19MVA | 8059.19MVA |
| QLD Average Load (27.7%) | 6380.61MVA | 5493.61MVA | 4762.49MVA | 5128.05MVA |
| QLD Load Factor (LF) (27.7%) | 0.784 | 0.771 | 0.669 | 0.720 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | 13.13% | 23.65% | 18.39% |

**(11) Table 6.2.4.1 – Scenario 3 - Effect of Residential Smart Grid 18<sup>th</sup> January 2011**

### 6.2.5 SCENARIO 4 – 9<sup>th</sup> June - Price Variation Control & PV

The following results are with:

- Time of Use control set at $0.40 per kWh
- Using PV
- All cooking appliances (stove, oven etc) are not switched off if prices get high

#### PEOPLE AT HOME DURING THE DAY

Note that due to the HAN controller intervention the following alterations to usage took place:

- Washing machine was postponed at 6:40am for 5 minutes
- Hot water unit was postponed from 7:40am till 8:20am (40 minutes)
- Exhaust Fan 1 was turned off at 8:15am for 5 minutes
- Hot water unit was postponed from 5:00pm till 9:00pm (4 hours)
- Hot water unit was postponed at 9:10pm for 10 minutes
- Exhaust Fan 1 was turned off at 6:40pm till 6:55pm (15 minutes)
- TV 2 was turned off at 6:35pm for 10 minutes
- TV 1 was turned off at 6:40pm for 5 minutes
- Dishwasher was postponed from 7:40pm till 2:10am (4 hours 30 minutes)

#### PEOPLE NOT HOME DURING THE DAY (9am to 4pm)

Note that due to the HAN controller intervention the following alterations to usage took place:

- Washing machine was postponed at 6:40am for 5 minutes
- Hot water unit was postponed from 7:40am till 8:20am (40 minutes)
- Exhaust Fan 1 was turned off at 8:15am for 5 minutes
- Hot water unit was postponed from 5:00pm till 9:00pm (4 hours)
- Hot water unit was postponed at 9:10pm for 10 minutes
- Exhaust Fan 1 was turned off at 6:40pm till 6:55pm (15 minutes)
- TV 2 was turned off at 6:35pm for 10 minutes
- TV 1 was turned off at 6:40pm for 5 minutes
- Dishwasher was postponed from 7:40pm till 2:10am (4 hours 30 minutes)

#### RESULTS

The following table shows key factors for scenarios of not using smart grid, using smart grid with people at home during the day, and using smart grid with people not home during the day.

| KEY FACTOR | Not Using SG | Using SG (People Home 9-4) | Using SG (People NOT Home 9-4) | Using SG AVERAGE |
|---|---|---|---|---|
| Cost of Electricity to Residence | $5.56 | $4.14 | $4.08 | $4.11 |
| Savings Percentage | 0% | 63.11% | 72.04% | 67.58% |
| PRT Peak Load | 147.053kVA | 131.028kVA | 131.028kVA | 131.028kVA |
| PRT Average Load | 54.221kVA | 29.908kVA | 23.365kVA | 26.637kVA |
| PRT Load Factor (LF) | 0.369 | 0.24 | 0.187 | 0.214 |
| PWC2 Peak Load | 2.810MVA | 2.744MVA | 2.744MVA | 2.744MVA |
| PWC2 Average Load | 1.77MVA | 1.33MVA | 1.211MVA | 1.2705MVA |
| PWC2 Load Factor (LF) | 0.631 | 0.524 | 0.477 | 0.501 |
| SSPWC Peak Load | 17.730MVA | 16.785MVA | 16.785MVA | 16.785MVA |
| SSPWC Average Load | 10.217MVA | 7.279MVA | 6.486MVA | 6.883MVA |
| SSPWC Load Factor (LF) | 0.576 | 0.468 | 0.417 | 0.443 |
| SST16 Peak Load | 61.789MVA | 59.273MVA | 59.273MVA | 59.273MVA |
| SST16 Average Load | 37.4MVA | 27.288MVA | 24.558MVA | 25.923MVA |
| SST16 Load Factor (LF) | 0.605 | 0.508 | 0.452 | 0.480 |
| QLD Peak Load | 7720.81MVA | 7690.26MVA | 7690.26MVA | 7690.26MVA |
| QLD Average Load | 6004.07MVA | 4851.41MVA | 4540.78MVA | 4696.095MVA |
| QLD Load Factor (LF) | 0.778 | 0.65 | 0.608 | 0.629 |
| Savings in QLD Electricity Generation Costs | 0.00% | 16.09% | 20.67% | 18.38% |
| QLD Peak Load (27.7%) | 7720.81MVA | 7538.74MVA | 7538.74MVA | 7538.74MVA |
| QLD Average Load (27.7%) | 6004.07MVA | 5291.84MVA | 5099.90MVA | 5195.87MVA |
| QLD Load Factor (LF) (27.7%) | 0.778 | 0.721 | 0.695 | 0.708 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | 9.86% | 12.68% | 11.27% |

**(12) Table 6.2.5 – Scenario 4 - Effect of Residential Smart Grid 9th June 2011**

## 6.2.6   SCENARIO 5 – 18<sup>th</sup> January - Price Variation Control, PV & Battery

The following results are with:
- Time of Use control set at $0.60 per kWh
- Using Solar and batteries.
- Battery charge current limited to 20A DC.
- Batter discharge current limited to 20A DC.
- Initial battery charge at 60%
- Battery discharge limited to 5am till 9am and 5pm till 8pm

<u>PEOPLE AT HOME DURING THE DAY</u>

Note that due to the HAN controller intervention the following alterations to usage took place:

- Air Conditioner was turned off from 8:45am till 9:15am (30 minutes)
- Vacuum was postponed at 8:50am till 9am (10 minutes)
- Air Conditioner was turned off from 12:35pm till 1:00pm (25 minutes)
- Hot water unit was postponed from 12:35pm till 12:55pm (20 minutes)
- TV 1 was turned off at 12:45pm for 5 minutes
- Fan 4 was turned off at 12:45pm for 5 minutes
- Air Conditioner was turned off at 3:05pm for 5 minutes
- Air Conditioner was turned off at 3:40pm for 5 minutes
- Air Conditioner was turned off at 4:50pm for 5 minutes
- Air Conditioner was turned off from 5:05pm till 5:55pm (50 minutes)
- Oven was postponed from 5:05pm till 5:40pm (35 minutes)
- Microwave was postponed from 5:20pm till 5:35pm (15 minutes)
- Oven was postponed from 6:05pm till 6:15pm (10 minutes)
- Air Conditioner was turned off at 6:10pm for 5 minutes
- Air Conditioner was turned off at 6:20pm for 5 minutes
- TV 1 was turned off at 6:20pm for 5 minutes
- TV 1 was turned off at 6:35pm for 5 minutes
- TV 2 was turned off at 6:35pm for 5 minutes
- Air Conditioner was turned off at 6:35pm for 5 minutes
- Exhaust Fan 1 was turned off at 6:35pm for 5 minutes
- TV 1 was turned off at 6:50pm for 5 minutes
- TV 2 was turned off at 6:50pm for 5 minutes
- Air Conditioner was turned off at 6:50pm for 5 minutes
- Lights 4 was turned off at 6:50pm for 5 minutes
- Lights 16 was turned off at 6:50pm for 5 minutes
- Fan 7 was turned off at 6:50pm for 5 minutes
- Hot water unit was turned off at 7:35pm for 5 minutes
- Air Conditioner was turned off at 7:40pm for 10 minutes
- Hot water unit was postponed from 7:40pm till 8:05pm (25 minutes)

- Air Conditioner was turned off at 8:05pm for 5 minutes
- Air Conditioner was turned off at 8:20pm for 5 minutes
- Air Conditioner was turned off at 8:50pm for 5 minutes
- Dishwasher was postponed from 7:40pm till 8:45pm (1 hour 5 minutes)

## PEOPLE NOT HOME DURING THE DAY (9am to 4pm)

Note that due to the HAN controller intervention the following alterations to usage took place:

- Air Conditioner was turned off from 8:50am till 9:00am (10 minutes)
- Air Conditioner was turned off at 4:30pm for 5 minutes
- Air Conditioner was turned off from 5:05pm till 5:55pm (50 minutes)
- Oven was postponed from 5:05pm till 5:40pm (35 minutes)
- Microwave was postponed from 5:20pm till 5:35pm (15 minutes)
- Oven was postponed from 6:05pm till 6:15pm (10 minutes)
- Air Conditioner was turned off at 6:20pm for 5 minutes
- TV 1 was turned off at 6:20pm for 5 minutes
- TV 1 was turned off at 6:35pm for 5 minutes
- TV 2 was turned off at 6:35pm for 5 minutes
- Air Conditioner was turned off at 6:35pm for 5 minutes
- Exhaust Fan 1 was turned off at 6:35pm for 5 minutes
- TV 1 was turned off at 6:50pm for 5 minutes
- TV 2 was turned off at 6:50pm for 5 minutes
- Air Conditioner was turned off at 6:50pm for 5 minutes
- Lights 4 was turned off at 6:50pm for 5 minutes
- Lights 16 was turned off at 6:50pm for 5 minutes
- Fan 7 was turned off at 6:50pm for 5 minutes
- Hot water unit was postponed at 7:30pm for 10 minutes
- Air Conditioner was turned off at 7:40pm for 5 minutes
- Hot water unit was postponed from 7:55pm till 8:20pm (25 minutes)
- Air Conditioner was turned off at 8:05pm for 5 minutes
- Air Conditioner was turned off at 8:20pm for 10 minutes
- Air Conditioner was turned off at 8:50pm for 5 minutes
- Dishwasher was postponed from 7:40pm till 8:20pm (40 minutes)

## RESULTS

The following table shows key factors for scenarios of not using smart grid, using smart grid with people at home during the day, and using smart grid with people not home during the day.

| KEY FACTOR | Not Using SG | Using SG (People Home 9-4) | Using SG (People NOT Home 9-4) | Using SG AVERAGE |
|---|---|---|---|---|
| Cost of Electricity to Residence | $8.91 | $5.83 | $4.34 | $5.09 |
| Savings Percentage | 0% | 38.07% | 46.92% | 42.50% |
| PRT Peak Load | 125.490kVA | 109.249kVA | 105.380kVA | 107.315kVA |
| PRT Average Load | 65.316kVA | 46.175kVA | 35.145kVA | 40.66kVA |
| PRT Load Factor (LF) | 0.52 | 0.423 | 0.334 | 0.379 |
| PWC2 Peak Load | 3.371MVA | 2.559MVA | 2.507MVA | 2.533MVA |
| PWC2 Average Load | 2.213MVA | 1.876MVA | 1.681MVA | 1.779MVA |
| PWC2 Load Factor (LF) | 0.656 | 0.733 | 0.671 | 0.702 |
| SSPWC Peak Load | 15.255MVA | 13.926MVA | 13.611MVA | 13.769MVA |
| SSPWC Average Load | 10.579MVA | 8.528MVA | 7.342MVA | 7.935MVA |
| SSPWC Load Factor (LF) | 0.693 | 0.612 | 0.54 | 0.576 |
| SST16 Peak Load | 58.606MVA | 47.722MVA | 46.559MVA | 47.141MVA |
| SST16 Average Load | 41.082MVA | 33.514MVA | 29.134MVA | 31.324MVA |
| SST16 Load Factor (LF) | 0.701 | 0.702 | 0.626 | 0.664 |
| QLD Peak Load | 8136.14MVA | 7146.28MVA | 7028.49MVA | 7087.39MVA |
| QLD Average Load | 6380.61MVA | 5448.62MVA | 4911.20MVA | 5179.91MVA |
| QLD Load Factor (LF) | 0.784 | 0.762 | 0.7 | 0.731 |
| Savings in QLD Electricity Generation Costs | 0.00% | 12.93% | 21.08% | 17.01% |
| QLD Peak Load (27.7%) | 8136.14MVA | 7016.83MVA | 6972.09MVA | 6994.46MVA |
| QLD Average Load (27.7%) | 6380.61MVA | 5885.61MVA | 5600.17MVA | 5742.89MVA |
| QLD Load Factor (LF) (27.7%) | 0.784 | 0.839 | 0.803 | 0.821 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | 9.34% | 12.06% | 10.70% |

**(13)  Table 6.2.6.1 – Scenario 5 - Effect of Residential Smart Grid 18th January 2011**

### 6.2.7 SCENARIO 6 – 9<sup>th</sup> June Price Variation Control, PV & Battery

The following results are with:

- Time of Use control set at $0.60 per kWh
- Using Solar and batteries.
- Battery charge current limited to 20A DC.
- Batter discharge current limited to 20A DC.
- Initial battery charge at 60%
- Battery discharge limited to 5am till 9am and 5pm till 8pm

PEOPLE AT HOME DURING THE DAY

Note that due to the HAN controller intervention the following alterations to usage took place:

- Vacuum was postponed at 8:50am till 9am (10 minutes)
- Lights 10 was turned off at 5:05pm for 5 minutes
- TV 1 was turned off at 5:05pm for 5 minutes
- Range hood was turned off at 5:05pm for 5 minutes
- Oven was postponed at 5:10pm till 5:45pm (35 minutes)
- Microwave was postponed from 5:20pm till 5:35pm (20 minutes)
- TV 1 was turned off at 5:35pm till 5:55pm (20 minutes)
- Hot water unit was postponed from 5:45pm till 7:15pm (1.5 hours)
- Oven was postponed at 6:05pm till 7:10pm (1 hour 5 minutes)
- TV2 was turned off at 7:10pm for 5 minutes
- Hot water unit was postponed at 7:10pm for 5 minutes
- Dishwasher was postponed from 7:10pm till 8:55pm (1 hour 45 minutes)

PEOPLE NOT HOME DURING THE DAY (9am to 4pm)

Note that due to the HAN controller intervention the following alterations to usage took place:

- Lights 10 was turned off at 5:05pm for 5 minutes
- TV 1 was turned off at 5:05pm for 5 minutes
- Range hood was turned off at 5:05pm for 5 minutes
- Oven was postponed at 5:10pm till 5:35pm (25 minutes)
- Microwave was postponed from 5:20pm till 5:35pm (15 minutes)
- TV 1 was turned off at 5:35pm for 5 minutes
- TV 1 was turned off at 5:45pm for 5 minutes
- Hot water unit was postponed from 5:45pm till 7:05pm (1.5 hours)
- Oven was postponed at 6:05pm till 7:05pm (1 hour)
- TV2 was turned off at 7:10pm for 5 minutes
- Hot water unit was postponed at 7:10pm for 5 minutes

- Dishwasher was postponed from 7:10pm till 8:55pm (1 hour 45 minutes)

RESULTS

The following table shows key factors for scenarios of not using smart grid, using smart grid with people at home during the day, and using smart grid with people not home during the day.

| KEY FACTOR | Not Using SG | Using SG (People Home 9-4) | Using SG (People NOT Home 9-4) | Using SG AVERAGE |
|---|---|---|---|---|
| Cost of Electricity to Residence | $5.56 | $4.20 | $4.02 | $4.11 |
| Savings Percentage | 0% | 23.94% | 32.19% | 28.07% |
| PRT Peak Load | 147.053kVA | 139.547kVA | 139.552kVA | 139.550kVA |
| PRT Average Load | 54.221kVA | 45.192kVA | 42.625kVA | 43.909kVA |
| PRT Load Factor (LF) | 0.369 | 0.324 | 0.305 | 0.315 |
| PWC2 Peak Load | 2.810MVA | 2.837MVA | 2.810MVA | 2.824MVA |
| PWC2 Average Load | 1.77MVA | 1.61MVA | 1.562MVA | 1.586MVA |
| PWC2 Load Factor (LF) | 0.631 | 0.567 | 0.551 | 0.559 |
| SSPWC Peak Load | 17.730MVA | 17.339MVA | 17.339MVA | 17.339MVA |
| SSPWC Average Load | 10.217MVA | 9.130MVA | 8.819MVA | 8.975MVA |
| SSPWC Load Factor (LF) | 0.576 | 0.527 | 0.509 | 0.518 |
| SST16 Peak Load | 61.789MVA | 58.955MVA | 58.955MVA | 58.955MVA |
| SST16 Average Load | 37.4MVA | 33.662MVA | 33.259MVA | 33.461MVA |
| SST16 Load Factor (LF) | 0.605 | 0.571 | 0.553 | 0.562 |
| QLD Peak Load | 7720.81MVA | 8177.94MVA | 8177.97MVA | 8177.94MVA |
| QLD Average Load | 6004.07MVA | 5576.44MVA | 5454.59MVA | 5515.52MVA |
| QLD Load Factor (LF) | 0.778 | 0.682 | 0.667 | 0.675 |
| Savings in QLD Electricity Generation Costs | 0.00% | 1.75% | 3.60% | 2.68% |
| QLD Peak Load (27.7%) | 7720.81MVA | 7705.48MVA | 7705.51MVA | 7705.50MVA |
| QLD Average Load (27.7%) | 6004.07MVA | 5739.84MVA | 5664.55MVA | 5702.20MVA |
| QLD Load Factor (LF) (27.7%) | 0.778 | 0.745 | 0.735 | 0.740 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | 1.95% | 2.64% | 2.30% |

(14) **Table 6.2.7.1 – Scenario 6 - Effect of Residential Smart Grid 9th June 2011**

### 6.2.8  SCENARIO 8 – 9<sup>th</sup> June Price Variation Control, PV & Battery (High Battery Use)

The following results are with:
- Time of Use control set at $0.60 per kWh
- Using Solar and batteries.
- Battery charge current at 20A or 30A DC.
- Battery discharge current at 20A or 34A DC.
- Initial battery charge at 60%
- Battery discharge limited to 5am till 9am and 5pm till 8pm

PEOPLE AT HOME DURING THE DAY

Note that due to the HAN controller intervention the following alterations to usage took place:

- Oven was postponed at 5:15pm till 5:40pm (25 minutes)
- Microwave was postponed from 5:20pm till 5:35pm (20 minutes)
- TV 1 was turned off at 5:35pm for 5 minutes
- Hot water unit was postponed from 5:45pm till 7:15pm (1.5 hours)
- Oven was postponed at 6:15pm till 7:10pm (55 minutes)
- TV2 was turned off at 7:10pm for 5 minutes
- Hot water unit was postponed at 7:10pm for 5 minutes
- Dishwasher was postponed from 7:10pm till 8:55pm (1 hour 45 minutes)

PEOPLE NOT HOME DURING THE DAY (9am to 4pm)

Note that due to the HAN controller intervention the following alterations to usage took place:

- Oven was postponed at 5:15pm till 5:40pm (25 minutes)
- Microwave was postponed from 5:20pm till 5:30pm (15 minutes)
- TV 1 was turned off at 5:35pm for 5 minutes
- Hot water unit was postponed from 5:45pm till 7:15pm (1.5 hours)
- Oven was postponed at 6:15pm till 7:05pm (50 minutes)
- TV2 was turned off at 7:10pm for 5 minutes
- Hot water unit was postponed at 7:10pm for 5 minutes

RESULTS

The following table shows key factors for scenarios of not using smart grid, using smart grid with people at home during the day, and using smart grid with people not home during the day.

| KEY FACTOR | Not Using SG | Using SG (People Home 9-4) | Using SG (People NOT Home 9-4) | Using SG AVERAGE |
|---|---|---|---|---|
| Cost of Electricity to Residence | $5.56 | $4.37 | $4.16 | $4.27 |
| Savings Percentage | 0% | 21.81% | 23.00% | 22.41% |
| PRT Peak Load | 147.053kVA | 138.830kVA | 138.834kVA | 138.832kVA |
| PRT Average Load | 54.221kVA | 50.454kVA | 48.920kVA | 49.69kVA |
| PRT Load Factor (LF) | 0.369 | 0.363 | 0.352 | 0.358 |
| PWC2 Peak Load | 2.810MVA | 2.793MVA | 2.793MVA | 2.793MVA |
| PWC2 Average Load | 1.77MVA | 1.70MVA | 1.677MVA | 1.689MVA |
| PWC2 Load Factor (LF) | 0.631 | 0.61 | 0.6 | 0.605 |
| SSPWC Peak Load | 17.730MVA | 17.051MVA | 17.051MVA | 17.051MVA |
| SSPWC Average Load | 10.217MVA | 9.768MVA | 9.582MVA | 9.675MVA |
| SSPWC Load Factor (LF) | 0.576 | 0.573 | 0.562 | 0.568 |
| SST16 Peak Load | 61.789MVA | 58.578MVA | 58.578MVA | 58.578MVA |
| SST16 Average Load | 37.4MVA | 35.857MVA | 35.217MVA | 35.537MVA |
| SST16 Load Factor (LF) | 0.605 | 0.612 | 0.601 | 0.607 |
| QLD Peak Load | 7720.81MVA | 7656.80MVA | 7691.62MVA | 7674.21MVA |
| QLD Average Load | 6004.07MVA | 5894.18MVA | 5753.37MVA | 5823.78MVA |
| QLD Load Factor (LF) | 0.778 | 0.77 | 0.712 | 0.741 |
| Savings in QLD Electricity Generation Costs | 0.00% | -1.01% | -0.34% | -0.68% |
| QLD Peak Load (27.7%) | 7720.81MVA | 7656.85MVA | 7656.89MVA | 7656.87MVA |
| QLD Average Load (27.7%) | 6004.07MVA | 5894.18MVA | 5849.16MVA | 5871.67MVA |
| QLD Load Factor (LF) (27.7%) | 0.778 | 0.77 | 0.764 | 0.767 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | 0.82% | 0.76% | 0.79% |

(15) Table 6.2.8.1 – Scenario 8 - Effect of Residential Smart Grid 9th June 2011

### 6.2.9  SCENARIO 9 – Load Reduction Incident 18<sup>th</sup> January (Scenario 1)

The following results are with:

- Time of Use control set at $0.60 per kWh all day
- All cooking appliances (stove, oven etc) are not switched off if prices get high (not subject to price variation control)

A fault occurs at 7pm which means that the power available to the HAN is limited to 600W for 10 minutes.

RESULTS

Note that due to the HAN controller intervention during the load reduction command, the following alterations to usage took place:

- Both TVs go off for 10 minutes (7:00pm-7:10pm)
- AC is switched off for 10 minutes (7:00pm-7:10pm)
- F7 is switched off for 5 minutes (7:05pm-7:10pm)
- The computer and computer room lights (L5) are switched off for 5 minutes (7:05pm-7:10pm)
- The freezer is switched off for 5 minutes (7:05pm-7:10pm)

Figure 6.2.9.1 shows a close-up of the load profile during the fault, with the red line representing normal power use, and the black line representing the actual power used during the load reduction. It can be seen that power usage is reduced by as much as 1600W which is a reduction of approximately 73% of the normal load at that time. If this load reduction were to be performed on a large scale, this could potentially avoid situations such as rolling blackouts, and save large branches of the grid from losing power entirely.
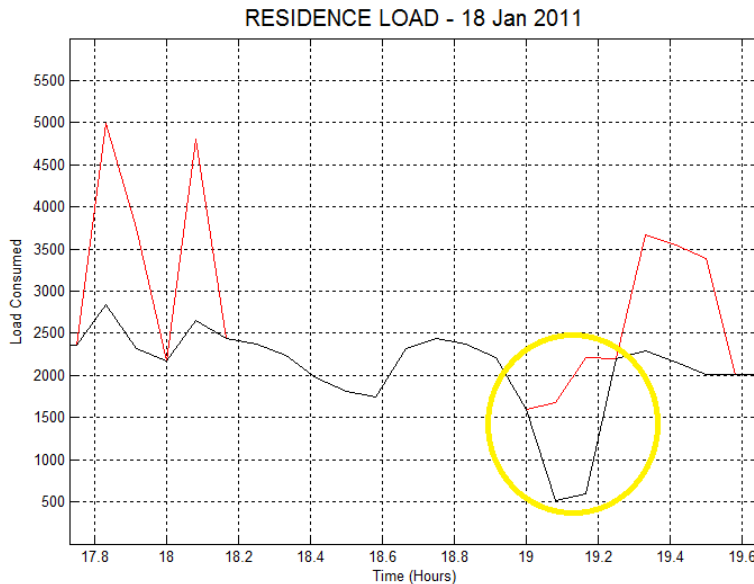
(72) **Figure 6.2.9.1 – Effect of Power Reduction on HAN 18<sup>th</sup> January 2011**

Although the above mentioned devices had to be switched off during this period, power to the fridge, dishwasher and all other lights being used at that time was maintained. Again, the priority of electrical devices depended upon the device designation, switching conditions and the HAN model being used (see sections 4.2.6, 4.3 and 4.5).

It is also important to note that if the same load reduction incident occurred and DG were being used, the batteries are allowed to discharge at approximately 960W. This would mean that the TVs, computer, computer room lights, freezer and ceiling fan would have all remained on, leaving only the AC off.

Overall, the results from this scenario are highly satisfactory, confirming one of the benefits of using Smart Grid; as potential disasters can be averted, and consumers experience relatively minor interruption.

## 6.2.10  SCENARIO 10 – Power Loss Incident 18<sup>th</sup> January (Scenario 7)

The following results are with:

- Time of Use control set at $0.60 per kWh
- Using Solar and batteries.
- Battery charge current at 20A or 30A DC.
- Battery discharge current at 20A or 34A DC.
- Initial battery charge at 50%
- Battery discharge limited to 5pm till 8pm

A fault occurs at 7pm which means that the power to the HAN is lost, and this lasts for 2 hours. In this condition, the HAN instigates the appropriate settings: Battery discharge set at 20A, and allowed to discharge lower than the normal 50%.

RESULTS

Note that due to the HAN controller intervention during the loss of power, the following alterations to usage took place:

- AC is switched off for the entire duration (7:00pm-9:00pm)
- TV1 is switched off from 7:00pm till 8:30pm (Allowed on from 8:30pm-9:00pm)
- TV2 is switched off from 7:00pm till 7:15pm and from 7:40pm-7:50pm
- CPU is switched off from 7:00pm till 8:30pm (Off for the entire duration of its normal use)
- Hot water unit is postponed from 7:35pm till 9:00pm
- Dishwasher is postponed from 7:15pm till 8:50pm

Figure 6.2.10.1 shows a close-up of the load profile during the loss of power. The red line is the normal power use, the black line is the actual power used during the power loss, and the blue line is the load on the grid.



**(72) Figure 6.2.10.1 – Effect of Power Loss on HAN - 18<sup>th</sup> January 2011**

As well as the aforementioned alterations to normal use, all required lighting is maintained as well as the fridge, freezer and ceiling fan (F7) during this period.

When power is restored at 9pm, the battery is left with 42.5% of its charge remaining, which will have little impact on the following day's usage.

This is obviously a good outcome, as power is able to be maintained at the residence with little disruption in lifestyle when compared with a total loss of power.

## 6.3   Summary of Simulation Results

The summary of all simulation results are shown in tables 6.3.1 and 6.3.2 below.  For both summer and winter, the best scenario for each key factor is highlighted in green, whilst the worst scenario for each key factor is highlighted in red.

| SUMMER | | | | | |
|--------|--|--|--|--|--|
| KEY FACTOR | Not Using SG | Scenario 1 | Scenario 3 | Scenario 5 | Scenario 7 |
| Savings Percentage | 0% | 14.32% | 65.01% | 42.50% | 31.79% |
| PRT Peak Load | 125.490kVA | 120.8kVA | 120.798kVA | 107.315kVA | 107.064kVA |
| PRT Average Load | 65.316kVA | 64.731kVA | 29.351kVA | 40.66kVA | 51.248kVA |
| PRT Load Factor (LF) | 0.52 | 0.536 | 0.152 | 0.379 | 0.479 |
| PWC2 Peak Load | 3.371MVA | 3.333MVA | 3.333MVA | 2.533MVA | 2.715MVA |
| PWC2 Average Load | 2.213MVA | 2.205MVA | 1.358MVA | 1.779MVA | 1.966MVA |
| PWC2 Load Factor (LF) | 0.656 | 0.658 | 0.535 | 0.702 | 0.726 |
| SSPWC Peak Load | 15.255MVA | 14.815MVA | 14.815MVA | 13.769MVA | 13.748MVA |
| SSPWC Average Load | 10.579MVA | 10.524MVA | 5.380MVA | 7.935MVA | 9.074MVA |
| SSPWC Load Factor (LF) | 0.693 | 0.711 | 0.387 | 0.576 | 0.66 |
| SST16 Peak Load | 58.606MVA | 57.734MVA | 57.734MVA | 47.141MVA | 47.619MVA |
| SST16 Average Load | 41.082MVA | 40.882MVA | 21.888MVA | 31.324MVA | 35.528MVA |
| SST16 Load Factor (LF) | 0.701 | 0.703 | 0.432 | 0.664 | 0.746 |
| QLD Peak Load | 8136.14MVA | 8008.91MVA | 8008.91MVA | 7087.39MVA | 7117.92MVA |
| QLD Average Load | 6380.61MVA | 6352.54MVA | 4022.285MVA | 5179.91MVA | 5695.69MVA |
| QLD Load Factor (LF) | 0.784 | 0.788 | 0.558 | 0.731 | 0.801 |

| | | | | | |
|---|---|---|---|---|---|
| Savings in QLD Electricity Generation Costs | 0.00% | 0.21% | 33.53% | 17.01% | 10.36% |
| QLD Peak Load (27.7%) | 8136.14MVA | 8059.19MVA | 8059.19MVA | 6994.46MVA | 7227.33MVA |
| QLD Average Load (27.7%) | 6380.61MVA | 6365.7 | 5128.05MVA | 5742.89MVA | 6016.83MVA |
| QLD Load Factor (LF) (27.7%) | 0.784 | 0.787 | 0.72 | 0.821 | 0.833 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | 0.18% | 18.39% | 10.70% | 7.24% |

**(16) Table 6.3.1 – Different Summer Smart Grid Scenarios Compared**

| KEY FACTOR | Not Using SG | Scenario 2 | Scenario 4 | Scenario 6 | Scenario 8 |
|---|---|---|---|---|---|
| **WINTER** | | | | | |
| Savings Percentage | 0% | 4.15% | 67.58% | 28.07% | 22.41% |
| PRT Peak Load | 147.053kVA | 131.327kVA | 131.028kVA | 139.550kVA | 138.832kVA |
| PRT Average Load | 54.221kVA | 58.058kVA | 26.637kVA | 43.909kVA | 49.69kVA |
| PRT Load Factor (LF) | 0.369 | 0.443 | 0.214 | 0.315 | 0.358 |
| PWC2 Peak Load | 2.810MVA | 2.745MVA | 2.744MVA | 2.824MVA | 2.793MVA |
| PWC2 Average Load | 1.77MVA | 1.845MVA | 1.2705MVA | 1.586MVA | 1.689MVA |
| PWC2 Load Factor (LF) | 0.631 | 0.672 | 0.501 | 0.559 | 0.605 |
| SSPWC Peak Load | 17.730MVA | 16.769MVA | 16.785MVA | 17.339MVA | 17.051MVA |
| SSPWC Average Load | 10.217MVA | 10.690MVA | 6.883MVA | 8.975MVA | 9.675MVA |
| SSPWC Load Factor (LF) | 0.576 | 0.637 | 0.443 | 0.518 | 0.568 |
| SST16 Peak Load | 61.789MVA | 57.213MVA | 59.273MVA | 58.955MVA | 58.578MVA |
| SST16 Average Load | 37.4MVA | 39.031MVA | 25.923MVA | 33.461MVA | 35.537MVA |
| SST16 Load Factor (LF) | 0.605 | 0.671 | 0.48 | 0.562 | 0.607 |
| QLD Peak Load | 7720.81MVA | 7693.81MVA | 7690.26MVA | 8177.94MVA | 7674.21MVA |
| QLD Average Load | 6004.07MVA | 6187.48MVA | 4696.095MVA | 5515.52MVA | 5823.78MVA |
| QLD Load Factor (LF) | 0.778 | 0.804 | 0.629 | 0.675 | 0.741 |
| Savings in QLD Electricity Generation Costs | 0.00% | -2.62% | 18.38% | 2.68% | -0.68% |
| QLD Peak Load (27.7%) | 7720.81MVA | 7374.85MVA | 7538.74MVA | 7705.50MVA | 7656.87MVA |
| QLD Average Load (27.7%) | 6004.07MVA | 6117.40MVA | 5195.87MVA | 5702.20MVA | 5871.67MVA |
| QLD Load Factor (LF) (27.7%) | 0.778 | 0.821 | 0.708 | 0.74 | 0.767 |
| Savings in QLD Electricity Generation Costs (27.7%) | 0.00% | -0.02% | 11.27% | 2.30% | 0.79% |

**(17) Table 6.3.2 – Different Winter Smart Grid Scenarios Compared**

## 6.4 Analysis and Discussion of Results

### 6.4.1 Discussion of Results

Each scenario will be looked at individually with comments and conclusions made. Refer to tables 6.3.1 and 6.3.2 as well as the respective scenarios in section 6.2.

Scenario 1
This scenario is in summer with only price variation control. As the cooking appliances were exempt from the price variation control, there is little interference other than the AC, hot water unit and dishwasher.  In table 6.3.1, it is clear that key factors are improved in every aspect, but is minimal in comparison with other summer

scenarios. This is not surprising, as the other scenarios take advantage of distributed generation, which reduces load on the grid. Greater results may be found with a more accurate way to assess the impact on higher levels of the grid (see sections 3.4, 5.2.2 and 5.2.3). Comments on this point will be given in section 6.4.2.

Scenario 2

This scenario is similar to scenario 1, but a different price limit was used in the price variation control (see section 5.3). This meant that heavier electrical loads were more 'encouraged' to delay their operation to off-peak times. It also meant slightly more interruption to the consumers electricity usage.

Again improvements are made in all key areas such as LF at all levels and peak loads at every level. The average QLD load has increased, but this is not an issue, as the load factor is increased and the peak load is reduced. This scenario (as opposed to scenario 1) appears to be better suited to winter months, but again, this may be due to imperfect analysis techniques.

Scenario 3

This scenario incorporates PV assistance with the price variation control, and the cooking appliances are still exempt from control. The effect on alterations to normal electricity usage was similar to that of scenario 1; however, due to the presence of PV input, there was less interruption during daylight hours. The PV also had a drastic effect on key factors.

Savings to the consumer and the QLD electricity generation costs were very high, as large amounts of electricity were being fed-back into the grid due to the wide spread PV usage. This actually had a negative impact on system load factors which were heavily reduced. This is because the electricity fed back is high, and only for a relatively short period of the day (daytime hours only). Also related is the reduction in the average loads at all levels of the grid. Given the goals of Smart Grid, it is therefore arguable as to the effectiveness of this particular scenario.

Scenario 4

Very similar comments can be made to that of scenario 3. It is interesting to note that when compared with scenario 3, the average loads are comparatively not as reduced. This is likely due to the fact that there are much higher loads during the middle of the day in summer than there are in winter, and the PV feed-in 'counter-acts' this load. The scenario where PV is used with price variation control is therefore probably better suited to the summer months.

Scenario 5

In this scenario, batteries are now used as well, and cooking appliances are now subject to the price variation control. With the price limit used, there is unsatisfactorily high interruption of the consumers electricity use.

As some of the PV output is used to charge the batteries, the negative effects of the PV on overall system key factors diminish. For example, the LF is much higher than that of scenario 3, but for PRT, SSPWC and SST16, is still not higher than if SG is not used. Naturally, savings to the consumer and QLD generation are lower than scenario 3, but still an excellent improvement on the current costs (ie. when not using SG).

The greatest result of this scenario is the reduction in peak loads, with a reduction of up to 14% in the QLD peak load. This is due to the usage of batteries during peak times, which is a key aspect of this scenario.

Scenario 6

As this scenario is the 'winter version' of scenario 5, similar effects are achieved. In terms of interruption to the electricity usage of the consumer, this impact is reduced; largely due to the fact that the AC, which is a significant load in summer, is not used in winter.

This reduction in interruption to electricity usage also sees comparatively lower positive impact on load factors and peak loads when compared with scenario 5. In fact, this scenario produces some of the worst peak load figures in winter, which must be attributed to imperfection in the analysis stage.

Use of the smart grid tends to reduce peak loads at a local level, but increase peak loads on a state wide level.

Scenario 7

This scenario is similar to scenario 5, but sees a greater use of the batteries. This means that more of the PV output is used to charge the batteries and hence the batteries can be more heavily used at peak times during the evening. Subsequently, less power from the PV is fed into the grid which means lesser savings for the customer, but greater impact on the other key factors in the network.

This is reflected by the fact that this scenario achieved the best LF on all levels of the grid, with a potential improvement of from 0.784 to 0.833. Also, peak loads are heavily reduced at all levels of the grid.

When compared with scenario 5, there is much less interruption to electricity use of the consumer, which was a primary aim of this scenario, although undesirable interruptions still occur.

Overall, this is thought to be the best scenario, having balance in terms of reduction in electricity costs, reduction in peak loads, and increase in load factors.

Scenario 8

When compared with scenario 7, this scenario in winter has the main benefit of very little interference with the consumer's electricity usage. In fact, of all the scenarios, this scenario is superior in that aspect.

Although load factors and peak loads are better than scenario 6, they are still not as good as was expected which again indicates an inaccuracy in the scaling from the test residence up to higher levels of the grid.

## 6.4.2    Summary of Results

In general the results prove the effectiveness of using Smart Grid in Queensland. There are different aspects that can be identified and expanded upon.

Potential Errors in Analysis

It is generally felt that the actual HAN model developed is effective in its intended purpose, however, it is apparent that there may be errors in the actual analysis used in sections 3.4, 5.2.2 and 5.2.3.

Of particular mention is the part of the analysis phase where changes in the residence load due to Smart Grid are applied to the PRT load. As mentioned in section 5.2.2:

In all simulations, the intervals used were:

- Midnight to 5am – Night time off-peak
- 5am to 9am – Morning Peak
- 9am to 4pm – Daytime off-peak
- 4pm to 5pm – Early night peak
- 5pm to 8:45pm – Night peak
- 8:45 to Midnight – Night time off-peak

As the control methods used in the HAN model often meant that loads were 'pushed' into the "8:45pm to midnight bracket", it meant that a spike would occur at around 9pm on the Smart Grid affected loads. This would sometimes create a new 'false peak load' which was detected by the Matlab program. In this way, the residential component of all higher level loads was in a sense 'corrupted'. In reality, these off-peak loads would be spread over the off peak period, and not bunched up at 9pm. This outlines the difficulties in modelling electricity usage, when this clearly varies greatly in one house to the next.

Although rational and valuable results were still found, it is believed that with a more accurate analysis technique, the results from the simulations would be more realistic. The likely outcome would be that the effects of using the Smart Grid scenarios would achieve even better results, i.e. even lower peak loads and higher load factors

Effects of Smart Grid without Distributed Generation (Scenarios 1 and 2)

Results consistently showed that using a HAN network and price variation control alone will improve the electricity network.

The best results seen were:

- Savings to the consumer of 14.32% (if a time of use tariff were used)
- Improvements of the Queensland Load Factor of from 0.778 up to 0.821
- Reduction in Queensland Peak Load of 4.5%
- Savings in QLD electricity generation costs of 0.21%

These results are impressive, but could be better, and depending upon the cost to implement this scenario, it may or may not be a viable option for Smart Grid in Queensland.

Other Possible Models

Depending upon the customers willingness to participate in demand side response, other viable options may include only controlling certain electrical appliances, rather than the whole house.

Results from the simulations consistently showed that main appliances to be switched off or postponed were the hot water unit, washing machine, dishwasher and air conditioner. These, along with other appliances such as the dryer, vacuum and iron are not considered as essential devices, and also consume large amounts of power during use.

It is therefore possible to have a HAN where only these key appliances are controlled by price variation control, or by the utilities. This of course would be a less 'smart' solution, but could be a compromise due to governmental, economical or social issues.

Summer Vs Winter

It has become apparent that demand side response is more effective in summer, simply due to the presence of higher refrigeration and air conditioning loads. Any form of smart grid would demonstrate a similar outcome, but regardless of this fact, it does not diminish the validity of using Smart Grid in Queensland

Effects of Smart Grid Using Distributed Generation (Scenarios 3-8)

In the results, it was typically found that DG enhanced HANs were more effective in reducing peak loads and improving load factors. Based on the results of the scenarios where only PV was used (and not batteries), it is concluded that this may not be a viable option for Smart Grid implementation, as it would make the grid too unstable due to the excessive amounts of power being fed back in. It is better that DG be used

locally, and this is best achieved if the energy generated can actually be used during peak times.

With this in mind, the best results achieved were:

- Savings to the consumer of 42.5% (if a time of use tariff were used)
- Improvements of the Queensland Load Factor of from 0.778 up to 0.833
- Reduction in Queensland Peak Load of 14%
- Savings in QLD electricity generation costs of 17.01%

Furthermore, it is suggested that scenario 7 and 8 would be the overall most beneficial implementation of Smart Grid in Queensland, depending upon cost to install.

Self Healing Network

Scenario 9 and 10 proved that this Smart Grid Model would effectively allow greater self healing within the network. It means that potential loss of power can be avoided, and that if power is lost, that customers maintain some electricity usage.

This also validated the HAN controller's role in smoothly integrating DG into the grid.

# 6.5  Future Work

Although the goals of this project have been met, there is still further work that could be performed based on this study:

1. A more comprehensive amount of data could be gathered regarding residential electrical loads. This particularly needs to be done for summer months, as some measurements for this study could only be taken in winter months.
2. As mentioned, the analysis of the simulation results could be improved upon. This may give more specific results to validate SG.
3. Other HAN models could be trialled.
4. Greater research into the specific devices and the cost of implementing the proposed Smart Grid model.

# Chapter 7    Conclusion

The current electricity network in Queensland is lacking in that there too many avoidable faults occurring is not enough control of electrical loads by consumers and utilities, and in general, systems are not as efficient as they could be. This project has demonstrated that the implementation of Smart Grid will help tackle these issues.

Through sensing, measurement and control, advanced control methods, and integrated communications, Smart Grid allows demand side response, allows integration of distributed generation, improves the quality of power and creates a self healing network.

This study utilises data obtained from the AEMO, Energex and the Bureau of Meteorology to analyse the current state of the network and provide a framework within which the effects of Smart Grid in Queensland can be simulated.

This project has focussed primarily upon domestic power use, and therefore a HAN model has been constructed to test the benefits that could be achieved from using Smart Grid principles in residential applications.

Simulations were designed, based upon the HAN model, using Matlab, and give a reference as to the effectiveness of several different Smart Grid scenarios. Analysis of these results was also performed using mathematical models and Matlab programs, and provides evidence of Smart Grid's relevance in Queensland in the form of quantitative data.

The results have shown that Smart Grid if used in this capacity, it could mean that Queensland Load Factors would improve from 0.778 up to as much as 0.833 in summer. It has also been found that Queensland's peak load could be reduced by up to 14% in summer. These kinds of improvements would lead to higher generating capacity utilisation, reduction in maintenance, increased capital investment efficiency, and consequently a reduction in negative environmental impacts.

Furthermore, results indicated that Smart Grid used in this way yielded better results in summer months as opposed to winter months, and that Smart Grid, when used with Distributed Generation can allow even greater benefits than Smart Grid alone.

Simulations were also performed which demonstrated the Smart Grid's ability to avoid disasters on the electricity network. Results showed that through automatic reduction of power enabled by the smart grid, that total loss of power can be avoided in some circumstances. Results also showed how a Smart Grid HAN when coupled with Distributed Generation can maintain power in a 'smart' way to the residence if mains power is lost.

In conclusion, the aims of this project have been met, in that evidence has been provided that suggests the potential benefits afforded if Smart Grid were used in

Queensland. It is hoped that the outcomes of this project will stimulate greater implementation of Smart Grid, and provide reference for future work in this area of study.

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# Appendix A1 – Project Specification

University of Southern Queensland

FACULTY OF ENGINERING AND SURVEYING

## ENG4111/4112 Research Project

## PROJECT SPECIFICATION

FOR:              Adam John HARRIMAN

TOPIC:          SMART GRID FOR TOMORROW'S ELECTRICITY DISTRIBUTION

SUPERVISOR:   Dr. Wei Xiang

SPONSOR:       Faculty of Engineering and Surveying, USQ

PROJECT AIM:   To research the principles of smart grid networks, prove their superiority and enhancement to existing electrical network systems, and to simulate the use of a smart grid network in order to obtain quantitative evidence.

PROGRAMME:    (Issue A, 04 April 2011)

1. Research existing studies relating to Smart Grid, and perform a literature review, particularly demonstrating the benefits of smart grid.

2. Gather and analyse current data regarding electricity demands and prices in Queensland. Also gather other relevant data which may influence electricity usage, such as average temperatures.

3. Assess the electricity usage of an 'average' SE Queensland household and present realistic scenarios which will model a daily energy usage cycle of the household. Will include an inventory of electrical appliances in use and/or use of smart meters.

4. Discuss/analyse the current daily electricity cycle of an average SE Queensland household in relation to current Queensland-wide electricity demand and prices.

5. Design and propose the actual layout and function of a smart grid within the home. Simulate (using Matlab software) a daily cycle of the household using Smart Grid technology and compare results with previous findings.

6. Using the found data, quantify the actual impact of the use of Smart Grid on a residential level, and in turn, the potential impact on the electricity network as a whole.

*As time permits:*

7. Research into and propose the actual devices that will be used in the residential smart grid.

8. Perform a similar simulation on a distribution / high voltage network. This will involve gathering more specific data and different analysis techniques.

AGREED:    _____(Student)  :
_____(Supervisor)

Date:    /  04  / 2011                    Date:    /  04  / 2011

# Appendix A2 – Project Methodology

## Obtaining Data

The first step is to choose a suitable location to assess.  This has been done and a residence in Plantation Rise Drive has been chosen.  The main types of data that need to be obtained are electrical load data and weather pattern data.   It can be broken down as follows:

<u>Weather and Daylight Data</u>

As shown in the literature review, electricity usage is affected by weather conditions.  This is mainly manifest by the link between temperatures and the use of devices that draw heavy current.  For example, in hot weather, air-conditioning is used, and in cold weather heating may be used.  Also, sunrise and sunset times affect the usage of artificial lighting.

Using weather data will help to choose on what days electrical loads should be assessed, and help find seasonal patterns and hence demonstrate the benefits possible with smart grid.  This weather data will be obtained from the Bureau of Meteorology.

<u>Measured Electrical Load Data</u>

Electrical loads will be measured at the residence to obtain information about current electricity usage. Simultaneously, loads will be measured at the transformer (SC1494340) which feeds the residence to find a relationship between the two.  These load measurements will be performed by Energex field staff, by using current transformers (CTs) and electricity meters, then tabulated using Energex software.

Load measurements will also be taken from the 11kV feeder (PWC2) as well as the 11kV and 33kV substations SSPWC and SST16, and will be accessed via the Energex SCADA system.  Additional load data will be found at SC1427301, which is another transformer on the PWC2 feeder, to find similarities.

Further load data will be obtained from the AEMO website (see section 1.3) to indicate Qld-wide loads on the same dates.

It is hoped that the similarities and relationships between different load profiles may show patterns and allow the projection of the results from one residence onto a larger network, thus showing potential gains on a larger scale.

<u>Assessed Electrical Load Data</u>

An inventory of all devices/equipment that use electricity within the residence will be performed. This involves locating all equipment and obtaining load/current ratings, and/or using tools to find the electrical current being drawn. There may be a need for thermodynamic modelling of AC performance.

All data that is acquired will be used to help design the HAN, will provide data inputs for the simulation, and will be useful in comparing the results in the analysis phase of the project.

# Network Design

An appropriate home area network (HAN) design must be formed in order to model a residential smart grid. This will take into account all existing electrical equipment at the residence, and will propose in what manner the HAN will operate. It will involve:

- Designating devices to circuits (eg. essential and non-essential)
- Designating switching conditions(eg. according to electricity prices)
- Proposing enhancements to the existing network (eg. solar panels)

Other aspects of design that can be specified are the actual communications topology and functioning of the HAN, as well as the 'smart devices' which may be used in the HAN network.

To aid in network design, other smart grid and associated studies will be taken into account, such as that found in the literature review (section 2).

# Simulation / Testing

Using the network design that is formulated, simulations can be performed which can assess the performance of a smart HAN. Simulations will be carried out with different scenarios such as:

- Existing electrical installation plus HAN
- Existing electrical installation plus HAN plus enhancements (eg. solar power)
- Reduction or loss of power on the network
- High electricity prices

Simulations will be performed using Matlab software and will consist of writing code in .m files, or using the associated simulink software.

The 'framework' of the simulation code will be the actual design of the network. The inputs to the code will represent signals from electricity utilities such as pricing and load data, as well as weather data (see section 4.1). Outputs from the code – will primarily be electricity usage at the residence in the form of a load profile, as well as information about system performance such as the load factor (LF).

# Analysis

This is an essential part of the project as it will largely determine the effectiveness of the Smart Grid. By comparing the real-life data obtained from the load measurements with the data obtained from the simulation, highly quantitative results can be found. This will show the exact gains that can be achieved by implementing the smart grid into residential settings in south east Queensland.

Again, some of the analysis of system performance will be performed using matlab, as well as producing tables and graphs to compare data. It is hoped that through using information found that relates loads at the residence to higher voltage loads (see section 4.1), that the benefits – such as reducing peak demand – can be predicted on a system wide basis.

# Appendix A3 – Consequential Effects, Implications and Ethics

1. **Is there any uncertainty about researching this project topic?**

   There is no uncertainty as to whether Smart Grid improves the efficiency and operation of the electricity grid. The exact benefits are unknown, and will hopefully be shown in this project. There is also question of the economic viability of fully implementing the Smart Grid.

2. **What impact will this project have on finite resources and waste production?**

   The actual project will generate no waste, and will not consume any resources.

3. **How could this project effect the environment?**

   This project will have no effect on the environment in any way.

4. **Are there any costs to reduce pollution within this project work?**

   Not necessary

5. **What could be the global impact of this project?**

   Globally, this project could lead to a greater acceptance of Smart Grid and essentially improve the way in which countries manage electricity.

6. **Are sustainability outcomes the same if this projects outcomes were used in all countries around the world?  Would it be different for undeveloped countries?**

   Sustainability outcomes would likely be the same regardless of where Smart Grid is used. It would probably be harder to bring about smart grid in underdeveloped countries that have poor economic structures and government planning.

7. **Are there any other ethical issues that may arise as a consequence of this project?**

   If governments/industries are to use smart grid and associated technologies as this project encourages, it may mean a loss of income to manufacturers and providers of redundant technologies. Overall, the outcomes of this project would be in the best interest of the community as a whole.

The purpose of this project is to conclude whether smart grid will improve current electrical networks, and if so, by how much.  If this is apparent and a feasible solution is discovered, it would be my ethical responsibility to present this information to appropriate authorities such as government bodies, so as to improve the electricity networks in south east Queensland and even around the world.

# Appendix A4 – Risk Assessment

The network design, simulation and analysis phases have no risks involved.  During the stage of obtaining data, there will be interaction with 240V AC equipment, which may be located in the ceiling space.  At the completion of the project, there are no future risks, as no outcomes would bring about harm to persons or property.

## Risk Management Chart

| Description of Hazard | People at Risk | Number at Risk | Parts of Body |
|---|---|---|---|
| Electrocution while inspecting electrical equipment | Persons performing inspection | 1 | All |
| **Risk Level** | | **Controls** | |
| High consequences - Low Likelihood | | Before inspection, the entire site will be isolated using the main switch | |

| Description of Hazard | People at Risk | Number at Risk | Parts of Body |
|---|---|---|---|
| Electrocution while taking current measurements | Persons taking measurements | 1 | All |
| **Risk Level** | | **Controls** | |
| High consequences - Low Likelihood | | Measurements will be taken with a 'current transformer' or 'Hall effect' type device, meaning no contact with live conductors.  Residence DB also uses RCCBs | |

| Description of Hazard | People at Risk | Number at Risk | Parts of Body |
|---|---|---|---|
| Falling from ladder while accessing ceiling space | Persons climbing ladder | 1 | All |
| **Risk Level** | | **Controls** | |

| Medium consequences - Low Likelihood | Appropriate ladder will be used.  A 'spotter' will help by stabilising ladder. |
| --- | --- |

# Appendix A5 – Resource Analysis

The major resources that will be required for this project are:

- Office equipment – Computer, printer, scanner, internet etc.

    Access to this equipment is available at no cost

- Simulation Software – Matlab R2008b version

    Access to this equipment is available at no cost

- USQ library and resources including IEEE Explore

    Access to this equipment is available at no cost, provided by USQ.

- Data pertaining to Elecrical loads, weather patterns and statistical data.

    Data will be gathered from AEMO, Bureau of Meteorology, ABS etc, and in some cases may incur a minimal fee.

- Access to a typical Residence on the Sunshine Coast, Qld.

    Access to a suitable residence has been identified, and permission to access details on electrical devices and usage habits have been granted at no cost.

- A clamp meter is needed to measure the current drawn by individual electrical devices at the residence.  For the most accurate results, a true RMS meter would be desirable.

| WE 26-Mar | WE 2-Apr | WE 9-Apr | WE 16-Apr | WE 23-Apr | WE 30-Apr | WE 7-May | WE 14-May | WE 21-May | WE 28-May | WE 4-Jun | WE 11-Jun | WE 18-Jun | WE 25-Jun |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Topic Approved

Project Specification

Research Theory

Project Appreciation

Obtaining (AEMO,BOM) Data pt.1

Obtaining Energex Data

COMPILE REPORT

| WE 18-Jun | WE 25-Jun | WE 2-Jul | WE 9-Jul | WE 16-Jul | WE 23-Jul | WE 30-Jul | WE 6-Aug | WE 13-Aug | WE 20-Aug | WE 27-Aug | WE 3-Sep | WE 10-Sep | WE 17-Sep | WE 24-Sep | WE 29-Oct |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Obtaining (AEMO,BOM) Data pt.2

Obtaining Electrical Device Data

Network Design

Simulation Design

Run Simulations

Analysis / Discussion of Results

Project
Speeches

COMPILE REPORT

## Appendix A6 – Project Timeline

# Appendix B1 – DATA LOG

| DATE | Reason | QUEENSLAND LOAD DATA | QUEENSLAND PRICE DATA | SUBSTATION LOAD DATA | TRANSFORMER LOAD DATA | HOUSE LOAD DATA | WEATHER DATA | DAY OF WEEK |
|---|---|---|---|---|---|---|---|---|
| 14-Aug-10 | COLD DAY | YES | YES | YES | N/A | N/A | YES | SAT |
| 17-Dec-10 | HOT DAY | YES | YES | YES | N/A | N/A | YES | FRI |
| 18-Jan-11 | HOT DAY | YES | YES | YES | N/A | N/A | YES | TUE |
| 12-May-11 | COLD DAY | YES | YES | YES | N/A | N/A | YES | THU |
| 9-Jun-11 | COLD DAY | YES | YES | YES | N/A | YES | N/A | THU |
| 19 MAY - 21 MAY 2011 | METERS | YES | YES | YES | YES | N/A | N/A | THU-SAT |
| 9 June - 11 June 2011 | METERS | YES | YES | YES | N/A | YES | N/A | THU-SAT |
| 14 July - 16 July 2011 | METERS | YES | YES | YES | YES | YES | N/A | THU-SAT |

= DATA READY

= DATA NOT AVAILABLE

*Note that Substation data is in VA
*Note that Queensland data is in MW
*Note that House & Transformer data is in Amps

# Appendix C1 – Residence Lighting Layout



LIGHTING LAYOUT
SCALE: 1:100 @ A4

LEGEND
L    DENOTES LIGHT
F    DENOTES CEILING FAN
EF   DENOTES EXHAUST FAN
S    DENOTES SWITCH
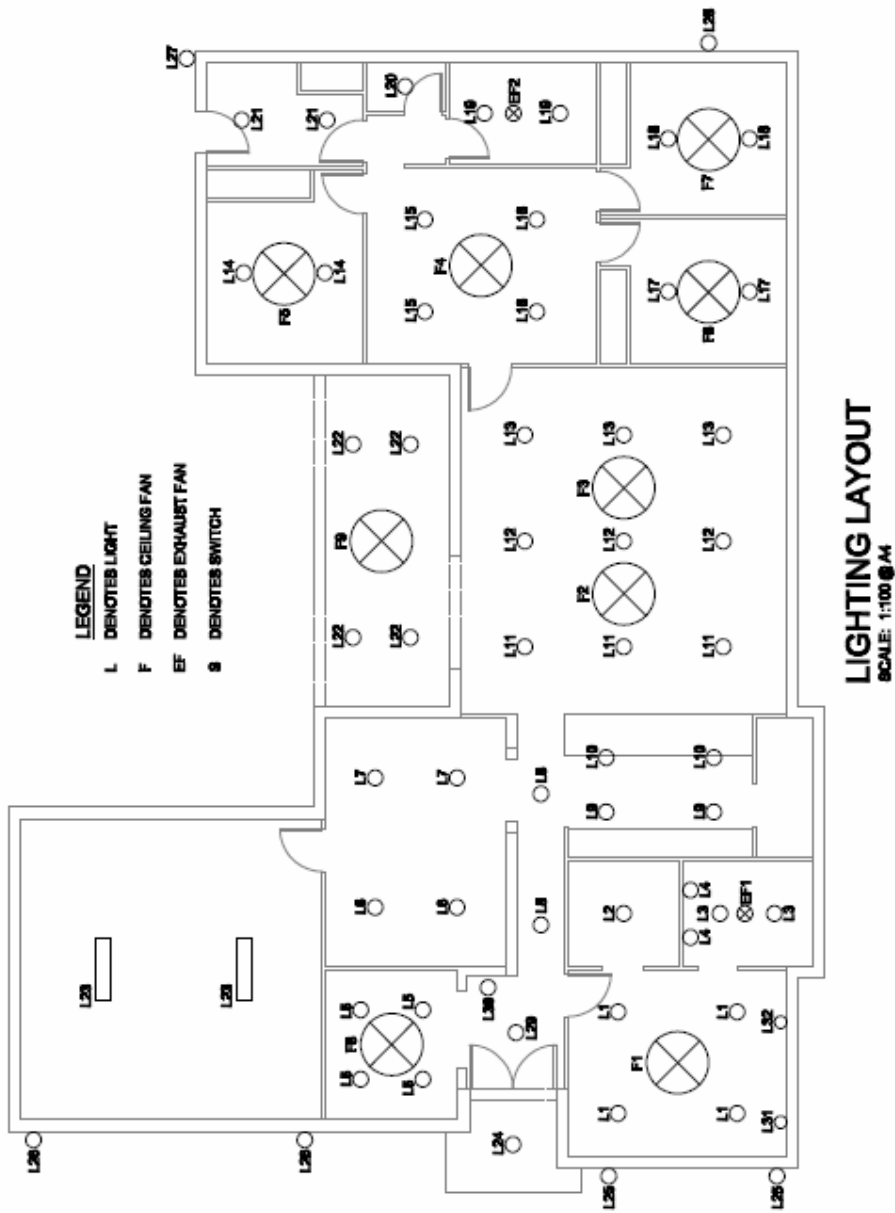
# Appendix C2 – Residence Power Layout



**POWER LAYOUT**
SCALE: 1:100 @ A4

**LEGEND**

| | |
|---|---|
| AC | AIR CONDITIONING UNIT - IN CEILING |
| CPU | COMPUTER & PRINTER - GPO |
| DR | DRYER - GPO |
| DW | DISHWASHER - GPO |
| DVD | DVD PLAYER - GPO |
| EF | ELECTRIC FRYING PAN - GPO |
| FR | FRIDGE - GPO |
| FRZ | FREEZER - GPO |
| HWU | HEAT PUMP HOT WATER UNIT |
| IR | CLOTHES IRON - GPO |
| MW | MICROWAVE - GPO |
| OV | OVEN |
| RH | RANGE HOOD - GPO |
| PMP | WATER PUMP - GPO |
| ST | STOVE |
| TV | TELEVISION - GPO |
| TR | TOASTER - GPO |
| WM | WASHING MACHINE - GPO |

# Appendix D1 – Occupant Lighting Usage Form

| TIME (AM) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ASLEEP | | | | | | | | | | | | | | | | | | | | |
| 0500 | | | | | | | | | | | | | | | | | | | | |
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| TIME (AM) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 30 | 31 |
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| TIME (AM) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 30 | 31 |
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| TIME (PM) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 30 | 31 |
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| 0430 | | | | | | | | | | | | | | | | | | | | |
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| TIME (PM) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 30 | 31 |
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| 0955 | | | | | | | | | | | | | | | | | | | | |
| 1000 | | | | | | | | | | | | | | | | | | | | |

■ Denotes lights typically on in summer & winter
■ Denotes lights typically on in winter only

*For comprehensive load values and times for particular dates, refer to the associated .txt files.

# Appendix D2 – Occupant Power Usage Form

| TIME (AM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0005 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0010 | | | | | | | | | | blue | | | | | red | | red | | | orange |
| 0015 | | | | | | | | | | orange | | | | | red | | red | | | orange |
| 0020 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0025 | | | | | | | | | | | | | | | red | | red | | red | orange |
| 0030 | | | | | | | | | | | | | | | red | | red | | orange | orange |
| 0035 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0040 | | | | | | | | | | | | | | | red | | red | | | red |
| 0045 | | | | | | | | | | | | | | | red | | red | | | red |
| 0050 | | | | | | | | | | | | | | | red | | red | | | |
| 0055 | | | | | | | | | | | | | | | red | | red | | orange | |
| 0100 | | | | | | | | | | | | | | | red | | red | | orange | |
| 0105 | | | | | | | | | | | | | | | red | | red | | | |
| 0110 | | | | | | | | | | | | | | | red | | red | | | |
| 0115 | | | | | | | | | | | | | | | red | | red | | | |
| 0120 | | | | | | | | | | | | | | | red | | red | | red | |
| 0125 | | | | | | | | | | | | | | | red | | red | | red | |
| 0130 | | | | | | | | | | | | | | | red | | red | | orange | |
| 0135 | | | | | | | | | | | | | | | red | | red | | | red |
| 0140 | | | | | | | | | | | | | | | red | | red | | | red |
| 0145 | | | | | | | | | | | | | | | red | | red | | | red |
| 0150 | | | | | | | | | | | | | | | red | | red | | | red |
| 0155 | | | | | | | | | | | | | | | red | | red | | orange | red |
| 0200 | | | | | | | | | | | | | | | red | | red | | orange | orange |
| 0205 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0210 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0215 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0220 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0225 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0230 | | | | | | | | | | blue | | | | | red | | red | | red | orange |
| 0235 | | | | | | | | | | orange | | | | | red | | red | | orange | orange |
| 0240 | | | | | | | | | | | | | | | red | | red | | | red |
| TIME (AM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
| 0245 | | | | | | | | | | | | | | | red | | red | | | red |
| 0250 | | | | | | | | | | | | | | | red | | red | | | |
| 0255 | | | | | | | | | | | | | | | red | | red | | red | |
| 0300 | | | | | | | | | | | | | | | red | | red | | orange | |

| TIME (AM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0305 | | | | | | | | | | | | | | | red | | red | | orange | |
| 0310 | | | | | | | | | | | | | | | red | | red | | | |
| 0315 | | | | | | | | | | | | | | | red | | red | | | |
| 0320 | | | | | | | | | | | | | | | red | | red | | | |
| 0325 | | | | | | | | | | | | | | | red | | red | | | |
| 0330 | | | | | | | | | | | | | | | red | | red | | red | red |
| 0335 | | | | | | | | | | | | | | | red | | red | | orange | red |
| 0340 | | | | | | | | | | | | | | | red | | red | | | red |
| 0345 | | | | | | | | | | | | | | | red | | red | | | red |
| 0350 | | | | | | | | | | | | | | | red | | red | | | red |
| 0355 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0400 | | | | | | | | | | | | | | | red | | red | | orange | orange |
| 0405 | | | | | | | | | | | | | | | red | | red | | orange | orange |
| 0410 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0415 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0420 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0425 | | | | | | | | | | | | | | | red | | red | | red | orange |
| 0430 | | | | | | | | | | | | | | | red | | red | | red | orange |
| 0435 | | | | | | | | | | | | | | | red | | red | | orange | red |
| 0440 | | | | | | | | | | | | | | | red | | red | | | red |
| 0445 | | | | | | | | | | | | | | | red | | red | | | |
| 0450 | | | | | | | | | | blue | | | | | red | | red | | | |
| 0455 | | | | | | | | | | orange | | | | | red | | red | | | |
| 0500 | | | | | | | | | | | | | | | red | | red | | orange | |
| 0505 | | | | | | | | | | | | | | | red | | red | | orange | |
| 0510 | | | | | | | | | | | | | | | red | | red | | | |
| 0515 | | | | | | | | | | | | | | | red | | red | | | |
| 0520 | | | | | | | | | | | | | | | red | | red | | | |
| 0525 | | | | | | | | | | | | | | | red | | red | | | red |
| TIME (AM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
| 0530 | | | | | | | | | | | | | | | red | | red | | red | red |
| 0535 | | | | | | | | | | | | | | | | | red | orange | orange | red |
| 0540 | | | | | | | | | | | | | | | | | red | orange | | red |
| 0545 | | | | | | | | | | | | | | | | | red | orange | | red |
| 0550 | | | | | | | | | | blue | | | | | | | red | | | orange |
| 0555 | | | | | | | | | | orange | | | | | | | red | | | orange |
| 0600 | | | | | | | | | | orange | | | | | | | red | | | orange |
| 0605 | | | | | | | orange | | | | | | | | | | red | | orange | orange |
| 0610 | | | | | | | orange | | | | | | | | | | red | | orange | orange |
| 0615 | | | | | | | orange | | | | | | | | | | red | | red | orange |
| 0620 | | | | | | | orange | | | | | | | | | | red | | | orange |
| 0625 | orange | | | | | | orange | | | | | | | | | | red | | | orange |

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| TIME (AM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0630 | O | | | | O | | O | | | | | | | | | | R | | O | R |
| 0635 | | | | | | | O | | | | | | O | | | | R | | O | R |
| 0640 | | | | | | | O | | | | | | O | | | | R | | O | |
| 0645 | | | | | | | O | | | | | | O | | | | R | | | |
| 0650 | | | | | | | O | | | | | | O | | | | R | | | |
| 0655 | | | | | | | O | | | | | | O | | | | | | | |
| 0700 | | | | | | | | | | | | | | | | | | | | |
| 0705 | | | O | | | | O | | | | | | | | | | | | O | |
| 0710 | | | O | | O | | O | | | | | | | | | | | | O | |
| 0715 | | | O | | | | O | | | | | | | | | | | | O | |
| 0720 | | | | | | | O | | | | | | O | | | | | | R | R |
| 0725 | | | | | | | O | | | | | | O | | | | | | | R |
| 0730 | | | | | | | O | | | | | | O | | | | | | | R |
| 0735 | | | | | | | O | | | | | | O | | | | | O | O | R |
| 0740 | | | | | | | O | | | B | | | O | | | | | O | O | R |
| 0745 | | | | | | | O | | | O | | | O | | | | | O | | R |
| 0750 | | | | | | | O | | | | | | O | | | | | O | | O |
| 0755 | | | | | | | O | | | | | | O | | | | | | | O |
| 0800 | | | | | | | O | | | | | | | | | | | O | | O |
| 0805 | | | | | | | O | | | | | | | | | | | O | R | O |
| 0810 | | | | | | | O | | | | | | | | | | | O | O | O |
| TIME (AM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
| 0815 | | | | | | | O | | | | | | | | | | | O | | O |
| 0820 | | | | | | | O | | | | | | | | | | | O | | O |
| 0825 | | | | | | | O | | | | | | | O | | O | | | | O |
| 0830 | | | | | | | O | | | | R | | | O | | O | | | | R |
| 0835 | | | | | | | O | | | | R | | | O | | | | | O | R |
| 0840 | | | | | | | O | | | | R | | | O | | | | | O | |
| 0845 | | | | | | | O | | | B | R | | | O | | | | | | |
| 0850 | | | | | | | O | | | O | R | | | O | | | | | | |
| 0855 | | | | | | | O | | | O | R | | | | | | | | | |
| 0900 | | | | | | | O | | | | R | | | O | | | | | R | |
| 0905 | | | | | | | | | | | R | | | | | | | | R | |
| 0910 | | | | | | | | | | | R | | | | | | | | O | |
| 0915 | | | | | | | | | | | R | | | | | | | | | R |
| 0920 | | | | | | | | | | | R | | | | | O | | | | R |
| 0925 | | | | | | | | | | | R | | | | | | | | | R |
| 0930 | | | | | | | | | | | R | | | | | O | | | O | O |
| 0935 | | | | | | | | | | | R | | | | | | | | O | R |
| 0940 | | | | | | | | | | | R | | | | | | | | O | R |
| 0945 | | | | | | | | | | | R | | | | | O | | | O | O |
| 0950 | | | | | | | | | | | R | | | | | O | | | | O |

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| TIME (AM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0955 | | | | | | | | | | | red | | | | | orange | | | | orange |
| 1000 | | | | | | | | | | | red | | | | | orange | | | | orange |
| 1005 | | | | | | | | | | | | | | | | orange | | | red | orange |
| 1010 | | | | | | | | | | | | | | | | orange | | | orange | orange |
| 1015 | | | | | | | | | | | | | | | | orange | | | | orange |
| 1020 | | | | | | | | | | | | | | | | orange | | | | red |
| 1025 | | | | | | | | | | | | | | | | orange | | | | red |
| 1030 | | | | | | | | | | blue | | | | | | | | | | |
| 1035 | | | | | | | | | | orange | | | | | | | | | red | |
| 1040 | | | | | | | | | | | | | | | | orange | | | orange | |
| 1045 | | | | | | | | | | | | | | | | orange | | | orange | |
| 1050 | | | | | | | | | | | | | | | | orange | | | | |
| 1055 | | | | | | | | | | | | | | | | orange | | | | |
| 1100 | | | | | | | | | | | | | | | | orange | | | | red |
| 1105 | | | | | | | | | | | | | | | | orange | | | | red |
| 1110 | | | | | | | | | | | | | | | | orange | | | red | red |
| 1115 | | | | | | | | | | | | | | | | orange | | | orange | red |
| 1120 | | | | | | | | | | | | | | | | orange | | | | red |
| 1125 | | | | | | | | | | | | | | | | orange | | | | red |
| 1130 | | | | | | | | | | | | | | | | orange | | | | orange |
| 1135 | | | | | | | | | | | | | | | | orange | | | | orange |
| 1140 | | | | | | | | | | | | | | | | orange | | | orange | orange |
| 1145 | | | | | | | | | | | | | | | | orange | | | orange | orange |
| 1150 | | | | | | | | | | | | | | | | orange | | | | orange |
| 1155 | | | | | | | | | | | | | | | | orange | | | | orange |
| 1200 | | | | | | | | | | | | | | | | orange | | | | orange |
| 1205 | | | | | | | | | | | | | | | | orange | | | red | orange |
| 1210 | | | | | | | | | | | | | | | | orange | | | red | orange |
| 1215 | | | | | | | | | | | | | | | | orange | | | orange | red |
| 1220 | | | | | | | | | | | | | | | | orange | | | | red |
| 1225 | | | | | | | | | | | | | | | | | | | | |
| 1230 | | | | | | | | | | blue | | | | | | | | | | |
| 1235 | | | orange | orange | | | orange | | | orange | red | | | | | | | | orange | |
| 1240 | | | orange | orange | | | orange | | | | red | | | | | | | | | |
| 1245 | orange | | orange | orange | | | orange | | | | red | | | | | | | | | |
| 1250 | | | orange | | | | orange | | | | red | | | | | | | | | |
| 1255 | | | | | | | orange | | | | red | | | | | | | | | |
| 0100 | | | | | | | orange | | | | red | | | | | | | | | red |
| 0105 | | | | | | orange | orange | | | | red | | | | | | | | red | red |
| 0110 | | | | | | orange | orange | | | | red | | | | | | | | orange | red |
| 0115 | | | | | | orange | orange | | | | red | | | | | | | | orange | red |

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| TIME (PM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0120 | | | | | | orange | orange | | | | red | | | | | orange | | | | red |
| 0125 | | | | | | orange | orange | | | | red | | | | | orange | | | | red |
| 0130 | | | | | | orange | orange | | | | red | | | | | orange | | | | orange |
| 0135 | | | | | | | orange | | | | red | | | | | orange | | | red | orange |
| 0140 | | | | | | | orange | | | | red | | | | | orange | | | red | orange |
| TIME (PM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
| 0145 | | | | | | | orange | | | | red | | | | | orange | | | orange | orange |
| 0150 | | | | | | | orange | | | | red | | | | | orange | | | | orange |
| 0155 | | | | | | | orange | | | | red | | | | | orange | | | | orange |
| 0200 | | | | | | | orange | | | | red | | | | | orange | | | | orange |
| 0205 | | | | | | | orange | | | | red | | | | | orange | | | | orange |
| 0210 | | | | | | | orange | | | | red | | | | | orange | | | red | orange |
| 0215 | | | | | | | orange | | | | red | | | | | orange | | | orange | orange |
| 0220 | | | | | | | orange | | | | red | | | | | orange | | | orange | red |
| 0225 | | | | | | | orange | | | | red | | | | | orange | | | | red |
| 0230 | | | | | | | orange | | | | red | | | | | orange | | | | |
| 0235 | | | | | | | orange | | | | red | | | | | orange | | | | |
| 0240 | | | | | | | orange | | | | red | | | | | orange | | | red | |
| 0245 | | | | | | | orange | | | orange | red | | | | | orange | | | red | |
| 0250 | | | | | | | orange | | | | red | | | | | orange | | | orange | |
| 0255 | | | | | | | orange | | | | red | | | | | orange | | | | red |
| 0300 | | | | | | | orange | | | | red | | | | | orange | | | | red |
| 0305 | | | | | | | orange | orange | | | red | | | | | | | | | red |
| 0310 | | | | | | | orange | orange | | | red | | | | | | | | | red |
| 0315 | | | | | | | orange | orange | | | red | | | | | | | | orange | red |
| 0320 | | | | | | | orange | orange | | | red | | | | | | | | orange | red |
| 0325 | | | | | | | orange | orange | | | red | | | | | orange | | | red | orange |
| 0330 | | | | | | | orange | orange | | | red | | | | | orange | | | | orange |
| 0335 | | | | | | | orange | | | | red | | | | | orange | | | | |
| 0340 | | | | | | | orange | orange | | | red | | | | | orange | | | red | orange |
| 0345 | | | | | | | orange | orange | | | red | | | | | orange | | | orange | orange |
| 0350 | | | | | | | orange | orange | | | red | | | | | orange | | | orange | orange |
| 0355 | | | | | | | orange | orange | | | red | | | | | | | | orange | orange |
| 0400 | | | | | | | orange | orange | | | red | | | | | orange | | | orange | orange |
| 0405 | | | | | | | orange | | | | red | | | | | | | | orange | orange |
| 0410 | | | | | | | orange | | | | red | | | | | | | | red | orange |
| 0415 | | | | | | | orange | | | | red | | | | | | | | orange | orange |
| 0420 | | | | | | | orange | | | | red | | | | | | | | orange | red |
| 0425 | | | | | | | orange | | | blue | red | | | | | | | | | red |
| TIME (PM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |

| TIME (PM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0430 |  |  |  |  |  |  | O |  |  | O | R |  |  |  |  |  |  |  |  |  |
| 0435 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  |  |
| 0440 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  | R |  |
| 0445 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  | O |  |
| 0450 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  | O |  |
| 0455 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  | R |
| 0500 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  | R |
| 0505 |  | O | O | O |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  | R |
| 0510 |  | O | O | O |  |  | O |  |  |  | R |  |  |  |  |  |  |  | R | R |
| 0515 | O | O | O | O |  |  | O |  |  |  | R |  |  |  |  |  |  |  | R | R |
| 0520 | O | O | O | O |  |  | O |  |  |  | R |  |  |  |  |  |  |  | O | R |
| 0525 |  | O | O | O |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  | O |
| 0530 |  | O | O | O |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  | O |
| 0535 |  | O |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  | R | O |
| 0540 |  | O |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  | O |
| 0545 |  | O |  |  |  |  | O |  |  | B | R |  |  |  |  |  |  |  |  |  |
| 0550 |  | O |  |  |  |  | O |  |  | O | R |  |  |  |  |  |  |  |  | O |
| 0555 |  | O |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  | O |
| 0600 |  | O |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  | O |
| 0605 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  | R | O |
| 0610 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  | O | O |
| 0615 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  | O | R |
| 0620 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  | R |
| 0625 |  |  |  |  |  |  |  |  |  |  | R |  |  |  |  |  |  |  |  |  |
| 0630 |  |  |  |  |  |  | O |  |  |  | R |  |  |  |  |  |  |  |  |  |
| 0635 |  |  |  |  |  |  | O |  | O |  | R |  |  |  |  |  |  | O |  |  |
| 0640 |  |  |  |  |  |  | O |  | O |  | R |  |  |  |  |  |  | O | O |  |
| 0645 |  |  |  |  |  |  | O |  | O |  | R |  |  |  |  |  |  | O | O |  |
| 0650 |  |  |  |  |  |  | O |  | O |  | R |  |  |  |  |  | R | O |  |  |
| 0655 |  |  |  |  |  |  | O |  | O |  | R |  |  |  |  |  | R |  |  |  |
| 0700 |  |  |  |  |  |  | O |  | O |  | R |  |  |  |  |  | R |  |  | R |
| 0705 |  |  |  |  |  | O | O |  | O |  | R | O |  |  |  |  | R |  | R | R |
| 0710 |  |  |  |  |  | O | O |  | O | B | R | O |  |  |  |  | R |  | O | R |
| **TIME (PM)** | **MW** | **OV** | **ST** | **RH** | **TOAST** | **CPU** | **TV1** | **DVD1** | **TV2** | **HWU** | **AC** | **DW** | **WM** | **VAC** | **F1** | **F4** | **F7** | **EF1** | **FRG** | **FRZ** |
| 0715 |  |  |  |  |  | O | O |  | O | O | R | O |  |  |  |  | R |  | O | R |
| 0720 |  |  |  |  |  | O | O |  | O | O | R | O |  |  |  |  | R |  |  | R |
| 0725 |  |  |  |  |  | O | O |  | O | O | R | O |  |  |  |  | R |  |  | R |
| 0730 |  |  |  |  |  | O | O |  | O |  | R | O |  |  |  |  | R |  |  | O |
| 0735 |  |  |  |  |  | O | O |  | O |  | R | O |  |  |  |  | R |  |  | O |
| 0740 |  |  |  |  |  | O | O |  | O | O | R | O |  |  |  |  | R |  | R | O |
| 0745 |  |  |  |  |  | O | O |  | O | O | R | O |  |  |  |  | R |  | O | O |
| 0750 |  |  |  |  |  | O | O |  | O | B | R | O |  |  |  |  | R |  | O | O |

| TIME (PM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0755 | | | | | | orange | orange | | orange | | red | orange | | | | | red | | | orange |
| 0800 | | | | | | orange | orange | | orange | | red | orange | | | | | red | | | orange |
| 0805 | | | | | | orange | orange | | orange | | red | orange | | | | | red | | | orange |
| 0810 | | | | | | orange | orange | | orange | | red | orange | | | | | red | | orange | orange |
| 0815 | | | | | | orange | orange | | orange | | red | orange | | | | | red | | orange | orange |
| 0820 | | | | | | orange | orange | | orange | | red | orange | | | | | red | | | red |
| 0825 | | | | | | orange | orange | | orange | orange | red | | | | | | red | | | red |
| 0830 | | | | | | orange | orange | | orange | | red | | | | | | red | | | |
| 0835 | | | | | | | orange | | | | red | | | | | | red | | red | |
| 0840 | | | | | | | orange | | | | red | | | | | | red | | red | |
| 0845 | | | | | | | orange | | | | red | | | | | | red | | orange | |
| 0850 | | | | | | | orange | | | | red | | | | | | red | | | |
| 0855 | | | | | | | orange | | | | red | | | | | | red | | | |
| 0900 | | | | | | | orange | | | | red | | | | | | red | | | |
| 0905 | | | | | | | | | | | | | | | | | red | | | red |
| 0910 | | | | | | | | | | | | | | | red | | red | | orange | red |
| 0915 | | | | | | | | | | blue | | | | | red | | red | | orange | red |
| 0920 | | | | | | | | | | orange | | | | | red | | red | | | red |
| 0925 | | | | | | | | | | | | | | | red | | red | | | red |
| 0930 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0935 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0940 | | | | | | | | | | | | | | | red | | red | | red | orange |
| 0945 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0950 | | | | | | | | | | | | | | | red | | red | | | orange |
| 0955 | | | | | | | | | | | | | | | red | | red | | | orange |
| TIME (PM) | MW | OV | ST | RH | TOAST | CPU | TV1 | DVD1 | TV2 | HWU | AC | DW | WM | VAC | F1 | F4 | F7 | EF1 | FRG | FRZ |
| 1000 | | | | | | | | | | | | | | | red | | red | | | orange |
| 1005 | | | | | | | | | | | | | | | red | | red | | red | orange |
| 1010 | | | | | | | | | | | | | | | red | | red | | orange | orange |
| 1015 | | | | | | | | | | | | | | | red | | red | | orange | orange |
| 1020 | | | | | | | | | | | | | | | red | | red | | | red |
| 1025 | | | | | | | | | | | | | | | red | | red | | | red |
| 1030 | | | | | | | | | | | | | | | red | | red | | | |
| 1035 | | | | | | | | | | | | | | | red | | red | | | |
| 1040 | | | | | | | | | | | | | | | red | | red | | red | |
| 1045 | | | | | | | | | | | | | | | red | | red | | orange | |
| 1050 | | | | | | | | | | | | | | | red | | red | | | |
| 1055 | | | | | | | | | | | | | | | red | | red | | | |
| 1100 | | | | | | | | | | | | | | | red | | red | | | |
| 1105 | | | | | | | | | | | | | | | red | | red | | | |
| 1110 | | | | | | | | | | blue | | | | | red | | red | | orange | red |
| 1115 | | | | | | | | | | orange | | | | | red | | red | | orange | red |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1120 | | | | | | | | | | | | | | | | 🟥 | | 🟥 | | | 🟥 |
| 1125 | | | | | | | | | | | | | | | | 🟥 | | 🟥 | | | 🟥 |
| 1130 | | | | | | | | | | | | | | | | 🟥 | | 🟥 | | | 🟧 |
| 1135 | | | | | | | | | | | | | | | | 🟥 | | 🟥 | | | 🟧 |
| 1140 | | | | | | | | | | | | | | | | 🟥 | | 🟥 | | 🟥 | 🟧 |
| 1145 | | | | | | | | | | | | | | | | 🟥 | | 🟥 | | 🟧 | 🟧 |
| 1150 | | | | | | | | | | | | | | | | 🟥 | | 🟥 | | | 🟧 |
| 1155 | | | | | | | | | | | | | | | | 🟥 | | 🟥 | | | 🟧 |
| 1200 | | | | | | | | | | | | | | | | 🟥 | | 🟥 | | | 🟧 |

🟧 Denotes typically on in summer & winter
🟥 Denotes typically on in summer only
🟦 Denotes typically on in winter only

*Note that Electric frypan (EFP), DVD2, Dryer, Iron, F2, F3, F5, F6, F8, F9, and EF2 are only used on limited occasions and are therefore not deemed as average use at this residence.
*Note that the Oven and Vacuum cleaner are used approximately 3 times per week.
*Note that the AC usage shown is based on 18th January 2011.
*For comprehensive load values and times for particular dates, refer to the associated .txt files.

# Appendix E3 – PWC2 Feeder 11kV Network Close-up
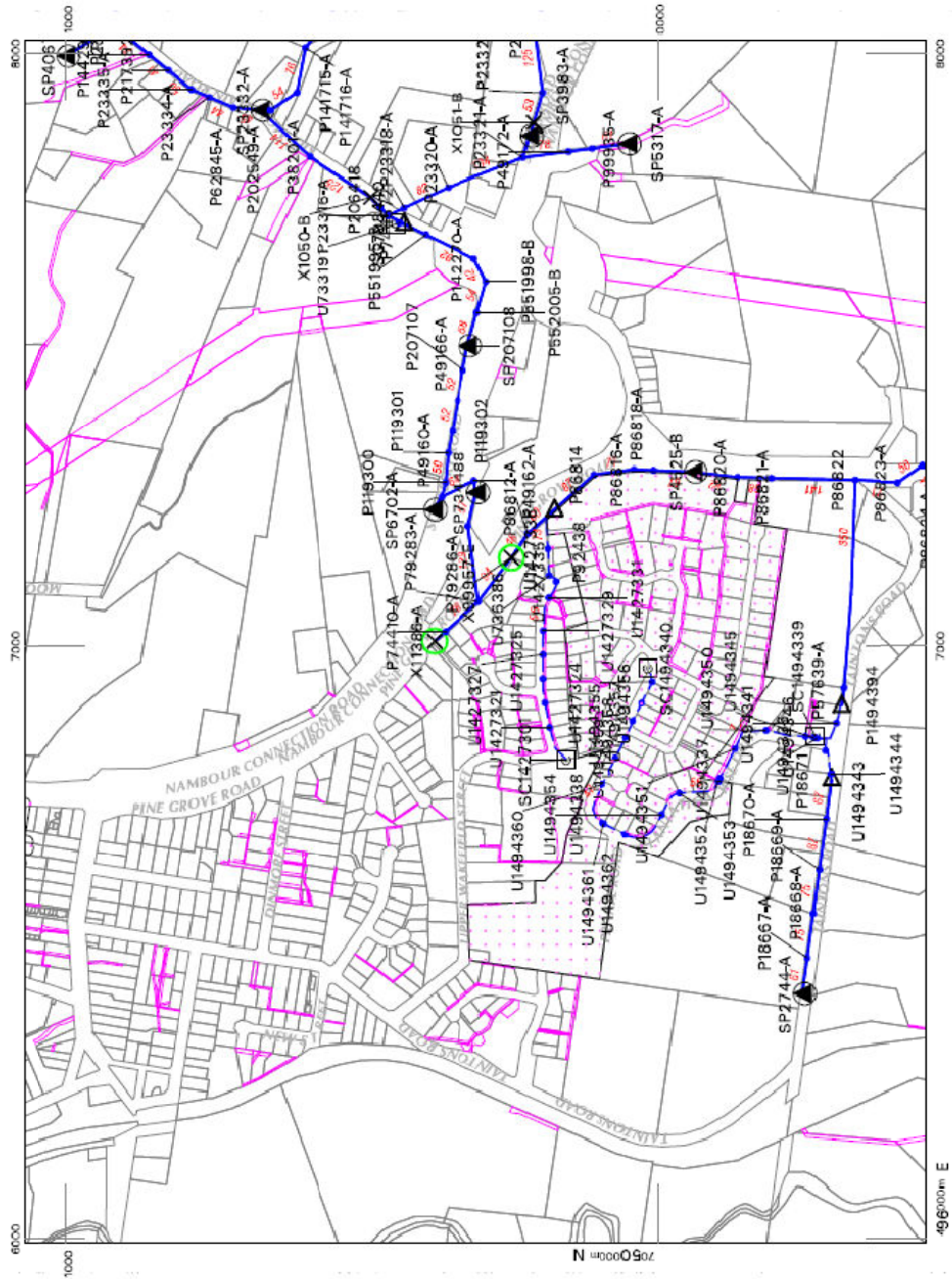
# Appendix E4 – PWC2 Feeder 11kV Schematic

PWC/A
PALMWOODS CENTRAL
SACS
PWC2
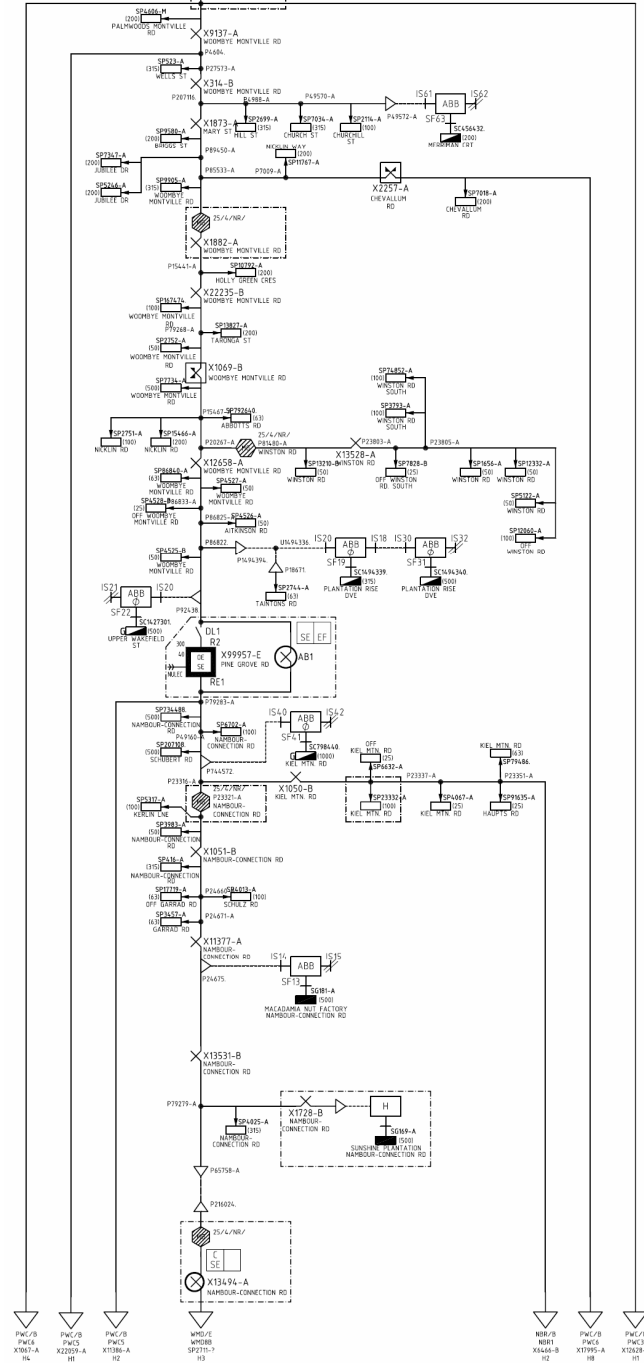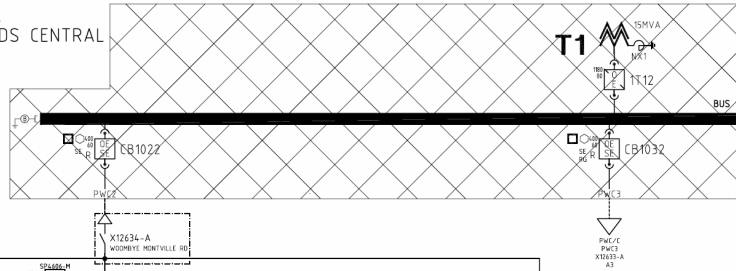
# Appendix E5 – SST16 - SSPWC 33kV Schematic
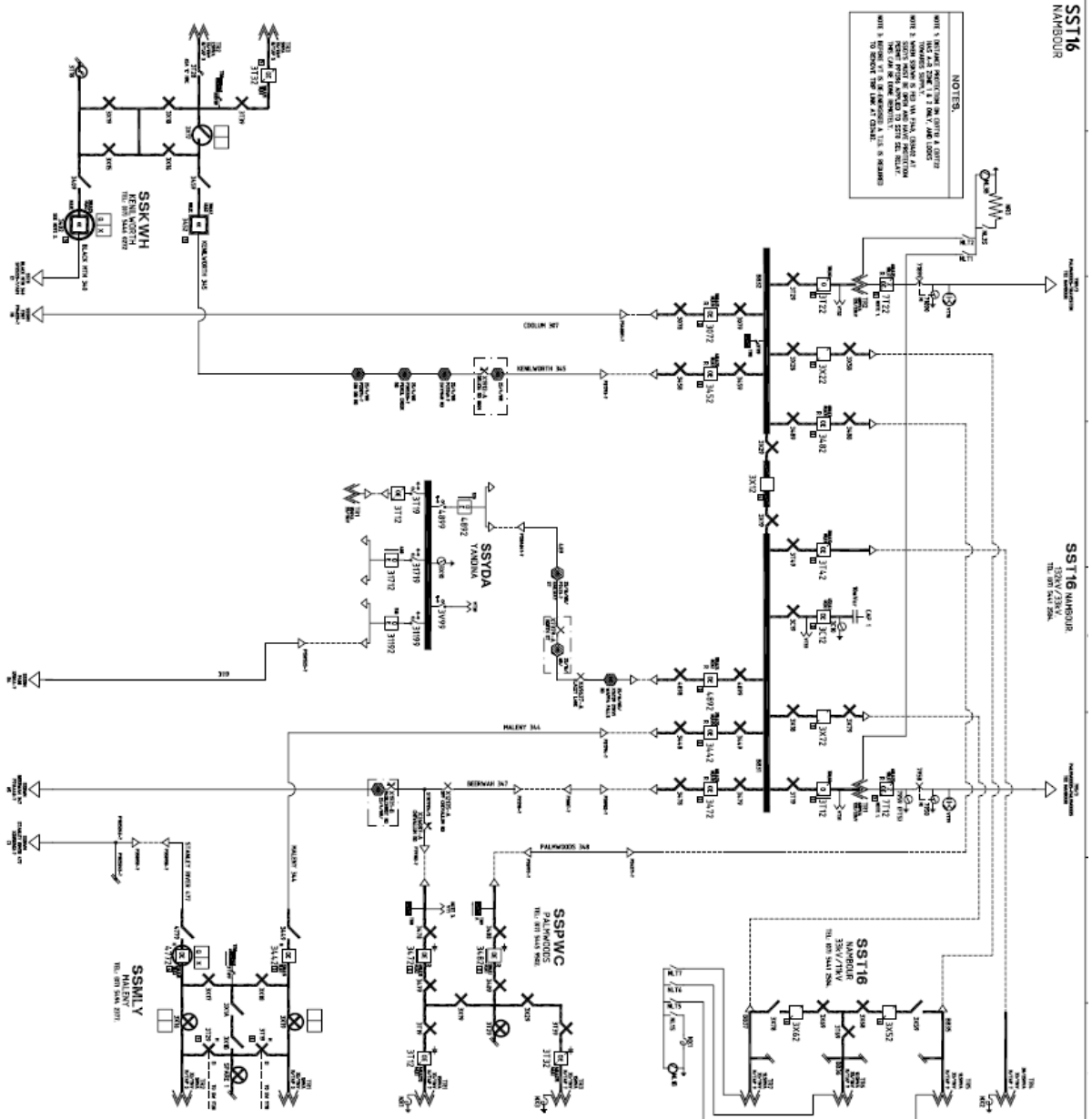
# Appendix F – Matlab Code

# Appendix F1 – Plotting AEMO Data

```matlab
%QLD_LOAD_Price_5min.M

load QLD_20110512_Load.txt; %loads data and produces an array
load QLD_20110512_Price.txt; %loads data and produces an array

L= QLD_20110512_Load(:,1); %vector representing load
P= QLD_20110512_Price(:,1); %vector representing price

L1 = L./200;

S = size(L,1)

T = [0:1:S-1];

t= (5/60).*T; %vector representing time

A = mean(L); %finds average Load

M = max(L);

m = min(L);

plot(t,L1,'r'),xlabel('Time (Hours)','FontSize',10),ylabel('Load and Price','FontSize',10),
hold
plot(t,P,'b')
title('QLD LOAD - DAILY CYCLE','FontSize',15),
%axis([0 24 4000 7500]),
grid on;


disp('Average Load (MW):');
disp(A);

disp('Peak Load (MW):');
disp(M);

disp('Load Factor:');
disp(A/M);


PL = L-m; %Find load which is over base (minimum) load
APL = mean(PL);  %finds average load on peak plant
MPL = max(PL); %finds peak of load on peak plant

disp('Plant Factor of Peak Load Plant:');
disp(APL/MPL);
```

```matlab
%QLD_LOAD_30min_week.M
%Adam Harriman
%16/05/2011

load QLD_2011041117Load.txt; %loads data and produces an array

L= QLD_2011041117Load(:,1); %vector representing load

S = size(L,1)

T = [0:1:S-1];

t= (0.5/24).*T; %vector representing time

A = mean(L); %finds average Load

M = max(L);

plot(t,L),xlabel('Time (Days)','FontSize',15),ylabel('Load (MW)','FontSize',15),
title('QLD LOAD - WEEKLY CYCLE','FontSize',20),
%axis([-1.5000000e-001 1.1000000e+000 -3.4000000e+002 3.4000000e+002]),
grid on;



disp('Average Load (MW):');
disp(A);

disp('Peak Load (MW):');
disp(M);

disp('Load Factor:');
disp(A/M);
```

# Appendix F2 – simulation_body.m

```matlab
load JAN_PRICE_AVG.txt;
load TEMP_20110118.txt;
load IRRAD_JAN.txt;
load LOAD_SHED.txt

%LOAD ALL ELECTRICITY CONSUMPTION DATA
%load LIGHTS_1.txt;
%load LIGHTS_2.txt;
load LIGHTS_3.txt;
load LIGHTS_4.txt;
load LIGHTS_5.txt;
%load LIGHTS_6.txt;
load LIGHTS_7.txt;
%load LIGHTS_8.txt;
load LIGHTS_9.txt;
%load LIGHTS_10.txt;
load LIGHTS_11.txt;
%load LIGHTS_12.txt;
%load LIGHTS_13.txt;
%load LIGHTS_14.txt;
%load LIGHTS_15.txt;
load LIGHTS_16.txt;
%load LIGHTS_17.txt;
load LIGHTS_18.txt;
%load LIGHTS_19.txt;
%load LIGHTS_20.txt;
%load LIGHTS_21.txt;
%load LIGHTS_22.txt;
%load LIGHTS_23.txt;
%load LIGHTS_24.txt;
%load LIGHTS_25.txt;
%load LIGHTS_26.txt;
%load LIGHTS_27.txt;
%load LIGHTS_28.txt;
%load LIGHTS_29.txt;
%load LIGHTS_30.txt;
load LIGHTS_31.txt;
load FAN_1.txt;
%load FAN_2.txt;
%load FAN_3.txt;
load FAN_4.txt;
%load FAN_5.txt;
%load FAN_6.txt;
load FAN_7.txt;
load EX_FAN_1.txt;
%load EX_FAN_2.txt;
%load EX_FAN_3.txt;
load AIR_CON.txt;
load FRIDGE.txt;
load FREEZER.txt;
load MICROWAVE.txt;
load OVEN.txt;
load STOVE.txt;
load RANGE_HOOD.txt;
```

```matlab
%load FRY_PAN.txt;
load COMPUTER.txt;
load TELEVISION_1.txt;
load TELEVISION_2.txt;
load DVD_1.txt;
%load DVD_2.txt;
load HOT_WATER.txt;
load DISHWASHER.txt;
load WASHING_MACHINE.txt;
load DRYER.txt;
%load IRON.txt;
load TOASTER.txt;
load VACUUM.txt;
%load PUMP.txt;
load UNKNOWN.txt;


%PRICE = 0.0002069;
PRICE = [0 JAN_PRICE_AVG(:,2)' JAN_PRICE_AVG(1:54,2)' ]';
PRICE_LIM = 0.20; %PRICE LIMIT AT 20 CENTS PER kWh
power_avail = 3*PRICE_LIM./PRICE;   %Total power available
%power_avail = repmat(2085,1,length(PRICE));
power_avail_initial = power_avail;
power_use = zeros(1,length(power_avail));%Will show total power being
used
grid_feed_back = zeros(1,length(power_avail));
grid_power_use = zeros(1,length(power_avail));
load_on_grid = zeros(1,length(power_avail));

%LOAD SHED OR LOSS CONDITIONS
LOAD_SHED_SIGNAL = [0 LOAD_SHED(:,2)' LOAD_SHED(1:54,2)' ]';

%L1 = [0 LIGHTS_1(:,2)' LIGHTS_1(1:54,2)' ]'; %Lights 1
%L2 = [0 LIGHTS_2(:,2)' LIGHTS_2(1:54,2)' ]';  %Lights 2
L3 = [0 LIGHTS_3(:,2)' LIGHTS_3(1:54,2)' ]';  %Lights 3 (essential)
L4 = [0 LIGHTS_4(:,2)' LIGHTS_4(1:54,2)' ]';  %Lights 4
L5 = [0 LIGHTS_5(:,2)' LIGHTS_5(1:54,2)' ]';  %Lights 5
%L6 = [0 LIGHTS_6(:,2)' LIGHTS_6(1:54,2)' ]';  %Lights 6
L7 = [0 LIGHTS_7(:,2)' LIGHTS_7(1:54,2)' ]'; %Lights 7
%L8 = [0 LIGHTS_8(:,2)' LIGHTS_8(1:54,2)' ]'; %Lights 8
L9 = [0 LIGHTS_9(:,2)' LIGHTS_9(1:54,2)' ]';  %Lights 9 (essential)
%L10 = [0 LIGHTS_10(:,2)' LIGHTS_10(1:54,2)' ]';  %Lights 10
L11 = [0 LIGHTS_11(:,2)' LIGHTS_11(1:54,2)' ]';  %Lights 11
%L12 = [0 LIGHTS_12(:,2)' LIGHTS_12(1:54,2)' ]';  %Lights 12
%L13 = [0 LIGHTS_13(:,2)' LIGHTS_13(1:54,2)' ]';  %Lights 13
%L14 = [0 LIGHTS_14(:,2)' LIGHTS_14(1:54,2)' ]';  %Lights 14
%L15 = [0 LIGHTS_15(:,2)' LIGHTS_15(1:54,2)' ]';  %Lights 15
L16 = [0 LIGHTS_16(:,2)' LIGHTS_16(1:54,2)' ]';  %Lights 16
%L17 = [0 LIGHTS_17(:,2)' LIGHTS_17(1:54,2)' ]';  %Lights 17
L18 = [0 LIGHTS_18(:,2)' LIGHTS_18(1:54,2)' ]';  %Lights 18
%L19 = [0 LIGHTS_19(:,2)' LIGHTS_19(1:54,2)' ]';  %Lights 19
%L20 = [0 LIGHTS_20(:,2)' LIGHTS_20(1:54,2)' ]';  %Lights 20
%L21 = [0 LIGHTS_21(:,2)' LIGHTS_21(1:54,2)' ]';  %Lights 21
%L22 = [0 LIGHTS_22(:,2)' LIGHTS_22(1:54,2)' ]';  %Lights 22
%L23 = [0 LIGHTS_23(:,2)' LIGHTS_23(1:54,2)' ]';  %Lights 23
%L24 = [0 LIGHTS_24(:,2)' LIGHTS_24(1:54,2)' ]';  %Lights 24
%L25 = [0 LIGHTS_25(:,2)' LIGHTS_25(1:54,2)' ]';  %Lights 25
%L26 = [0 LIGHTS_26(:,2)' LIGHTS_26(1:54,2)' ]';  %Lights 26
```

```matlab
%L27 = [0 LIGHTS_27(:,2)' LIGHTS_27(1:54,2)' ]';  %Lights 27
%L28 = [0 LIGHTS_28(:,2)' LIGHTS_28(1:54,2)' ]';  %Lights 28
%L29 = [0 LIGHTS_29(:,2)' LIGHTS_29(1:54,2)' ]';  %Lights 29
%L30 = [0 LIGHTS_30(:,2)' LIGHTS_30(1:54,2)' ]';  %Lights 30
L31 = [0 LIGHTS_31(:,2)' LIGHTS_31(1:54,2)' ]';  %Lights 31


F1 = [0 FAN_1(:,2)' FAN_1(1:54,2)' ]'; %vector representing Fan 1
%F2 = [0 FAN_2(:,2)' FAN_2(1:54,2)' ]'; %vector representing Fan 2
%F3 = [0 FAN_3(:,2)' FAN_3(1:54,2)' ]'; %vector representing Fan 3
F4 = [0 FAN_4(:,2)' FAN_4(1:54,2)' ]'; %vector representing Fan 4
%F5 = [0 FAN_5(:,2)' FAN_5(1:54,2)' ]'; %vector representing Fan 5
%F6 = [0 FAN_6(:,2)' FAN_6(1:54,2)' ]'; %vector representing Fan 6
F7 = [0 FAN_7(:,2)' FAN_7(1:54,2)' ]'; %vector representing Fan 7
EF1 = [0 EX_FAN_1(:,2)' EX_FAN_1(1:54,2)' ]'; %vector representing
Exhaust Fan 1
%EF2 = [0 EX_FAN_2(:,2)' EX_FAN_2(1:54,2)' ]'; %vector representing
Exhaust Fan 2
%EF3 = [0 EX_FAN_3(:,2)' EX_FAN_3(1:54,2)' ]'; %vector representing
Exhaust Fan 3
FRG = [0 FRIDGE(:,2)' FRIDGE(1:54,2)' ]'; %Fridge (essential)
FRZ = [0 FREEZER(:,2)' FREEZER(1:54,2)' ]'; %vector representing
Freezer (essential)
MW = [0 MICROWAVE(:,2)' MICROWAVE(1:54,2)' ]'; %vector representing
Microwave Oven
OVN = [0 OVEN(:,2)' OVEN(1:54,2)' ]'; %vector representing Oven
STV = [0 STOVE(:,2)' STOVE(1:54,2)' ]'; %vector representing Stove
RH = [0 RANGE_HOOD(:,2)' RANGE_HOOD(1:54,2)' ]'; %vector representing
Range Hood
%EFP = [0 FRY_PAN(:,2)' FRY_PAN(1:54,2)' ]'; %vector representing
Electric Frying Pan
CPU = [0 COMPUTER(:,2)' COMPUTER(1:54,2)' ]'; %vector representing
Computer
TV1 = [0 TELEVISION_1(:,2)' TELEVISION_1(1:54,2)' ]'; %vector
representing Television 1
TV2 = [0 TELEVISION_2(:,2)' TELEVISION_2(1:54,2)' ]'; %vector
representing Television 2
DVD1 = [0 DVD_1(:,2)' DVD_1(1:54,2)' ]'; %vector representing DVD
Player 1
%DVD2 = [0 DVD_2(:,2)' DVD_2(1:54,2)' ]'; %vector representing DVD
Player 2
HWU = [0 HOT_WATER(:,2)' HOT_WATER(1:54,2)' ]'; %vector representing
Hot water unit
AC = [0 AIR_CON(:,2)' AIR_CON(1:54,2)' ]'; %vector representing Air
Conditioner (Heat or cool)
DW = [0 DISHWASHER(:,2)' DISHWASHER(1:54,2)' ]'; %Dish Washer
DW_stat = zeros(1,length(DW));     %Shows status of washing machine
DW_IND = 0;                   %Indicates if DW is running (to
dissallow other
                              %appliances if there is not enough
power)
WM = [0 WASHING_MACHINE(:,2)' WASHING_MACHINE(1:54,2)' ]';  %Washing
machine
WM_stat = zeros(1,length(WM));      %Shows status of washing machine
WM_IND = 0;                   %Indicates if WM is running (to
dissallow other
```

```
                                   %appliances if there is not enough
power)
DRY = [0 DRYER(:,2)' DRYER(1:54,2)' ]';%Dryer
DRY_stat = zeros(1,length(DRY));       %Shows status of Dryer
DRY_IND = 0;                    %Indicates if Dryer is running (to
dissallow other
                                   %appliances if there is not enough
power)
%IRN = [0 IRON(:,2)' IRON(1:54,2)' ]'; %vector representing clothes
iron
TSR = [0 TOASTER(:,2)' TOASTER(1:54,2)' ]'; %vector representing
toaster
VAC = [0 VACUUM(:,2)' VACUUM(1:54,2)' ]'; %vector representing vacuum
%PMP = [0 PUMP(:,2)' PUMP(1:54,2)' ]'; %vector representing water
pump
UK = [0 UNKNOWN(:,2)' UNKNOWN(1:54,2)' ]';


%SHOW WHAT LOAD WOULD BE WITHOUT SMART GRID
RES_LOAD_ASSESS =
L3+L4+L5+L7+L9+L11+L16+L18+L31+F1+F4+F7+EF1+FRG+FRZ+MW+OVN+STV+RH+CPU
+TV1+TV2+DVD1+HWU+DW+WM+TSR+VAC+DRY+UK+AC;


%DEFINE PV SOLAR AND BATTERY VARIABLES:
IR = [0 IRRAD_JAN(:,2)' IRRAD_JAN(1:54,2)' ]';  %vector showing
radiation levels
TEMP = [0 TEMP_20110118(:,2)' TEMP_20110118(1:54,2)' ]'; %vector
showing temperature
MF = 0.9;  %Mounting Factor
A = 21;  %Area of PV cells
PVE = 0.153;  %PV Efficiency
TC = 0.004;  %PV Temperature coefficient
PMAX = 3640;  %Max power output of PV cells
CC = 20;  %Charging current of batteries (A)
CC2 = 30; %Higher charging current of batteries (A)
DC = 20;  %Discharging current of batteries (A)
VDC = 48;  %System DC Voltage
RB = 0.01176;  %Internal resistance of batteries
IE = 0.96;  %Inverter efficiency
BATT_CHARGE = 0.6;  %Initial charge of battery
BATT_OUT = zeros(1,length(PRICE)); %Initial value for output from
batteries
PV = zeros(1,length(PRICE));
PV_OUT = zeros(1,length(PRICE)); %Initial value for output from solar
DG_OUT = zeros(1,length(PRICE));  %Initial value for combined output
from PV & batteries


%CALCULATE OUTPUT FROM SOLAR CELLS:
i=1;
while (i<=length(PRICE))
    PV(i) = ((IR(i)*MF*A*PVE) - (TEMP(i)*TC*PMAX));

    if PV(i)>PMAX
        PV(i) = PMAX;
    else if PV(i)< 0
        PV(i) = 0;
        end
    end
```

```matlab
    i=i+1;
end


S1 = length(power_avail);
T1 = [1:1:S1];
t1= (5/60).*T1; %vector representing time in hours (each point is
5mins)


k=2;
while (k<=S1)

     if LOAD_SHED_SIGNAL(k) == 1
      power_avail(k) = 600;
     end

    if LOAD_SHED_SIGNAL(k) == 2
      power_avail(k) = 0;

    end
    %CONTROL OF PV AND BATTERY

    if LOAD_SHED_SIGNAL(k) == 2 && power_avail(k)<RES_LOAD_ASSESS(k)
        BATT_OUT(k) = DC*VDC;
        BATT_CHARGE = BATT_CHARGE - (1/120); %Discharge rate of
0.833% per 5 min at 20 Amps

    else
        if BATT_CHARGE > 0.5 && (960+(RB*CC^2))>PV(k) &&
power_avail(k)<RES_LOAD_ASSESS(k) && 5<t1(k)<9
        BATT_OUT(k) = DC*VDC;
        BATT_CHARGE = BATT_CHARGE - (1/120); %Discharge rate of
0.833% per 5 min at 20 Amps
        else if BATT_CHARGE > 0.5 && (960+(RB*CC^2))>PV(k) &&
power_avail(k)<RES_LOAD_ASSESS(k) && 17<t1(k)<20
        BATT_OUT(k) = DC*VDC;
        BATT_CHARGE = BATT_CHARGE - (1/120); %Discharge rate of
0.833% per 5 min at 20 Amps
            else
            BATT_OUT(k) = 0;
            end
        end

    end


    if PV(k) > (960+(RB*CC^2))
        PV_OUT(k) = PV(k)- (960+(RB*CC^2));
        BATT_CHARGE = BATT_CHARGE + (0.5/240); %Recharge rate of 0.2%
per 5 min at 20 Amps
    else
        PV_OUT(k) = PV(k);
    end
```

```matlab
DG_OUT(k) = (PV_OUT(k) + BATT_OUT(k))*IE;
power_avail(k) = power_avail(k)+DG_OUT(k);



%CONTROL OF UNKNOWN
if power_avail(k) >= UK(k)
    power_use(k) = UK(k) + power_use(k);
    power_avail(k) = power_avail(k) - UK(k);
else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('UNKNOWN OFF AT:');
    UK_OFF = sprintf('   %g Hours',t1(k-1));
    disp(UK_OFF);
end



%CONTROL OF L9 (ESSENTIAL)
if power_avail(k) >= L9(k)
    power_use(k) = L9(k) + power_use(k);
    power_avail(k) = power_avail(k) - L9(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('L9 OFF AT:');
    L9_OFF = sprintf('   %g Hours',t1(k-1));
    disp(L9_OFF);
end

%CONTROL OF FRIDGE (ESSENTIAL)
if power_avail(k) >= FRG(k)
    power_use(k) = FRG(k) + power_use(k);
    power_avail(k) = power_avail(k) - FRG(k);
else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;
    disp('FRIDGE OFF AT:');
    FRIDGE_OFF = sprintf('   %g Hours',t1(k-1));
    disp(FRIDGE_OFF);
end

%CONTROL OF FREEZER (ESSENTIAL)
if power_avail(k) >= FRZ(k)
    power_use(k) = FRZ(k) + power_use(k);
    power_avail(k) = power_avail(k) - FRZ(k);
else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;
    disp('FREEZER OFF AT:');
    FREEZER_OFF = sprintf('   %g Hours',t1(k-1));
    disp(FREEZER_OFF);
end
```

```matlab
%CONTROL OF L3 (ESSENTIAL)
if power_avail(k) >= L3(k)
    power_use(k) = L3(k) + power_use(k);
    power_avail(k) = power_avail(k) - L3(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('L3 OFF AT:');
    L3_OFF = sprintf('   %g Hours',t1(k-1));
    disp(L3_OFF);
end


%CONTROL OF STOVE
if power_avail(k) >= STV(k)
    power_use(k) = STV(k) + power_use(k);
    power_avail(k) = power_avail(k) - STV(k);
else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;
    STV(k+1:end) = STV(k:end-1); %postpone use of stove
    disp('STOVE POSTPONED AT:');
    STOVE_OFF = sprintf('   %g Hours',t1(k-1));
    disp(STOVE_OFF);
end


%CONTROL OF MICROWAVE
if power_avail(k) >= MW(k)
    power_use(k) = MW(k) + power_use(k);
    power_avail(k) = power_avail(k) - MW(k);
else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;
    MW(k+1:end) = MW(k:end-1); %postpone use of microwave
    disp('MICROWAVE POSTPONED AT:');
    MICROWAVE_OFF = sprintf('   %g Hours',t1(k-1));
    disp(MICROWAVE_OFF);
end

 %CONTROL OF OVEN
if power_avail(k) >= OVN(k)
    power_use(k) = OVN(k) + power_use(k);
    power_avail(k) = power_avail(k) - OVN(k);
else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;
    OVN(k+1:end) = OVN(k:end-1); %postpone use of oven
    disp('OVEN POSTPONED AT:');
    OVEN_OFF = sprintf('   %g Hours',t1(k-1));
    disp(OVEN_OFF);
end

%CONTROL OF TOASTER
```

```matlab
if power_avail(k) >= TSR(k)
    power_use(k) = TSR(k) + power_use(k);
    power_avail(k) = power_avail(k) - TSR(k);
else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;
    TSR(k+1:end) = TSR(k:end-1); %postpone use of toaster
    disp('TOASTER POSTPONED AT:');
    TOASTER_OFF = sprintf('    %g Hours',t1(k-1));
    disp(TOASTER_OFF);
end

%CONTROL OF L18
if power_avail(k) >= L18(k)
    power_use(k) = L18(k) + power_use(k);
    power_avail(k) = power_avail(k) - L18(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('L18 OFF AT:');
    L18_OFF = sprintf('    %g Hours',t1(k-1));
    disp(L18_OFF);
end

%CONTROL OF L31
if power_avail(k) >= L31(k)
    power_use(k) = L31(k) + power_use(k);
    power_avail(k) = power_avail(k) - L31(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('L31 OFF AT:');
    L31_OFF = sprintf('    %g Hours',t1(k-1));
    disp(L31_OFF);
end

%CONTROL OF L16
if power_avail(k) >= L16(k)
    power_use(k) = L16(k) + power_use(k);
    power_avail(k) = power_avail(k) - L16(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('L16 OFF AT:');
    L16_OFF = sprintf('    %g Hours',t1(k-1));
    disp(L16_OFF);
end

%CONTROL OF L11
```

```matlab
if power_avail(k) >= L11(k)
    power_use(k) = L11(k) + power_use(k);
    power_avail(k) = power_avail(k) - L11(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('L11 OFF AT:');
    L11_OFF = sprintf('   %g Hours',t1(k-1));
    disp(L11_OFF);
end

%CONTROL OF L5
if power_avail(k) >= L5(k)
    power_use(k) = L5(k) + power_use(k);
    power_avail(k) = power_avail(k) - L5(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('L5 OFF AT:');
    L5_OFF = sprintf('   %g Hours',t1(k-1));
    disp(L5_OFF);
end

%CONTROL OF L4
if power_avail(k) >= L4(k)
    power_use(k) = L4(k) + power_use(k);
    power_avail(k) = power_avail(k) - L4(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('L4 OFF AT:');
    L4_OFF = sprintf('   %g Hours',t1(k-1));
    disp(L4_OFF);
end

%CONTROL OF L7
if power_avail(k) >= L7(k)
    power_use(k) = L7(k) + power_use(k);
    power_avail(k) = power_avail(k) - L7(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('L7 OFF AT:');
    L7_OFF = sprintf('   %g Hours',t1(k-1));
    disp(L7_OFF);
end
```

```matlab
%CONTROL OF TV1
if power_avail(k) >= TV1(k)
    power_use(k) = TV1(k) + power_use(k);
    power_avail(k) = power_avail(k) - TV1(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('TV1 OFF AT:');
    TV1_OFF = sprintf('   %g Hours',t1(k-1));
    disp(TV1_OFF);
end

%CONTROL OF DVD1
if power_avail(k) >= DVD1(k)
    power_use(k) = DVD1(k) + power_use(k);
    power_avail(k) = power_avail(k) - DVD1(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('DVD1 OFF AT:');
    DVD1_OFF = sprintf('   %g Hours',t1(k-1));
    disp(DVD1_OFF);
end

%CONTROL OF TV2
if power_avail(k) >= TV2(k)
    power_use(k) = TV2(k) + power_use(k);
    power_avail(k) = power_avail(k) - TV2(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('TV2 OFF AT:');
    TV2_OFF = sprintf('   %g Hours',t1(k-1));
    disp(TV2_OFF);
end

%CONTROL OF CPU
if power_avail(k) >= CPU(k)
    power_use(k) = CPU(k) + power_use(k);
    power_avail(k) = power_avail(k) - CPU(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('CPU OFF AT:');
    CPU_OFF = sprintf('   %g Hours',t1(k-1));
    disp(CPU_OFF);
end
```

```matlab
%CONTROL OF HWU
if power_avail(k) >= HWU(k)
    power_use(k) = HWU(k) + power_use(k);
    power_avail(k) = power_avail(k) - HWU(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;
    HWU(k+1:end) = HWU(k:end-1); %postpone use of HWU
    disp('HWU POSTPONED AT:');
    HWU_OFF = sprintf('   %g Hours',t1(k-1));
    disp(HWU_OFF);
end

%CONTROL OF VAC
if power_avail(k) >= VAC(k)
    power_use(k) = VAC(k) + power_use(k);
    power_avail(k) = power_avail(k) - VAC(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;
    VAC(k+1:end) = VAC(k:end-1); %postpone use of VAC
    disp('VAC POSTPONED AT:');
    VAC_OFF = sprintf('   %g Hours',t1(k-1));
    disp(VAC_OFF);
end

%CONTROL OF RH
if power_avail(k) >= RH(k)
    power_use(k) = RH(k) + power_use(k);
    power_avail(k) = power_avail(k) - RH(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('RH OFF AT:');
    RH_OFF = sprintf('   %g Hours',t1(k-1));
    disp(RH_OFF);
end

%CONTROL OF EF1
if power_avail(k) >= EF1(k)
    power_use(k) = EF1(k) + power_use(k);
    power_avail(k) = power_avail(k) - EF1(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('EF1 OFF AT:');
    EF1_OFF = sprintf('   %g Hours',t1(k-1));
    disp(EF1_OFF);
```

```matlab
    end

%CONTROL OF F7
if power_avail(k) >= F7(k)
    power_use(k) = F7(k) + power_use(k);
    power_avail(k) = power_avail(k) - F7(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('F7 OFF AT:');
    F7_OFF = sprintf('   %g Hours',t1(k-1));
    disp(F7_OFF);
end

%CONTROL OF F1
if power_avail(k) >= F1(k)
    power_use(k) = F1(k) + power_use(k);
    power_avail(k) = power_avail(k) - F1(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('F1 OFF AT:');
    F1_OFF = sprintf('   %g Hours',t1(k-1));
    disp(F1_OFF);
end

%CONTROL OF F4
if power_avail(k) >= F4(k)
    power_use(k) = F4(k) + power_use(k);
    power_avail(k) = power_avail(k) - F4(k);

else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;

    disp('F4 OFF AT:');
    F4_OFF = sprintf('   %g Hours',t1(k-1));
    disp(F4_OFF);
end

%CONTROL OF DISHWASHER
if power_avail(k) >= DW(k)
    power_use(k) = DW(k) + power_use(k);
    power_avail(k) = power_avail(k) - DW(k);
else
    power_use(k) = power_use(k) + 0;
    power_avail(k) = power_avail(k) - 0;
    DW(k+1:end) = DW(k:end-1); %postpone use of DW
    disp('DISHWASHER POSTPONED AT:');
    STOVE_OFF = sprintf('   %g Hours',t1(k-1));
    disp(STOVE_OFF);
```

```matlab
        end

    %CONTROL OF WASHING MACHINE
    if power_avail(k) >= WM(k)
        power_use(k) = WM(k) + power_use(k);
        power_avail(k) = power_avail(k) - WM(k);
    else
        power_use(k) = power_use(k) + 0;
        power_avail(k) = power_avail(k) - 0;
        WM(k+1:end) = WM(k:end-1); %postpone use of WM
        disp('WASHING MACHINE POSTPONED AT:');
        STOVE_OFF = sprintf('   %g Hours',t1(k-1));
        disp(STOVE_OFF);
    end

    %CONTROL OF DRYER
    if power_avail(k) >= DRY(k)
        power_use(k) = DRY(k) + power_use(k);
        power_avail(k) = power_avail(k) - DRY(k);
    else
        power_use(k) = power_use(k) + 0;
        power_avail(k) = power_avail(k) - 0;
        DRY(k+1:end) = DRY(k:end-1); %postpone use of DRY
        disp('DRYER POSTPONED AT:');
        STOVE_OFF = sprintf('   %g Hours',t1(k-1));
        disp(STOVE_OFF);
    end


    %CONTROL OF AC
    if power_avail(k) >= AC(k)
        power_use(k) = AC(k) + power_use(k);
        power_avail(k) = power_avail(k) - AC(k);

    else
        power_use(k) = power_use(k) + 0;
        power_avail(k) = power_avail(k) - 0;

        disp('AC OFF AT:');
        AC_OFF = sprintf('   %g Hours',t1(k-1));
        disp(AC_OFF);
    end


  grid_feed_back(k) = DG_OUT(k) - power_use(k);
if grid_feed_back(k) < 0
    grid_feed_back(k)=0;
end

grid_power_use(k) = power_use(k) - DG_OUT(k);
if grid_power_use(k) < 0
    grid_power_use(k)= 0;
end
```

```matlab
 load_on_grid(k) = grid_power_use(k)- grid_feed_back(k); %Total load
taken from grid (includes DG feed-in)PASS ON TO NORMALISED_RES_LOAD


k=k+1;

end

feed_back_income = sum(grid_feed_back.*0.00044*5/60);      %feed-in
tarriff = $0.44 per kWh
disp('Income generated by DG feed-in:');
        DG_IN = sprintf('  $ %g ',feed_back_income);
        disp(DG_IN);


elec_cost = sum(grid_power_use'.*PRICE.*5/60);
disp('Cost of electricity to residence:');
        E_COST = sprintf('  $ %g ',elec_cost);
        disp(E_COST);


elec_cost_noSG = sum(RES_LOAD_ASSESS.*PRICE.*5/60);
disp('Cost of electricity to residence without SG or DG:');
        E_COST_noSG = sprintf('  $ %g ',elec_cost_noSG);
        disp(E_COST_noSG);


SAVINGS = elec_cost_noSG - elec_cost + feed_back_income;
disp('Savings using SG & DG:');
        SAV = sprintf('  $ %g ',SAVINGS);
        disp(SAV);


SAVINGS_PERCENTAGE = ((SAVINGS)/elec_cost_noSG)*100;
disp('Savings percentage using SG & DG:');
        SAV_PER = sprintf('   %g % ',SAVINGS_PERCENTAGE);
        disp(SAV_PER);


AVG_A = mean(RES_LOAD_ASSESS);  %finds average assessed load
MAX_A = max(RES_LOAD_ASSESS);   %finds maximum assessed load
MIN_A = min(RES_LOAD_ASSESS);   %finds minimum assessed load (base
load)
LF_A = AVG_A/MAX_A;   %finds the load factor of the assessed load

AVG_SG = mean(grid_power_use);  %finds average assessed load
MAX_SG = max(grid_power_use);   %finds maximum assessed load
MIN_SG = min(grid_power_use);   %finds minimum assessed load (base
load)
LF_SG = AVG_SG/MAX_SG;   %finds the load factor of the assessed load

disp('Load Factor without SG & DG:');
        LFNOSG = sprintf('  %g ',LF_A);
        disp(LFNOSG);


disp('Load Factor using SG & DG:');
        LFNSG = sprintf('  %g ',LF_SG);
        disp(LFNSG);


%PLOTTING:
```

```matlab
%plot(t1(1:288),power_avail(2:289),'r');
%xlabel('Time (Hours)','FontSize',10),ylabel('Load
Consumed','FontSize',10),
%hold
%plot(t1(1:288),power_avail_initial(2:289)','k');
%plot(t1(1:288),power_use(2:289),'b')
%title('RESIDENCE LOAD - 12 May 2011','FontSize',15),
%axis([0 24 0 4100]),
%grid on;


plot(t1(2:(length(t1))),RES_LOAD_ASSESS(2:(length(t1))),'r');
xlabel('Time (Hours)','FontSize',10),ylabel('Load
Consumed','FontSize',10),
hold
plot(t1(2:(length(t1))),grid_power_use(2:(length(t1))),'b')
plot(t1(2:(length(t1))),power_use(2:(length(t1))),'k')
title('RESIDENCE LOAD - 18 Jan 2011','FontSize',15),
grid on;
```

# Appendix F3 – NORMALISED_RES_LOAD.m

```matlab
%load RES_20110609_Load.txt;
load QLD_20110118_Price.txt;
load TEMP_20110118.txt;
%load RES_20110118_Load.txt;
load PRT_20110118_Load.txt;
load RES_SG_20110118_Load.txt;


%LOAD ALL ELECTRICITY CONSUMPTION DATA
%load LIGHTS_1.txt;
%load LIGHTS_2.txt;
load LIGHTS_3.txt;
load LIGHTS_4.txt;
load LIGHTS_5.txt;
%load LIGHTS_6.txt;
load LIGHTS_7.txt;
%load LIGHTS_8.txt;
load LIGHTS_9.txt;
%load LIGHTS_10.txt;
load LIGHTS_11.txt;
%load LIGHTS_12.txt;
%load LIGHTS_13.txt;
%load LIGHTS_14.txt;
%load LIGHTS_15.txt;
load LIGHTS_16.txt;
%load LIGHTS_17.txt;
load LIGHTS_18.txt;
%load LIGHTS_19.txt;
%load LIGHTS_20.txt;
%load LIGHTS_21.txt;
%load LIGHTS_22.txt;
%load LIGHTS_23.txt;
%load LIGHTS_24.txt;
%load LIGHTS_25.txt;
%load LIGHTS_26.txt;
%load LIGHTS_27.txt;
%load LIGHTS_28.txt;
%load LIGHTS_29.txt;
%load LIGHTS_30.txt;
load LIGHTS_31.txt;
load FAN_1.txt;
%load FAN_2.txt;
%load FAN_3.txt;
load FAN_4.txt;
%load FAN_5.txt;
%load FAN_6.txt;
load FAN_7.txt;
load EX_FAN_1.txt;
%load EX_FAN_2.txt;
%load EX_FAN_3.txt;
load AIR_CON.txt;
```

```matlab
load FRIDGE.txt;
load FREEZER.txt;
load MICROWAVE.txt;
load OVEN.txt;
load STOVE.txt;
load RANGE_HOOD.txt;
%load FRY_PAN.txt;
load COMPUTER.txt;
load TELEVISION_1.txt;
load TELEVISION_2.txt;
load DVD_1.txt;
%load DVD_2.txt;
load HOT_WATER.txt;
load DISHWASHER.txt;
load WASHING_MACHINE.txt;
load DRYER.txt;
%load IRON.txt;
load TOASTER.txt;
load VACUUM.txt;
%load PUMP.txt;
load UNKNOWN.txt;


%L1 = [LIGHTS_1(:,2)' LIGHTS_1(1:54,2)' ]'; %Lights 1
%L2 = [LIGHTS_2(:,2)' LIGHTS_2(1:54,2)' ]';  %Lights 2
L3 = [LIGHTS_3(:,2)' LIGHTS_3(1:54,2)' ]';  %Lights 3 (essential)
L4 = [LIGHTS_4(:,2)' LIGHTS_4(1:54,2)' ]';  %Lights 4
L5 = [LIGHTS_5(:,2)' LIGHTS_5(1:54,2)' ]';  %Lights 5
%L6 = [LIGHTS_6(:,2)' LIGHTS_6(1:54,2)' ]';  %Lights 6
L7 = [LIGHTS_7(:,2)' LIGHTS_7(1:54,2)' ]'; %Lights 7
%L8 = [LIGHTS_8(:,2)' LIGHTS_8(1:54,2)' ]'; %Lights 8
L9 = [LIGHTS_9(:,2)' LIGHTS_9(1:54,2)' ]';  %Lights 9 (essential)
%L10 = [LIGHTS_10(:,2)' LIGHTS_10(1:54,2)' ]';  %Lights 10
L11 = [LIGHTS_11(:,2)' LIGHTS_11(1:54,2)' ]';  %Lights 11
%L12 = [LIGHTS_12(:,2)' LIGHTS_12(1:54,2)' ]';  %Lights 12
%L13 = [LIGHTS_13(:,2)' LIGHTS_13(1:54,2)' ]';  %Lights 13
%L14 = [LIGHTS_14(:,2)' LIGHTS_14(1:54,2)' ]';  %Lights 14
%L15 = [LIGHTS_15(:,2)' LIGHTS_15(1:54,2)' ]';  %Lights 15
L16 = [LIGHTS_16(:,2)' LIGHTS_16(1:54,2)' ]';  %Lights 16
%L17 = [LIGHTS_17(:,2)' LIGHTS_17(1:54,2)' ]';  %Lights 17
L18 = [LIGHTS_18(:,2)' LIGHTS_18(1:54,2)' ]';  %Lights 18
%L19 = [LIGHTS_19(:,2)' LIGHTS_19(1:54,2)' ]';  %Lights 19
%L20 = [LIGHTS_20(:,2)' LIGHTS_20(1:54,2)' ]';  %Lights 20
%L21 = [LIGHTS_21(:,2)' LIGHTS_21(1:54,2)' ]';  %Lights 21
%L22 = [LIGHTS_22(:,2)' LIGHTS_22(1:54,2)' ]';  %Lights 22
%L23 = [LIGHTS_23(:,2)' LIGHTS_23(1:54,2)' ]';  %Lights 23
%L24 = [LIGHTS_24(:,2)' LIGHTS_24(1:54,2)' ]';  %Lights 24
%L25 = [LIGHTS_25(:,2)' LIGHTS_25(1:54,2)' ]';  %Lights 25
%L26 = [LIGHTS_26(:,2)' LIGHTS_26(1:54,2)' ]';  %Lights 26
%L27 = [LIGHTS_27(:,2)' LIGHTS_27(1:54,2)' ]';  %Lights 27
%L28 = [LIGHTS_28(:,2)' LIGHTS_28(1:54,2)' ]';  %Lights 28
%L29 = [LIGHTS_29(:,2)' LIGHTS_29(1:54,2)' ]';  %Lights 29
%L30 = [LIGHTS_30(:,2)' LIGHTS_30(1:54,2)' ]';  %Lights 30
L31 = [LIGHTS_31(:,2)' LIGHTS_31(1:54,2)' ]';  %Lights 31



F1 = [FAN_1(:,2)' FAN_1(1:54,2)' ]'; %vector representing Fan 1
%F2 = [FAN_2(:,2)' FAN_2(1:54,2)' ]'; %vector representing Fan 2
```

```matlab
%F3 = [FAN_3(:,2)' FAN_3(1:54,2)' ]'; %vector representing Fan 3
F4 = [FAN_4(:,2)' FAN_4(1:54,2)' ]'; %vector representing Fan 4
%F5 = [FAN_5(:,2)' FAN_5(1:54,2)' ]'; %vector representing Fan 5
%F6 = [FAN_6(:,2)' FAN_6(1:54,2)' ]'; %vector representing Fan 6
F7 = [FAN_7(:,2)' FAN_7(1:54,2)' ]'; %vector representing Fan 7
EF1 = [EX_FAN_1(:,2)' EX_FAN_1(1:54,2)' ]'; %vector representing
Exhaust Fan 1
%EF2 = [EX_FAN_2(:,2)' EX_FAN_2(1:54,2)' ]'; %vector representing
Exhaust Fan 2
%EF3 = [EX_FAN_3(:,2)' EX_FAN_3(1:54,2)' ]'; %vector representing
Exhaust Fan 3
FRG = [FRIDGE(:,2)' FRIDGE(1:54,2)' ]'; %Fridge (essential)
FRZ = [FREEZER(:,2)' FREEZER(1:54,2)' ]'; %vector representing
Freezer (essential)
MW = [MICROWAVE(:,2)' MICROWAVE(1:54,2)' ]'; %vector representing
Microwave Oven
OVN = [OVEN(:,2)' OVEN(1:54,2)' ]'; %vector representing Oven
STV = [STOVE(:,2)' STOVE(1:54,2)' ]'; %vector representing Stove
RH = [RANGE_HOOD(:,2)' RANGE_HOOD(1:54,2)' ]'; %vector representing
Range Hood
%EFP = [FRY_PAN(:,2)' FRY_PAN(1:54,2)' ]'; %vector representing
Electric Frying Pan
CPU = [COMPUTER(:,2)' COMPUTER(1:54,2)' ]'; %vector representing
Computer
TV1 = [TELEVISION_1(:,2)' TELEVISION_1(1:54,2)' ]'; %vector
representing Television 1
TV2 = [TELEVISION_2(:,2)' TELEVISION_2(1:54,2)' ]'; %vector
representing Television 2
DVD1 = [DVD_1(:,2)' DVD_1(1:54,2)' ]'; %vector representing DVD
Player 1
%DVD2 = [DVD_2(:,2)' DVD_2(1:54,2)' ]'; %vector representing DVD
Player 2
HWU = [HOT_WATER(:,2)' HOT_WATER(1:54,2)' ]'; %vector representing
Hot water unit
AC = [AIR_CON(:,2)' AIR_CON(1:54,2)' ]'; %vector representing Air
Conditioner (Heat or cool)
DW = [DISHWASHER(:,2)' DISHWASHER(1:54,2)' ]'; %Dish Washer
DW_stat = zeros(1,length(DW));     %Shows status of washing machine
DW_IND = 0;                 %Indicates if DW is running (to
dissallow other
                            %appliances if there is not enough
power)
WM = [WASHING_MACHINE(:,2)' WASHING_MACHINE(1:54,2)' ]';  %Washing
machine
WM_stat = zeros(1,length(WM));      %Shows status of washing machine
WM_IND = 0;                 %Indicates if WM is running (to
dissallow other
                            %appliances if there is not enough
power)
DRY = [DRYER(:,2)' DRYER(1:54,2)' ]';%Dryer
DRY_stat = zeros(1,length(DRY));      %Shows status of Dryer
DRY_IND = 0;                  %Indicates if Dryer is running (to
dissallow other
                            %appliances if there is not enough
power)
%IRN = [IRON(:,2)' IRON(1:54,2)' ]'; %vector representing clothes
iron
```

```matlab
TSR = [TOASTER(:,2)' TOASTER(1:54,2)' ]'; %vector representing
toaster
VAC = [VACUUM(:,2)' VACUUM(1:54,2)' ]'; %vector representing vacuum
%PMP = [PUMP(:,2)' PUMP(1:54,2)' ]'; %vector representing water pump
UK = [UNKNOWN(:,2)' UNKNOWN(1:54,2)' ]';




S1 = length(L3);
T1 = [1:1:S1];
t1= (5/60).*T1; %vector representing time in hours (each point is
5mins)




RES_LOAD_ASSESS =
L3+L4+L5+L7+L9+L11+L16+L18+L31+F1+F4+F7+EF1+FRG+FRZ+MW+OVN+STV+RH+CPU
+TV1+TV2+DVD1+HWU+DW+WM+TSR+VAC+DRY+UK+AC;
RES_LOAD_MEASURE = (([PRT_20110118_Load(:,2)'
PRT_20110118_Load(1:54,2)' ]'./65));
RES_LOAD_SG = RES_SG_20110118_Load(:,2);
PRT_LOAD = ([PRT_20110118_Load(:,2)' PRT_20110118_Load(1:54,2)' ]');
PRT_LOAD_SG = zeros(1,length(RES_LOAD_SG));
SC_PRT = PRT_LOAD./65;
SG_IMPROVE = RES_LOAD_SG./RES_LOAD_ASSESS;




PRT_LOAD_SG(1:60)= PRT_LOAD(1:60)'.*mean(SG_IMPROVE(1:60)); %NIGHT
LOAD PERIOD 11pm till 5am
PRT_LOAD_SG(61:108)= PRT_LOAD(61:108)'.*mean(SG_IMPROVE(61:108));
%MORNING LOAD PERIOD 5am till 9am
PRT_LOAD_SG(109:180)= PRT_LOAD(109:180)'.*mean(SG_IMPROVE(109:180));
%DAYTIME LOAD PERIOD 9am till 4pm
PRT_LOAD_SG(181:204)= PRT_LOAD(181:204)'.*mean(SG_IMPROVE(181:204));
%EARLY PEAK LOAD PERIOD 4pm till 5pm
PRT_LOAD_SG(205:258)=
PRT_LOAD(205:258)'.*mean(SG_IMPROVE(205:258))*0.95; %MID PEAK LOAD
PERIOD 5pm till 8:30pm
PRT_LOAD_SG(259:342)=
PRT_LOAD(259:342)'.*mean(SG_IMPROVE(259:342))*1.05; %LATE PEAK LOAD
PERIOD 8:30pm till 11pm
%PRT_LOAD_SG(277:342)= PRT_LOAD(277:342)'.*mean(SG_IMPROVE(277:342));
%NIGHT LOAD PERIOD 11pm till 5am

%PRT_LOAD_SG =
smooth((smooth(PRT_LOAD,10).*smooth(SG_IMPROVE,10)),40);

MAX_PRT = max(PRT_LOAD);
disp('PRT Peak Load without SG =');
MAXPRT = sprintf('   %g VA',MAX_PRT);
disp(MAXPRT);

MAX_PRT_SG = max(PRT_LOAD_SG);
disp('PRT Peak Load using SG =');
```

```matlab
MAXPRTSG = sprintf('    %g VA',MAX_PRT_SG);
disp(MAXPRTSG);


MIN_PRT = min(PRT_LOAD);
disp('PRT Base Load without SG =');
MINPRT = sprintf('    %g VA',MIN_PRT);
disp(MINPRT);


MIN_PRT_SG = min(PRT_LOAD_SG);
disp('PRT Base Load Using SG =');
MINPRTSG = sprintf('    %g VA',MIN_PRT_SG);
disp(MINPRTSG);


AVG_PRT = mean(PRT_LOAD);
disp('PRT Average Load without SG =');
AVGPRT = sprintf('    %g VA',AVG_PRT);
disp(AVGPRT);


AVG_PRT_SG = mean(PRT_LOAD_SG);
disp('PRT Average Load Using SG =');
AVGPRTSG = sprintf('    %g VA',AVG_PRT_SG);
disp(AVGPRTSG);


LF_PRT = (AVG_PRT/MAX_PRT);
disp('PRT LF without SG =');
LFPRT = sprintf('    %g',LF_PRT);
disp(LFPRT);


LF_PRT_SG = (AVG_PRT_SG/MAX_PRT_SG);
disp('PRT LF using SG =');
LFPRTSG = sprintf('    %g',LF_PRT_SG);
disp(LFPRTSG);




%PLOTTING:

figure(1)
plot(t1,RES_LOAD_ASSESS,'r');
xlabel('Time (Hours)','FontSize',10),ylabel('Load Consumed
(VA)','FontSize',10),
hold
plot(t1,RES_LOAD_MEASURE,'b')
plot(t1,SC_PRT,'k')
title('RESIDENCE LOAD - 09 June 2011','FontSize',15),
%axis([0 24 0 50]),
grid on;

figure(2)
plot(t1,smooth(PRT_LOAD,1),'r');
hold
plot(t1,smooth(PRT_LOAD_SG,1),'b')
xlabel('Time (Hours)','FontSize',10),ylabel('Load Consumed
(VA)','FontSize',10),
title('PRT Load With and Without SG - 09 June 2011','FontSize',15),
```

```
grid on;
```

# Appendix F4 – SG_GRID_IMPROVEMENT.m

```
load QLD_20110118_Price.txt;
load PRT_SG_20110118_Load.txt;
load PRT_20110118_Load.txt;
load PWC2_20110118_Load.txt;
load SSPWC_20110118_Load.txt;
load SST16_20110118_Load.txt;
load QLD_20110118_Load.txt;


%DEFINE OTHER VARIABLES:
PRT_LOAD = smooth(([PRT_20110118_Load(:,2)'
PRT_20110118_Load(1:54,2)' ]'),20);
PRT_LOAD_SG = smooth((PRT_SG_20110118_Load(:,2)),20);
PWC2_LOAD = [PWC2_20110118_Load(1:48,2)' PWC2_20110118_Load(1:10,2)'
]';
SSPWC_LOAD = [SSPWC_20110118_Load(1:48,2)'
SSPWC_20110118_Load(1:10,2)' ]';
SST16_LOAD = [SST16_20110118_Load(1:48,2)'
SST16_20110118_Load(1:10,2)' ]';
QLD_LOAD = ([QLD_20110118_Load(:,2)' QLD_20110118_Load(1:54,2)'
]').*1000000;


S1 = length(PRT_LOAD);
T1 = [1:1:S1];
t1= (5/60).*T1; %vector representing time in hours (each point is
5mins)


%Perform interpolation of 30min vectors, SST16, SSPWC, PWC2
S2 = length(SST16_LOAD);  %finds size (length) of (30min) vector
T2 = [0:1:S2-1];
T3 = [0:(5/30):S2-1];
t2= (30/60).*T2; %vector representing time in hours (each point is
30mins)
t3= (30/60).*T3;


PWC2_LOAD_INTERP = interp1(t2,PWC2_LOAD,t3); %PWC2 Vector
interpolated
SSPWC_LOAD_INTERP = interp1(t2,SSPWC_LOAD,t3); %PWC2 Vector
interpolated
SST16_LOAD_INTERP = interp1(t2,SST16_LOAD,t3); %PWC2 Vector
interpolated


%FIND IMPROVEMENT TO PWC2
PWC2_KEY_RATIO = 17.69;
PWC2_RES_COM = PWC2_KEY_RATIO.*PRT_LOAD;
PWC2_RES_COM_SG = PWC2_KEY_RATIO.*PRT_LOAD_SG;
PWC2_LOAD_SG = PWC2_LOAD_INTERP(2:length(PWC2_LOAD_INTERP))' -
(PWC2_RES_COM - PWC2_RES_COM_SG);
```

```matlab
MAX_PWC2 = max(PWC2_LOAD_INTERP);
disp('PWC2 Peak Load without SG =');
MAXPWC = sprintf('    %g VA',MAX_PWC2);
disp(MAXPWC);


MAX_PWC2_SG = max(PWC2_LOAD_SG);
disp('PWC2 Peak Load using SG =');
MAXPWCSG = sprintf('    %g VA',MAX_PWC2_SG);
disp(MAXPWCSG);


MIN_PWC2 = min(PWC2_LOAD_INTERP);
disp('PWC2 Base Load without SG =');
MINPWC = sprintf('    %g VA',MIN_PWC2);
disp(MINPWC);


MIN_PWC2_SG = min(PWC2_LOAD_SG);
disp('PWC2 Base Load Using SG =');
MINPWCSG = sprintf('    %g VA',MIN_PWC2_SG);
disp(MINPWCSG);


AVG_PWC2 = mean(PWC2_LOAD_INTERP);
disp('PWC2 Average Load without SG =');
AVGPWC = sprintf('    %g VA',AVG_PWC2);
disp(AVGPWC);


AVG_PWC2_SG = mean(PWC2_LOAD_SG);
disp('PWC2 Average Load Using SG =');
AVGPWCSG = sprintf('    %g VA',AVG_PWC2_SG);
disp(AVGPWCSG);


LF_PWC2 = (AVG_PWC2/MAX_PWC2);
disp('PWC2 LF without SG =');
LFPWC2 = sprintf('    %g',LF_PWC2);
disp(LFPWC2);


LF_PWC2_SG = (AVG_PWC2_SG/MAX_PWC2_SG);
disp('PWC2 LF using SG =');
LFPWC2SG = sprintf('    %g',LF_PWC2_SG);
disp(LFPWC2SG);


figure(1)
plot(t1,PWC2_LOAD_INTERP(2:length(PWC2_LOAD_INTERP)),'r');
hold
plot(t1,PWC2_LOAD_SG,'b')
plot(t1,PWC2_RES_COM,'r--')
plot(t1,PWC2_RES_COM_SG,'b--')
xlabel('Time (Hours)','FontSize',10),ylabel('Load Consumed
(VA)','FontSize',10),
title('PWC2 Load With and Without SG - 09 June 2011','FontSize',15),
grid on;

%FIND IMPROVEMENT TO SSPWC
SSPWC_KEY_RATIO = 107.521;
SSPWC_RES_COM = SSPWC_KEY_RATIO.*PRT_LOAD;
SSPWC_RES_COM_SG = SSPWC_KEY_RATIO.*PRT_LOAD_SG;
```

```matlab
SSPWC_LOAD_SG = SSPWC_LOAD_INTERP(2:length(SSPWC_LOAD_INTERP))' -
(SSPWC_RES_COM - SSPWC_RES_COM_SG);

MAX_SSPWC = max(SSPWC_LOAD_INTERP);
disp('SSPWC Peak Load without SG =');
MAXSSPWC = sprintf('   %g VA',MAX_SSPWC);
disp(MAXSSPWC);

MAX_SSPWC_SG = max(SSPWC_LOAD_SG);
disp('SSPWC Peak Load using SG =');
MAXSSPWCSG = sprintf('   %g VA',MAX_SSPWC_SG);
disp(MAXSSPWCSG);

MIN_SSPWC = min(SSPWC_LOAD_INTERP);
disp('SSPWC Base Load without SG =');
MINSSPWC = sprintf('   %g VA',MIN_SSPWC);
disp(MINSSPWC);

MIN_SSPWC_SG = min(SSPWC_LOAD_SG);
disp('SSPWC Base Load Using SG =');
MINSSPWCSG = sprintf('   %g VA',MIN_SSPWC_SG);
disp(MINSSPWCSG);

AVG_SSPWC = mean(SSPWC_LOAD_INTERP);
disp('SSPWC Average Load without SG =');
AVGSSPWC = sprintf('   %g VA',AVG_SSPWC);
disp(AVGSSPWC);

AVG_SSPWC_SG = mean(SSPWC_LOAD_SG);
disp('SSPWC Average Load Using SG =');
AVGSSPWCSG = sprintf('   %g VA',AVG_SSPWC_SG);
disp(AVGSSPWCSG);

LF_SSPWC = (AVG_SSPWC/MAX_SSPWC);
disp('SSPWC LF without SG =');
LFSSPWC = sprintf('   %g',LF_SSPWC);
disp(LFSSPWC);

LF_SSPWC_SG = (AVG_SSPWC_SG/MAX_SSPWC_SG);
disp('SSPWC LF using SG =');
LFSSPWCSG = sprintf('   %g',LF_SSPWC_SG);
disp(LFSSPWCSG);

figure(2)
plot(t1,SSPWC_LOAD_INTERP(2:length(SSPWC_LOAD_INTERP)),'r');
hold
plot(t1,SSPWC_LOAD_SG,'b')
plot(t1,SSPWC_RES_COM,'r--')
plot(t1,SSPWC_RES_COM_SG,'b--')
xlabel('Time (Hours)','FontSize',10),ylabel('Load Consumed
(VA)','FontSize',10),
title('SSPWC Load With and Without SG - 09 June 2011','FontSize',15),
grid on;
```

```matlab
%FIND IMPROVEMENT TO SST16
SST16_KEY_RATIO = 397.067;
SST16_RES_COM = SST16_KEY_RATIO.*PRT_LOAD;
SST16_RES_COM_SG = SST16_KEY_RATIO.*PRT_LOAD_SG;
SST16_LOAD_SG = SST16_LOAD_INTERP(2:length(SST16_LOAD_INTERP))' -
(SST16_RES_COM - SST16_RES_COM_SG);

MAX_SST16 = max(SST16_LOAD_INTERP);
disp('SST16 Peak Load without SG =');
MAXSST16 = sprintf('    %g VA',MAX_SST16);
disp(MAXSST16);

MAX_SST16_SG = max(SST16_LOAD_SG);
disp('SST16 Peak Load using SG =');
MAXSST16SG = sprintf('    %g VA',MAX_SST16_SG);
disp(MAXSST16SG);

MIN_SST16 = min(SST16_LOAD_INTERP);
disp('SST16 Base Load without SG =');
MINSST16 = sprintf('    %g VA',MIN_SST16);
disp(MINSST16);

MIN_SST16_SG = min(SST16_LOAD_SG);
disp('SST16 Base Load Using SG =');
MINSST16SG = sprintf('    %g VA',MIN_SST16_SG);
disp(MINSST16SG);

AVG_SST16 = mean(SST16_LOAD_INTERP);
disp('SST16 Average Load without SG =');
AVGSST16 = sprintf('    %g VA',AVG_SST16);
disp(AVGSST16);

AVG_SST16_SG = mean(SST16_LOAD_SG);
disp('SST16 Average Load Using SG =');
AVGSST16SG = sprintf('    %g VA',AVG_SST16_SG);
disp(AVGSST16SG);

LF_SST16 = (AVG_SST16/MAX_SST16);
disp('SST16 LF without SG =');
LFSST16 = sprintf('    %g',LF_SST16);
disp(LFSST16);

LF_SST16_SG = (AVG_SST16_SG/MAX_SST16_SG);
disp('SST16 LF using SG =');
LFSST16SG = sprintf('    %g',LF_SST16_SG);
disp(LFSST16SG);

figure(3)
plot(t1,SST16_LOAD_INTERP(2:length(SST16_LOAD_INTERP)),'r');
hold
plot(t1,SST16_LOAD_SG,'b')
plot(t1,SST16_RES_COM,'r--')
plot(t1,SST16_RES_COM_SG,'b--')
xlabel('Time (Hours)','FontSize',10),ylabel('Load Consumed
(VA)','FontSize',10),
title('SST16 Load With and Without SG - 09 June 2011','FontSize',15),
```

```matlab
grid on;


%FIND IMPROVEMENT TO QLD
QLD_KEY_RATIO = 48714.2;
QLD_RES_COM = smooth(QLD_KEY_RATIO.*PRT_LOAD,20);
QLD_RES_COM_SG = smooth(QLD_KEY_RATIO.*PRT_LOAD_SG,20);
QLD_LOAD_SG = QLD_LOAD - (QLD_RES_COM - QLD_RES_COM_SG);

MAX_QLD = max(QLD_LOAD);
disp('QLD Peak Load without SG =');
MAXQLD = sprintf('    %g VA',MAX_QLD);
disp(MAXQLD);


MAX_QLD_SG = max(QLD_LOAD_SG);
disp('QLD Peak Load using SG =');
MAXQLDSG = sprintf('    %g VA',MAX_QLD_SG);
disp(MAXQLDSG);


MIN_QLD = min(QLD_LOAD);
disp('QLD Base Load without SG =');
MINQLD = sprintf('    %g VA',MIN_QLD);
disp(MINQLD);


MIN_QLD_SG = min(QLD_LOAD_SG(108:342));
disp('QLD Base Load Using SG =');
MINQLDSG = sprintf('    %g VA',MIN_QLD_SG);
disp(MINQLDSG);


AVG_QLD = mean(QLD_LOAD);
disp('QLD Average Load without SG =');
AVGQLD = sprintf('    %g VA',AVG_QLD);
disp(AVGQLD);


AVG_QLD_SG = mean(QLD_LOAD_SG);
disp('QLD Average Load Using SG =');
AVGQLDSG = sprintf('    %g VA',AVG_QLD_SG);
disp(AVGQLDSG);


LF_QLD = (AVG_QLD/MAX_QLD);
disp('QLD LF without SG =');
LFQLD = sprintf('    %g',LF_QLD);
disp(LFQLD);


LF_QLD_SG = (AVG_QLD_SG/MAX_QLD_SG);
disp('QLD LF using SG =');
LFQLDSG = sprintf('    %g',LF_QLD_SG);
disp(LFQLDSG);


%PL_QLD = RES_LOAD_ASSESS - MIN_A;   %Find load which is over base
(minimum) load
%APL_QLD = mean(PL);  %finds average load on peak plant
%MPL_QLD = max(PL);   %finds peak of load on peak plant
%PLF_QLD = APL/MPL;   %finds plant factor of the peak load plant
```

```matlab
figure(4)
plot(t1,QLD_LOAD,'r');
hold
plot(t1,QLD_LOAD_SG,'b')
plot(t1,QLD_RES_COM,'r--')
plot(t1,QLD_RES_COM_SG,'b--')
xlabel('Time (Hours)','FontSize',10),ylabel('Load Consumed
(VA)','FontSize',10),
title('QLD Load With and Without SG - 09 June 2011','FontSize',15),
grid on;


%FIND IMPROVEMENT TO QLD IWTH 27.7% RATIO
QLD_KEY_RATIO2 = 25873.3;
QLD_RES_COM2 = smooth(QLD_KEY_RATIO2.*PRT_LOAD,20);
QLD_RES_COM_SG2 = smooth(QLD_KEY_RATIO2.*PRT_LOAD_SG,20);
QLD_LOAD_SG2 = QLD_LOAD - (QLD_RES_COM2 - QLD_RES_COM_SG2);

MAX_QLD2 = max(QLD_LOAD);
disp('QLD Peak Load without SG (using 27.7% Ratio) =');
MAXQLD2 = sprintf('   %g VA',MAX_QLD2);
disp(MAXQLD2);


MAX_QLD_SG2 = max(QLD_LOAD_SG2);
disp('QLD Peak Load using SG (using 27.7% Ratio) =');
MAXQLDSG2 = sprintf('   %g VA',MAX_QLD_SG2);
disp(MAXQLDSG2);


MIN_QLD2 = min(QLD_LOAD);
disp('QLD Base Load without SG (using 27.7% Ratio) =');
MINQLD2 = sprintf('   %g VA',MIN_QLD2);
disp(MINQLD2);


MIN_QLD_SG2 = min(QLD_LOAD_SG2(108:342));
disp('QLD Base Load Using SG (using 27.7% Ratio) =');
MINQLDSG2 = sprintf('   %g VA',MIN_QLD_SG2);
disp(MINQLDSG2);


AVG_QLD2 = mean(QLD_LOAD);
disp('QLD Average Load without SG (using 27.7% Ratio) =');
AVGQLD2 = sprintf('   %g VA',AVG_QLD2);
disp(AVGQLD2);


AVG_QLD_SG2 = mean(QLD_LOAD_SG2);
disp('QLD Average Load Using SG (using 27.7% Ratio) =');
AVGQLDSG2 = sprintf('   %g VA',AVG_QLD_SG2);
disp(AVGQLDSG2);


LF_QLD2 = (AVG_QLD2/MAX_QLD2);
disp('QLD LF without SG (using 27.7% Ratio) =');
LFQLD2 = sprintf('   %g',LF_QLD2);
disp(LFQLD2);


LF_QLD_SG2 = (AVG_QLD_SG2/MAX_QLD_SG2);
```

```
disp('QLD LF using SG (using 27.7% Ratio) =');
LFQLDSG2 = sprintf('   %g',LF_QLD_SG2);
disp(LFQLDSG2);


figure(5)
plot(t1,QLD_LOAD,'r');
hold
plot(t1,QLD_LOAD_SG2,'b')
plot(t1,QLD_RES_COM2,'r--')
plot(t1,QLD_RES_COM_SG2,'b--')
xlabel('Time (Hours)','FontSize',10),ylabel('Load Consumed
(VA)','FontSize',10),
title('QLD Load With and Without SG (using 27.7% Ratio) - 09 June
2011','FontSize',15),
grid on;
%FIND ESTIMATED COST TO GENERATE ELECTRICITY
CTR_BASE = 1; % $1000 per kW
CTR_PEAK = 1.2; % $1000 per kW
FCR = 0.16;
COP_BASE = 0.00005; %5cents per kW
COP_PEAK = 0.00004; %4cents per kW


%WITHOUT SG
QLD_LOAD_PEAK = QLD_LOAD - MIN_QLD;
QLD_LOAD_BASE = QLD_LOAD - QLD_LOAD_PEAK;
ENERGY_COST_BASE = (CTR_BASE*FCR/(8760)) + COP_BASE; %cost in $ per
WattHour
ENERGY_COST_PEAK =
(CTR_PEAK*FCR/((sum(QLD_LOAD_PEAK)/(max(QLD_LOAD_PEAK)*length(QLD_LOA
D))*(8760))) + COP_PEAK; %cost in $ per WattHour
COST_BASE = ENERGY_COST_BASE*sum(QLD_LOAD_BASE)*(5/60);
COST_PEAK = ENERGY_COST_PEAK*sum(QLD_LOAD_PEAK)*(5/60);
COST_TOTAL = COST_BASE + COST_PEAK;


%WITH SG
QLD_LOAD_PEAK_SG = QLD_LOAD_SG - MIN_QLD_SG;
QLD_LOAD_BASE_SG = QLD_LOAD_SG - QLD_LOAD_PEAK_SG;
ENERGY_COST_BASE_SG = (CTR_BASE*FCR/(8760)) + COP_BASE; %cost in $
per WattHour
ENERGY_COST_PEAK_SG =
(CTR_PEAK*FCR/((sum(QLD_LOAD_PEAK_SG)/(max(QLD_LOAD_PEAK_SG)*length(Q
LD_LOAD)))*(8760))) + COP_PEAK; %cost in $ per WattHour
COST_BASE_SG = ENERGY_COST_BASE_SG*sum(QLD_LOAD_BASE_SG)*(5/60);
COST_PEAK_SG = ENERGY_COST_PEAK_SG*sum(QLD_LOAD_PEAK_SG)*(5/60);
COST_TOTAL_SG = COST_BASE_SG + COST_PEAK_SG;


%WITH SG (27.7%)
QLD_LOAD_PEAK_SG2 = QLD_LOAD_SG2 - MIN_QLD_SG2;
QLD_LOAD_BASE_SG2 = QLD_LOAD_SG2 - QLD_LOAD_PEAK_SG2;
ENERGY_COST_BASE_SG2 = (CTR_BASE*FCR/(8760)) + COP_BASE; %cost in $
per WattHour
ENERGY_COST_PEAK_SG2 =
(CTR_PEAK*FCR/((sum(QLD_LOAD_PEAK_SG2)/(max(QLD_LOAD_PEAK_SG2)*length
(QLD_LOAD)))*(8760))) + COP_PEAK; %cost in $ per WattHour
COST_BASE_SG2 = ENERGY_COST_BASE_SG2*sum(QLD_LOAD_BASE_SG2)*(5/60);
COST_PEAK_SG2 = ENERGY_COST_PEAK_SG2*sum(QLD_LOAD_PEAK_SG2)*(5/60);
COST_TOTAL_SG2 = COST_BASE_SG2 + COST_PEAK_SG2;
```

```matlab
%SAVINGS
SAVINGS_SG = (1 - (COST_TOTAL_SG/COST_TOTAL))*100;
disp('Savings in cost to generate electricity =');
SAVINGSSG = sprintf('   %g percent',SAVINGS_SG);
disp(SAVINGSSG);

SAVINGS_SG2 = (1 - (COST_TOTAL_SG2/COST_TOTAL))*100;
disp('Savings in cost to generate electricity (using 27.7% Ratio)
=');
SAVINGSSG2 = sprintf('   %g percent',SAVINGS_SG2);
disp(SAVINGSSG2);
```

# Appendix G1 – Solar Module and Inverter information

# Monocrystalline Solar Module 125X125mm 8x12 Cells

## Electrical Charateristics

| TUV-Model | UL-235D-96 | UL-240D-96 | UL-245D-96 | UL-250D-96 | UL-255D-96 | UL-260D-96 |
|---|---|---|---|---|---|---|
| UL-Model | UL-235D | UL-240D | UL-245D | UL-250D | UL-255D | UL-260D |
| Max Power Pm(W) | 235 | 240 | 245 | 250 | 255 | 260 |
| Max Power Voltage Vm(V) | 47.3 | 47.6 | 47.7 | 47.8 | 47.9 | 48.0 |
| Max Power Current Im(A) | 4.97 | 5.04 | 5.14 | 5.23 | 5.33 | 5.42 |
| Open-Circuit Voltage Voc(V) | 59.1 | 59.3 | 59.6 | 59.9 | 60.0 | 60.1 |
| Short-Circuit Current Isc(A) | 5.42 | 5.52 | 5.62 | 5.73 | 5.82 | 5.89 |
| Cell Efficiency | 16.5% | 16.8% | 17.2% | 16.8% | 17.2% | 17.5% |
| Module Efficiency | 13.8% | 14.1% | 14.4% | 14.7% | 15.0% | 15.3% |
| Power Tolerance | ±3% | | | | | |
| Maximum System Voltage(V) | 1000(TUV)/600(UL) | | | | | |
| Temperture Coefficient of Isc | 0.065%/℃ | | | | | |
| Temperture Coefficient of Voc | -0.35%/℃ | | | | | |
| Temperture Coefficient of Pmax | -0.40/℃ | | | | | |
| Operating Temperature | -40℃~+85℃ | | | | | |
| NOCT | 47±2℃ | | | | | |
| Series Fuse Rating(A) | 10 | | | | | |

STC:irrdiance:1000W/mm$^2$;solar spectrum: AM1.5; cell temperature: 25°C

## Mechanical Charateristics

| | |
|---|---|
| Module Dimension (mm) | 1602x1061x46 |
| Cell Dimension (mm) | 125x125 |
| Array (PCS) | 8x12 |
| Weight(Kg) | 21 |

| CHARACTERISTICS | PVI-2000 | PVI-3600 |
|---|---|---|
| **INPUT PARAMETERS** | | |
| Nominal DC Power [kW] | 2,1 | 3,8 |
| Max. Recommended DC Power [kW] | 2,3 | 4,2 |
| Operating Input Voltage Range [V] | 90 - 580 (360 nominal) | |
| Full Power MPPT input voltage range (symmetrical load) [V] | 210-530 | 190-530 |
| Full asymmetrical load input voltage range [V] | NA | 200-530 (@ 2kW) / 180-530 (@ 1,8kW) |
| Absolute Max. Input Voltage [V] | 600 | |
| Activation voltage "Vstart" [V] | 200 nominal (adjustable within the range 120Vdc-350Vdc, independently/each input) | |
| No of independent MPPT trackers | 1 | 2 |
| Max. Input Power, each MPPT [kW] | 2 | 2 |
| No. of DC Inputs | 1 | 2 (1 each MPPT) |
| Max. DC Current, each MPPT [A] | 10 (12 shortcircuit) | 10 (12 shortcircuit) |
| DC Connection | 2 (1 positive, 1 negative) | 4 (2 positive, 2 negative) |
| | MultiContact Ø 3mm (male - positive input + female - negative input) | |
| | Mating cable connector included | |
| | Conductor cross section: 4-6mmq/AWG12-10 - Cable Ø w/insulator: 3-6mm | |
| **INPUT PROTECTION** | | |
| Reverse polarity protection | Yes | |
| Fuse rating, each input (-FS suffix versions only) | NA | NA |
| DC side varistors | 2, thermally protected | 4 ( 2 for each MPPT ), thermally protected |
| PV array Insulation Control | according to VDE0126-1-1 | |
| DC Switch (-S/-FS suffix versions only) | NA | |
| **OUTPUT PARAMETERS** | | |
| Nominal AC Power [up to 40°C, kW] | 2 | 3,6 |
| Max. AC Power [kW] | 2 | 3,6 |
| AC Grid Connection | single phase 230Vac 50Hz + PE | |
| Nominal AC Voltage [V] | 230 | |
| Maximum AC Voltage Range [V] | 180-264 | |
| Nominal AC Frequency [Hz] | 50 | |
| Max. AC Line Current [A] | 9 | 16 |
| AC Connection | Circular Bayonet Connector | |
| | Conductor Cross Section: Solid / Stranded: 0,5-2,5mmq / AWG 20-14 | |
| | Outer Cable Ø: 10-12mm | |
| Line Power Factor | 1 | |
| AC Current Distortion [THD%] | <2,5% at rated power with sine wave voltage | |
| **OUTPUT PROTECTION** | | |
| AC side varistors | 2, plus gas arrester to ground | |
| Ground fault protection (AC + DC leakage current) | according to VDE0126-1-1 | |
| **CONVERSION EFFICIENCY** | | |
| Max. Efficiency | 96% | |
| Euro Efficiency | 95,00% | |
| **ENVIRONMENTAL PARAMETERS** | | |
| Cooling | Forced cooling | |
| Ambient Temp. Range [°C] | -25 / +55 (output power derating above 40°C) | |
| Operating Altitude [m] | 2000 | |
| Acoustical Noise [dBA] | <30 @1mt (<50 @1mt with fan at full speed) | |
| Environmental IP Rating | IP21 | |
| Relative Humidity | 0-90% non condensing | |
| **MECHANICAL** | | |
| Dimensions [H x W x D] | 440 x 465 x 57 | |
| Weight [kg] | 6 | 7,5 |
| **OTHER** | | |
| Stand-By Consumption [W] | 8 | |
| Feed In Power Threshold [W] | 10 | |
| Night Time consumption [W] | 0,3 | |
| Isolation | No isolation, Transformer-less | |
| Display | YES (Grafico) | |
| Communication | RS485 (cage-clamp connector - Conductor cross section: 0,08-1,5mmq/AWG28-16); RS232 (DB9) | |
| | Optional "Aurora Easy Control" remote monitoring system | |
| **AVAILABLE PRODUCT VARIANTS** | | |
| Standard - no options | PVI-2000 | PVI-3600 |
| With DC switch | NA | NA |
| With DC switch and protection fuse/each input | NA | NA |

# Appendix G2 – Deep Cycle Battery Information

A600

| Type designation acc. to DIN 40742 | Part number | Nominal voltage | Nominal capacity $C_{10}$ 1.8 V/C 20°C | Discharge current $I_{10}$ | Length (l) | Width (b) | Height ($h_1$) | Height ($h_2$) | Installed length (B) | Pole pairs | Weight | Internal resistance acc. to IEC 896-2 | Short circuit current acc. to IEC 896-2 | Term |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | V | Ah | A | max. mm | max. mm | max. mm | max. mm | mm | | approx. kg | m Ω | A | |
| 4 OPzV 200 | NGA6020200HS0FA | 2 | 200 | 20 | 105 | 208 | 360 | 398 | 113 | 1 | 20 | 0.94 | 2235 | F-I |
| 5 OPzV 250 | NGA6020250HS0FA | 2 | 250 | 25 | 126 | 208 | 360 | 398 | 134 | 1 | 23 | 0.78 | 2706 | F-I |
| 6 OPzV 300 | NGA6020300HS0FA | 2 | 300 | 30 | 147 | 208 | 360 | 398 | 155 | 1 | 27 | 0.60 | 3414 | F-I |
| 5 OPzV 350 | NGA6020350HS0FA | 2 | 350 | 35 | 126 | 208 | 475 | 513 | 134 | 1 | 30 | 0.61 | 3418 | F-I |
| 6 OPzV 420 | NGA6020420HS0FA | 2 | 420 | 42 | 147 | 208 | 475 | 513 | 155 | 1 | 35 | 0.49 | 4220 | F-I |
| 7 OPzV 490 | NGA6020490HS0FA | 2 | 490 | 49 | 168 | 208 | 475 | 513 | 176 | 1 | 40 | 0.51 | 4096 | F-I |
| 6 OPzV 600 | NGA6020600HS0FA | 2 | 600 | 60 | 147 | 208 | 650 | 688 | 155 | 1 | 48 | 0.44 | 4743 | F-I |
| 8 OPzV 800 | NGA6020800HS0FA | 2 | 800 | 80 | 212 | 193 | 650 | 688 | 220 | 2 | 67 | 0.30 | 6818 | F-I |
| 10 OPzV 1000 | NGA6021000HS0FA | 2 | 1000 | 100 | 212 | 235 | 650 | 688 | 220 | 2 | 80 | 0.25 | 8200 | F-I |
| 12 OPzV 1200 | NGA6021200HS0FA | 2 | 1200 | 120 | 212 | 277 | 650 | 688 | 220 | 2 | 94 | 0.21 | 9840 | F-I |
| 12 OPzV 1500 | NGA6021500HS0FA | 2 | 1500 | 150 | 212 | 277 | 800 | 838 | 220 | 2 | 118 | 0.19 | 10500 | F-I |
| 16 OPzV 2000 | NGA6022000HS0FA | 2 | 2000 | 200 | 215 | 400 | 775 | 815 | 223 | 3 | 160 | 0.15 | 14000 | F-I |
| 20 OPzV 2500 | NGA6022500VS0FA | 2 | 2500 | 250 | 215 | 490 | 775 | 815 | 223 | 4 | 200 | 0.12 | 17500 | F-I |
| 24 OPzV 3000 | NGA6023000VS0FA | 2 | 3000 | 300 | 215 | 580 | 775 | 815 | 223 | 4 | 240 | 0.10 | 21000 | F-I |

| Type | Part number | 10min | 15min | 30min | 1h | 2h | 3h | 5h | 8h | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 4OPzV200 | NGA6020200HS0FA | 157 | 148 | 128 | 95 | 66 | 50 | 34 | 24 | 20 |
| 5OPzV250 | NGA6020250HS0FA | 196 | 185 | 160 | 119 | 82 | 63 | 43 | 30 | 25 |
| 6OPzV300 | NGA6020300HS0FA | 235 | 222 | 192 | 143 | 98 | 76 | 52 | 36 | 30 |
| 5OPzV350 | NGA6020350HS0FA | 238 | 223 | 196 | 155 | 109 | 86 | 63 | 44 | 35 |
| 6OPzV420 | NGA6020420HS0FA | 261 | 244 | 215 | 176 | 124 | 100 | 75 | 52 | 42 |
| 7OPzV490 | NGA6020490HS0FA | 284 | 264 | 234 | 198 | 140 | 114 | 87 | 61 | 49 |
| 6OPzV600 | NGA6020600HS0FA | 304 | 282 | 252 | 220 | 157 | 129 | 101 | 71 | 60 |
| 8OPzV800 | NGA6020800HS0FA | 470 | 424 | 363 | 318 | 222 | 181 | 137 | 96 | 78 |
| 10OPzV1000 | NGA6021000HS0FA | 485 | 452 | 406 | 369 | 266 | 222 | 171 | 118 | 98 |
| 12OPzV1200 | NGA6021200HS0FA | 500 | 480 | 449 | 420 | 309 | 262 | 204 | 140 | 118 |
| 12OPzV1500 | NGA6021500HS0FA | 654 | 619 | 557 | 485 | 369 | 315 | 241 | 172 | 147 |
| 16OPzV2000 | NGA6022000HS0FA | 884 | 842 | 760 | 608 | 466 | 384 | 289 | 213 | 184 |
| 20OPzV2500 | NGA6022500HS0FA | 993 | 957 | 895 | 760 | 583 | 480 | 362 | 266 | 230 |
| 24OPzV3000 | NGA6023000HS0FA | 1124 | 1094 | 1044 | 930 | 709 | 614 | 478 | 340 | 288 |
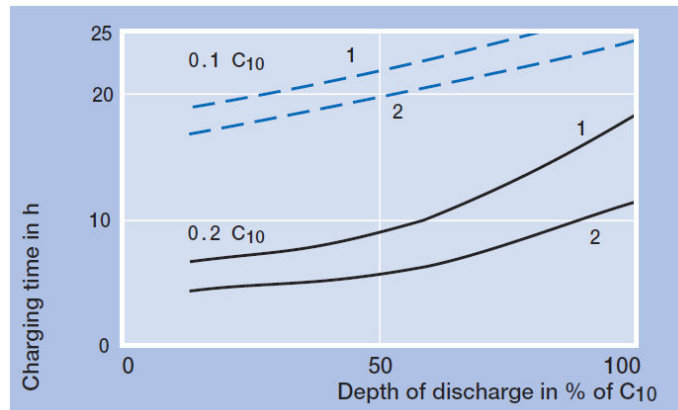
1.87 V/C – Discharge in A

# Appendix G3 – Solar Irradiation Data

**Brisbane Irradiation chart - W/m$^2$**

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5:00 | 3 | | | | | | | | | | 7 | 8 | 18 |
| 6:00 | 38 | 18 | 6 | 2 | | | | 3 | 10 | 34 | 75 | 61 | 247 |
| 7:00 | 184 | 155 | 116 | 48 | 24 | 15 | 18 | 39 | 152 | 224 | 248 | 222 | 1445 |
| 8:00 | 368 | 354 | 348 | 314 | 261 | 240 | 235 | 323 | 398 | 421 | 437 | 413 | 4112 |
| 9:00 | 536 | 538 | 504 | 521 | 455 | 438 | 424 | 526 | 617 | 575 | 576 | 554 | 6264 |
| 10:00 | 686 | 662 | 631 | 653 | 610 | 587 | 577 | 690 | 772 | 703 | 697 | 688 | 7956 |
| 11:00 | 785 | 763 | 735 | 711 | 669 | 667 | 654 | 767 | 841 | 784 | 745 | 781 | 8902 |
| 12:00 | 832 | 808 | 776 | 733 | 670 | 665 | 669 | 797 | 866 | 783 | 774 | 811 | 9184 |
| 13:00 | 825 | 808 | 794 | 699 | 601 | 632 | 624 | 752 | 823 | 738 | 725 | 779 | 8800 |
| 14:00 | 754 | 714 | 731 | 616 | 508 | 549 | 539 | 652 | 732 | 640 | 614 | 688 | 7737 |
| 15:00 | 618 | 587 | 563 | 472 | 387 | 414 | 418 | 504 | 552 | 487 | 460 | 525 | 5987 |
| 16:00 | 419 | 413 | 379 | 284 | 209 | 224 | 248 | 315 | 351 | 311 | 309 | 341 | 3803 |
| 17:00 | 223 | 223 | 178 | 65 | 22 | 17 | 29 | 50 | 91 | 129 | 147 | 183 | 1357 |
| 18:00 | 58 | 50 | 22 | 4 | | | | 2 | 6 | 10 | 26 | 44 | 222 |
| 19:00 | 8 | 4 | | | | | | | | | | 6 | 18 |
| Total | 6337 | 6097 | 5783 | 5122 | 4416 | 4448 | 4435 | 5420 | 6211 | 5839 | 5840 | 6104 | 55504 |

# Appendix H1 – Fridge and Freezer Raw data

<u>Freezer</u>

Fichier ML0291
Energie Mètre 01030069

| Date | Watts |
|------|-------|
| 22/02/11 11:42:00 | - |
| 22/02/11 11:43:00 | 0.3 |
| 22/02/11 11:44:00 | 0.3 |
| 22/02/11 11:45:00 | 0.3 |
| 22/02/11 11:46:00 | 0.3 |
| 22/02/11 11:47:00 | 0.3 |
| 22/02/11 11:48:00 | 0.3 |
| 22/02/11 11:49:00 | 0.3 |
| 22/02/11 11:50:00 | 0.3 |
| 22/02/11 11:51:00 | 0.3 |
| 22/02/11 11:52:00 | 0.3 |
| 22/02/11 11:53:00 | 0.3 |
| 22/02/11 11:54:00 | 0.3 |
| 22/02/11 11:55:00 | 0.3 |
| 22/02/11 11:56:00 | 0.3 |
| 22/02/11 11:57:00 | 0.3 |
| 22/02/11 11:58:00 | 0.3 |
| 22/02/11 11:59:00 | 0.3 |
| 22/02/11 12:00:00 | 0.3 |
| 22/02/11 12:01:00 | 0.3 |
| 22/02/11 12:02:00 | 0.3 |
| 22/02/11 12:03:00 | 0.3 |
| 22/02/11 12:04:00 | 0.3 |
| 22/02/11 12:05:00 | 0.3 |
| 22/02/11 12:06:00 | 0.4 |
| 22/02/11 12:07:00 | 33.0 |
| 22/02/11 12:08:00 | 97.8 |
| 22/02/11 12:09:00 | 99.2 |
| 22/02/11 12:10:00 | 96.6 |
| 22/02/11 12:11:00 | 96.6 |
| 22/02/11 12:12:00 | 97.0 |
| 22/02/11 12:13:00 | 97.3 |
| 22/02/11 12:14:00 | 97.7 |
| 22/02/11 12:15:00 | 97.9 |
| 22/02/11 12:16:00 | 98.9 |

# Fridge

Fichier ML0290
Energie Mètre 01030052

| Date | Watts |
|------|-------|
| 22/02/11 11:39:00 | - |
| 22/02/11 11:40:00 | 130.5 |
| 22/02/11 11:41:00 | 130.5 |
| 22/02/11 11:42:00 | 130.1 |
| 22/02/11 11:43:00 | 129.3 |
| 22/02/11 11:44:00 | 127.8 |
| 22/02/11 11:45:00 | 126.4 |
| 22/02/11 11:46:00 | 84.3 |
| 22/02/11 11:47:00 | 7.1 |
| 22/02/11 11:48:00 | 7.0 |
| 22/02/11 11:49:00 | 7.0 |
| 22/02/11 11:50:00 | 7.0 |
| 22/02/11 11:51:00 | 6.6 |
| 22/02/11 11:52:00 | 6.5 |
| 22/02/11 11:53:00 | 6.6 |
| 22/02/11 11:54:00 | 6.6 |
| 22/02/11 11:55:00 | 6.5 |
| 22/02/11 11:56:00 | 6.8 |
| 22/02/11 11:57:00 | 6.7 |
| 22/02/11 11:58:00 | 6.5 |
| 22/02/11 11:59:00 | 6.5 |
| 22/02/11 12:00:00 | 6.6 |
| 22/02/11 12:01:00 | 6.5 |
| 22/02/11 12:02:00 | 6.6 |
| 22/02/11 12:03:00 | 6.5 |
| 22/02/11 12:04:00 | 6.6 |
| 22/02/11 12:05:00 | 6.6 |
| 22/02/11 12:06:00 | 79.4 |
| 22/02/11 12:07:00 | 145.2 |
| 22/02/11 12:08:00 | 129.4 |
| 22/02/11 12:09:00 | 128.1 |

# Appendix H2 – BOM Raw Data

hm,Station Number,Day/Month/Year Hour24:Minutes in DD/MM/YYYY HH24:MI format in Local time,Day/Month/Year Hour24:Minutes in DD/MM/YYYY HH24:MI format in Local standard time,Precipitation since 9am local time in mm,Quality of precipitation since 9am local time,Air Temperature in degrees C,Quality of air temperature,Wet bulb temperature in degrees C,Quality of Wet bulb temperature,Dew point temperature in degrees C,Quality of dew point temperature,Relative humidity in percentage %,Quality of relative humidity,AWS Flag,#

hm, 40988,09/06/2010 00:00,09/06/2010 00:00,  0.0,N, 15.5,N, 14.7,N, 14.0,N, 91,N, 1,#

hm, 40988,09/06/2010 00:30,09/06/2010 00:30,  0.0,N, 15.4,N, 14.5,N, 13.8,N, 90,N, 1,#

hm, 40988,09/06/2010 01:00,09/06/2010 01:00,  0.0,N, 15.1,N, 14.4,N, 13.8,N, 92,N, 1,#

hm, 40988,09/06/2010 01:30,09/06/2010 01:30,  0.0,N, 15.2,N, 14.5,N, 13.9,N, 92,N, 1,#

hm, 40988,09/06/2010 02:00,09/06/2010 02:00,  0.0,N, 14.5,N, 13.8,N, 13.2,N, 92,N, 1,#

hm, 40988,09/06/2010 02:30,09/06/2010 02:30,  0.0,N, 14.4,N, 13.7,N, 13.1,N, 92,N, 1,#

hm, 40988,09/06/2010 03:00,09/06/2010 03:00,  0.0,N, 14.4,N, 13.8,N, 13.3,N, 93,N, 1,#

hm, 40988,09/06/2010 03:30,09/06/2010 03:30,  0.0,N, 13.9,N, 13.2,N, 12.6,N, 92,N, 1,#

hm, 40988,09/06/2010 04:00,09/06/2010 04:00,  0.0,N, 13.9,N, 13.2,N, 12.6,N, 92,N, 1,#

# Appendix H3 – Energex Raw Data

| Counter | Event | Date | Time (sec) | VA | VB | VC | IA | IB | IC |
|---|---|---|---|---|---|---|---|---|---|
| | IN | | | | | | | | |
| 1 | 1 | 15-07-2011 | 0.000 | 249.00 | 253.48 | 251.96 | 113.03 | 83.59 | 73.24 |
| | 0.00 | | | | | | | | |
| 2 | 1 | 15-07-2011 | 0.010 | 250.60 | 252.69 | 251.96 | 113.41 | 83.21 | 73.24 |
| | 0.00 | | | | | | | | |
| 3 | 1 | 15-07-2011 | 0.020 | 250.60 | 252.69 | 251.96 | 113.79 | 83.21 | 72.86 |
| | 0.00 | | | | | | | | |
| 4 | 1 | 15-07-2011 | 0.030 | 250.60 | 252.69 | 251.96 | 113.03 | 83.97 | 72.48 |
| | 0.00 | | | | | | | | |
| 5 | 1 | 15-07-2011 | 0.040 | 250.60 | 252.69 | 251.96 | 113.41 | 82.83 | 72.86 |
| | 0.00 | | | | | | | | |
| 6 | 1 | 15-07-2011 | 0.050 | 250.60 | 252.69 | 251.96 | 114.17 | 83.97 | 73.24 |
| | 0.00 | | | | | | | | |
| 7 | 1 | 15-07-2011 | 0.060 | 249.00 | 253.48 | 251.96 | 113.03 | 83.59 | 72.86 |
| | 0.00 | | | | | | | | |
| 8 | 1 | 15-07-2011 | 0.070 | 250.60 | 252.69 | 251.96 | 113.79 | 83.59 | 72.86 |
| | 0.00 | | | | | | | | |
| 9 | 1 | 15-07-2011 | 0.080 | 250.60 | 252.69 | 251.96 | 113.79 | 83.59 | 72.48 |
| | 0.00 | | | | | | | | |
| 10 | 1 | 15-07-2011 | 0.090 | 250.60 | 252.69 | 251.96 | 113.79 | 83.97 | 73.62 |
| | 0.00 | | | | | | | | |
| 11 | 1 | 15-07-2011 | 0.100 | 250.60 | 252.69 | 251.96 | 113.79 | 82.83 | 72.48 |
| | 0.00 | | | | | | | | |
| 12 | 1 | 15-07-2011 | 0.110 | 250.60 | 252.69 | 251.96 | 113.79 | 83.97 | 73.24 |
| | 0.00 | | | | | | | | |
| 13 | 1 | 15-07-2011 | 0.120 | 250.60 | 252.69 | 251.96 | 113.79 | 83.59 | 72.48 |
| | 0.00 | | | | | | | | |
| 14 | 1 | 15-07-2011 | 0.130 | 249.00 | 253.48 | 251.96 | 113.41 | 83.59 | 73.62 |
| | 0.00 | | | | | | | | |
| 15 | 1 | 15-07-2011 | 0.140 | 250.60 | 252.69 | 251.96 | 113.79 | 83.21 | 72.86 |
| | 0.00 | | | | | | | | |
| 16 | 1 | 15-07-2011 | 0.150 | 250.60 | 252.69 | 251.96 | 114.17 | 83.97 | 72.86 |
| | 0.00 | | | | | | | | |
| 17 | 1 | 15-07-2011 | 0.160 | 250.60 | 252.69 | 251.96 | 113.79 | 82.83 | 72.48 |
| | 0.00 | | | | | | | | |
| 18 | 1 | 15-07-2011 | 0.170 | 250.60 | 252.69 | 251.96 | 113.79 | 83.97 | 72.86 |
| | 0.00 | | | | | | | | |
| 19 | 1 | 15-07-2011 | 0.180 | 250.60 | 252.69 | 251.96 | 114.17 | 83.21 | 72.86 |
| | 0.00 | | | | | | | | |
| 20 | 1 | 15-07-2011 | 0.190 | 249.00 | 253.48 | 251.96 | 113.41 | 83.59 | 72.86 |
| | 0.00 | | | | | | | | |

# Appendix H4 – AEMO Raw Data

| DateTime | RRP | Total Demand (5 min) |
|---|---|---|
| 8/14/2010 0:05 | 13.72 | 5451.2 |
| 8/14/2010 0:10 | 18.56 | 5434.86 |
| 8/14/2010 0:15 | 20.14 | 5473.61 |
| 8/14/2010 0:20 | 19.96 | 5443.92 |
| 8/14/2010 0:25 | 17.41 | 5362.61 |
| 8/14/2010 0:30 | 18.6818 | 5388.75 |
| 8/14/2010 0:35 | 12.54 | 5248.89 |
| 8/14/2010 0:40 | 17.41 | 5313.01 |
| 8/14/2010 0:45 | 17.41 | 5290.06 |
| 8/14/2010 0:50 | 17.37 | 5265.3 |
| 8/14/2010 0:55 | 16.05 | 5244.75 |
| 8/14/2010 1:00 | 12.54 | 5169.5 |
| 8/14/2010 1:05 | 13.67 | 5149.82 |
| 8/14/2010 1:10 | 13.67 | 5114.35 |
| 8/14/2010 1:15 | 12.54 | 5062.61 |
| 8/14/2010 1:20 | 4.7799 | 5030.42 |
| 8/14/2010 1:25 | 12.54 | 4970.61 |
| 8/14/2010 1:30 | 12.54 | 4955.11 |
| 8/14/2010 1:35 | 12.54 | 4911.22 |
| 8/14/2010 1:40 | 12.54 | 4885.83 |
| 8/14/2010 1:45 | 12.54 | 4851.95 |
| 8/14/2010 1:50 | 4.78 | 4794.27 |
| 8/14/2010 1:55 | 12.54 | 4807.82 |
| 8/14/2010 2:00 | 12.54 | 4773.14 |
| 8/14/2010 2:05 | 14 | 4813.3 |
| 8/14/2010 2:10 | 12.54 | 4745.71 |
| 8/14/2010 2:15 | 12.54 | 4729.78 |
| 8/14/2010 2:20 | 13.67 | 4731.47 |
| 8/14/2010 2:25 | 13.67 | 4714.46 |
| 8/14/2010 2:30 | 12.54 | 4716.67 |
| 8/14/2010 2:35 | 6.5502 | 4669.87 |
| 8/14/2010 2:40 | 12.54 | 4662.69 |
| 8/14/2010 2:45 | 12.54 | 4617.44 |
| 8/14/2010 2:50 | 12.54 | 4605.01 |
| 8/14/2010 2:55 | 12.54 | 4618.84 |