University of Southern Queensland

Faculty of Health, Engineering and Sciences

Power Quality Improvement Using a STATCOM Inverter

A dissertation submitted by

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ABSTRACT

Most loads on an electrical network are reactive and have a lagging power factor, this reactive power is mostly supplied from the electricity generators and needs to be transmitted through the network just like any other load. The transmission of this reactive power also increases losses and causes unnecessary heating in infrastructure.

An increase in Photovoltaic (PV) penetration in an electrical system has imposed several Power Quality (PQ) and voltage stability issues, the intermittent nature of solar generation mean there is a variable output of power to the system which leads to power imbalance issues and voltage sags and swells. A solution to this may in fact lie in the problem, there is a potential for the installed inverters associated with these systems to be utilised to improve local power quality by supplying or absorbing reactive power, day or night. Currently inverters are only being utilised during daylight hours, leaving an expensive piece of equipment lying dormant for the majority of a day.

This research outlines the gathering of relevant information, compiles a feasibility assessment and documents expected outcomes and benefits. A research methodology is provided together with a risk assessment, project schedule and quality assurance plan and timeline.

This research will provide useful information into the feasibility of grid controlled Static Compensator (STATCOM) inverters and the benefits this would have on power factor and subsequently voltage regulation to the immediate network.

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Limitations of Use

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.

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Signature

ACKNOWLEDGEMENT

This research project would not have been possible without the assistance of Dr Les Bowtell. The topic was chosen with guidance from Les after discussions surrounding my interest in renewable energy and a more efficient future. Les' involvement in the project included assisting in the research and dissecting results from the field survey. He suggested areas that required further investigation and improvements to my site surveying technique. I thank Les sincerely for his encouraging guidance, friendly advice and generous time donated to me throughout this project.

I would also like to thank my family, especially my wife and daughter, thank you for encouraging me in all of my pursuits and inspiring me to complete this degree. I always knew that you believed in me, you have been my inspiration I needed during the years of study.

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NOMENCLATURE

The following abbreviations have been used throughout the text: -

PV	Photovoltaic
DC	Direct Current
AC	Alternating Current
CT	Current Transformer
STATCOM	Static Compensator
FACTS	Flexible Alternating Current Transmission System
PQ	Power Quality
PLCC	Power Line Communication
PLN	Power Line Networking
THD	Total Harmonic Distortion
VSI	Voltage Source Inverter
Hz	Hertz
VAr	Reactive Power
VSC	Voltage Source Converter
TX	Transformer
LV	Low Voltage
HV	High Voltage
USQ	University of Southern Queensland

CHAPTER 1

INTRODUCTION

1.1 Outline of the Study

There is a need to become more efficient with our energy usage, this includes not only reducing energy demand, but improving the way in which energy is being delivered. This study is an ongoing look at the feasibility of converting existing solar system inverters to STATCOMs. Under the proposal the local energy requirements would not only be supplied by a customer's solar system, but could also help improve the PQ of surrounding electrical installations.

The broader study will investigate the impact of converting an installed inverter, or replacing a near end of life inverter with a STATCOM, and what benefits that will have to not only the local installation, but also upstream and downstream customers as well as the electricity distributor. A STATCOM is a voltage source converter made up of power electronics, it is currently used on large installations for power factor correction, and on electricity grids for voltage regulation (VR). A STATCOM has the added benefit of being able to rapidly respond to changes in PQ and rectify them within their rated capacity.

1.2 Background

1.2.1 Solar Energy

The potential for future shortages of fossil-fuel sources of electric power has led to the development of the technology needed to use non-polluting renewable fuel sources such as the sun, wind, and fuel cells (Kirawanich & O'Connell 2000). Generation of solar energy using small scale PV arrays is becoming increasingly common amongst residential electrical consumers as a means of offsetting their carbon footprint. These PV modules convert the sunlight into a Direct Current (DC) voltage; this can then be converted into an Alternating Current (AC) voltage via the means of an inverter so it can be used in parallel with the electricity grid.

1.2.2 STATCOM

A STATCOM invertor is a Flexible Alternating Current Transmission System (FACTS), it is used to control the power flow through an electrical transmission line (Sen 1999). By absorbing and supplying reactive power the STATCOM can control the power factor of a local load by altering the phase angle of the current in relation to the voltage. The STATCOM can either be connected directly to the generation source or can be used through a storage device such as a battery. Many of these devices are active during the day but often lay dormant during the night time when there is no sunlight. The ideal output of a STATCOM would be a pure sinusoidal AC waveform, but this is not possible even with the most advanced technology, there still exists a small DC output from the inverter into the grid. There are limits the electricity distribution authority will allow of this DC output and also the amount of harmonic distortion.

1.2.3 The Problem

There is potential for STATCOM inverters used in Solar PV arrays to improve PQ at the local premises as well as the local electrical grid. This could be done around the clock as opposed to the relatively short hours of operation that the inverters are used now during daylight hours only. As the many of the initial batch of inverters purchased in Australia circa 2007. Purchased under the federal government PV rebate scheme, reach their expected life cycles in the next few years, it is a poignant time to look for smarter alternatives for the estimated 10-20yrs of the installed PV panels.

The electricity grid’s voltage is dependent on the amount of reactive power that is needed and hence can be controlled with the inducement or absorption of reactive power. This can be done remotely or preferable locally, as locally will not require the transmission of the reactive power over long distances.

1.3 Project Aim

The aim of this work is to carry out power surveys on a selection of sites that have a PV array installed. The load survey will include load cycle information as well as apparent and reactive power readings. Records from the Australian Bureau of Meteorology on the radiance of the sites will also be used. This will provide the radiance during the time of the survey at each site, the use of this data will avoid the need to survey the radiance at the same time as the power survey.

The results from the survey will then be modelled in MATLAB so they can be simulated with a known accurate simulation of a STATCOM inverter, previously created by Dr Les Bowtell.

1.4 Project Objective

The specific objectives of this project area: -

1. Conduct a literature review on the STATCOM inverter and their PQ improvement capabilities. Using the literature review determine if these capabilities are going to be able to provide a significant improvement to the PQ at selected premises.
2. Perform a load survey of a commercial and high density residential load.
3. Analyse load data and develop a system model for use in MATLAB.
4. Evaluate the transient capabilities of a STATCOM inverter on the system loads modelled in MATLAB.
5. Report on the potential benefits that can be expected to both the consumer and electricity distributor from a locally installed STATCOM.

1.5 Thesis Overview

Chapter 2 of the dissertation contains the literature review which has been carried out to better understand the research subject. Previous techniques for controlling PQ by the electricity distributors and locally are explored and weighed up.

Chapter 3 outlines the methodology that was adopted for completing this project, whilst Chapter 4 reports the data obtained from the load surveys and the results from the simulation of the system loads modelled in MATLAB. Chapter 5 contains the in depth discussion surrounding the results.

Finally, Chapter 6 will provide recommendations and conclusions on the study, as well as suggestions for future research into the development of this project.

1.6 Summary

As can clearly be seen this project will test the feasibility of converting existing solar system inverters into STATCOMs for the purpose of supplying reactive power to improve PQ. There is a clear and present need for this study as we shift more of our load onto renewable energies and look to becoming more energy efficient. It is hoped this research will offer an alternative method to solving PQ issues on the network using existing equipment.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

A literature review was undertaken to further develop the idea towards a research project. The purpose of the review was to gather relevant information about:

- Reactive power effect on voltage regulation
- Control of STATCOM's reactive power
- Power Quality
- SMART meters
- Grid connected PV systems with battery storage
- ITI Curve

The literature review is provided as Appendix A, the following is a brief summary of the more important points. The review is expected to be continuously revised throughout the length of the project.

2.2 Reactive Powers Effect on Voltage Regulation

A study by Petoussis (Petoussis et al. 2006) has found that the presence of reactive power in the network has a significant impact on the electricity market equilibrium and the power distribution in the network. Reactive power and voltage control is one of the ancillary services used to maintain the voltage profile through injecting or absorbing reactive power (Dapu et al. 2005).

If the voltage on a system is too low it will not be able to supply active power, thus reactive power is required to provide the voltage levels needed on the system. An increase in reactive power being supplied by the electricity distributor means more power is required to be transmitted down the suppliers' infrastructure which will increase losses. During times of high load there is a drop in voltage in the network, as the voltage drops there is an increase in current to maintain the amount of power supplied. This causes the system to absorb more reactive power and thus the voltage drops even further potentially creating a cascading effect until voltage failure.

2.3 Reactive Power Control in a Distribution Network

There are a number of ways reactive power can be controlled in a distribution network, some with static control equipment and some dynamic. Examples of the more common control will be discussed in this review.

2.3.1 Generators

An electric generators main function is to convert energy into electric power, this output power can be considered in terms of their terminal voltage and their reactive power output. Reactive power is produced by increasing the magnetic field in the generator by increasing the current in the rotating field winding. Production of reactive power limits a generators real-power production and so ideally it would be desirable to be kept to a minimum.

2.3.2 Reactors and Capacitor Banks

Electricity distributors install reactors and capacitor banks at the local zone substations to assist with the generation and absorption of reactive power for the local area. A capacitor bank will produce reactive power at times of high load where the voltage in the system has dropped. A reactor will absorb reactive power when the network voltage is high, normally during low load periods such as the late evening to early morning. They are both passive devices and as such need to be switched on and off, usually after the network voltage has reached a set limit away from nominal.

2.3.3 Static Compensator (STATCOM)

A Static Compensator (STATCOM) is a device that can provide reactive support to a bus. It consists of a voltage sourced converters connected to an energy storage device on one side and to the power system on the other (Rao, Crow & Yang 2000). It is a power electronics device, consisting of insulated-gate bipolar transistor's (IGBT) which have a high efficiency and fast switching. Currently they are used on the electricity grid by the distributor, or as part of large commercial installations for power factor correction.

2.4 Control of STATCOM's Reactive Power Output

Studies from Escobar (Escobar, Stankovic & Mattavelli 2000) has found that STATCOM's offer several advantages over conventional thyristor-based convertors solutions for voltage control due to that speed of response, flicker compensation, flexibility, and minimal interaction with the supply grid.

The output of the STATCOM's power can be controlled by adjusting the phase angle between the voltage and current, this is shown in Figure 2.1. If a leading phase angle is needed then reactive power will be absorbed by the STATCOM by, however if a lagging phase angle is applied then the STATCOM will produce reactive power. This control of the STATCOM can be carried out by using a VAr controller. This VAr controller can be installed locally to the STATCOM to assist with improving the power factor of the local load by supplying or absorbing reactive power as needed. The VAr controller can be implemented with the use of logic algorithms and a programmable logic controller (PLC).

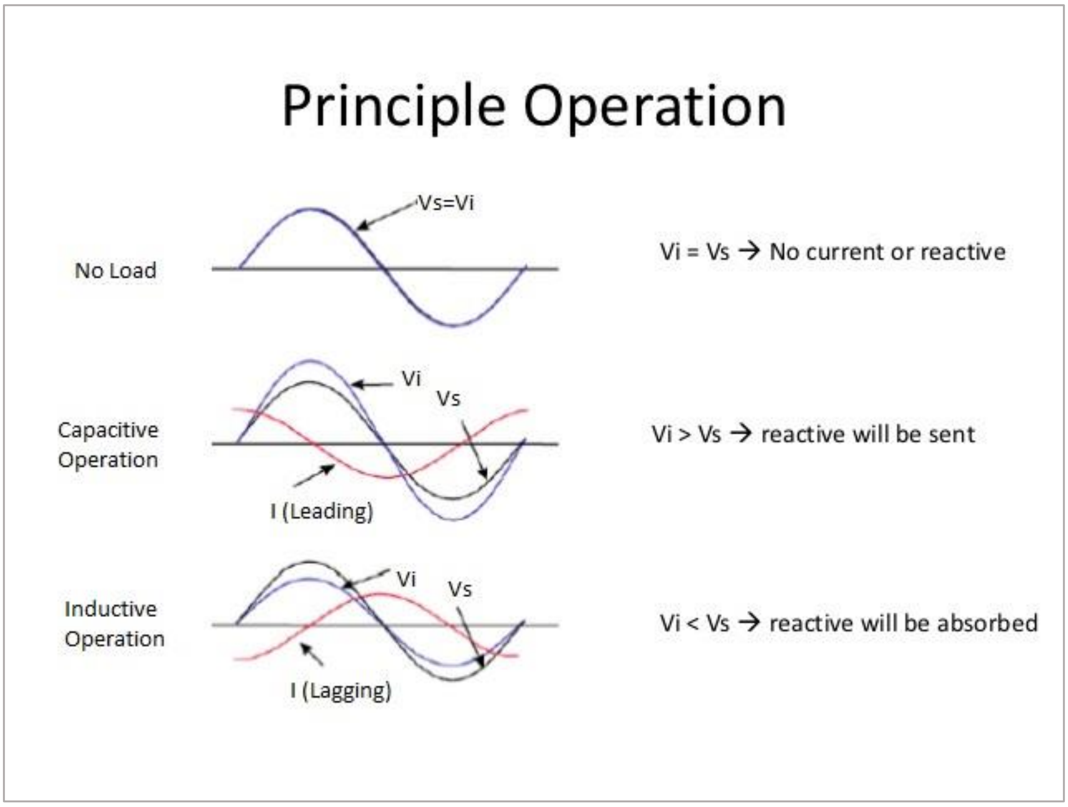

Figure 2.1 Principle Operation of a STATCOM (Yohan Fajar Sidik, 2012)

2.5 Power Quality

The term PQ has been used to describe the variation of the voltage, current, and frequency on the power system (Reid 1994). Maintaining PQ on an electrical system refers to maintaining a near perfect sinusoidal waveform of voltage and current. Many factors on an electrical system can alter and distort these waveforms including, harmonics, unbalanced loads, transformer vibration and noise. Harmonic distortion of the power waveform occurs when the fundamental, second, third and other harmonics are combined. The result is voltage and current contaminations on the sinusoidal waveform (Henderson & Rose 1993). Poor PQ on a system can lead to problems with overvoltage, voltage unbalance, dips and swells, and harmonics.

2.6 Smart Meters

SMART meters will play a very important role in the future with customers having an increased interest in how much energy they used and when. The old disc meters were only able to give limited energy usage information such as how much was used, and an indication of how much was being used currently was only possible by seeing how fast the disc was spinning. The advent of the SMART meter allows energy companies to charge in a tariff known as time of use, where energy can be charged at different amounts depending on what time of the day it is being consumed.

The increase in embedded generation has also seen an increase in SMART meters as these meters are required for such generation as they allow for a bidirectional energy flow between the grid and the consumer.

Communication with the SMART meter can be done in a variety of ways, the three most common ways that have been reviewed by Ali (Ali, Maroof & Hanif 2010) are:

- RS-232 As Local transmission medium
- PLCC Using main power line
- Short Messaging Service on GSM

Power line communication (PLCC) or Power line networking (PLN) which utilises the same wired medium through which power is delivered to the customer as a communication channel (Ali, Maroof & Hanif 2010). This is the medium that will be focused on in this project as no further wiring would be required.

2.7 Grid connected PV systems with battery storage

Junbiao (Junbiao et al. 2012) states that the integration of PV generation brings numerous challenges to the system operators and designers such as:

- Changing solar irradiance profile.
- Remote location of PV due to solar energy.
- Inability to meet expected energy output levels without storage or auxiliary device.

Active power can be balanced by STATCOM with battery storage when battery is charged when system voltage is higher than upper set value, and discharged when system voltage is lower than lower set value (Junbiao et al. 2012).

It is expected that as the manufacturing costs of battery storage comes down there will be an increased uptake of this energy storage at the consumer level. With the increase of battery storage there is real potential for power factor correction to be carried out locally rather that via large reactors and capacitor banks that are currently operated and maintained by the electricity distributors. Figure 2.2 represents a typical grid-tied PV system on a household with battery storage. The sun’s energy is converted into DC which is either stored in the battery or converted into AC via the inverter to be used around the house or supplied back into the grid.

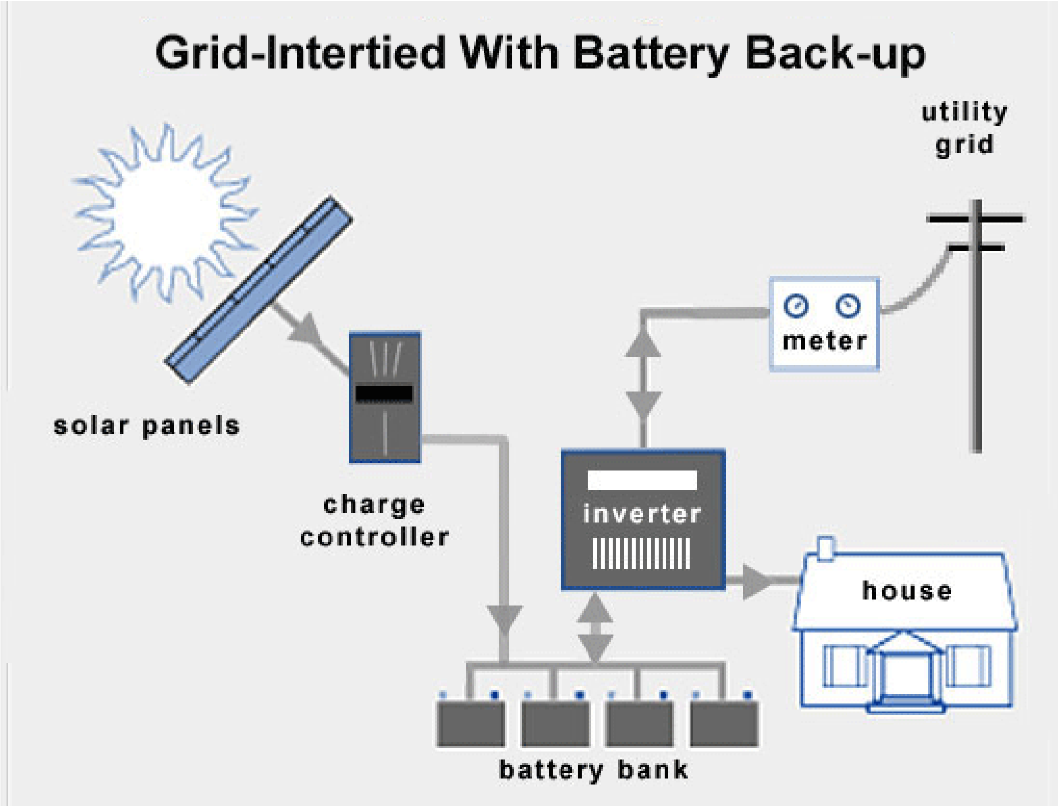

Figure 2.2 Grid-Tied PV System with Battery Storage (Solar 2016)

2.7.1 PV Impacts on PQ

The increasing penetration of PV systems on the Low Voltage (LV) network is creating several PQ and voltage stability issues. The electricity distributor has to maintain the PQ for all situations, this is becoming increasing difficult due to the time that PV systems are operating. On a residential load, they are at their peak load in the evening when there is no sunlight and no PV generation, this would bring voltages down to their lowest limit. During the day the loads are low by comparison, but there is also daylight and hence PV generation, this decreases load on the system and increases voltages. The difference between the high daytime voltage and low evening voltage becomes larger when there is a higher penetration of PV. Single phase PV systems also contribute to PQ issues, by suppressing the load on just one phase the systems existing nonlinear load now becomes even further exaggerated.

2.7.2 Intermittency of PV Systems

PV systems by nature rely on sunlight to produce energy, the amount of energy produced varies over the day depending on the amount of solar radiance. Figure 2.3 shows the typical profile of PV generation throughout the day, with the maximum being generated in the middle of the day, and no generation during the night time. Throughout the year the amount of energy being generated varies for each month as the earth transitions through its seasons and the distance from the sun increases and decreases. A major problem with this type of resource is the variable output power and limited predictability results in intermittent generation (Chidurala, Saha & Mithulananthan 2013), this can be caused by large clouds blocking the amount of solar radiation reaching the PV panels.

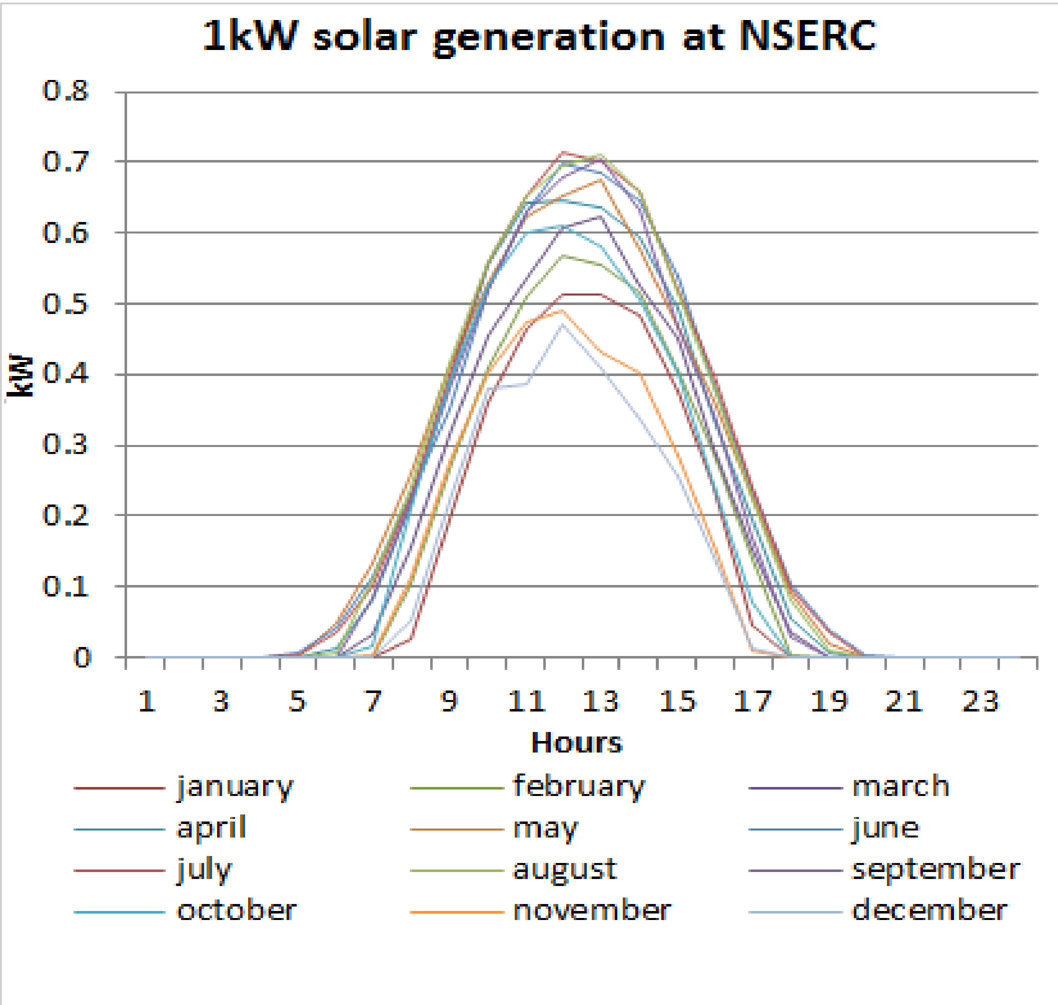

Figure 2.3 Typical PV System Generation (University 2016)

2.8 ITI (CBEMA) Curve

The ITI, formerly CBEMA, curve was developed by the Information Technology Industry Council of the United States of America(USA) (Elphick & Smith 2010). The curve attempts to shows the voltages that can be tolerated by Information Technology (IT) equipment without causing damage or interruption. Whilst the curve has been developed for the USA and their 120 V nominal voltage, the curve with its percentage of nominal voltage on the y-axis can be translated into the Australian 230 V standard, a copy of the curve can be seen in Figure 2.4.

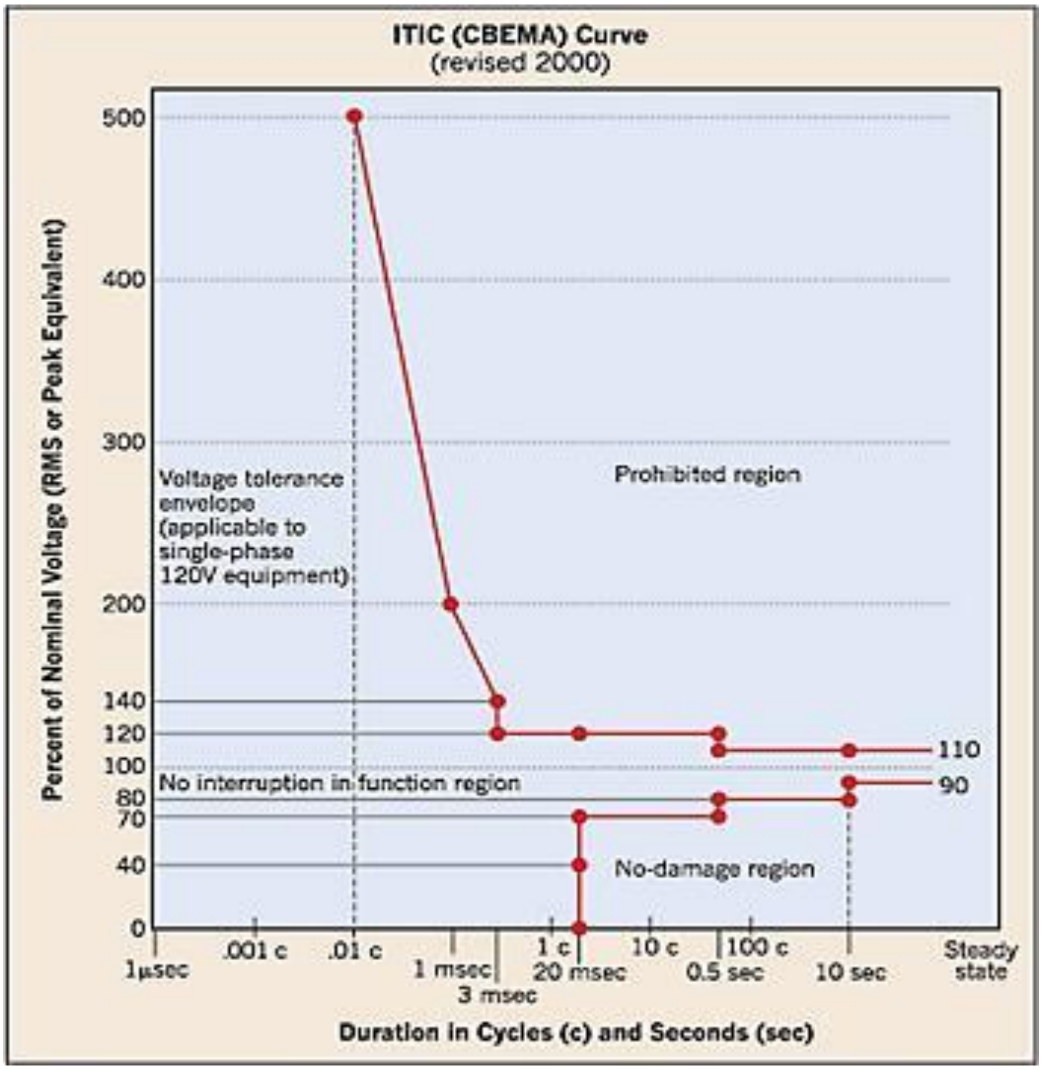

Figure 2.4 ITI Curve ((ITI) 2000)

The x-axis represents the time spent in that range. There are two prohibited regions on the curve, the upper region is for over voltages and will likely cause damage to IT equipment. The lower region is for under voltages and whilst it is unlikely it will cause damage to electronic equipment it will tend to cause interruptions.

2.9 Voltage Control

On an AC system voltage control is managed by absorbing and producing reactive power. Managing reactive power in this way in affect changes the phase shift between the current and the supply voltage, producing reactive power will have a capacitive effect and will cause a leading power factor, whereas absorbing reactive power will have an inductive effect and cause a lagging power factor. Tanaka (Tanaka et al. 2009) states that reactive power control has a possibility to contribute for reduction of distribution loss. In 2011 the Australian Standards PQ Committee published AS 61000.3.100-2011 (Standards 2011), this defines that the voltage at a premises needs to be within the rage of 230 V +10% or -6%. The further away from a transformer (TX) a supply is generally means the lower their supply voltage will be. This problem is worsened during periods of high load, which for residential loads tends to be in the early evening.

2.10 Review of Information

It is clear from the literature review that using a STATCOM inverter to improve power factor is efficient and has a fast response, which will be ideal in the scope of this project as the power factor will be read in real time from the SMART meter. The STATCOM will act as either capacitor or inductor as it is instructed to absorb or produce reactive power when improving power factor. Communication with the SMART meter will be carried out using Power Line Communication which will negate the need for extra wiring.

Further review will be required throughout the project to improve knowledge in these areas and any further areas uncovered or recommended by the supervisor.

CHAPTER 3

RESEARCH AND TEST METHODOLOGY

3.1 PQ Survey Sites

PQ surveys were collected from various sites around the Northern Sydney region during the Autumn and Winter months in 2016. Targeted sites for the survey were either a medium density apartment block or a mix commercial and residential property needing to have a solar PV array installed. A variety of sites were initially chosen and PV arrays confirmed using the high resolution aerial imagery service from nearmaps. Only two sites, one of each load profile was required so the list was narrowed down to sites with a supply from above ground substations to facilitate an easier and safer installation of the PQ meter. The measurement device was installed and left capturing for the same length of time. Sites chosen for the survey were:

- **High-rise Building in Manly** – Mixed residential and commercial load
- **Apartment Block in Artarmon** – Residential load

Unfortunately, time did not permit the survey of an industrial factory and previous surveys carried out were not set at a suitable time interval for this projects requirements. At each of the above sites their load was surveyed over a period of one week. Although due to the finite amount of internal memory in the PQ meter a whole week was sometimes not possible to be captured depending on how many events were captured. The PQ meter was installed at the supplying substation of the load. Ideally the meters would have been best installed on the terminals of the customer's main switchboard, but access to these terminals was not possible due to security metering tags clipped onto the protective covers preventing unauthorized access or meter tampering.

3.2 Contingency Plan for PQ Survey

If the required measurement devices are not available for use on my project, or the data I obtain from the survey is corrupt or unusable, a contingency plan was devised. Numerous surveys are carried out as part of the distributor's Low Voltage Network PQ Survey every year to ensure that suitable conditions provided to customers in terms of voltage ranges, voltage fluctuations, and voltage harmonics etc. are being adhered to. It was decided that in the event a survey specifically carried out for this project was unable to occur, two surveys previously carried out on suitable sites would be obtained from the distributor with permission and used as part of this research project.

3.3 PQ Survey

All survey work was carried out around Northern Sydney during the second quarter of 2016. Measuring equipment and software to download the data was provided by the company, as was the person protective equipment used when installing and recovering the metering equipment. Risk assessments were carried out for the hazardous work and copies can be found in Appendix B -. Pre work hazard assessment checks were also carried out before any works, these can be found in Appendix F -.

3.3.1 PQ Meter

In this survey the sites were each monitored for one week by a high end PQ meter for a range of PQ parameters including Current, Voltage, Energy (P, Q, P+, P-, Q+, Q-), Harmonics & Total Harmonic Distortion (THD), Voltage Fluctuations (Flicker) and Frequency. The measurement device used for the survey was a PQ-Box 100 Network Analyser, shown in Figure 3.1. This meter is suitable for low, medium and high-voltage networks. The meter has annual calibration and was within calibration for the entire surveying timeline.

Figure 3.1 PQ-Box 100 network analyser used to survey selected sites

3.3.2 Meter Installation / Recovery Procedure

The PQ meters were installed at the supplying substations. Sites were selected ensuring that they had a direct distributor supplying them so that only the load of the site would be surveyed. In the case of the High Rise Building in Manly the supply was from a firm rated two TX chamber substation. Due to the size of the consumer mains the current transformers (CTs) had to be installed around the cabling from one of the TXs, shown in Figure 3.2. There were LV bus links on the LV board separating the customers load from the network distributors so even though the load being surveyed was from the TX it could be guaranteed that only the desired customers load was being surveyed.

Figure 3.2 PQ Meter installed at Manly on transformer cabling

The other site was supplied via a direct distributor from a ground kiosk. The direct distributor was a multicore cable but the CTs were able to be installed around each core separately inside the kiosk underneath the LV board. The voltage clamps were also installed at the kiosk on the distributor.

3.3.3 Meter Configuration Settings

The meter was set up for a 50 Hz 4 wire system with a nominal voltage of 230 V phase to neutral and 398.4 V phase to phase. The measuring interval was set to 1 second which was the fastest setting, to get the most accurate and true reading. Flexi current TXs were placed around each distributors cables including the neutral, and voltage clamps were placed on the exposed terminations at the substation for each phase of the distributor and neutral. The basic settings for the PQ meter are shown in Figure 3.3.

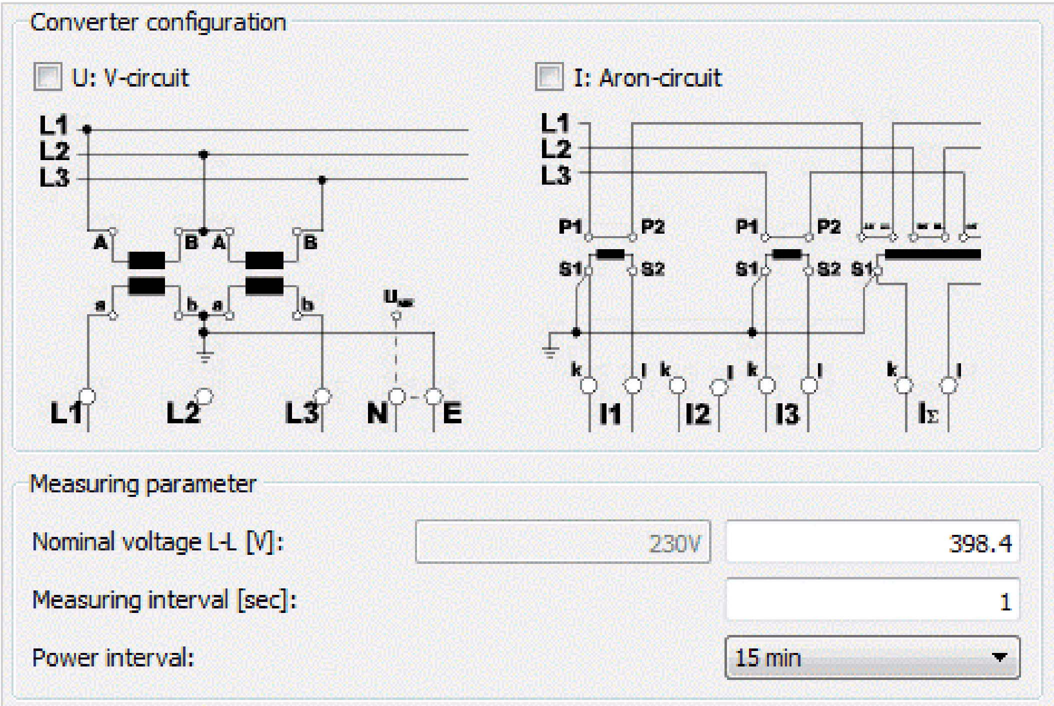

Figure 3.3 PQ Meter Setup for Basic Settings

3.3.4 Event Trigger Settings

The event trigger function of the meter was set to capture any voltage variations outside the configurable thresholds, configuration used to show in Figure 3.4 In the event the voltage went outside the thresholds the meter would start recording at intervals of 10ms with a pre event record time of 1000ms and a total record time of 3000ms. For this survey the lower threshold was set to 90% of RMS, and the upper threshold to 110% of RMS. These limits were chosen as operating outside these limits may cause damage to customer's electrical equipment as shown in the ITI Curve.

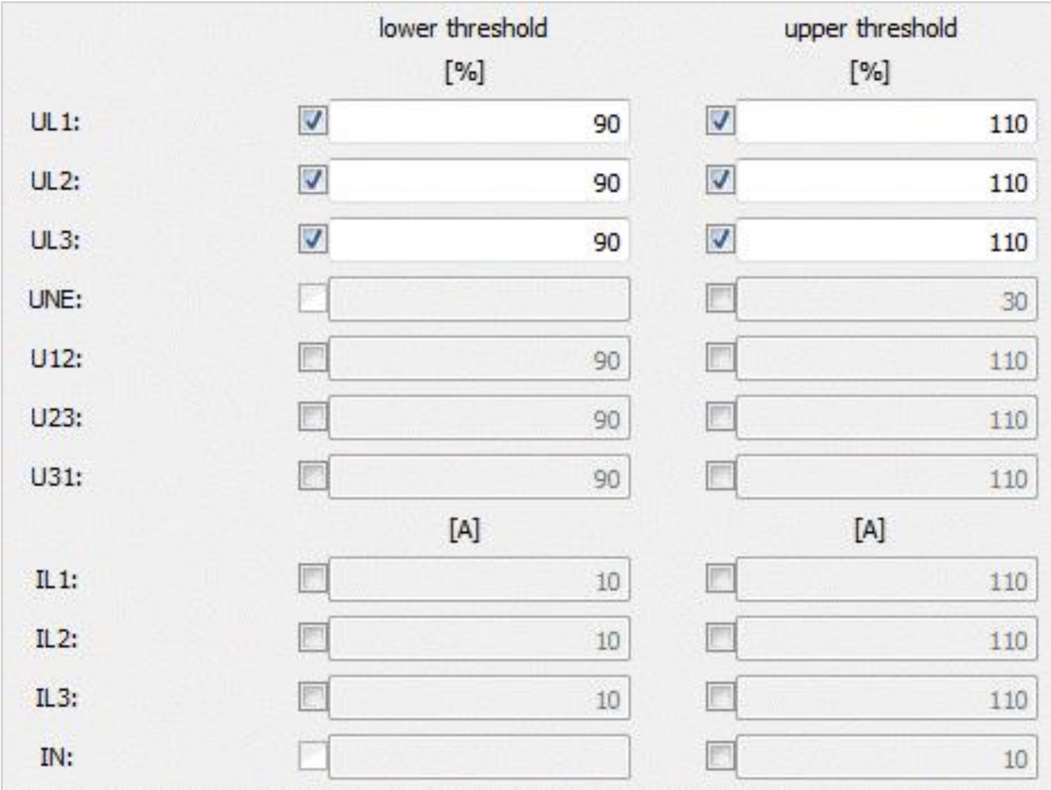

Figure 3.4 PQ Meter Event Trigger Settings

3.4 Bureau of Meteorology Information

The daily solar exposure information was obtained from the Australian Government Bureau of Meteorology (BOM) website. This data is from a computer model that is run by the BOM and produces an estimate of the total amount of solar radiation that reaches the earth on a given day.

3.5 Development of the System Model

A model of a radial electrical system was developed and used to study the transient capabilities a STATCOM inverter would have on the system loads, shown in Figure 3.5. The data from the power surveys was used to produce typical radial systems in a suburban area. The models have one large generator, one transmission line going to a zone TX feeding one high voltage feeder. The feeder is supplying four Load Buses which will act as typical loads on a system. Bus 4 was chosen to be the location of the installed STATCOM used as the inverter to a PV system with storage capabilities. This is so the effects could be seen not only at the localised load, but also for the upstream and downstream loads.

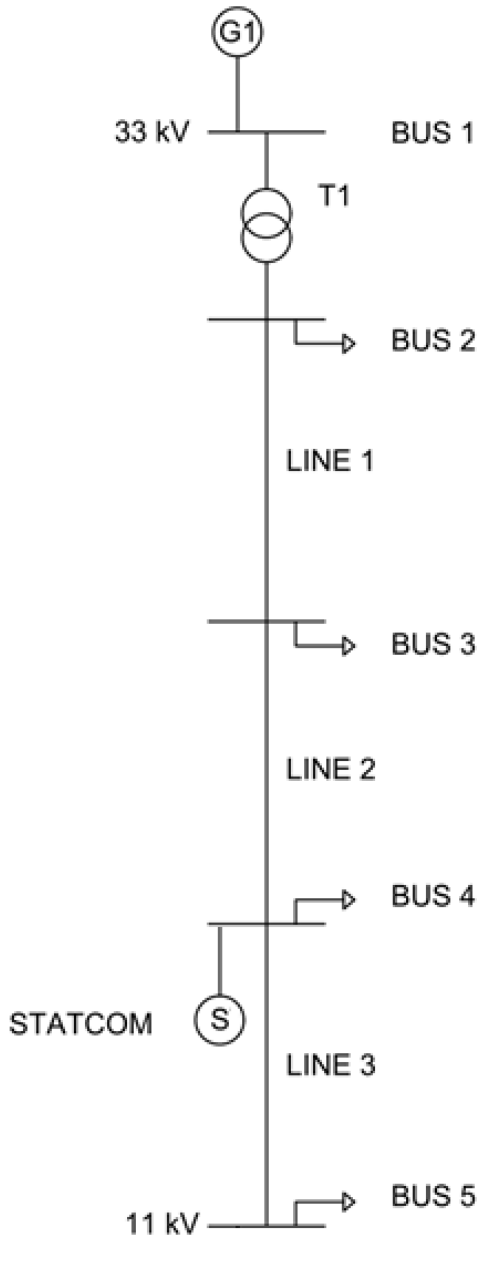

Figure 3.5 Radial System Model Used for all Load Profiles

Three models have been made up to represent different load profiles that are commonly found on an electrical network. These include an industrial load model, a commercial load model, and a residential rural load model. Figure 3.6 is a graph of load profiles for an electrical network in California, but closely resembles that of loads in the Sydney region, with the commercial and industrial loads being higher during the business hours of the day and the residential loads having a small peak in the morning and a larger peak in the evening once residents have returned home from work.

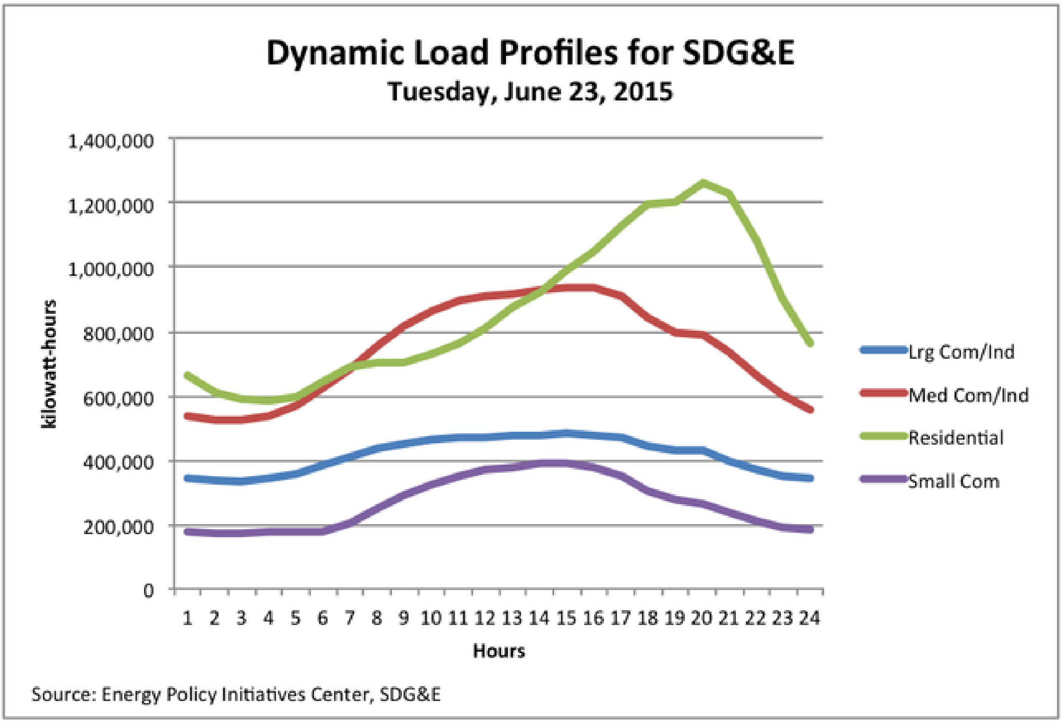

Figure 3.6 Dynamic Load Profiles for SDG&E (Anders 2015)

All models have the same radial setup as shown in Figure 3.5, but will have different Bus and Line data as well as different loading. Each models data will be discussed in more detail later. For the data to be used in MATLAB all the values needed to be Per Unit values. In order to use the per unit method we had to normalise all the system impedances to a common base. Any values that were sourced from data sheets also needed to be converted from their base to the new base.

The following selections were made for per unit calculations:

$$S_{base} = 20\ MVA$$

$$V_{base} = 11\ kV$$

$$I_{base} = \frac{S_{base}}{V_{base}\sqrt{3}} = \frac{20}{11 \times \sqrt{3}} = 1.050\ kA$$

$$Z_{base} = \frac{V_{base}}{I_{base}\sqrt{3}} = \frac{11}{1.050 \times \sqrt{3}} = 6.048\ \Omega$$

$$Y_{base} = \frac{1}{Z_{base}} = \frac{1}{6.048} = 0.165\ S$$

The zone TX is a 20 MVA TX (33/11 kV) with 6% impedance at 100 MVA, this needs to be converted to the 20 MVA base.

$$Z_{Tx1}\% = 6\%\ \times \frac{S_{newbase}}{S_{oldbase}} = 6\%\ \times \frac{20}{100} = 1.2\%$$

$$\therefore Z_{pu\,Tx1} = \frac{S_{base}}{S_{Tx1}} \times \frac{Z_{Tx1}}{100} = \frac{20}{20} \times \frac{1.2}{100} = 0.012\ pu$$

3.5.1 Industrial System Model Calculations

The industrial model was designed around a typical feeder layout found in an industrial area around Northern Sydney. It is an underground feeder which has been direct laid using 11kV 300 AL3 P H L SW J cable. The cable has an impedance of 0.094 + j0.069 Ohms/km, and a Susceptance of 0.251 mS/km. For simplicity the distance between each bus has been taken at an average of 600 metres. This gives an impedance of 0.056 + j0.041 Ohms and a susceptance of 0.151 mS for all segments of the feeder. All line and TX data can be seen in Table 3.1,and has been converted into per unit values.

Table 3.1 TX and Line Data for Industrial System Model

TX / Line Number	Impedance p.u.	Susceptance p.u.
TX 1	0.005 + j0.012	
Line 1	0.009 + j0.007	j0.0009
Line 2	0.009 + j0.007	j0.0009
Line 3	0.009 + j0.007	j0.0009

The loading on each of the buses was based off the power surveys carried out, for the industrial load profile it was found to have a peak during the day between normal working hours, and relatively low load was seen over night. The values for loads can be seen later on in CHAPTER 4.

3.5.2 Commercial System Model Calculations

The commercial model was designed around a typical feeder layout found in a commercial area such as that of North Sydney, predominantly made up of commercial high rise buildings with little residential loading. Like the industrial area the it has been modelled off an underground feeder, but due to the density of the high-rises the distance between each bus has been reduced to 400 metres. This gives an impedance of 0.038 + j0.028 Ohms, and a susceptance of 0.1004 mS for all segments of the model. All line and TX data can be seen in Table 3.2, and has been converted to per unit values.

Table 3.2 TX and Line Data for Commercial System Model

TX / Line Number	Impedance p.u.	Susceptance p.u.
TX 1	0.005 + j0.012	
Line 1	0.006 + j0.005	j0.0006
Line 2	0.006 + j0.005	j0.0006
Line 3	0.006 + j0.005	j0.0006

From the power survey data, it was showed that the loading for the commercial profile was found to be similar to that of the industrial load profile, with its peak occurring during normal working hours of the day, and a relatively low load in the evening.

3.5.3 Residential Rural System Model

The rural model was designed around a typical feeder layout found in a rural area with residential load such as that of North West Sydney around Berowra. On rural lines the feeder is predominantly made up of long overhead lines feeding pole top TXs. The distance between the buses has been increased due to the geographical nature of a rural line and residences being further apart, the average line distance has been taken as 800 metres. Whilst this distance is longer than the underground models it is considered a short length line in terms of overhead lines, as such the shunt admittance and therefore line susceptance can be neglected for short lines. A typical cable used in rural areas is 66 CDCU3, this has an impedance of 0.338 + j0.371 Ohms/km, with the average length of 800 metres this gives an impedance of 0.270 + j0.297 Ohms for each line segment.

Table 3.3 TX and Line Data for Rural System Model

TX / Line Number	Impedance p.u.	Susceptance p.u.
TX 1	0.005 + j0.012	
Line 1	0.045 + j0.049	NA
Line 2	0.045 + j0.049	NA
Line 3	0.045 + j0.049	NA

The residential load profile data obtained from the power survey showed that there was a small peak for load in the morning, when people woke and got ready to go to work, and another in the early evening when they arrived home and proceeded to get dinner ready. During the day the load was low, but it was lowest overnight between the hours of 11 pm till 5am, when most people are asleep.

3.6 Power Flow Analysis in MATLAB

To solve the power flow problem in the model the Newton-Raphson method will be used, calculated using MATLAB. The idea behind the method is that an initial estimate of the root of the function is made. From that estimate a tangent line is computed and the x-intercept of this tangent is found, this new root value is checked against the initial estimate and in most cases will be a better approximation to the functions root. Using the new approximation, the process is repeated until convergence.

When the Newton-Raphson method is applied to power flow problems it is being used to solve the bus voltage magnitudes and angles. The swing bus or slack bus is the only bus which the voltage is known and specified. In the model developed the swing bus is G1 which is the generator bus. The voltages are estimated for all other buses, and their real power (P) and reactive power (Q) are entered. For this model P and Q were surveyed for one of the buses (Bus 5) and all others have been chosen from typical loads found on a suburban feeder.

Each non slack bus of the system will have two unknowns, voltage (V_i) and angle (δ_i), and two knowns P_i and Q_i. If we collect all the mismatched equations into Jacobian matrix it yields:

$$\underbrace{\left[\begin{array}{ccc|ccc} \frac{\delta P_2}{\delta\delta_2} & \cdots & \frac{\delta P_5}{\delta\delta_5} & |V_2|\frac{\delta P_2}{\delta|V_2|} & \cdots & |V_5|\frac{\delta P_2}{\delta|V_5|} \\ \vdots & J_{11} & \vdots & \vdots & J_{12} & \vdots \\ \frac{\delta P_4}{\delta\delta_2} & \cdots & \frac{\delta P_5}{\delta\delta_5} & |V_2|\frac{\delta P_5}{\delta|V_2|} & \cdots & |V_5|\frac{\delta P_5}{\delta|V_5|} \\ \hline \frac{\delta Q_2}{\delta\delta_2} & \cdots & \frac{\delta Q_5}{\delta\delta_5} & |V_2|\frac{\delta Q_2}{\delta|V_2|} & \cdots & |V_5|\frac{\delta Q_2}{\delta|V_5|} \\ \vdots & J_{21} & \vdots & \vdots & J_{22} & \vdots \\ \frac{\delta Q_4}{\delta\delta_2} & \cdots & \frac{\delta Q_5}{\delta\delta_5} & |V_2|\frac{\delta Q_5}{\delta|V_2|} & \cdots & |V_5|\frac{\delta Q_5}{\delta|V_5|} \end{array}\right]}_{Jacobian} \underbrace{\left[\begin{array}{c} \Delta\delta_2 \\ \vdots \\ \Delta\delta_5 \\ \hline \frac{\Delta|V_2|}{|V_2|} \\ \vdots \\ \frac{\Delta|V_5|}{|V_5|} \end{array}\right]}_{Corrections} = \underbrace{\left[\begin{array}{c} \Delta P_2 \\ \vdots \\ \Delta P_5 \\ \hline \Delta Q_2 \\ \vdots \\ \Delta Q_5 \end{array}\right]}_{Mismatches}$$

Each element of the submatrix J11 can be found using the following formula:

$$\frac{\delta P_i}{\delta\delta_j} = -\left|V_i V_j Y_{ij}\right| \sin\left(\theta_{ij} + \delta_j - \delta_i\right)$$

With the diagonal elements found using:

$$\frac{\delta P_i}{\delta\delta_i} = -\sum_{\substack{n=1 \\ n\neq i}}^{N} \frac{\delta P_i}{\delta\delta_n} = -Q_i - |V_i|^2 B_{ii}$$

In a similar manner the elements of submatrix J21 can be found using the following formula:

$$\frac{\delta Q_i}{\delta\delta_j} = -\left|V_i V_j Y_{ij}\right| \cos\left(\theta_{ij} + \delta_j - \delta_i\right)$$

With the diagonal elements found using:

$$\frac{\delta Q_i}{\delta \delta_j} = -\sum_{\substack{n=1\\n\neq i}}^{N} \frac{\delta Q_i}{\delta \delta_n} = P_i - |V_i|^2 G_{ii}$$

The elements of submatrix J12 can be found using the following formula:

$$|V_j| \frac{\delta P_i}{\delta |V_j|} = -\frac{\delta Q_i}{\delta \delta_j}$$

With the diagonal elements found using:

$$|V_i| \frac{\delta P_i}{\delta |V_i|} = \frac{\delta Q_i}{\delta \delta_i} + 2|V_i|^2 G_{ii} = P_i + |V_i|^2 G_{ii}$$

And finally the elements of submatrix J22 can be found using the following formula:

$$|V_j| \frac{\delta Q_i}{\delta |V_j|} = \frac{\delta P_i}{\delta \delta_j}$$

With the diagonal elements found using:

$$|V_i| \frac{\delta Q_i}{\delta |V_i|} = -\frac{\delta P_i}{\delta \delta_i} + 2|V_i|^2 B_{ii} = Q_i - |V_i|^2 B_{ii}$$

3.7 Risk Assessment

This research did involve tasks that had an element of risk to them. Safety of personal involved in the research and the public was of the utmost importance during this project and as such a risk assessment was undertaken to minimize the chance of injury to oneself or others, and damage to equipment. The project contained numerous risks, some which were of small risk and others which were a larger risk are considered far more dangerous.

3.7.1 PQ Survey Risks

The first and major risk to be analysed is associated with the PQ Survey. More specifically the installation and removal of the metering devices for the survey. This task could only be performed by coming within close proximity to exposed live low voltage switchgear where the various clips and tongs would need to be installed. The task could be considered medium risk as it is possible that contact could be made with exposed LV mains and apparatus. The consequence of the risk could be anywhere from Moderate to Severe in the worst case scenario and as such a Medium Risk level was assigned to this task. To control this risk several measures, and as such correct Personal Protective Equipment was needed to minimise the risk of accidental contact. Ideally it would have been nest to have the LV switchgear de-energised during the installation but this would have required an interruption to a large number of customers so was not done. Further risk mitigation included having an observer on site during the works who was competent in low voltage release and rescue in the unlikely chance that contact was made with the live mains. Site awareness of all live mains and apparatus was documented in a pre-works Hazard Assessment Check (HAC) to ensure all parties present knew of the risks. The project risk assessment is summarised in Appendix B, and the Hazard Assessment Check Forms used during the site surveys can be found in Appendix F -.

3.7.2 PQ Survey Data Risks

Whilst these may not result in harm or injury to one's person, the risk is in relation to the timely completion on this project. Data obtained from the power surveys shall be immediately checked against corruption, and if found to be corrupt the site will need to be resurveyed. Once the data has been validated it shall be stored on the cloud to minimise the chance that it could be lost due to accidental deletion or a failed hard drive. This will also ensure that it will be accessible from multiple locations.

3.7.3 MATLAB Simulation Risks

Other foreseeable risks are attributed to the MATLAB simulation portion of the project. It is possible that the data obtained from the sites may be within the threshold limits and would record zero threshold events. In this case a lower threshold will need to be applied post survey using MATLAB software or equivalent to locate times in the survey of interest. There is also the real chance that the data will not be able to be read into MATLAB and simulated due to inexperience. To mitigate this risk a revision of previous learned techniques in loading external data in to MATLAB shall be refreshed early on in the project timeline.

Other risk mitigations techniques include using the PQ survey data for load profile usage only, and using only the maximum and minimum loads observed for simulation in the model. This will provide theoretical results but not a real world example. If also no transients are recorded during the time of the surveys, a transient can be simulated by increasing the required active and reactive load on one of the buses in the model. This transient would be in relation to a large piece of equipment starting up such as an induction motor or furnace.

CHAPTER 4

DATA AND RESULTS ANALYSIS

Surveys were carried out at the local substation supplying different load profiles, one apartment block with residential load, and one high rise with a mixed commercial and residential load. The surveys ran smoothly and data was logged correctly, load profiles were obtained over a 5-day period on 2 separate occasions for each site. The issue with the data lay in the type of loads at each site. The intention of the survey was to capture data where voltage transients could be seen rising above the threshold of 110% or falling below 90% of nominal voltage. At both locations the only instances where voltage dropped outside these ranges was when there was an interruption to supply from the distributor.

An attempt to get data from a local electricity distributor was undertaken where voltage transients had been present throughout a power survey, but was unsuccessful after the contact at the distributor was unavailable to provide data in the timeline required. The maximum and minimum loads were recorded and will be used in the model to simulate peak and off-peak demand. Load profiles for an industrial, commercial and rural system were developed and the following tests carried out.

4.1 STATCOM on a Single Bus During Normal Conditions

To determine the impact a STATCOM can have on an electrical network, the STATCOM was installed on a single Bus only. Bus 4 was chosen so that the effects could be seen on the other Load Buses upstream and downstream of the STATCOM. To make the results more apparent the same active and reactive loads were chosen for all of the load Buses in the model. Peak loads and Off-Peak Loads were derived from the power surveys that were carried out.

A number of scenarios were run for each model, firstly the base case where no STATCOM is installed to allow all effects from other scenarios to be quantified.

Secondly, where the STATCOM is installed on Bus 4 and acting in Power Factor Correction mode, where the inductive load that is being consumed by Bus 4 is being supplied from the STATCOM operating in a capacitive manner, these will theoretically cancel one another out and leave the sum of reactive power for Bus 4 equal to zero. Thirdly, the STATCOM will be operating in VR mode where it will be exporting excess reactive power to the model to bring the voltage at Bus 4 back up to 1 p.u.

It must be noted that during simulation the STATCOM was only supplying reactive power, normally an inverter installed by a customer would be supplying active power. Australian Standards (Australia 2015) stipulate that an inverter must maintain a power factor between 0.95 lagging and 0.95 leading. The reasoning for going beyond this limit was to show what effect this would have on the immediate customer, surrounding customers, and the electricity grid.

4.1.1 Industrial Modelled Systems during Peak Load

In the case where a STATCOM was installed at Bus 4 for Power Factor Correction the voltage drops from Bus 1 to 4 was reduced by 0.26 %, this is an improvement of 14.27 %. A reduction can also be seen for the other load buses upstream and downstream. The power factor was improved to unity for Bus 4, but the remaining load buses power factor remained unchanged. There was also a change in the power factor of Bus 1 which improved by 0.062, this is due to the reduced reactive power generation of 2.03 MVArs.

In the second case where a STATCOM was installed at Bus 4 for full VR there was no voltage drop between Bus 1 to 4, a very significant improvement can also be seen at all other load buses. The voltage rise on Bus 2 is due to the leakage reactance of the TX between Buses 1 and 2. The power factor at Bus 4 however was dramatically affected by increased exportation of reactive power, and became 0.236 leading. This was left off the graph due to it being so far off scale. The power factors of the remaining load buses were unchanged. The generator on Bus 1 has started to absorb reactive power instead of supplying and has a leading power factor of 0.892.

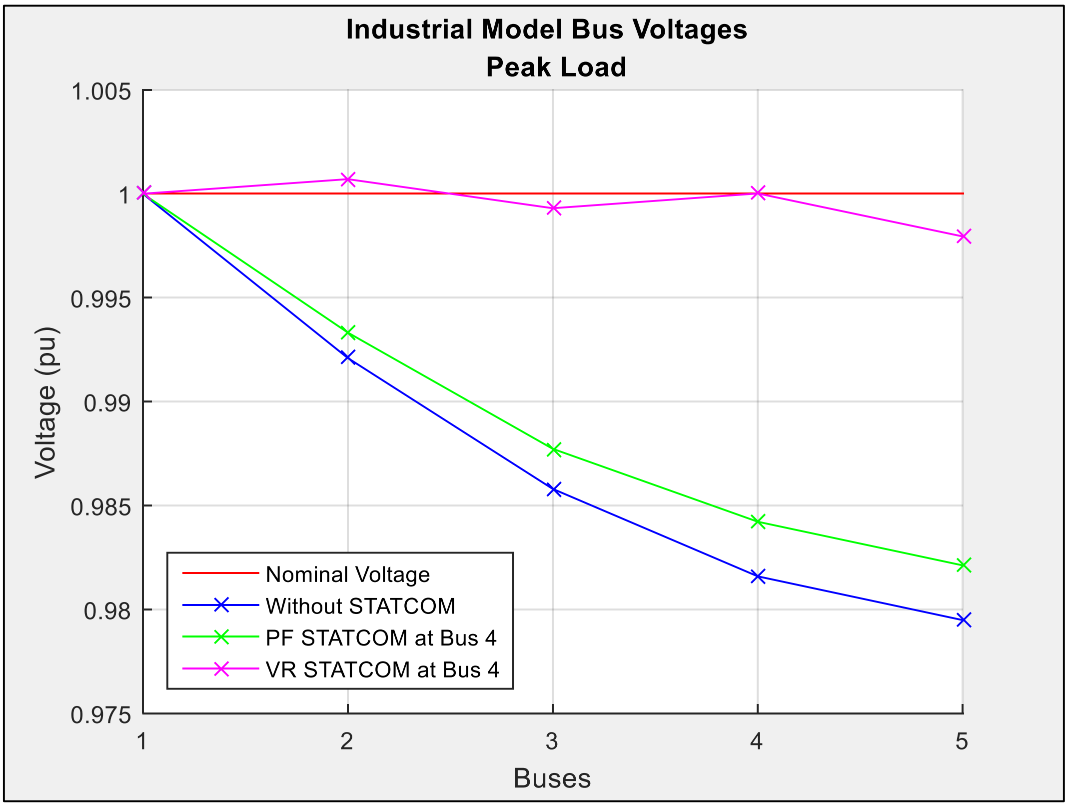

Figure 4.1 Industrial Models Bus Voltages during Peak Load

Table 4.1 Industrial Model Bus and Load Data during Peak Load

	Bus No.	Voltage (p.u.)	Angle Degree	Generation		Load	
				MW	MVAR	MW	MVAR
Without STATCOM	1	1.000	0.000	12.140	8.139	0	0
	2	0.992	-0.005	0	0	3	2
	3	0.986	-0.006	0	0	3	2
	4	0.982	-0.006	0	0	3	2
	5	0.979	-0.006	0	0	3	2
Power Factor STATCOM at Bus 4	1	1.000	0.000	12.118	6.109	0	0
	2	0.993	-0.006	0	0	3	2
	3	0.988	-0.007	0	0	3	2
	4	0.984	-0.008	0	2	3	2
	5	0.982	-0.008	0	0	3	2
Voltage Regulation STATCOM at Bus 4	1	1.000	0.000	12.190	-6.183	0	0
	2	1.001	-0.009	0	0	3	2
	3	0.999	-0.016	0	0	3	2
	4	1.000	-0.023	0	14.345	3	2
	5	0.998	-0.023	0	0	3	2

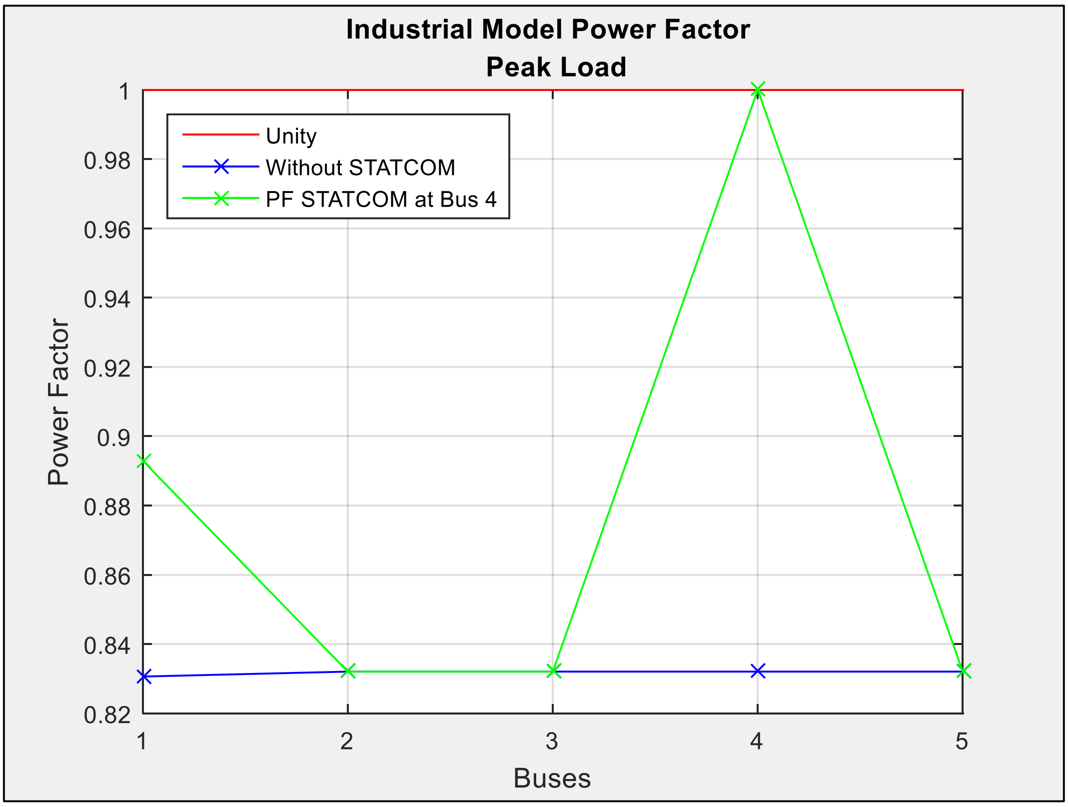

Figure 4.2 Industrial Models Power Factor during Peak Load

4.1.2 Industrial Modelled Systems during Off-Peak Load

In the case where a STATCOM was installed at Bus 4 for Power Factor Correction the voltage drops from Bus 1 to 4 was reduced by 0.01 %, this is an improvement of 9.49 %. A reduction can also be seen for the other load buses upstream and downstream. The power factor was improved to unity for Bus 4, but the remaining load buses power factor remained unchanged. There was also a change in the power factor of Bus 1 which improved by 0.019, this was due to the reduced reactive power generation by 0.1 MVars.

In the second case where a STATCOM was installed at Bus 4 for full VR there was no voltage drop between Bus 1 to 4, a very significant improvement can also be seen at all other load buses. The power factor at Bus 4 however was dramatically affected by increased exportation of reactive power, and became 0.300 leading. This was left off the graph due to it being so far off scale. The power factors of the remaining load buses were unchanged. The generator on Bus 1 has started to absorb reactive power instead of supplying and has a leading power factor of 0.862.

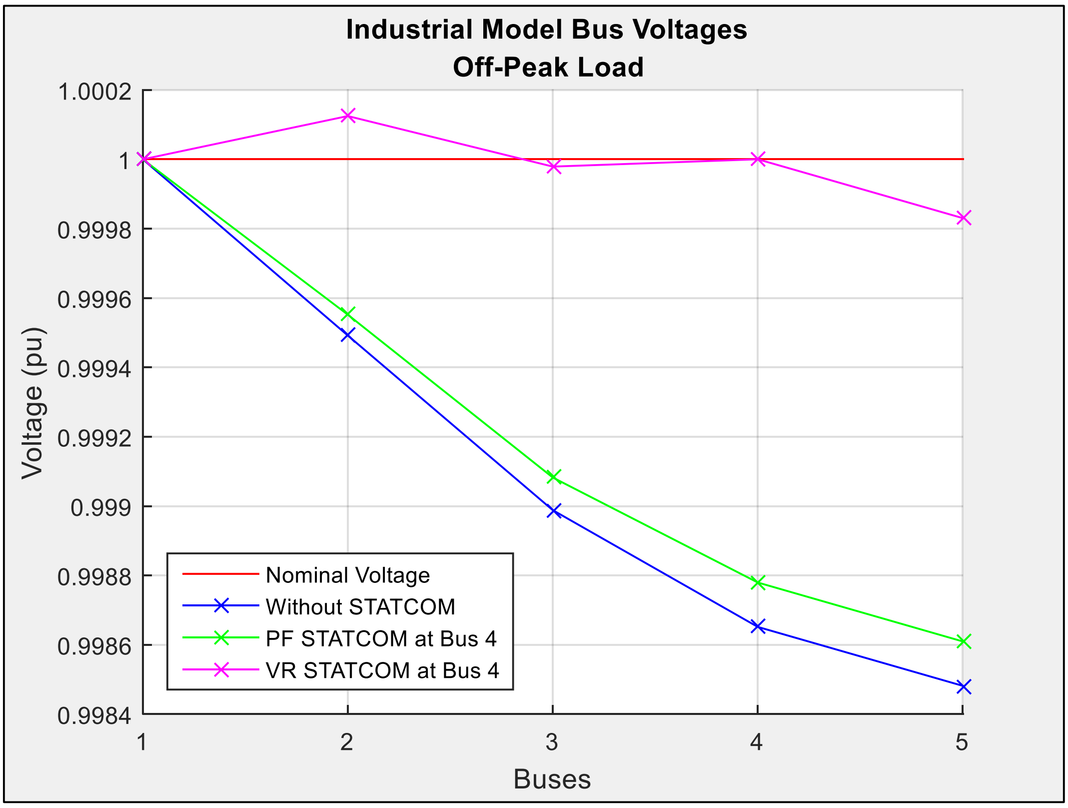

Figure 4.3 Industrial Models Bus Voltages during Off-Peak Load

Table 4.2 Industrial Model Bus and Load Data during Off-Peak Load

	Bus No.	Voltage (p.u.)	Angle Degree	Generation		Load	
				MW	MVAR	MW	MVAR
Without STATCOM	1	1.000	0.000	1.201	0.347	0	0
	2	0.999	-0.001	0	0	0.3	0.1
	3	0.999	-0.001	0	0	0.3	0.1
	4	0.999	-0.001	0	0	0.3	0.1
	5	0.998	-0.001	0	0	0.3	0.1
Power Factor STATCOM at Bus 4	1	1.000	0.000	1.201	0.247	0	0
	2	1.000	-0.001	0	0	0.3	0.1
	3	0.999	-0.001	0	0	0.3	0.1
	4	0.999	-0.001	0	0.1	0.3	0.1
	5	0.999	-0.001	0	0	0.3	0.1
Voltage Regulation STATCOM at Bus 4	1	1.000	0.000	1.202	-0.708	0	0
	2	1.000	-0.001	0	0	0.3	0.1
	3	1.000	-0.002	0	0	0.3	0.1
	4	1.000	-0.002	0	1.055	0.3	0.1
	5	1.000	-0.002	0	0	0.3	0.1

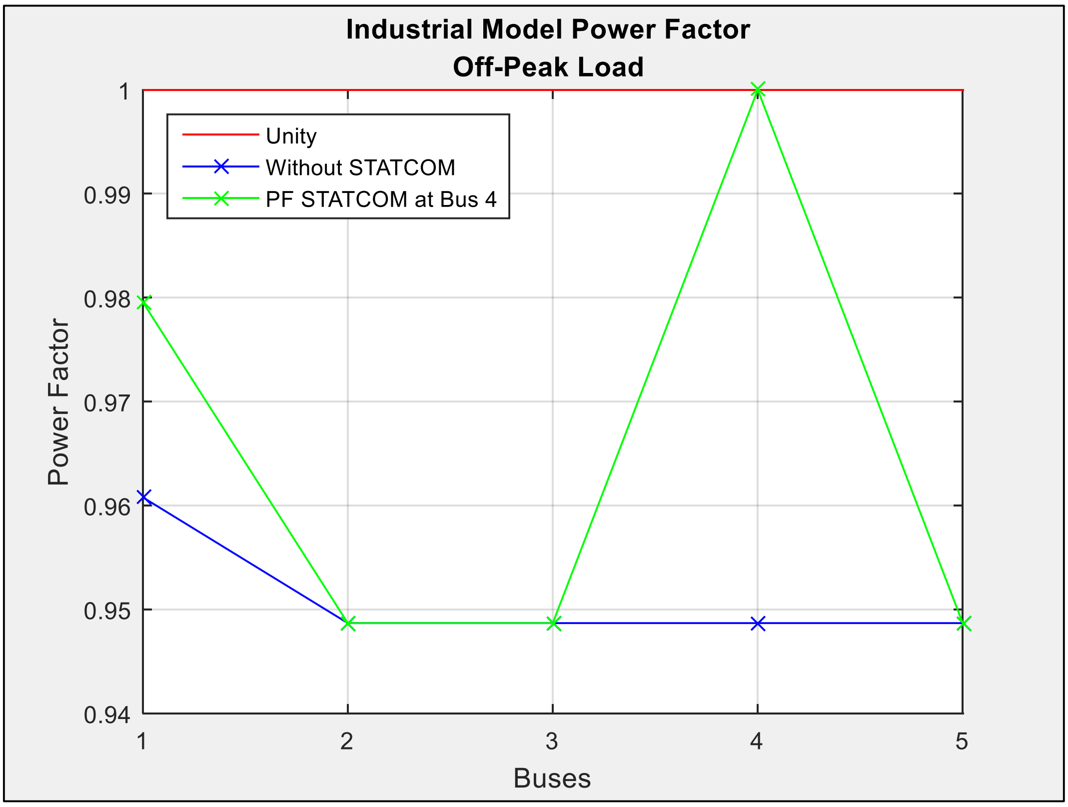

Figure 4.4 Industrial Models Power Factor during Off-Peak Load

4.1.3 Commercial Modelled Systems Peak Load

In the case where a STATCOM was installed at Bus 4 for Power Factor Correction the voltage drops from Bus 1 to 4 was reduced by 0.08 %, this is an improvement of 11.81 %. A reduction can also be seen for the other load buses upstream and downstream. The power factor was improved to unity for Bus 4, but the remaining load buses power factor remained unchanged. There was also a change in the power factor of Bus 1 which improved by 0.093, this was due to the reduced reactive power generation of 0.70 MVars.

In the second case where a STATCOM was installed at Bus 4 for full VR there was no voltage drop between Bus 1 to 4, a very significant improvement can also be seen at all other load buses. The power factor at Bus 4 however was dramatically affected by increased exportation of reactive power, and became 0.274 leading. This was left off the graph due to it being so far off scale. The power factors of the remaining load buses were unchanged. The generator on Bus 1 has started to absorb reactive power instead of supplying and has a leading power factor of 0.885.

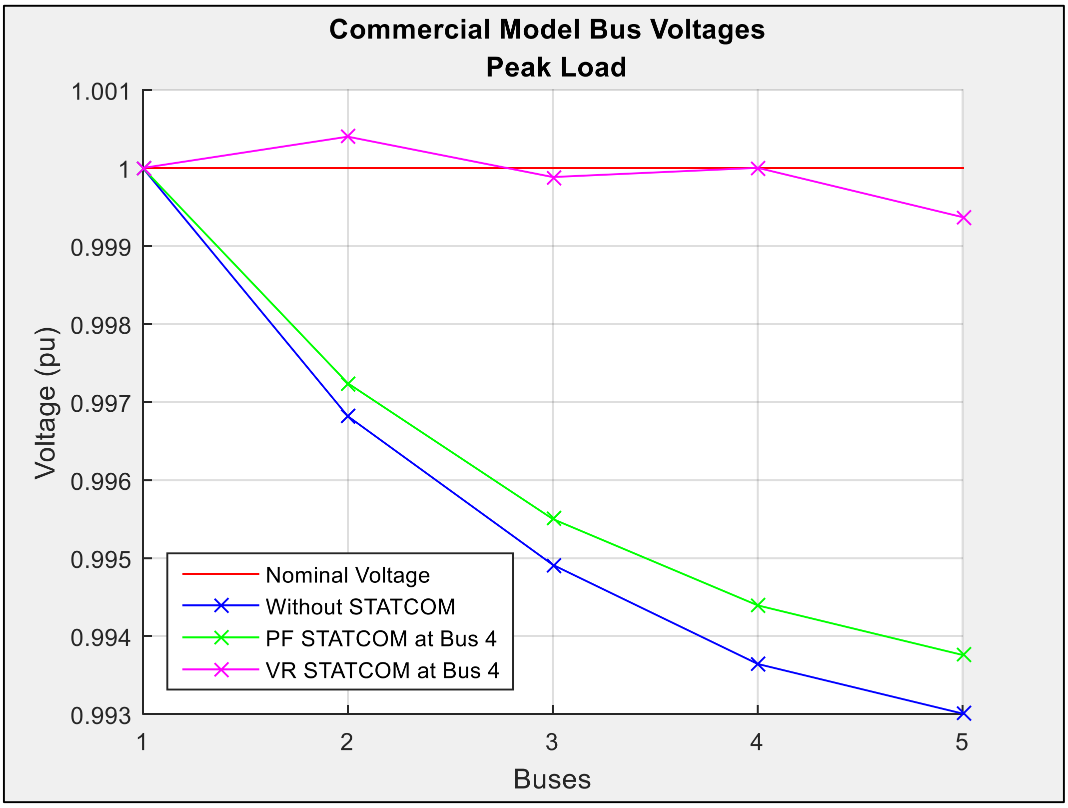

Figure 4.5 Commercial Models Bus Voltages during Peak Load

Table 4.3 Commercial Model Bus and Load Data during Peak Load

	Bus No.	Voltage (p.u.)	Angle Degree	Generation		Load	
				MW	MVAR	MW	MVAR
Without STATCOM	1	1.000	0.000	6.023	2.799	0	0
	2	0.997	-0.003	0	0	1.5	0.7
	3	0.995	-0.003	0	0	1.5	0.7
	4	0.994	-0.004	0	0	1.5	0.7
	5	0.993	-0.004	0	0	1.5	0.7
Power Factor STATCOM at Bus 4	1	1.000	0.000	6.021	2.096	0	0
	2	0.997	-0.003	0	0	1.5	0.7
	3	0.996	-0.004	0	0	1.5	0.7
	4	0.994	-0.004	0	0.7	1.5	0.7
	5	0.994	-0.004	0	0	1.5	0.7
Voltage Regulation STATCOM at Bus 4	1	1.000	0.000	6.033	-3.167	0	0
	2	1.000	-0.004	0	0	1.5	0.7
	3	1.000	-0.007	0	0	1.5	0.7
	4	1.000	-0.009	0	5.974	1.5	0.7
	5	0.999	-0.009	0	0	1.5	0.7

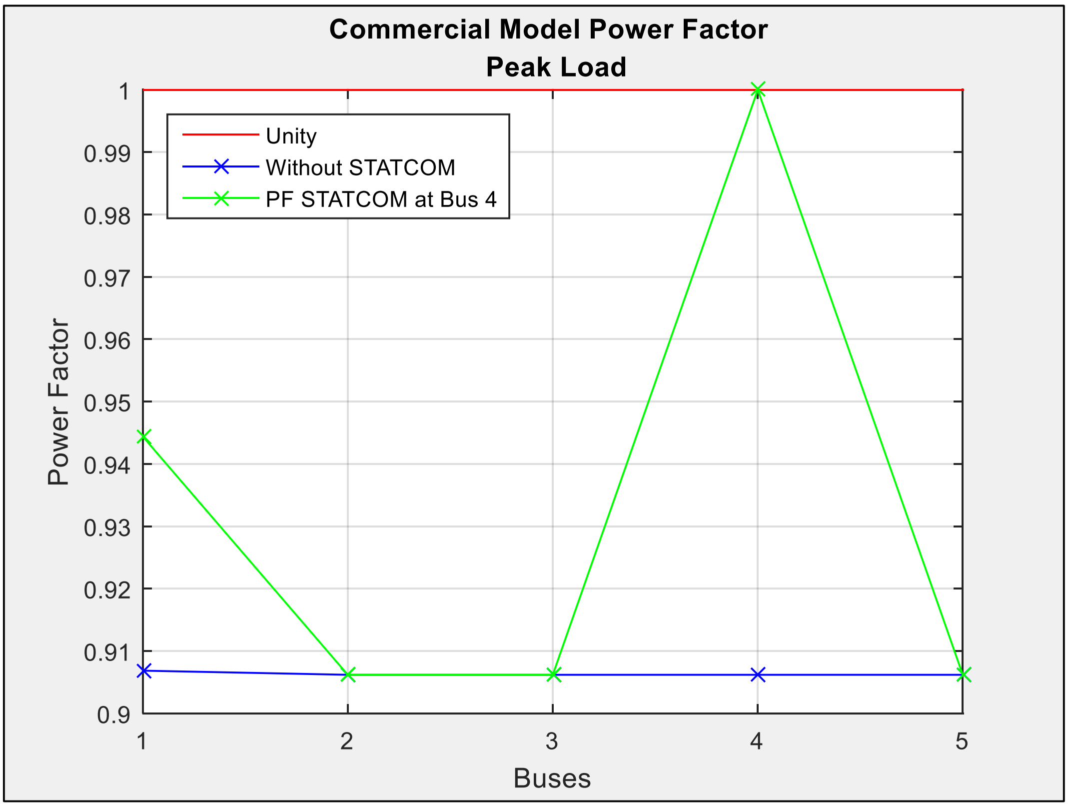

Figure 4.6 Commercial Models Power Factor during Peak Load

4.1.4 Commercial Modelled Systems Off-Peak Load

In the case where a STATCOM was installed at Bus 4 for Power Factor Correction there was a very slight reduction in the voltage drop from Bus 1 to 4 but this was less than 0.001% so will be ignored, a reduction can also be seen for the other load buses upstream and downstream. The power factor was improved to unity for Bus 4, but the remaining load buses power factor remained unchanged. There was also a change in the power factor of Bus 1 which improved by 0.0002, this was due to the reduced reactive power generation of 0.02 MVars.

In the second case where a STATCOM was installed at Bus 4 for full VR there was no voltage drop between Bus 1 to 4, an improvement can also be seen at all other load buses. The power factor at Bus 4 however was dramatically affected by increased exportation of reactive power, and became 0.377 leading. This was left off the graph due to it being so far off scale. The power factors of the remaining

load buses were unchanged. The generator on Bus 1 has started to absorb reactive power instead of supplying and has a leading power factor of 0.858.

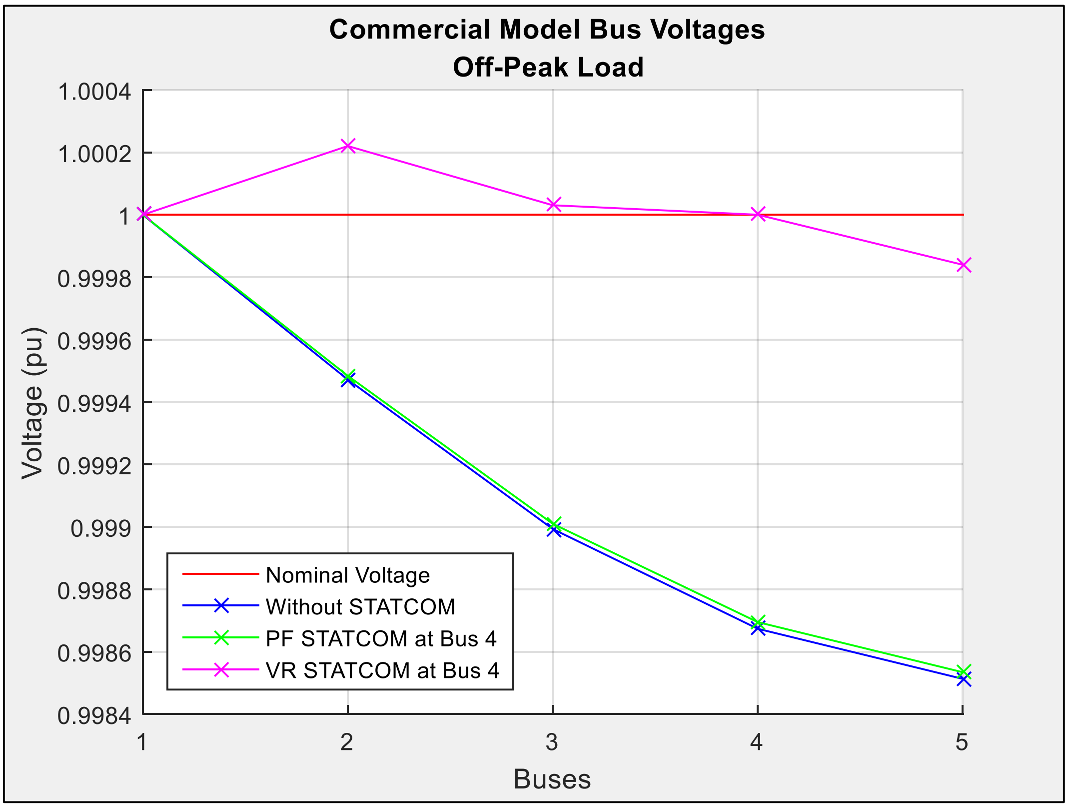

Figure 4.7 Commercial Models Bus Voltages during Off-Peak Load

Table 4.4 Commercial Model Bus and Load Data during Off-Peak Load

	Bus No.	Voltage (p.u.)	Angle Degree	Generation		Load	
				MW	MVAR	MW	MVAR
Without STATCOM	1	1.000	0.000	2.002	0.047	0	0
	2	0.999	-0.001	0	0	0.5	0.02
	3	0.999	-0.002	0	0	0.5	0.02
	4	0.999	-0.002	0	0	0.5	0.02
	5	0.999	-0.002	0	0	0.5	0.02
Power Factor STATCOM at Bus 4	1	1.000	0.000	2.002	0.027	0	0
	2	0.999	-0.001	0	0	0.5	0.02
	3	0.999	-0.002	0	0	0.5	0.02
	4	0.999	-0.002	0	0.02	0.5	0.02
	5	0.999	-0.002	0	0	0.5	0.02
Voltage Regulation STATCOM at Bus 4	1	1.000	0.000	2.003	-1.200	0	0
	2	1.000	-0.002	0	0	0.5	0.02
	3	1.000	-0.002	0	0	0.5	0.02
	4	1.000	-0.003	0	1.249	0.5	0.02
	5	1.000	-0.003	0	0	0.5	0.02

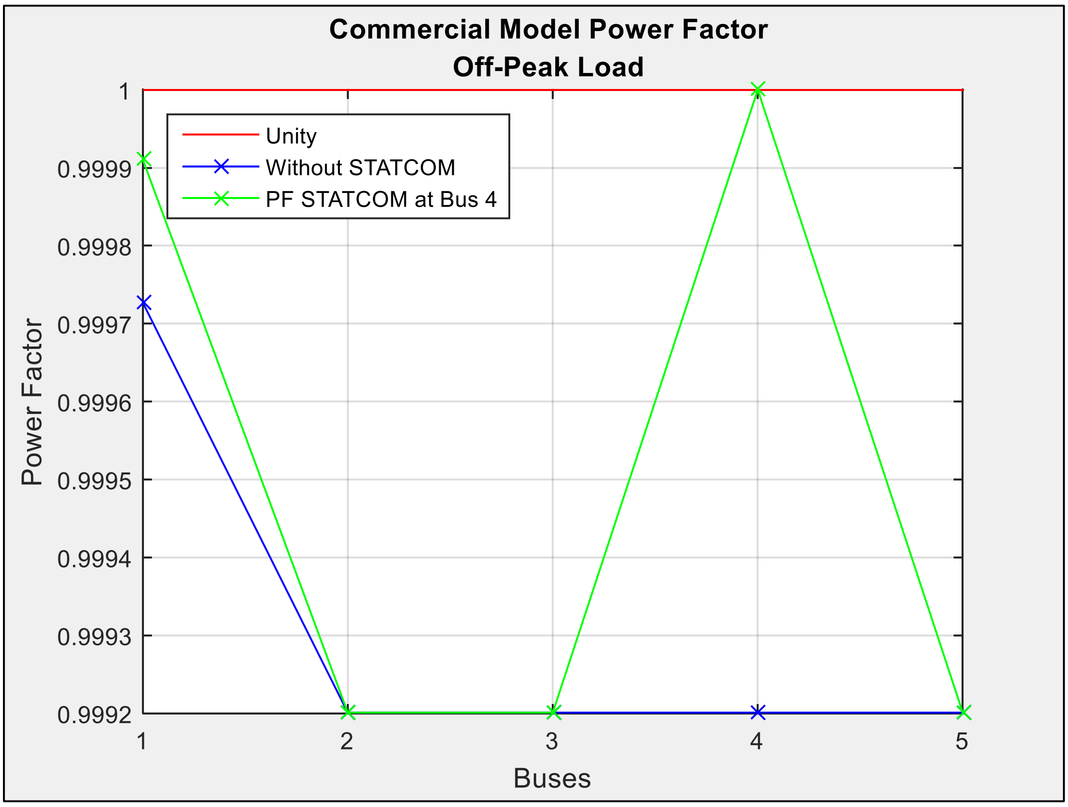

Figure 4.8 Commercial Models Power Factor during Off-Peak Load

4.1.5 Residential Modelled Systems during Peak Load

In the case where a STATCOM was installed at Bus 4 for Power Factor Correction the voltage drops from Bus 1 to 4 was reduced by 0.04 %, this is an improvement of 11.14 %. A reduction can also be seen for the other load buses upstream and downstream. The power factor was improved to unity for Bus 4, but the remaining load buses power factor remained unchanged. There was also a change in the power factor of Bus 1 which improved by 0.024, this was due to the reduced reactive power generation of 0.07 MVars.

In the second case where a STATCOM was installed at Bus 4 for full VR there was no voltage drop between Bus 1 to 4, an improvement can also be seen at all other load buses. The power factor at Bus 4 however was dramatically affected by increased exportation of reactive power, and became 0.336 leading. This was left off the graph due to it being so far off scale. The power factors of the remaining

load buses were unchanged. The generator on Bus 1 has started to absorb reactive power instead of supplying and has a leading power factor of 0.917.

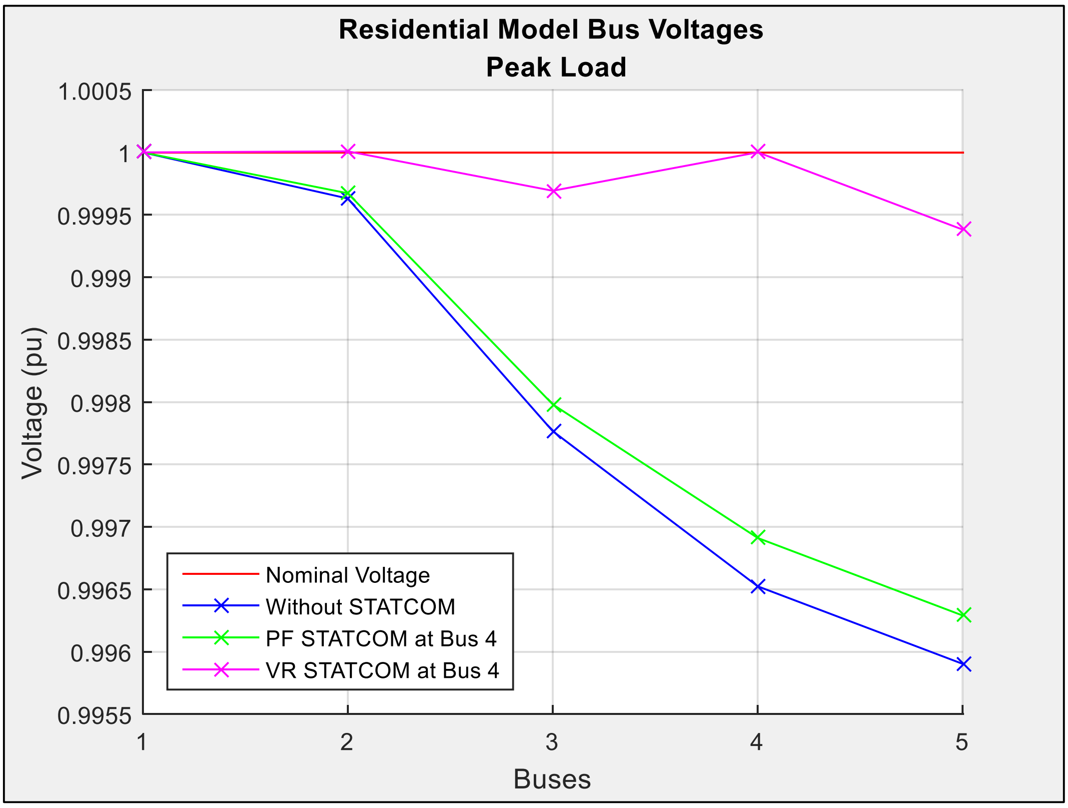

Figure 4.9 Residential Models Bus Voltages during Peak Load

Table 4.5 Residential Model Bus and Load Data during Peak Load

	Bus No.	Voltage (p.u.)	Angle Degree	Generation		Load	
				MW	MVAR	MW	MVAR
Without STATCOM	1	1.000	0.000	0.802	0.282	0	0
	2	1.000	0.000	0	0	0.2	0.07
	3	0.998	-0.001	0	0	0.2	0.07
	4	0.997	-0.002	0	0	0.2	0.07
	5	0.996	-0.002	0	0	0.2	0.07
Power Factor STATCOM at Bus 4	1	1.000	0.000	0.801	0.212	0	0
	2	1.000	0.000	0	0	0.2	0.07
	3	0.998	-0.002	0	0	0.2	0.07
	4	0.997	-0.002	0	0.07	0.2	0.07
	5	0.996	-0.003	0	0	0.2	0.07
Voltage Regulation STATCOM at Bus 4	1	1.000	0.000	0.802	-0.348	0	0
	2	1.000	-0.001	0	0	0.2	0.07
	3	1.000	-0.003	0	0	0.2	0.07
	4	1.000	-0.005	0	0.631	0.2	0.07
	5	0.999	-0.005	0	0	0.2	0.07

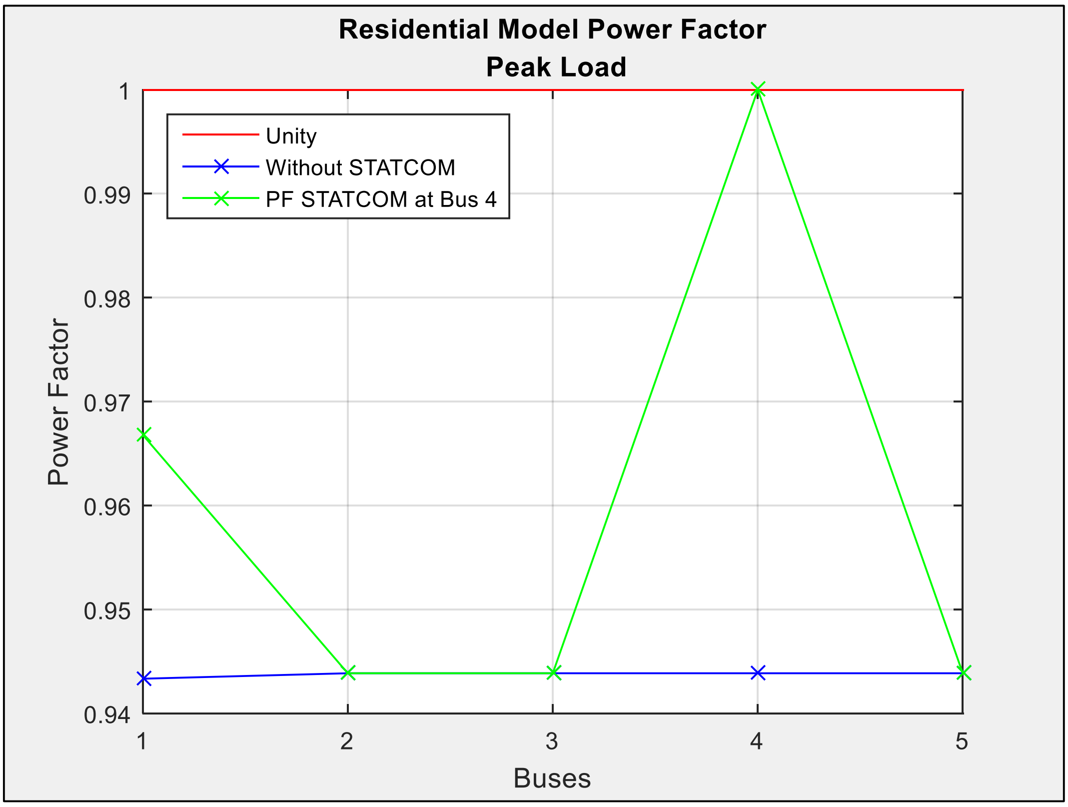

Figure 4.10 Residential Models Power Factor during Peak Load

4.1.6 Residential Modelled Systems during Off-Peak Load

In the case where a STATCOM was installed at Bus 4 for Power Factor Correction there was a very slight reduction in the voltage drop from Bus 1 to 4 but this was less than 0.001% so will be ignored, a reduction can also be seen for the other load buses upstream and downstream. The power factor was improved to unity for Bus 4, but the remaining load buses power factor remained unchanged. There was also a change in the power factor of Bus 1 which improved by 0.022, this was due to the reduced reactive power generation of 0.01 MVars.

In the second case where a STATCOM was installed at Bus 4 for full VR there was no voltage drop between Bus 1 to 4, an improvement can also be seen at all other load buses. The power factor at Bus 4 however was dramatically affected by increased exportation of reactive power, and became 0.340 leading. This was left off the graph due to it being so far off scale. The power factors of the remaining

load buses were unchanged. The generator on Bus 1 has started to absorb reactive power instead of supplying and has a leading power factor of 0.915.

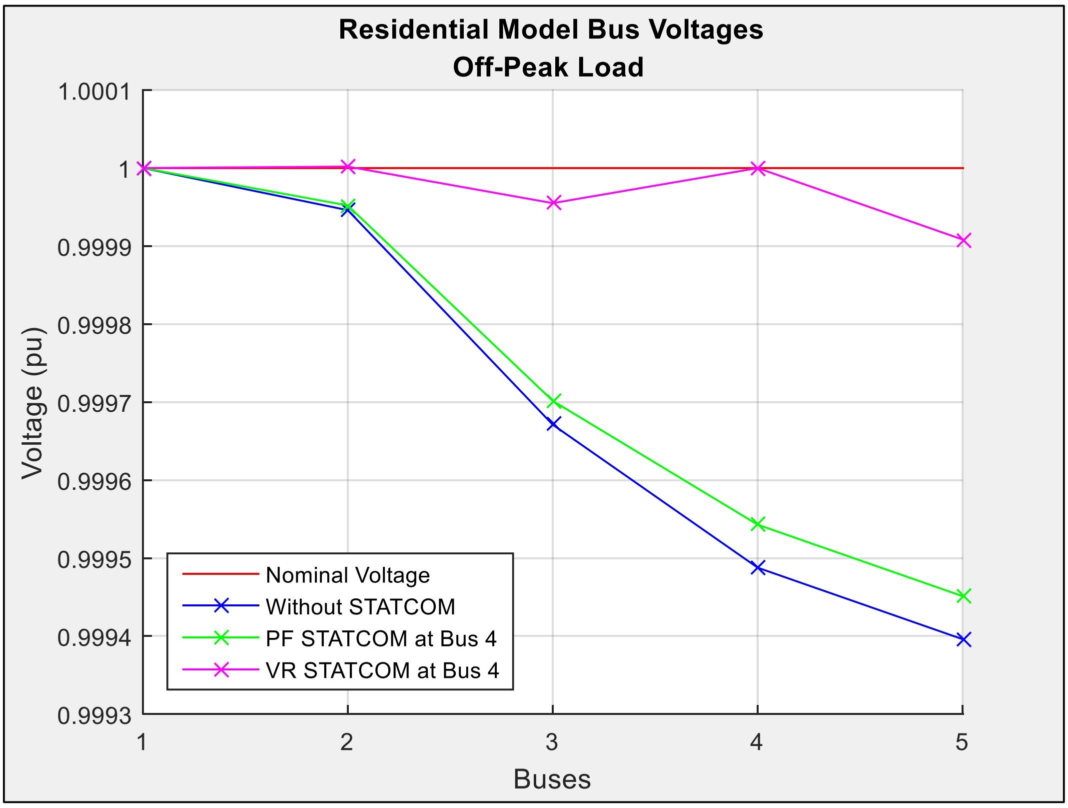

Figure 4.11 Residential Models Bus Voltages during Off-Peak Load

Table 4.6 Residential Model Bus and Load Data during Off-Peak Load

	Bus No.	Voltage (p.u.)	Angle Degree	Generation		Load	
				MW	MVAR	MW	MVAR
Without STATCOM	1	1.000	0.000	0.120	0.040	0	0
	2	1.000	0.000	0	0	0.03	0.01
	3	1.000	0.000	0	0	0.03	0.01
	4	0.999	0.000	0	0	0.03	0.01
	5	0.999	0.000	0	0	0.03	0.01
Power Factor STATCOM at Bus 4	1	1.000	0.000	0.120	0.030	0	0
	2	1.000	0.000	0	0	0.03	0.01
	3	1.000	0.000	0	0	0.03	0.01
	4	1.000	0.000	0	0.01	0.03	0.01
	5	0.999	0.000	0	0	0.03	0.01
Voltage Regulation STATCOM at Bus 4	1	1.000	0.000	0.120	-0.053	0	0
	2	1.000	0.000	0	0	0.03	0.01
	3	1.000	0.000	0	0	0.03	0.01
	4	1.000	-0.001	0	0.093	0.03	0.01
	5	1.000	-0.001	0	0	0.03	0.01

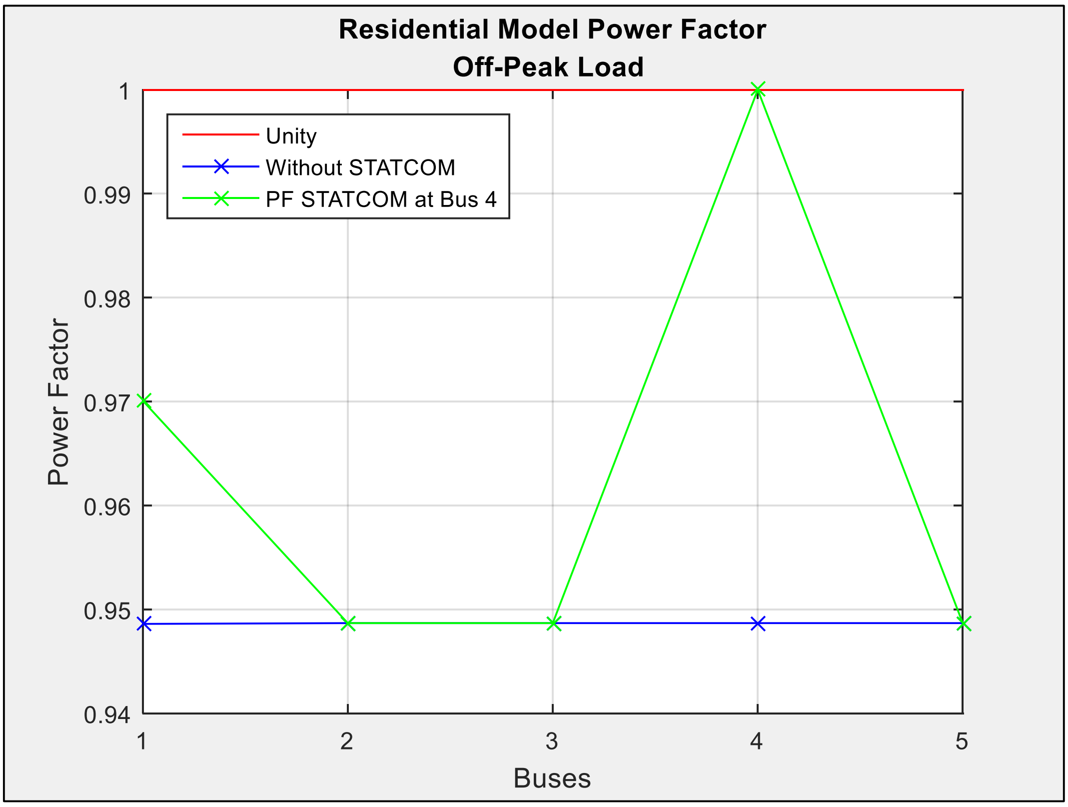

Figure 4.12 Residential Models Power Factor during Off-Peak Load

4.2 STATCOM on a Single Bus During Transient Conditions

To determine the effects of a STATCOM connected to a single bus during transient conditions the same model was used, but the reactive load of Bus 4 was adjusted. It was apparent after the first lot of simulations for normal conditions that the results were similar but the magnitude of the reduction or improvements varied with the loading of the model. Thus only the industrial model during peak load was chosen for evaluation of the transient due to its well defined difference between all three scenarios.

The transient load applied to the model was that of a typical induction motor starting or other heavy plant turning on where a sudden inrush of reactive power is required. This was only applied to Bus 4 and was taken as 2.5 times the normal reactive load. All other Load Buses remained the same and the three scenarios were run again.

In the case where a STATCOM was installed at Bus 4 for Power Factor Correction the voltage drops from Bus 1 to 4 was reduced by 2.24 %, this is an improvement of 29.51 %. A reduction can also be seen for the other load buses upstream and downstream. The power factor was improved to unity for Bus 4, this is a quite significant improvement of 0.486 from the scenario where no STACOM was installed. The remaining load buses power factor remained unchanged, but there was also a change in the power factor of Bus 1 which improved by 0.157, this was due to the reduced reactive power generation of 5.09 MVars during the transient condition.

In the second case where a STATCOM was installed at Bus 4 for full VR there was no voltage drop between Bus 1 to 4, an improvement can also be seen at all other load buses. The power factor at Bus 4 however was dramatically affected by increased exportation of reactive power, and became 0.236 leading. This was left off the graph due to it being so far off scale. The power factors of the remaining load buses were unchanged. The generator on Bus 1 has started to absorb reactive power instead of supplying and has a leading power factor of 0.892.

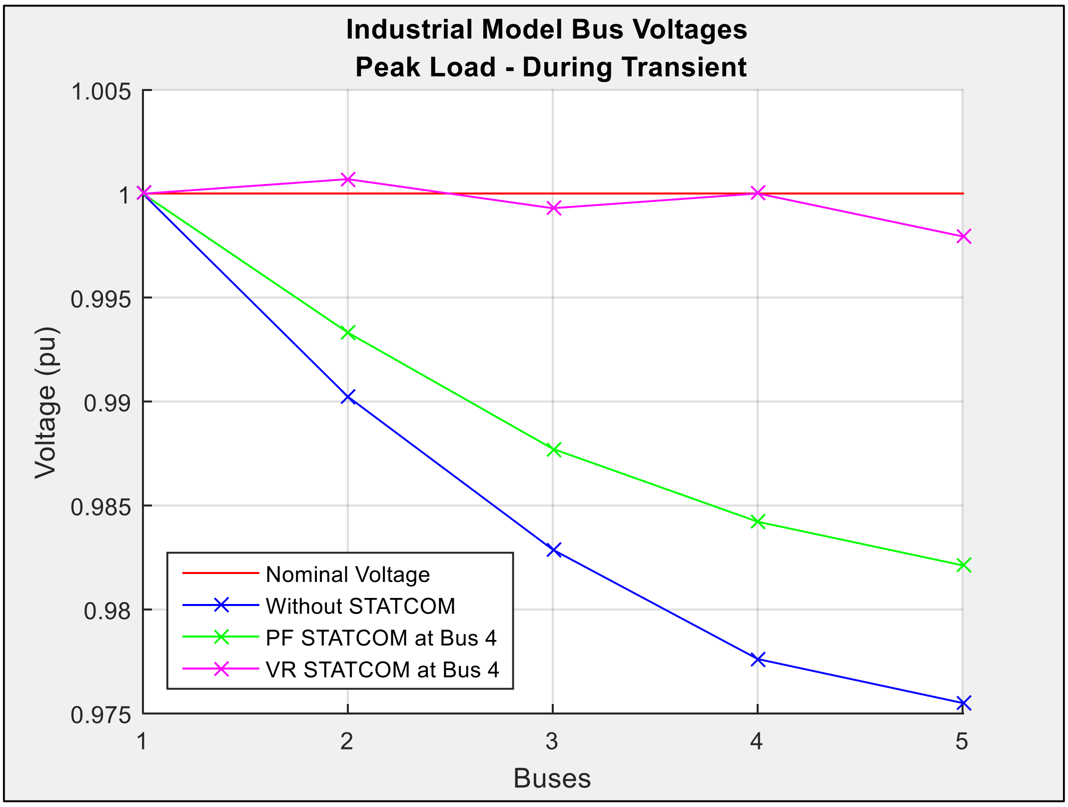

Figure 4.13 Industrial Model Bus Voltage during Transient Condition

Table 4.7 Industrial Model Bus and Load Data during Transient Conditions

	Bus No.	Voltage (p.u.)	Angle Degree	Generation		Load	
				MW	MVAR	MW	MVAR
Without STATCOM	1	1.000	0.000	12.194	11.203	0	0
	2	0.990	-0.005	0	0	3	2
	3	0.983	-0.003	0	0	3	2
	4	0.978	-0.002	0	0	3	5
	5	0.975	-0.002	0	0	3	2
Power Factor STATCOM at Bus 4	1	1.000	0.000	12.118	6.109	0	0
	2	0.993	-0.006	0	0	3	2
	3	0.988	-0.007	0	0	3	2
	4	0.984	-0.008	0	5	3	5
	5	0.982	-0.008	0	0	3	2
Voltage Regulation STATCOM at Bus 4	1	1.000	0.000	12.190	-6.183	0	0
	2	1.001	-0.009	0	0	3	2
	3	0.999	-0.016	0	0	3	2
	4	1.000	-0.023	0	17.345	3	5
	5	0.998	-0.023	0	0	3	2

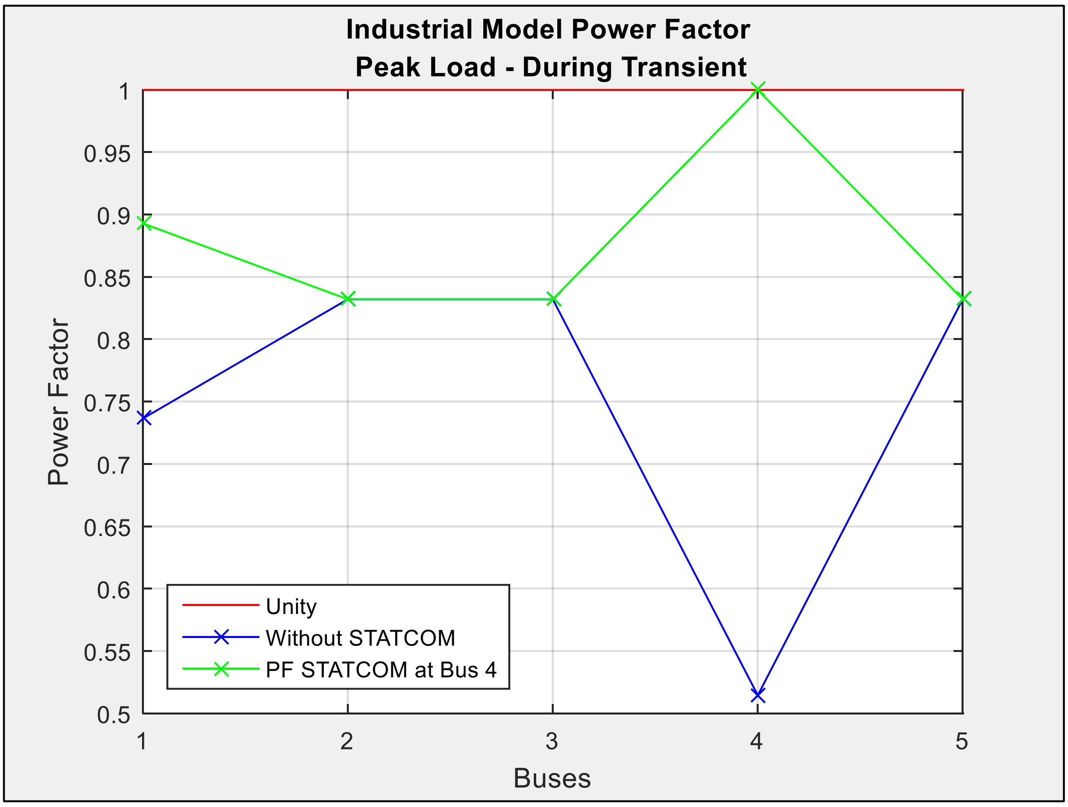

Figure 4.14 Industrial Model Power Factor during Transient Condition

CHAPTER 5

DISCUSSION AND IMPLICATIONS

5.1 STATCOM used for Power Factor Improvement

In the MATLAB simulations conducted, the STATCOM proved to be effective at improving the Power Factor not only at the Load Bus that it was installed, but also at the Bus 1 where the generator was connected to. The performance of the STATCOM would be limited by the rating, and as such if a customer was installing a STATCOM it would be best if a power survey was first carried out to discover their reactive power requirements. A STATCOM that was able to fully improve their power factor to unity might not be necessary or most economical, as The Service and Installation Rules of New South Wales currently states that electricity users must maintain a power factor of 0.9 lagging or above, so improving it beyond this must be taken on a case by case basis looking at the cost of the equipment and the savings made from reduced kVAr consumption.

The results from all models clearly showed an improvement in power factor for the electricity distributor. An improvement for the electricity distributor mean that there will be less losses associated with transmission, and less reactive power will need to be generated. This extra capacity means more load can be supplied to future customers without the need for upgrading existing equipment. The benefit also extends to customers upstream and downstream of the installed STATCOM via reduced voltage drop. Because of this improvement for the distributor and surrounding customers there may be cause in future for the distributor to provide further financial incentives to improving an electrical installations power factor beyond the minimum 0.9 lagging. This would be ideal in the case of residential customers who currently are not charged for their kVAr consumption, whereby comparison commercial customers with high loads are.

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5.1.1 Power Factor During Transients

During the second round of simulations conducted, transient conditions were looked at for the Industrial Model during Peak Load. The performance of the STATCOM in this simulation is where it excels by comparison to the no STATCOM scenario. Figure 4.14 shows that during a transient condition the power factor would drop considerable with no STATCOM installed, this has an adverse effect not only on the customer at Bus 4 but also on the distributor. By comparison, when the STATCOM is installed, due to its fast response time it would be able to react to this load change and supply more reactive power for the short time required. Again this would also have benefit to the distributor as the reactive load requirements are been met by the onsite STATCOM, and not needing to be generated and transmitted.

5.2 STATCOM used for Full Voltage Regulation

MATLAB simulations were also run for when the STATCOM was installed in Full VR mode. This scenario is where the distributor is able to remotely control the customers STATCOM and use it for the greater benefit of the electrical system. Interestingly this would require a much larger rated STATCOM than would normally be installed by a customer as it would now not only look after the local installation, but the reactive loads of the surrounding installations also. Figure 5.1 shows the size of STATCOM required for each scenario, in all cases the size required for full VR exceeds the load requirements by a factor of 7. This would equate to a large financial investment by the customer to install equipment much larger than their current load requirements. This would not happen unless there were financial incentives available from the distributor or government. This could come in the form of them partially paying for the cost of the STATCOM, or perhaps a feed in tariff introduced for the reactive power being supplied to the grid.

Another interesting result to come from these simulations was that in all cases the generator at Bus 1 went from supplying reactive load to absorbing reactive load when the STATCOM was in VR mode. All the Load Buses reactive requirements were being fed from the STATCOM plus what was required in the Lines, and the excess, which was required to maintain a 1 p.u voltage at Bus 4, was feeding back into the generator. This side effect and its impact on the system was not investigated as part of this study.

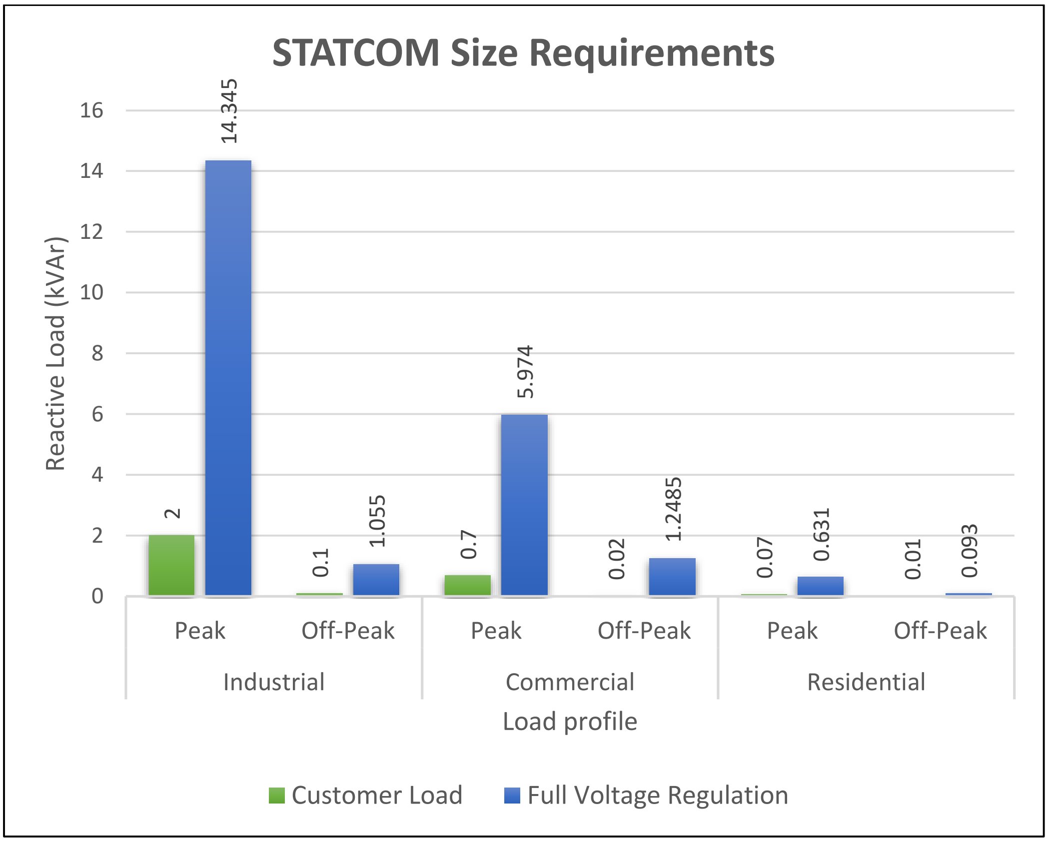

Figure 5.1 STATCOM Size Required for Full Voltage Regulation at Bus 4

5.2.1 Voltage Regulation During Transients

The performance of the STATCOM for VR was also evident during transient conditions. It performed as though it was running still in normal conditions. By comparison the voltage drops from the normal conditions to transient conditions where no STATCOM is installed there was an increase in voltage drop of 0.4 %. The simulation was carried out on fixed loads and neglects the small time it would take the STATCOM to respond to the transient.

5.3 Compliance with Current Australian Standards

Current Australian Standards (Australia 2015) require that any embedded generation connected to the electricity grid needs to have the inverters displacement power factor operating at unity, within the range 0.95 leading to 0.95 lagging. During my simulations, when the STATCOM was set to power factor correction mode, it was correcting the whole of the electrical systems power factor to unity, this required the STATCOM to operate at a power factor well outside this range as it was solely supplying reactive power and no active power. The worst case was when the STATCOM was in Full VR mode and supplying in excess of 7 times the amount of reactive power to the local customer as well as the grid.

The current issue with having inverters suppling at unity is that this reduces the amount of active power consumed but leaves the systems reactive power untouched, this puts additional burden on the grid to supply only reactive power to customers with embedded generation installed. This additional reactive power means the voltage will rise for the local and surrounding customers.

5.4 Multiple STATCOM Installations

The study has only looked at if there was a single STATCOM installed, some of the ratings required of the installed STATCOM were unpractically large for a single customer to installed. A more practical model would be one with multiple STATCOM installations, that way the burden of reactive power supply could be shared and the required rating of each could be reduced to a level much closer to that required by the local installation.

5.5 STATCOM Active and Reactive Power Supply

It is worth mentioning that the simulations performed had the STATCOM inverter supplying only reactive power. This situation is unlikely as customers who install solar systems want firstly to generate the power that they will used on site, this includes both active and reactive power. Unless changes to current standards are made it is also not allowed. Incentives from the government in the form of a reactive power tariff like the existing active power tariff would increase customers interest in installing or converting existing inverters to have STATCOM capabilities.

CHAPTER 6

CONCLUSIONS

Throughout this project a comprehensive literature review was carried out on STATCOMs and various techniques surrounding PQ improvement in electrical systems. Sites were selected for a PQ survey, capturing customers of different load profiles with PV arrays currently installed. This data was analysed and developed into a model to be run in MATLAB. Various simulations testing the different modes the STATCOM could be used for was carried out, including that of the STATCOM under transient conditions. Benefits pertaining to the installation of a STATCOM as the inverter for a PV array were discussed in view from both the electricity distributor and the local customer.

6.1 PQ Improvements using a STATCOM Inverter

VR was found to not only be improved for the location of the installed STATCOM, but extended to customers upstream and downstream. This improvement was a direct result of the reduced voltage drop on the system due to the reactive load being supplied closer to the load and not needing to be transmitted from the generator. Added benefits to supply being generated closer to the load is the system now has freed up capacity, this will delay the need for current equipment to be upgraded to cope with future load growth.

The STATCOM running in Full VR mode case showed that all of the electricity systems reactive power was needed to be supplied from the Bus where the STATCOM was installed to bring the voltage level up to 1 p.u. It was also noted that the generator also went from supplying reactive power to absorbing reactive power from the STATCOM, this may have undesirable effects and will need to be further investigated.

The STATCOM running in Power Factor Correction mode showed improvements only to the Bus where the STATCOM was installed and the generator’s Bus, all other load buses power factor remained unchanged. From a grid perspective it is in their best interest if all customers were able to operate at close to unity to reduce the amount of reactive power needed to be generated and transmitted.

As can be seen clearly throughout the study, a STATCOM being installed as the inverter of a PV array has the ability to supply the reactive power needs of the local customer. The main beneficiary of this depends on the type of customer load, if it is for a large industrial customer who is being charge for their kVAr usage then they will see a financial benefit in reduced electricity bills, whereas residential and small commercial customers will not as they only pay for their kW consumption. The electricity distributor was always seen to benefit from a customer installing a STATCOM, this makes a good case for the distributor to support customers who want to install STATCOMs via means of a financial incentive or rebate. In the future energy pricing schemes may change for residential and commercial customers and they could end up being charged for their kVAr usage, this would inevitably see an increase in power factor correction equipment such as the STATCOM on small residential and commercial loads.

6.2 Future Research

This dissertation forms only a small part of the broader study to investigate the feasibility of converting existing solar inverters to have STATCOM capabilities. Further study remains in the areas of simulation of a known problem feeder due to high PV penetration, communications between SMART Meter and SMART Grid, and a review of current standards relating to inverter requirements.

6.2.1 Investigate feeder with High PV Penetration and VR Issues

The study has provided information regarding a STATCOM installation from a theoretical standpoint only. There are numerous known feeders currently on the NSW network that have VR issues resulting from the recent increase of PV installations. Time constraints meant that a study of one of these feeders could not be carried out, however future research should involve modelling one of these feeders, preferably in software such as HOMER. The aim should be to convert a portion, or all of the inverters on the feeder to STATCOMs and investigate and results on PQ.

6.2.2 Communication between SMART Meter and SMART Grid

Work also remains to research and test communication methods between currently installed SMART Meters with the electricity grid. A STATCOM is capable of reading and improving local PQ issues, but a high penetration of STATCOMs all attempting to fix the same issue, such as maintaining voltage stability, may actually have a detrimental effect if there was no communication between devices. Investigation needs to be done into how a SMART Grid could instruct the STATCOMs to resolve voltage issues efficiently and effectively.

6.2.3 Review of Current Standards for Inverters

This study has outlines constraints that are imposed by current standards on inverters. The PQ of the model in all scenarios was improved by operating the STATCOM outside current standards. This study was an extreme approach where only reactive power was supplied at a power factor of 0. Further study looking into the optimum power factor for a STATCOM to operate where the benefit was maximised for both the customer and the electricity grid should be undertaken.

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APPENDICES

Appendix A - Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

Project Specification

For: Phillip Nicholson

Title: Power Factor Improvement Using a STATCOM Inverter

Major: Electrical Engineering – Power Engineering

Supervisors: Dr Les Bowtell

Sponsorship: Nil

Enrolment: ENG4111 – EXT S1, 2016
ENG4112 – EXT S2, 2016

Project Aim: To investigate the impact a STATCOM inverter can have on improving load power factor for commercial and high density residential loads.

Programme: **Issue A, 10th March, 2016**

1. Research background information relating to Power Quality.
2. Perform a load survey of a commercial and high density residential load.
3. Analyse load data and develop a system model for use in MATLAB.
4. Evaluate the transient capabilities of a STATCOM inverter on the system loads modelled in MATLAB.
5. Report on the potential benefits that can be expected to both the consumer and electricity distributor from a locally installed STATCOM.

If time and resources permit:

6. Carry out laboratory testing of a STATCOM inverter improving a loads power factor using data read from a SMART meter.

Appendix B - Project Risk Assessment

The risk assessment accounts for two different perspectives in relation to the project. The first assessment adapted from the company's Be Safe Pro 10 Managing WHS and outlined in Tables B-2 and B-3, considers the potential hazards that may be encountered by the student whilst performing laboratory testing at the University of Southern Queensland, and also whilst installing and removing PQ meters from distribution substations on the electricity network. This assessment identifies the hazard, identifies the risk associated with this hazard if no counter measure were in place (based on the likelihood – consequence matrix Table B-1) and then recommendations on what can be done to minimise this risk is considered, finally with a new re-evaluated risk taken from index is given to each task. The second assessment, provided in Table B-3, considers aspects that may pose a risk to timely completion of the project using a simpler risk scale of low, medium and high. The issue of not being able to carry out complete laboratory testing in the short timeframe whilst on USQ campus is the major concern as this data will be used and simulated in MATLAB along with the PQ data from the selected sites.

Table B-1 Personal Risk Matrix - Be Safe Pro 10 Managing WHS

		CONSEQUENCE				
		Insignificant	Minor	Moderate	Major	Severe
LIKELIHOOD	Almost Certain	11	16	20	23	25
	Likely	7	12	17	21	24
	Possible	4	8	13	18	22
	Unlikely	2	5	9	14	19
	Rare	1	3	6	10	15

Legend	Low Risk	Medium Risk	High Risk

Table B-2 Personal Risk Assessment

Hazard	Risk	Control Measures	Re-evaluated Risk
Uncontrolled discharge or contact with electricity	22	• Site Awareness • Correct use of PPE if coming within minimum clearances (500mm for voltages < 1000 V AC) • Have a standby person present	15
Motor vehicle accident	9	• Wear Hi Vis if near the roadway • Take care when driving to and from site	6
Slips and trips	8	• Site awareness • Note down and potential hazards in area on pre work assessment	3
Exposure to hazardous materials	9	• Assess work site prior to beginning work • Wear correct PPE if in doubt	6
Insects	8	• Site awareness • Spray site if insects present and allow time for insecticide to clear	3
Exposure to UV	20	• Apply sunscreen • Wear appropriate PPE	6

Table B-3 Project Risk Assessment

Hazard	Risk	Control Measure	Re-evaluated Risk
Unable to attend campus to perform testing	**High Risk**	• Ensure Annual Leave is booked in early and Supervisor is available during lab period	Low Risk
STATCOM testing phase incomplete	Medium Risk	• Plan all testing stages prior to attending campus • Ensure partial testing complete so results can be used in report	Low Risk
PQ meter unavailable from company	Medium Risk	• Book meter in early stages of project • Rebook as necessary • Obtain previously surveyed sites from company	Low Risk
Insufficient time to complete write up of dissertation	Medium Risk	• Start early and allocate time weekly to write up dissertation	Low Risk

Appendix C - Project Timeline

Table C-1 Project Timeline

Activity	Semester 1 2016											
					Recess							
	1	2	3	4	5	6	7	8	9	10	11	12
	29 Feb	07 Mar	14 Mar	21 Mar	28 Mar	4 Apr	11 Apr	18 Apr	25 Apr	2 May	9 May	16 May
1. STARTUP PHASE			Project Spec									
1A. Conduct Initial Literature Review												
1B. Continue Literature Review												
1C. Define Project Specification												
1D. Select sites for Survey												
2. DATA GATHERING PHASE												
2A. Install Power Quality Meters at selected sites												
2B. Retrieve Power Quality Meters												
2C. Colate results												
2D. Project Preliminary report												
3. DATA ALANYSIS PHASE												
3A. Assess hourly power quality of sites												
3B. Simulate power quality improvements at selected sites												
3C. Review data												
4. WRITEUP PHASE												
4A. Prepare Draft Dissertation												
4B. Review Partial Dissertation												
4C. Prepare for Presentation												
4D. Attend Conference Seminar and Present												
4E. Finalise dissertation and submit!												

Table C-2 Project Timeline

Activity	Semester 1 2016							Semester 2, 2016			
				Exams Recess							
	13	14	15	16	17	18	19	20	21	22	23
	23 May	30 May	6 Jun	13 Jun	20 Jun	27 Jun	4 Jul	11 Jul	18 Jul	25 Jul	1 Aug
1. STARTUP PHASE	Preliminary Report Due										
1A. Conduct Initial Literature Review											
1B. Continue Literature Review											
1C. Define Project Specification											
1D. Select sites for Survey											
2. DATA GATHERING PHASE											
2A. Install Power Quality Meters at selected sites											
2B. Retrieve Power Quality Meters											
2C. Colate results											
2D. Project Preliminary report											
3. DATA ALANYSIS PHASE											
3A. Assess hourly power quality of sites											
3B. Simulate power quality improvements at selected sites											
3C. Review data											
4. WRITEUP PHASE											
4A. Prepare Draft Dissertation											
4B. Review Partial Dissertation											
4C. Prepare for Presentation											
4D. Attend Conference Seminar and Present											
4E. Finalise dissertation and submit!											

Table C-3 Project Timeline

Activity	Semester 2, 2016									
							Recess			
	24	25	26	27	28	29	30	31	32	33
	8 Aug	15 Aug	22 Aug	29 Aug	5 Sep	12 Sep	19 Sep	26 Sep	3 Oct	10 Oct
1. STARTUP PHASE					Partial Draft Dissertation Due		Project Conference on Campus			Dissertation Submission
1A. Conduct Initial Literature Review										
1B. Continue Literature Review										
1C. Define Project Specification										
1D. Select sites for Survey										
2. DATA GATHERING PHASE										
2A. Install Power Quality Meters at selected sites										
2B. Retrieve Power Quality Meters										
2C. Colate results										
2D. Project Preliminary report										
3. DATA ALANYSIS PHASE										
3A. Assess hourly power quality of sites										
3B. Simulate power quality improvements at selected sites										
3C. Review data										
4. WRITEUP PHASE										
4A. Prepare Draft Dissertation										
4B. Review Partial Dissertation										
4C. Prepare for Presentation										
4D. Attend Conference Seminar and Present										
4E. Finalise dissertation and submit!										

Appendix D - Resource Requirements

A resource analysis outlining equipment and data requirements for the project is provided in Tables D-1-3. The majority of resources are available at either the USQ laboratories or via the company. The company has allowed the use of the PQ loggers for the purpose of this project. Software has previously been purchased as part of previous studies at USQ.

Table D-1 Project Resources

Task	Item	Amount	Source	Cost	Image
2A - 2B	PQ Logger	One (1)	Company	Nil	
2A - 2B	Safety Gloves	Two (2)	Company	Nil	
2A - 2B	Safety Glasses	One (1)	Company	Nil	

Table D-2 Project Resources

Task	Item	Amount	Source	Cost	Image
2A - 2B	Hard Hat	One (1)	Company	Nil	
2A - 2B	Hi-Vis Shirt	One (1)	Company	Nil	
2A - 2B	Heavy Duty Pants	One (1)	Company	Nil	
2A - 2B	Safety Boots	Two (2)	Company	Nil	

Table D-3 Project Resources

Task	Item	Amount	Source	Cost	Image
4B	MATLAB Software	One (1)	Student	Previously purchased	
5A-5B	Office Software	One (1)	Student	Previously purchased	
5A-5B	Endnote	One (1)	USQ	License provided by USQ	

Appendix E - MATLAB Programs

Appendix E.1 Main Program Code

```
% Engineering Project USQ - 2016
% Power Quality Improvement Using a STATCOM Inverter
% Author - Phillip Nicholson
% Student Number - 61040542
%

% This script will solve the power flow analysis problem for a 5 bus
radial
% model. Data is to be entered for the line impedances and susceptances,
as
% well as the active and reactive loads on the 4 load buses. It calls on
% another function file called newtonrhapson.m to solve for the bus
% voltages of the load buses and any slack or swing bus power outputs.
This
% program is specific to the model used in the above mentioned thesis,
but
% can be ported across to another model with minimal modifications.
Several
% scenarios were run and plotted for each model, for more information on
% the scenarios please see the above thesis.

clc, clear, close all
```

DATA entered from Model developed during research project

User to input impedances and admittances in pu

```
Sbase = 20;      % MVA
Vbase = 11;      % kV
Zbase = 6.048;   % Ohms
Ybase = 0.165;   % Siemens

% Number of voltage controlled buses
vcbus = 0;

% Impedance of Tx1
zt1 = 0.005 + 0.012i;

% Series impedances of Lines
zline = zeros(3,5);
zline(1,:) = 0.056 + 0.041i;     % Industrial
zline(2,:) = 0.038 + 0.028i;     % Commercial
zline(3,:) = 0.2704 + 0.2968i;   % Residential
zline = zline/Zbase;

% Total per phase susceptance of Lines
bline = zeros(3,5);
bline(1,:) = 0.151i;             % Industrial
bline(2,:) = 0.1004i;            % Commercial
bline(3,:) = 0;                  % Residential
bline = bline/Ybase/1000;
```

```
% User specified value of active power for load buses
Pl = zeros(6,5);
Pl(1,2:5) = 3;          % Industrial Peak
Pl(2,2:5) = 0.3;        % Industrial Off-Peak
Pl(3,2:5) = 1.5;        % Commercial Peak
Pl(4,2:5) = 0.5;        % Commercial Off-Peak
Pl(5,2:5) = 0.2;        % Residential Peak
Pl(6,2:5) = 0.03;       % Residential Off-Peak
Pl = Pl/Sbase;


% User specified value of reactive power for load buses
Ql = zeros(6,5);
Ql(1,2:5) = 2;          % Industrial Peak
Ql(2,2:5) = 0.1;        % Industrial Off-Peak
Ql(3,2:5) = 0.7;        % Commercial Peak
Ql(4,2:5) = 0.02;       % Commercial Off-Peak
Ql(5,2:5) = 0.07;       % Residential Peak
Ql(6,2:5) = 0.01;       % Residential Off-Peak
Ql = Ql/Sbase;

% Ql(1,4) = 5/Sbase; % Transient load at Bus 4 only

% User specified values of active power for generators
Pg = zeros(30,5);

% User specified values of reactive power for generators
Qg = zeros(30,5);

% Below is for power factor correction at Bus 4 only
for j = 7:12
    Pg(j,4) = Pl(j-6,4);
%     Qg(j,4) = Ql(j-6,4);
end

% Below is for full voltage regulation at Bus 4
% Value obtained by running program with vcbus = 2 and summing Ql at
Buses
% 4 and 5
Qg(13,4)  = 7.4870/Sbase + sum(Ql(1,4:5));
Qg(14,4)  = 0.5782/Sbase  + sum(Ql(2,4:5));
Qg(15,4)  = 3.3178/Sbase  + sum(Ql(3,4:5));
Qg(16,4)  = 0.7936/Sbase  + sum(Ql(4,4:5));
Qg(17,4)  = 0.3183/Sbase  + sum(Ql(5,4:5));
Qg(18,4)  = 0.0473/Sbase  + sum(Ql(6,4:5));

for j = 7:12
   Pg(j+6,4) = Pl(j-6,4);   % Bus 4 P generation for full VR
end

% Below is for values relating to current regulation limitations for pf
to
% be within 0.95 leading and lagging
for j = 19:24
    Pg(j,4) = Pl(j-18,4);
    Pg(j+6,4) = Pg(j,4);
    Qg(j,4) = sqrt((Pg(j,4)/0.95)^2 - Pg(j,4)^2);
```

```
    Qg(j+6,4) = Ql(j-18,4);
end



% Define arrays to store calculated data
[pf, P, Q, v] = deal(zeros(30,5));
```

Call function to calculate

```
for i = 1:6;
    switch i
        case (Council 2000)
            k = 1;
        case (Abu-Sharkh et al. 2006)
            k = 2;
        otherwise
            k = 3;
    end
    vcbus = 0;
    [pf(i,:), P(i,:), Q(i,:), v(i,:)] =...
        newtonrhapson(zline(k,:),bline(k,:),Pg(i,:),Qg(i,:),...
        Pl(i,:),Ql(i,:),zt1,vcbus);

%     vcbus = 2;  % Uncomment to get reactive power required for VR at
Bus4

    [pf(i+6,:), P(i+6,:), Q(i+6,:), v(i+6,:)] =...
        newtonrhapson(zline(k,:),bline(k,:),Pg(i+6,:),Qg(i+6,:),...
        Pl(i,:),Ql(i,:),zt1,vcbus);

    [pf(i+12,:), P(i+12,:), Q(i+12,:), v(i+12,:)] =...
        newtonrhapson(zline(k,:),bline(k,:),Pg(i+12,:),Qg(i+12,:),...
        Pl(i,:),Ql(i,:),zt1,vcbus);

    [pf(i+18,:), P(i+18,:), Q(i+18,:), v(i+18,:)] =...
        newtonrhapson(zline(k,:),bline(k,:),Pg(i+18,:),Qg(i+18,:),...
        Pl(i,:),Ql(i,:),zt1,vcbus);

    [pf(i+24,:), P(i+24,:), Q(i+24,:), v(i+24,:)] =...
        newtonrhapson(zline(k,:),bline(k,:),Pg(i+24,:),Qg(i+24,:),...
        Pl(i,:),Ql(i,:),zt1,vcbus);

end
% pf(13:18,4)=pf(13:18,4)*-1;
```

Plot Graphs

```
buses = 1:5;

Headv = ['Industrial Model Bus Voltages ';...
    'Commercial Model Bus Voltages ';...
    'Residential Model Bus Voltages'];

Headpf = ['Industrial Model Power Factor ';...
```

```
    'Commercial Model Power Factor ';...
    'Residential Model Power Factor'];

Headpeak = ['   Peak Load  ';'Off-Peak Load '];


% Voltage Graph
x = buses;

for i = 1:6
    switch i
        case 1
            k = 1; j = 1;
        case 2
            k = 1; j = 2;
        case 3
            k = 2; j = 1;
        case 4
            k = 2; j = 2;
        case 5
            k = 3; j = 1;
        otherwise
            k = 3; j = 2;
    end
    y1 = abs(v(i,:));
    y2 = abs(v(i+6,:));
    y3 = abs(v(i+12,:));
    y4 = abs(v(i+18,:));
    y5 = abs(v(i+24,:));
    figure(i)
    ax = gca;
    hold on, grid on,
    plot([1 5], [1 1],'r'), xlabel 'Buses', ylabel 'Voltage (pu)',...
    plot(x,y3,'bx-'),
    plot(x,y4,'mx-'),
    plot(x,y2,'gx-'),
    plot(x,y1,'cx-'),
    plot(x,y5,'o-'),
    title({Headv(k,:);Headpeak(j,:)}),...
%   Uncomment below to get data labels for all points
%     text(x(2:4)-0.2,y1(2:4),num2str(y1(2:4)','%3.4f'),...
%       'HorizontalAlignment','right')
%     text(x(5)-0.3,y1(5)+(y1(4)-y1(5))/5,num2str(y1(5),'%3.4f'),...
%       'HorizontalAlignment','right')
%     text(x(2:4),y2(2:4)+(y2(4)-y2(5))/4,num2str(y2(2:4)','%3.4f'),...
%       'HorizontalAlignment','center')
    legend('Nominal Voltage','VR STATCOM at Bus 4',...
        '0.95 leading STATCOM at Bus 4','Unity STATCOM at Bus 4',...
        'Without STATCOM','Full load STATCOM','Location','best')
    ax.XTick = buses;

 % Produce Power Factor Graph
    y1 = pf(i,:);
    y2 = pf(i+6,:);
    y3 = pf(i+12,:);
    y4 = pf(i+18,:);
    y5 = pf(i+24,:);
    figure(i+6)
```

```
    ax = gca;
    plot([1 5], [1 1],'r'),hold on, grid on,
    plot(x,y3,'bx-'), xlabel 'Buses', ylabel 'Power Factor',
    plot(x,y4,'mx-'),
    plot(x,y2,'gx-'),
    plot(x,y1,'cx-'),
    plot(x,y5,'o-'),
    title({Headpf(k,:);Headpeak(j,:)})
%   Uncomment below to get data labels for all points
%     text(x(2:4)-0.2,y1(2:4)+(1-y1(2))/10,num2str(y1(2:4)','%3.4f'),...
%       'HorizontalAlignment','right')
%     text(x(5)-0.2,y1(5)+(1-y1(2))/10,num2str(y1(5),'%3.4f'),...
%       'HorizontalAlignment','right')
    legend('Unity','VR STATCOM at Bus 4',...
        '0.95 leading STATCOM at Bus 4','Unity STATCOM at Bus 4',...
        'Without STATCOM','Full Load STATCOM','Location','best')
    ax.XTick = buses;
end
```

Output data to CSV file for use in Excel

Uncomment below to produce excel file, commented out for faster runtime when it wasn't required

```
% filename = 'NewBusDatatransient.xlsx';
% xlRange = 'B3';
% for i = 1:18
%     A = [abs(v(i,:))',angle(v(i,:))',abs(P(i,:)*20)',abs(Q(i,:)*20)'];
%     sheet = i;
%     xlswrite(filename,A,sheet,xlRange);
% end
```

Appendix E.2 Newton Rhapson Function Code

```
% Engineering Project USQ - 2016
% Power Quality Improvement Using a STATCOM Inverter
% Author - Phillip Nicholson
% Student Number - 61040542
%

% This script will solve the power flow analysis problem for a 5 bus
radial
% model using the Newton Rhapson Method. It was developed from a script
% supplied during the subject ELE3807 Power Systems Analysis.


function [pf,P,Q,v]=newtonrhapson(zline, bline, Pg, Qg, Pl, Ql, zt1,
vcbus)
iter = 0;    % Number of iterations calculated

% Initial estimates for bus voltages for load buses, swing and slack
buses
% to be specified, complex numbers in pu
v = [1.0; 1.0; 1.0; 1.0; 1.0];
```

Calculations of user inputs

```
yt1 = 1/zt1;            % Conversion to admittance
yline = 1./zline;

% Admittance Matrix

Y = zeros(5);
Y(1,1)=yt1;     Y(1,2)=-Y(1,1);        Y(1,3)=0;    Y(1,4)=0;    Y(1,5)=0;
Y(2,1)=Y(1,2);  Y(2,2)=Y(1,1)+yline(1)+bline(1)/2; Y(2,3)=-yline(1);
Y(2,4)=0;    Y(2,5)=0;
Y(3,1)=Y(1,3);  Y(3,2)=Y(2,3);  Y(3,3)=sum(yline(1:2))+sum(bline(1:2))/2;
Y(3,4)=-yline(2);  Y(3,5)=0;
Y(4,1)=Y(1,4);  Y(4,2)=Y(2,4);  Y(4,3)=Y(3,4);
Y(4,4)=sum(yline(2:3))+sum(bline(2:3))/2;    Y(4,5)=-yline(3);
Y(5,1)=Y(1,5);  Y(5,2)=Y(2,5);  Y(5,3)=Y(3,5);  Y(5,4)=Y(4,5);
Y(5,5)=yline(3)+bline(3)/2;
```

Set up Jacobian Matrices

```
[J11, J12, J21, J22] = deal(zeros(5));

Jsize = 8 - vcbus;      % 2*(num buses-slack)-num voltage controlled
buses
Jcomb = zeros(Jsize);   % Combination of all Jacobian Matrices

% Calculation of power mismatches
[P, Q] = deal(zeros(1,5));
PQmm = ones(1,Jsize);

% Carry out calculations until power mismatches are within tolerances
```

```
while abs(PQmm(1))> 1e-14 %iter <10

    for j = 1:5
        P(j) = 0;
        Q(j) = 0;
        for k = 1:5
            vvy = v(j,1)'*v(k,1)*Y(j,k);
            P(j) = P(j) +real(vvy);      % P is est of injected active p
            Q(j) = Q(j) -imag(vvy);      % Q is est of injected reactive p
        end
    end

    Pmm = Pg - Pl - P;                   % Pmm is active power mismatch
    Qmm = Qg - Ql - Q;                   % Qmm is reactive power mismatch
    PQmm(1:4) = Pmm(2:5);
    PQmm(5:Jsize) = Qmm(2:5-vcbus);

    % Evaluation of the Jacobian

    for j = 1:5
        for k = 1:5
            vvy = v(j,1)'*v(k,1)*Y(j,k);
            if j ~= k
                J11(j,k) = -imag(vvy);
                J21(j,k) = -real(vvy);
                J12(j,k) = -J21(j,k);
                J22(j,k) =  J11(j,k);
            else
            end
        end
    end

    for j = 1:5
        J11(j,j) = -sum(J11(j,:));
        J21(j,j) = -sum(J21(j,:));
        J12(j,j) =  J21(j,j) + 2*abs(v(j,1)).^2*real(Y(j,j));
        J22(j,j) = -J11(j,j) - 2*abs(v(j,1)).^2*imag(Y(j,j));
    end

    % Slack bus not to be considered
    Jcomb(1:4,1:4) = J11(2:5,2:5);
    % VC Buses not to be considered
    Jcomb(5:Jsize,5:Jsize) = J22(2:5-vcbus,2:5-vcbus);
    % Slack and VC buses not to be considered
    Jcomb(1:4,5:Jsize) = J12(2:5,2:5-vcbus);
    % Slack and VC buses not to be considered
    Jcomb(5:Jsize,1:4) = J21(2:5-vcbus,2:5);

    % Evaluation of angle and voltage corrections

    avcor = Jcomb\PQmm';
    avcor(Jsize+1:8,1) = 0;

    % Evaluation of new angles and new voltages

    newangle(2:5) = angle(v(2:5,1)) + avcor(1:4,1);
    newmag(2:5) = abs(v(2:5,1)).*(ones(4,1) + avcor(5:8,1));
```

```
    for j = 2:5
        v(j) = newmag(j)*exp(1i*newangle(j));
    end

    iter = iter+1;
end

% Calculate Power Factor at Buses
S = sqrt(P.^2 + Q.^2);
pf = abs(P)./S;
```

Appendix F - Hazard Assessment Check Forms

Be Safe Pro10.1F

HAZARD ASSESSMENT CHECK (HAC) FORM

Ausgrid | Be Safe Stop. Think. Do.

HAC	Identify	Assess	Control	Monitor	Re-Assess	Emergency Initial Below

Supervisor: B Thoms. Date: 15 Jul 16 Time: 11:00

Site Assessment led by: Workgroup Section: WM

Location / Address / Worksite: Central Ave Manly. **Multi Site 1-9** Yes☐ No☑

In an emergency initial above with site details, make the site safe & complete the HAC ASAP

Talk about the job! Use the grid to sketch a plan view of the worksite.
Everybody involved! Does anything on this site change the way we normally do our work?

Describe the site: (Identify the layout, features & boundaries of the worksite) in writing with a sketch for single site as required.
Chamber Substation

Describe the Job / Tasks to be completed: (Identify the major steps & who is doing the work)
Install PQ Meter

Address Details		Multi site ALARP
1	S15902	(Y) N
2		Y N
3		Y N
4		Y N
5		Y N
6		Y N
7		Y N
8		Y N
9		Y N

SWMS	Summary of SWMS name	Applicable tasks	SWMS	Summary of SWMS name	Applicable tasks
Aus002	Inspection	1-3			
NR18	Load Survey	14 20-24 45			

STOP! After a work break, team membership changes, site conditions change or something causes you to change your work processes.
THINK! About current and additional controls and re-assess the job.
DO! If the Pre-Work Discussion highlights safety issues, they must be resolved with your Supervisor before commencing work.

Mandatory Discussion Prompts (Refer to Blue Folder – Be Safe Pro 10.2F and Be Safe Pro 10.5F)

Emergency Contact Numbers ....112.......... First Aid Kit Location - Ausgrid Vehicle **Yes** ☑ **Other** ☐ ....
Evacuation Point..........Vehicle..........

Job packet information is on site? **Yes** ☑ **N/A** ☐
Asset / Dial Before You Dig plans on site? **Yes** ☐ **N/A** ☑
Will we affect other people on site or they affect us? **Yes** ☑ **No** ☐
Additional supervision? Contractor☐ Apprentice☐ Visitor☐ Other☐
If so, what will we do? Stop work talk to them.
The responsible person (RP) will be providing this. N/A
Transmission HV Energised ☐ Isolated ☐ AP No.....N/A.....
LV Energised ☑ De-energised ☐ De-energised & shorted ☐
Distribution HV Energised ☑ Isolated ☐ AP No..........
Isolated ☐ Permit No. (if applicable) ....

Job Discussion – Fatal Risk and Key Site Specific Safety Hazards

✓	Uncontrolled discharge or contact with electricity	
✓	Exposure to Hazardous Materials	
	Fall from Heights	
✓	Motor Vehicle Accident	
	Unintended contact with Mobile Powered Plant	
	Struck by falling/moving object	
✓	Incident whilst undertaking lifting operations	
	Uncontrolled collapse of excavation work	
	Breach of controlled worksite when working near or around traffic	

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Review Date: December 2014

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HAZARD ASSESSMENT CHECK (HAC) FORM

Ausgrid | Be Safe Stop. Think. Do.

HAC

Fatal and or Additional Risk Assessment Table
Refer to the Blue Folder for Hazard Prompts and HAC Instructions

Identify Hazards (As discussed in the Job Discussion)	Assess Risk	Control	Residual Risk
Traffic	23	Awareness PPE	18
Slips Trips Falls	13	Awareness PPE	9
Electrical	23	Training Awareness PPE	18
Manual Handling	13	Awareness PPE	9

Monitor

On-going monitoring of hazards and controls is required for the duration of the work. Has anything changed?

Re-Assess any new hazards below

Have the risks been reduced to As Low As Reasonably Practicable (ALARP)? No ☐ Yes ☑

If NO do not commence work & contact your supervisor. (For Multi site ALARP see multi site address box)

ALL WORKSITE STAFF

All persons signing on this form declare that they are fit for work and all staff, contractors and public involved with this work activity must discuss the hazards, implement risk controls and sign on to accept this hazard check prior to commencing work. All work conducted will be in accordance with the identified SWMS. If you are an apprentice (A), contractor (C), visitor (V) or other (O) – you must place an identifying initial next to your name

Name	Signature	RP	Time	Name	Signature	RP	Time
C Cree	[signature]		11:00				
P Kramel	[signature]		11:00				

HAC reviewed by	Name:	Signature:	Date:

Version number: 6 – A.439
Issue Date: January 2014
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Be Safe Pro10.1F

HAZARD ASSESSMENT CHECK (HAC) FORM

Ausgrid | Be Safe Stop. Think. Do.

HAC	Identify	Assess	Control	Monitor	Re-Assess	Emergency Initial Below

Supervisor: B Thoms. | Date: 14 Jul 16 | Time: 7:36

Site Assessment led by: Workgroup. | Section: WM

Location / Address / Worksite: Broughton Rd Artarmon | **Multi Site 1-9** Yes☐ No☑

In an emergency initial above with site details, make the site safe & complete the HAC ASAP

Talk about the job! Use the grid to sketch a plan view of the worksite.
Everybody involved! Does anything on this site change the way we normally do our work?

Describe the site: (Identify the layout, features & boundaries of the worksite) in writing with a sketch for single site as required.
Kiosk Substation

Describe the Job / Tasks to be completed: (Identify the major steps & who is doing the work)
Install PQ Meter.

Address Details		Multi site ALARP	
1	S4508 Broughton Hampden	(Y)	N
2		Y	N
3		Y	N
4		Y	N
5		Y	N
6		Y	N
7		Y	N
8		Y	N
9		Y	N

SWMS	Summary of SWMS name	Applicable tasks	SWMS	Summary of SWMS name	Applicable tasks
AUS002	Inspection	1-3			
NE18	Load Survey	1-4 15-19 45			

STOP! After a work break, team membership changes, site conditions change or something causes you to change your work processes.
THINK! About current and additional controls and re-assess the job.
DO! If the Pre-Work Discussion highlights safety issues, they must be resolved with your Supervisor before commencing work.

Mandatory Discussion Prompts (Refer to Blue Folder – Be Safe Pro 10.2F and Be Safe Pro 10.5F)

Emergency Contact Numbers ......112...... First Aid Kit Location - Ausgrid Vehicle **Yes** ☑ **Other** ☐ ....
Evacuation Point......Vehicle..........

Job packet information is on site? **Yes** ☑ **N/A** ☐ | Asset / Dial Before You Dig plans on site? **Yes** ☐ **N/A** ☑

Will we affect other people on site or they affect us? **Yes** ☑ **No** ☐ | Additional supervision?Contractor☐Apprentice☐Visitor☐Other☐

If so, what will we do? Stop work talk to them | The responsible person (RP) will be providing this. N/A

Transmission HV Energised ☐ Isolated ☐ AP No...N/A..... | LV Energised ☑ De-energised ☐ De-energised & shorted ☐

Distribution HV Energised ☑ Isolated ☐ AP No.................. | Isolated ☐ Permit No. (if applicable) ....

Job Discussion – Fatal Risk and Key Site Specific Safety Hazards

✓ Uncontrolled discharge or contact with electricity	
✓ Exposure to Hazardous Materials	
Fall from Heights	
✓ Motor Vehicle Accident	
Unintended contact with Mobile Powered Plant	
Struck by falling/moving object	
✓ Incident whilst undertaking lifting operations	
Uncontrolled collapse of excavation work	
Breach of controlled worksite when working near or around traffic	

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Be Safe Pro10.1F

HAZARD ASSESSMENT CHECK (HAC) FORM

Ausgrid | Be Safe Stop. Think. Do.

HAC — **Fatal and or Additional Risk Assessment Table**
Refer to the Blue Folder for Hazard Prompts and HAC Instructions

Identify Hazards (As discussed in the Job Discussion)	Assess Risk	Control	Residual Risk
Traffic	23	Awareness PPE	18
Slips Trips Falls	13	Awareness PPE	9
Electrical	23	Training Awareness PPE	18
Manual Handling	13	Awareness PPE	9

Monitor
On-going monitoring of hazards and controls is required for the duration of the work. Has anything changed?

Re-Assess any new hazards below

Have the risks been reduced to As Low As Reasonably Practicable (ALARP)? No ☐ Yes ☑

If NO do not commence work & contact your supervisor. (For Multi site ALARP see multi site address box)

ALL WORKSITE STAFF

All persons signing on this form declare that they are fit for work and all staff, contractors and public involved with this work activity must discuss the hazards, implement risk controls and sign on to accept this hazard check prior to commencing work. All work conducted will be in accordance with the identified SWMS. If you are an apprentice (A), contractor (C), visitor (V) or other (O) – you must place an identifying initial next to your name

Name	Signature	RP	Time	Name	Signature	RP	Time
C. Gee	[signature]		736				
C. Hilkman	[signature]		736				

HAC reviewed by	Name:	Signature:	Date:

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Issue Date: January 2014
Review Date: December 2014

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Appendix G - PQ Survey Data

Appendix G.1 Apartment Block in Artarmon

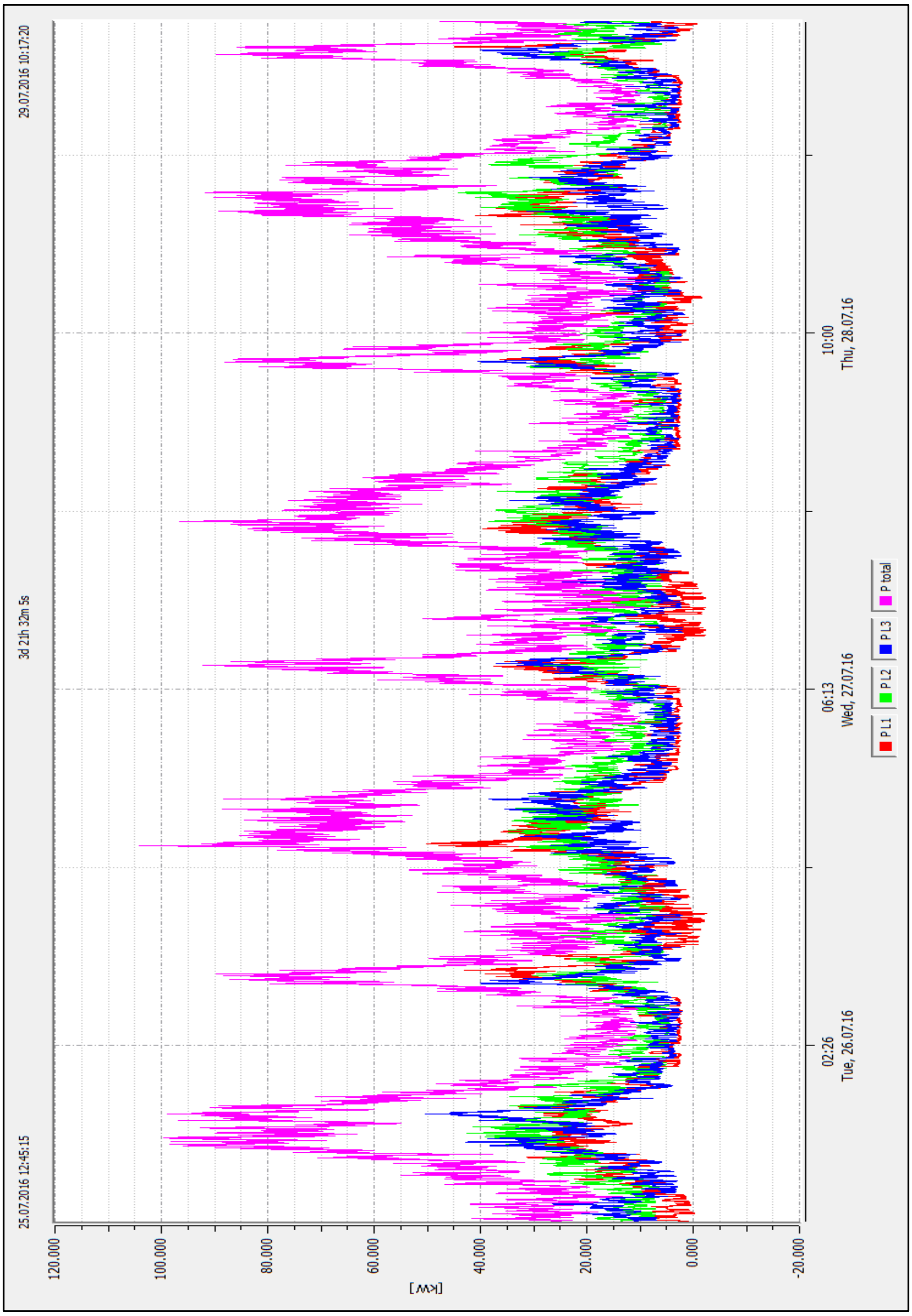

Figure G-1 Real Power Consumption at Artarmon Site

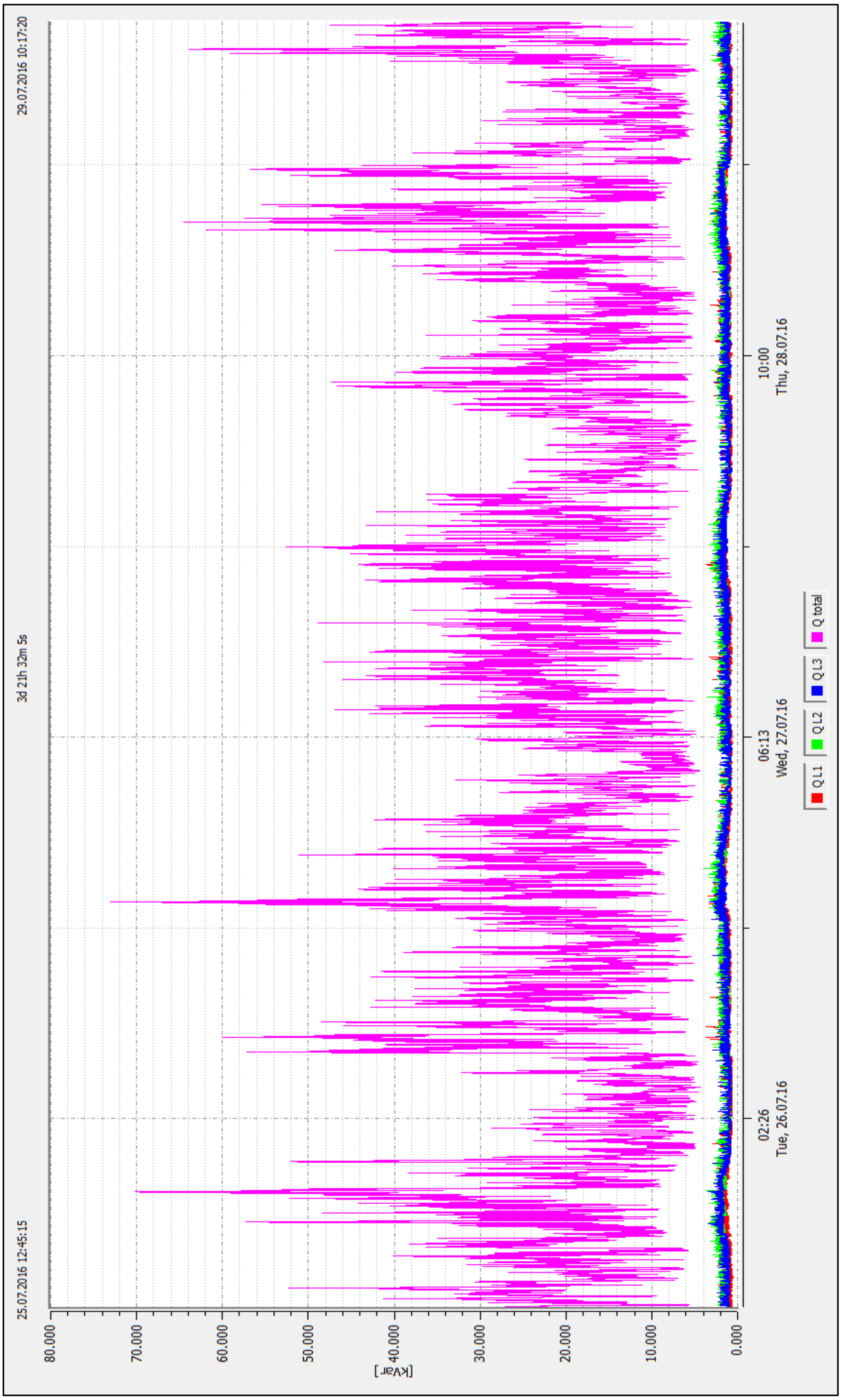

Figure G-2 Reactive Power Consumption at Artarmon Site

Appendix G.2 High-rise in Manly

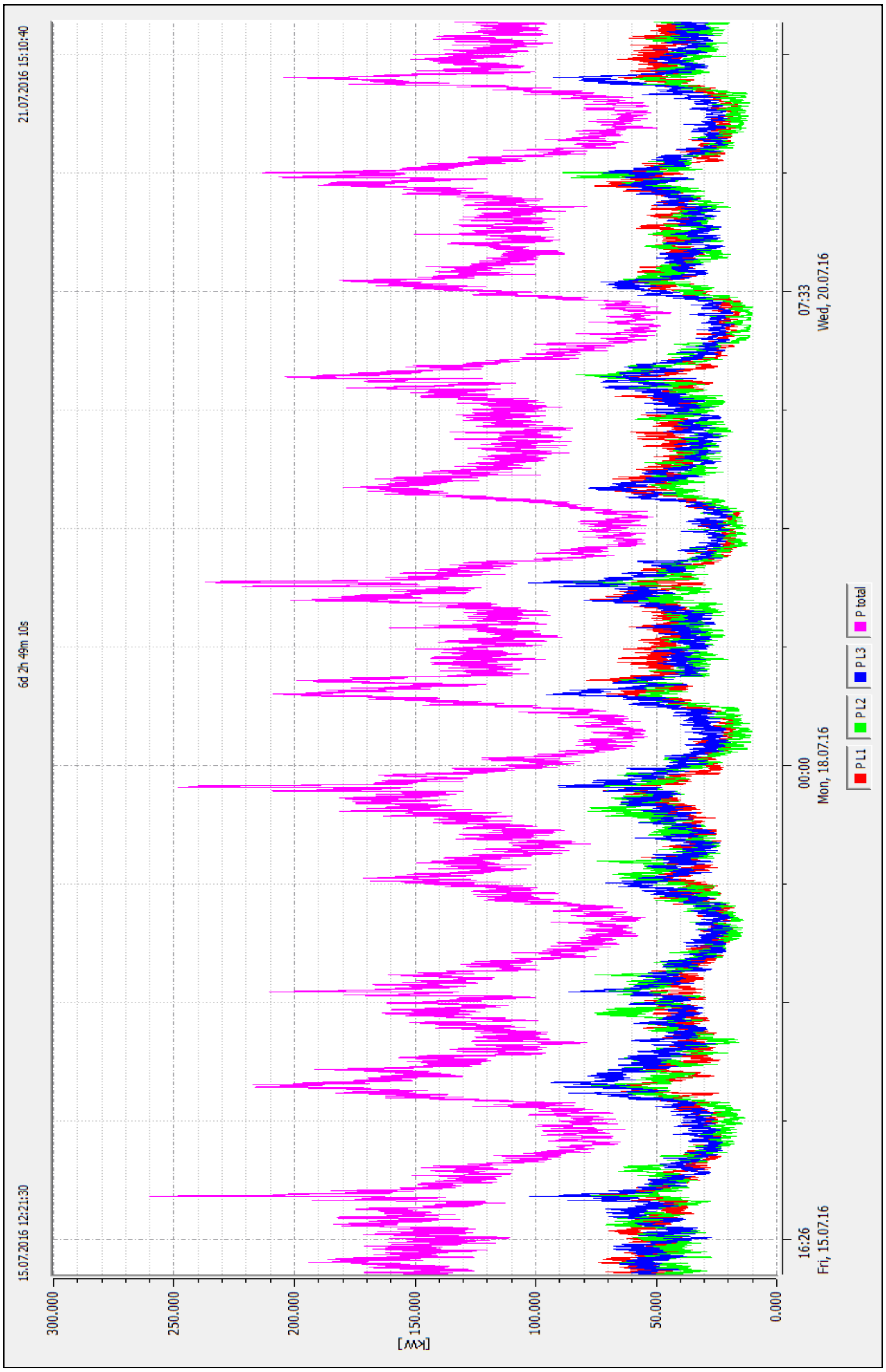

Figure G-3 Real Power Consumption for Manly High-rise

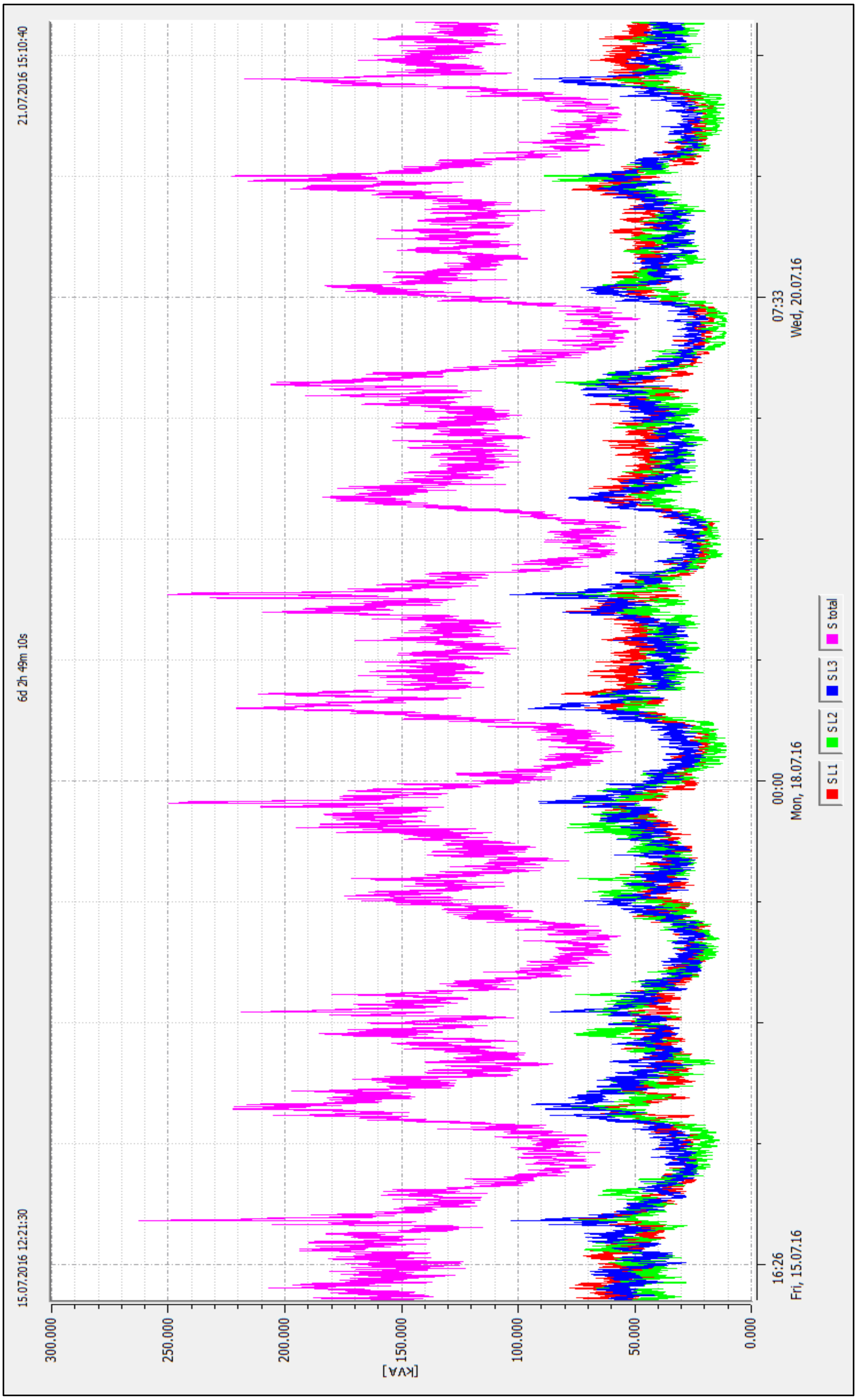

Figure G-4 Reactive Power Consumption for Manly High-rise

Appendix H - Literature Review

Introduction

The literature review for this project will focus on 4 main areas. The initial investigation will focus on Distributed generation, mainly from renewable energies. Secondly, the impact reactive power has on the power factor and supply voltage of individual premises. Thirdly, the use of SMART meters in Australia and what information is capable of being read from a SMART meter in real time. Lastly a comprehensive review of STATCOM's and their ability to supply and absorb reactive power. Conducting this research will provide sound knowledge which will be needed during the laboratory testing early on in the project. The aim of the testing will be to see if the STATCOM is able to vary the amount of reactive power depending on the power factor of the installation which is being read from the SMART meter.

Distributed Generation

The use of renewable energy sources for the generation of electricity is seen as one of the important ways of reducing carbon dioxide emissions(Abu-Sharkh et al. 2006). This distributed generation is also known as embedded generation, the most common form of this embedded generation in Australia is the installation of PV arrays and these tend to be small scale. These systems generate power from the sunlight during the day and lay dormant during the night time, often when domestic load requirements are at their peak.

Benefits of Embedded Generation

The customer who has installed the embedded generation will be the one who sees the most benefit of the embedded generation as would be expected. If they are savvy with their electrical load they can ensure that the majority of the power that they are generating is consumed by necessary electrical equipment in their household during the day, such as a washing machine, dishwasher or scheduling a pool pump for more hours of operating during the day. This ensures that the electricity they use will be from their generation and not supplied form the grid at an extra cost to them.

There are also the Environmental benefits to be gained from local embedded generation. Using the solar energy from the sun produces no carbon emissions as appose to obtaining that energy from the grid which is most likely generating energy from burning coal and producing large amounts of greenhouse gas emissions.

Disadvantages of Embedded Generation

Embedded generation can have adverse effects on the distribution authority's electricity grid, some of these effects include an increase in fault levels, potential reverse power flow problems during blackouts, and increases in steady state voltage levels.

Bhattacharya (Bhattacharya, Saha & Hossain 2013) states that even though the fault current contribution from individual PV systems installed on residences is not high, collective contribution from multiple PV systems connected across the network can make a significant increase in fault current. The electricity network will need to monitor the amount of penetration of embedded generation in local areas to ensure that the increase in fault level is manageable.

Power previously has flowed from the large scale generators through the transmission network, to the distribution network to the end customer. Having a higher penetration of embedded generation is changing this traditional linear flow into a bi directional flow. Also cause for concern is if multiple embedded systems are only connected to one phase from a TX this will create a large unbalanced power flow and will increase return current in the neutral conductors.

Reactive Power

Reactive power and voltage control is one of the ancillary services used to maintain the voltage profile through injecting or absorbing reactive power (Dapu et al. 2005).

Reactive power plays an important role in the voltage control of an electrical system. An electrical system supplies two types of power, real power or true power, which is the actual amount of power being used to do useful work and is measured in watts (W). The other power is reactive power and is measured in Volt-Amps-Reactive (VAR). If the voltage on a system is too low it will not be able to supply active power, thus reactive power is required to provide the voltage levels needed on the system.

Zhao states reactive power is location dependent, and long distance transfer is not wanted (Dapu et al. 2005). For this reason, it is best that the reactive power be produced as close to the load as possible, this will also save on transmission losses associated with the reactive power.

Voltage Control

On an AC system voltage control is managed by absorbing and producing reactive power. Managing reactive power in this way in affect changes the phase shift between the current and the supply voltage, producing reactive power will have a capacitive effect and will cause a leading power factor, whereas absorbing reactive power will have an inductive effect and cause a lagging power factor. Tanaka (Tanaka et al. 2009) states that reactive power control has a possibility to contribute for reduction of distribution loss.

In 2011 the Australian Standards PQ Committee published AS 61000.3.100-2011 (Standards 2011), this defines that the voltage at a premises needs to be within the rage of 230 V +10% or -6%. The further away from a TX a supply is generally means the lower their supply voltage will be. This problem is worsened during periods of high load, which for residential loads tends to be in the early evening.

SMART Meters

Many electricity distributors around Australia have begun the roll out of SMART meters to its residential customers. These smart meters are able to supply far more information than the previously installed disc meters which only gave a reading of how much energy had been used. Capua (De Capua et al. 2014) states that in recent years there has been a significant growth in the diffusion of renewable energy systems. This increase in renewable energies at the local load will call for a substantial change being required from the electricity distributors. They will be required to gradually change from a ‘passive’ network, in which electricity flows only from the place of production to the point of consumption, to an ‘active’ and ‘smart’ network, that is Smart Grid, which is able to manage and regulate electrical flow traveling in a discontinuous and bidirectional way (Molderink et al. 2010).

Communication with the SMART meter is a variety of ways, the three most common ways that have been reviewed by Ali (Ali, Maroof & Hanif 2010) are:

- RS-232 As Local transmission medium
- PLCC Using main power line
- Short Messaging Service on GSM

Ali acknowledges that the PLCC medium is the more efficient and preferable medium of transmission, Power line communication or Power line networking (PLN) which utilises the same wired medium through which power is delivered to the customer as a communication channel (Ali, Maroof & Hanif 2010). Using PLCC as a medium means there would not be any further wiring required for the communication.

STATCOM

STATCOM, as an advanced compensator, consists of a Voltage Source Inverter (VSI) which is connected through shunt TX to the network (Toodeji, Farokhnia & Riahy 2009). They are commonly used and installed onto electricity networks to improve power factor and decrease the effects of poor VR. A DC voltage source is converted into an AC waveform using a STATCOM. Alone the STATCOM has very little active power capability due to the voltage source coming from a DC capacitor, but this can be improved if use in conjunction with a suitable energy storage device such as a battery. Han (Junbiao et al. 2012) has studied and shown that in a weak system with PV generation, STATCOM has an excellent scope for mitigating most of the PQ issues such as harmonics, voltage flicker, and transient voltage.