University of Southern Queensland
Faculty of Health, Engineering & Sciences

Optimised renewable generator schemes to improve the utilisation of network assets while maintaining safe operation of primary plant in accordance with the National Electricity Rules.

A dissertation submitted by

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Abstract

Due to the recent rise in renewable energy penetration on the Queensland distribution and sub-transmission network, Energy Queensland is looking to optimise the utilisation of renewable energy generation. This dissertation focuses on the selection, design and justification of a suitable control system scheme which utilises currently unused capcity generator connected line. The dissertation uses the results from a historic analysis data to justify the design of a control system which enacts a ramp-back scheme allowing renewable generators to export more power whilst remaining in accordance with the National Electricity Rules. Subsequent to the design of the control scheme, a simulation was run to ensure proper implementation of the control logic, a detailed analysis of which can be found in chapter 6.

Keywords: Renewable power generation , Capacity utilisation, Network control, Safe operation, Australian national electricity rules.

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Limitations of Use

Certification of Dissertation

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

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

M. Elsasser

[redacted]

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Chapter 1

Introduction

1.1 Chapter Overview

The purpose of this chapter is to introduce the research area, background, specific objectives and the overall outcome of the dissertation. The background will cover historical problems associated with the topic and will lead to the problem statement, which will shape the rest of the dissertation.

1.2 Background

Renewable energy is a booming industry which has seen rapid growth in recent times. According to the Clean Energy Council (2019) more than 2.3GW of new renewable energy capacity was installed across Australia in 2018 through 38 major renewable projects with a further 1.55 GW of capacity being added through rooftop solar. "250'000 GWh of energy was produced in Australia in 2018 of which 50'000 GWh was produced by renewable generators, which was an increase of 25% from 2017"(Nowa Energia 2019). Figure 1.1 shows the downward trend associated with the cost of solar power generation per watt from 2010 to 2017 in USD.

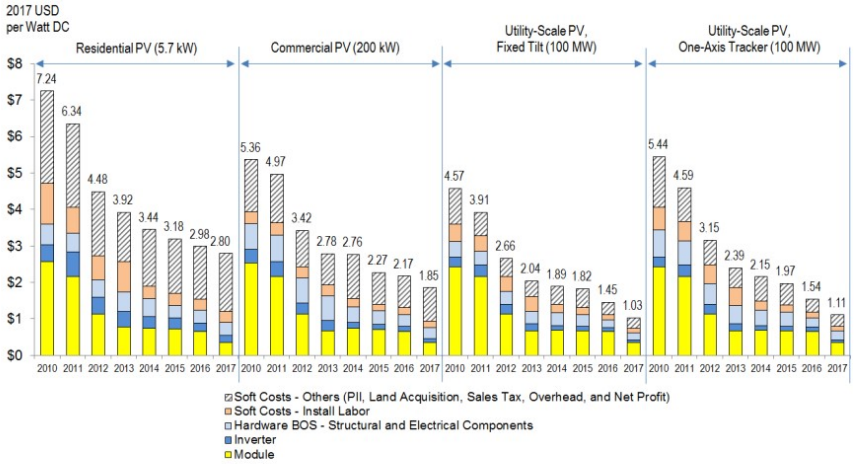


Figure 1.1: NREL PV system cost benchmark summary (inflation adjusted), 2010–2017 (Meehan 2016)

The National Electricity Rules are a set of rules are made by the Australian Energy Market Commision (AEMC) which govern the operation of the national electricity market (NEM). Energy Queensland have Identified two rules from the national electricity rules document which relate to the rating of generator connected lines. The full wording of these two rules can be found in the National Electricty Rules document. The following two statements are a summarised version of the two rules from Energy Queensland's rating parameters and assumptions for large scale renewables document.

- The rating of equipment shall account for S5.2.5.1 Reactive power capability being capable of supplying or absorbing continuously at the connection point an amount of reactive power the product of 0.395 and real active power of the generating system, or a power factor of 0.93.
- the rating of equipment shall account for S5.2.5.4 Generating system response to voltage disturbances where the generator is to be capable of continuous uninterrupted operation at 90% of the normal voltage.

(Caldwell 2018)

These two rules are part of the automatic access standard, which refers to the highest level of technical compliance according to the national electricity rules.

To comply with these rules, transmission lines and other equipment must be rated to account for the additional reactive power and voltage disturbances as voltage and exported power affect the calculations of static line ratings. Generally, the extra line capacity as a result of these factors causes a discrepancy between the rating of equipment for normal and abnormal system events. Under system normal, lines and equipment are therefore underutilised. Research into this area may allow for the use of the entire capacity of transmission lines, leading to an increase of utilisation of currently installed assets..

1.3 Project feasibility analysis and study justification

Many studies have been conducted into power distribution, however, Energy Queensland has identified that there is the potential for a more balanced approach to the utilisation of the transmission system by increasing available capacity under normal system conditions while still complying with the National Electricity Rules. There is a major need for this research as currently, transmission lines have an unused capacity which could allow for more renewable energy to be utilised on Queensland's network without the need for asset upgrades.

1.4 Project Objectives

The main purpose of this dissertation is to propose a management scheme which exploits the full capacity of conductors, enabling renewable generators to safely export more power without incurring further costs. This research will also consider the protection requirements of network assets to ensure thermal limits are maintained as well as the need for dynamic monitoring.

The specific objectives of this dissertation are as follows (the project objectives are also stated in Project Specifications, Appendix A):

1. Research rating methods for generator connected lines and analyse previous management strategies used for mitigation of congestion on lines.
2. Analyse historical data to determine past trends for system normal operating voltage, power factor and current.
3. Evaluate and compare potential management schemes and their suitability based

on the data trends established in (2.).

4. Reccomend a management scheme and determine suitable parameters based on the system response times and protection requirements.

5. Propose logic for the system which will prevent the system from overloading and/or exceeding other parameters.

1.5 Project Scope, Limitations and Restrictions

The following limitations and restrictions apply for the project and dissertation:

- The research will only consider:
    - Non-scheduled generators
    - Generator connected lines which are rated using static ratings
- For confidentiality reasons Energy Queensland assets will be referred to using generic names (‘Substation x’ and ‘Bus A’), and voltage levels and power measurements will be referred to per unit. Chapter 4 will utilise this convention as the data analysed will be historical real-time data from an Energy Queensland substation.

1.6 Overview of the Dissertation

This dissertation is organized as follows:

Chapter 1 introduces the topic of the dissertation.

Chapter 2 presents the reviewed literature necessary to contextualise the dissertation.

Chapter 3 discusses the methods used to complete the dissertation.

Chapter 4 explains the trends and limitaions of presented data.

Chapter 5 presents a suitable control system design.

Chapter 6 presents results from the simulation of the control system proposed in chapter 5.

Chapter 7 concludes the dissertation.

1.7 Chapter Summary

This chapter presents an introduction, background and purpose for the dissertation. Firstly the current generation and market trends associated with renewable power generation were discussed to provide context into the extent of underutilisation of generator connected lines. Recent trends show that renewable energy generation if a massive growth industry which should be fully utilised to minimise the need for fossil-fuel based generation. The need for the project was explained by emphasising the National Electricity Rules and how the phraseology allows for renewable generators to safely export more power in accordance with the rules. The introduction chapter concluded with a statement of the project objectives (which are frequently referred to throughout the dissertation); project scope, applicable limitations and restrictions; and a brief overview of each chapter.

Chapter 2

Literature Review

2.1 Chapter Overview

To better understand the topics associated with the project, a literature review was undertaken. The literature review contains relevant information about the following topics:

- Topics relating to the scope of the project
- The National Electricity Rules
- Reactive power generation and how it relates to voltage regulation
- Topics around the risk factors related to the operation of a generator connected lines at their rated operating current

The primary aim of this dissertation is to produce a method of operating generator connected lines at, or close to, their rated operating current and therefore, the research undertaken in the literature review will be related to this topic.

2.2 Project Scope

2.2.1 Overhead Conductor Ratings

The physical properties of overhead transmission lines have been studied by professionals since their inception. “The line rating represents the line current which corresponds to the maximum allowable conductor temperature for a particular line without clearance infringements or significant loss in conductor tensile strength due to annealing” (Fernandez, Albizu, Bedialauneta, Mazon & Leite 2016). Annealing of the conductor occurs when it overheats, this overheating releases internal stresses, causing a reduction of tensile strength, which can cause the failure of the line (Morgan 1979). Dynamic line ratings are outside the scope of the project, and therefore, only a brief overview of this concept will be provided to allow for a comparison with static ratings and how they differ.

Static Ratings

A static rating of an overhead transmission line determines the maximum current (A) that the line can carry, based on a defined set of parameters. Static ratings are generally based on worst case assumptions and are therefore quite conservative. However, this is done so that the rating can be considered safe during general operation hence reducing the failure rate of the equipment. According to Olmsted (1943), there are 8 factors which create an allowable rating of an overhead conductor. The most important factors to be considered are:

- The ability of the conductor to withstand the operating temperature without excessive loss of mechanical strength by annealing.
- The ability of clamps, connectors, and joints on the conductor to withstand the operating temperature without oxidation of the contact surfaces and local heating in excess of the allowable conductor temperature.
- The adequacy of span clearances to permit the additional sag caused by the conductor temperature associated with the proposed rating.
- The adequacy of substation and terminal equipment to carry the currents for which the transmission conductors may be rated.

- The ability of voltage-regulating equipment to compensate for the voltage variation which accompany heavy load conditions.

Dynamic Ratings

Dynamic ratings of overhead transmission rely on real time data in order to provide feedback on line temperature and current. There are numerous ways in which dynamic ratings can be modelled, designed, and maintained. Dino, Ketley & McDougall (2009) suggests two possible approaches for the design of a dynamic rating system, these two methods are; a temperature/weather based model and Sag Based Model.

A temperature/weather based model which uses temperature parameters to find the instantaneous conductor temperature rise available, and hence, the allowable current that can be transferred. Field data used for this modelling includes the following:

1. Wind speed;
2. Wind direction;
3. Air temperature;
4. Solar heat intensity; and
5. Conductor parameters

(Dino et al. 2009)

In a sag-based model, however, the line rating is determined by direct measurement of the conductor's state. This model uses the proportional relationship between conductor sag and conductor temperature. The actual conductor temperature can be calculated using a predetermined relationship between conductor position/tension and temperature. The heat balance equation is used to determine the additional current that can be transferred before the conductor's maximum operating temperature is achieved

Field data Required for this model includes:

1. Conductor position and/or tension;

2. Air temperature;
3. Wind speed;
4. Wind direction;
5. Solar heat intensity;
6. Line current;
7. Conductor material parameters;

Whist this method still uses indirect parameters to calculate the rating of the line, the method is considered more direct as it also has the added benefit of providing an alarm if the conductor sag exceeds or tension falls below a predetermined point that represents a violation of the required statutory ground clearance. (Dino et al. 2009)

As the time restriction on the dissertation was too great, dynamic line ratings are outside the scope of this dissertation.

2.2.2 Types of Generators

The Australian Energy Market Operator (AEMO) separates generators into three catagories:

1. Scheduled Generators;
2. Semi-Scheduled Generators;
3. and Non-Scheduled Generators;

Scheduled Generation

According to Australian Energy Market Operator (2008), scheduled generators are defined as “A generator with an aggregate nameplate capacity of 30 MW or more is usually classified as scheduled if it has the appropriate equipment to participate in the central dispatch process managed by AEMO.” Scheduled Generators are generally large scale Generators with the capability of continuously meeting specific output demands. Because of the high demand required by scheduled generators, AEMO must approve all changes in generation output. Scheduled generation is considered to be outside the scope of this dissertation as the timing of the authorisation process cannot be calculated and accounted for within any control scheme.

Semi-Scheduled Generation

Semi-scheduled generators are defined as “A generating system with intermittent output (such as a wind or solar farm), and an aggregate nameplate capacity of 30 MW or more is usually classified as a semi-scheduled unless AEMO approves its classification as a scheduled or non-scheduled generating unit. AEMO can limit a semi-scheduled generator’s output in response to network constraints, but at other times the generator can supply up to its maximum registered capacity” (Australian Energy Market Operator 2008). As semi-scheduled generators participate in the central dispach process some changes in generation must be approved by AEMO and therefore is outside the scope of the project.

Non-Scheduled Generation

According to Australian Energy Market Operator (2008), “A generator will normally be classified as non-scheduled if:

- Its primary purpose is for local use and the aggregate sent out generation rarely if ever, exceeds 30 MW; or
- Its physical and technical attributes make it impracticable for it to participate in central dispatch.

Non-scheduled generators do not participate in the central dispatch process, but AEMO can specify additional conditions with which they must comply, usually for power system security reasons”. As non-scheduled generators do not participate in the central dispatch process, authorisation is not needed for changes in a generation output; therefore, will be permitted in the scope of the project.

2.3 National Energy Rules

The National Electricity Rules are made by the Australian Energy Market Commission (AEMC) and are "designed to promote efficient investment in, and efficient operation and use of, energy services for the long-term interests of consumers with respect to price, quality, safety, reliability, and security of supply" (NER 2018). The two main rules that this project is concerned with are restated below:

- The rating of equipment shall account for S5.2.5.1 Reactive power capability being capable of supplying or absorbing continuously at the connection point an amount of reactive power the product of 0.395 and real active power of the generating system, or a power factor of 0.93.
- the rating of equipment shall account for S5.2.5.4 Generating system response to voltage disturbances where the generator is to be capable of continuous uninterrupted operation at 90% of the normal voltage.

(Caldwell 2018)

When these two rules are applied to a transmission line it creates a gap of unusable current as the lower voltage level and power factor lead to a much higher rated current than normal operating current. An example of this can be seen below:

The line current expected on a 33kV feeder connected to a 30MW generator would therefore be:

$$\begin{aligned}\text{Rated Current} &= \frac{\text{Generator Rated Power}}{0.93 \times 0.9 \times \text{System Rated Voltage} \times \sqrt{3}} \\ &= \frac{30\text{MW}}{0.93 \times 0.9 \times 33\text{kV} \times \sqrt{3}} = 627 \text{ Amps} \qquad (2.1)\end{aligned}$$

$$\begin{aligned}\text{Normal Operating Current} &= \frac{\text{Generator Rated Power}}{\text{System Rated Voltage} \times \sqrt{3}} \\ &= \frac{30\text{MW}}{33\text{kV} \times \sqrt{3}} = 526 \text{ Amps} \qquad (2.2)\end{aligned}$$

From this example it can be seen that a gap of 101 amps exists between the normal operating current and the rated current. The following diagram visually represents this gap.

Figure 2.1: Theoretical underutilisation of generator connected line capacity

2.4 Reactive power Generation

Reactive power generation is a critical function of large-scale generators as it performs many functions for an electrical network. Voltage rise due to photovoltaic generation within distribution networks is currently a key factor limiting deployment of distributed renewable energy systems (Collins & Ward 2015). Reactive power generation is a method of voltage regulation and is hence an important part of any renewable generator.

According to Joules law, active power generation is proportional to the square of system voltage:

$$P = V^2/R \tag{2.3}$$

where P is active power, V is system Voltage and R is the real component of system impedance

Because generators are able to export active power independently of the system load demands the system voltage is forced high to ensure power is dissipated. However, active power is also proportional to the cosine of the power factor angle:

$$P = V^2/Z * cos(\theta) \tag{2.4}$$

where P is generated active power, V is system Voltage and , Z is the system impedance and θ is the power factor angle.

Assuming that load impedance is kept constant, this proportionality and the independence of generator export to load impedance means that an increase in reactive power export would result in a system voltage drop. This supports the findings of Kigen & Odero (2012) who found that reactive power control could be used to optimise voltage profiles and reduce active power losses in a system.

Renewable generators are now performing the tasks of old reactive power technology by producing and consuming VAR's to regulate bus voltage (Turitsyn, Sulc, Backhaus & Chertkov 2011); however, it must be designed to work with existing technology. AEMC state in clause S5.2.5.4 that a generator must demonstrate that the Generating System continueously operates when the system voltage fluctuates between 90-110% of normal voltage at the connection point (NER 2018). Therefore, a generator must also be able to provide voltage control if a disturbance causes the voltage to fluctuate between 90-110%. During times of high load, there is a voltage drop in the network due to the increased active power generation in the system. As the system 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 collapse.

2.5 Risks of Full Capacity Operation

According to the Ratings Parameters and Assumptions for Large Renewable Connections document published by Energy Queensland, "Ramp back schemes and ramp rates for overhead lines are to limit line temperatures to 100°C following activation of a scheme"

(Caldwell 2018). this mean taht any implimented control measure must be able to limit the line temperatures to 100°C.

Two major risks can be identified when allowing generator connected lines to operate at, or near, the rated operating current of the line; approaching the mechanical limits of the line may lead to a higher rate of deterioration, which results in the line losing it's capability of continuously exporting power according to the national electricity rules. The first risk can be negated by ensuring that the rated current of the line is not exceeded for long periods as proper maintenance of lines will negate any risk of over deterioration. This factor must be accounted for choosing the system to utilise the operation of the line. The second risk closely relates to the first as the occurrence of 'worst case conditions' (90% line voltage and a power factor of 0.93) would require the generator to continueously export above the capacity of the generator connected line. Therefore, any implemented system would have to be able to decrease generation if the bus voltage drops or if the power factor varies from unity. Current methods of congested line mitigation include:

- Rescheduling of Generators
- Demand Side Management (DSM)
- Ramp-Back Systems

2.5.1 Rescheduling of Generators

One of the major methods of decongestion is Generator rescheduling. "A method of energy management is presented to remove congestion on transmission lines by rescheduling generators with the objective of minimizing energy rescheduling cost on day-ahead and hour-ahead basis" (Nesamalar, Venkatesh & Raja 2016). Generator rescheduling works by rescheduling the amount of active and reactive power output by a generator to change the active load which is supplied by said generator. This usually mean power must then be supplied by another generator, generally on a different node, meaning less power is directed through the congested line. Generators are usually chosen for rescheduling based on their sensitivity to the line (Nesamalar et al. 2016). A graphical representation of generator rescheduling can be seen below.

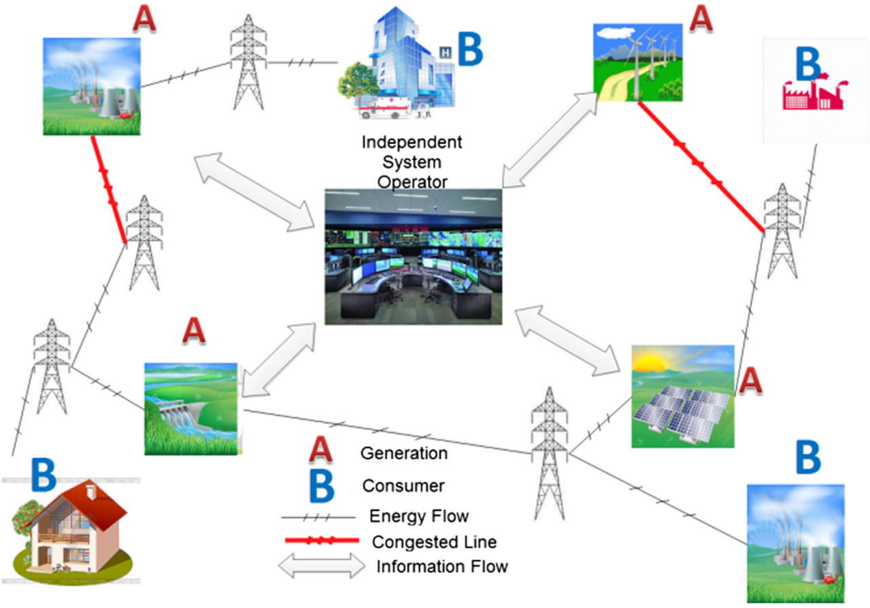


Figure 2.2: Generator rescheduling in this example may be achived by reducing power output by generators connected to congested lines and increasing generation on the other generators. (Nesamalar et al. 2016)

2.5.2 Demand Side Management (DSM)

DSM refers to initiatives and technologies that encourage consumers to optimise their energy use (Energy Market Authority of Singapore 2018). “Demand side management has two aspects: develop efficient utilization for electricity (less electricity for each utilization), and take measures to encourage the customer to help flattening the load curve” (Boivin 1995). The best example of this is the tariff system used by most electricity providers which encourages customers to use energy outside of peak times.

2.5.3 Ramp-Back Schemes

Ramp-back schemes are being used by Energy Queensland to maintain a safe system under all network conditions. These schemes use real time information such as circuit breaker status and feeder loading to prevent overloading of lines and other network assets. Ramp-back schemes are capable of automated regulation of generator power output. In the context of this project, ramp back schemes will be investigated for their effectiveness to manage abnormal system events, increase utilisation during system normal while complying with the provisions of the National Electricity Rules. The major downfall to a system like this is that is adds extra strain to other generators as the power output from the generator in question must be reduced in order to maintain balance with the system.

2.6 Control Systems

In respect to this dissertation, control systems have two major aspects which change the overall operation of the system. The first is the control strategy which controls how the hardware or software operates the control system and how well the process parameters are controlled. The second aspect to be consisered is the type of control system is dependant on the functionality and complexity of the control action.

2.6.1 Control Strategies

ON – OFF control

On – Off (O/I) control systems are the most basic strategy of control. In an O/I control system the input signal is compared against a pre-set threshold and dependant of the amplitude of the signal compared to the threshold the output signal is set to on or off (EdgeFX 2019). An example of this type of control system is a transformer cooling system where a specified temperature is set and when the ambient temperature inside the transformer is higher than the threshold, the cooling system activates to 100% until the temperature falls below the threshold again at which point the cooling system deactivates. The following figure diagrammatically represents an O/I control system with a varied input signal (Process Variable).

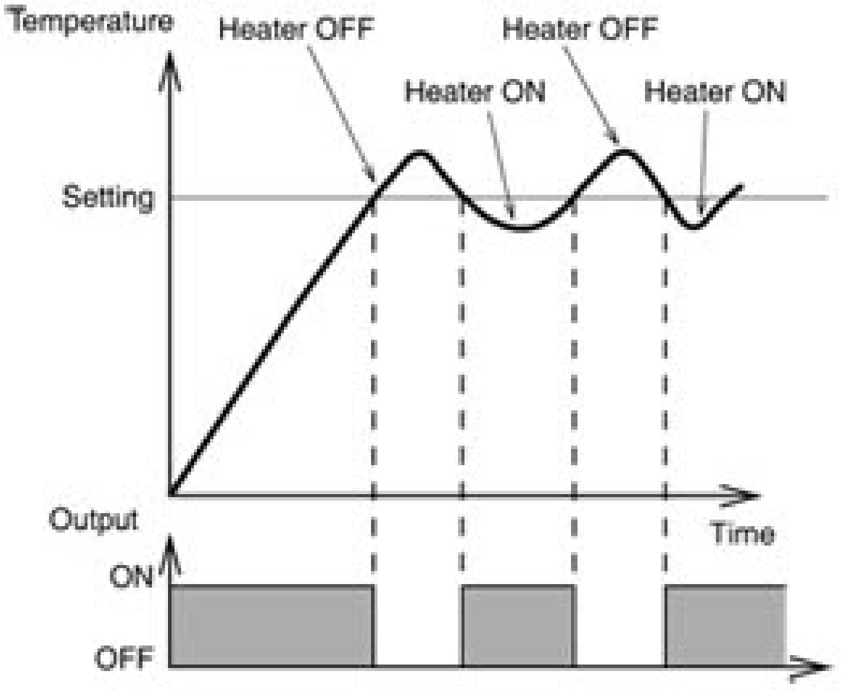


Figure 2.3: Input and output signals of a O/I control system.(EdgeFX 2019)

Open Loop Control

An open loop control system, also referred to as a non-feedback system, is a system in which the output has effect on the input to the system (Instrumentation Tools 2019). The open loop system is widely used as it will continuously follow the input command regardless of the output signal. Open loop systems independently calculate the output signal based of all of the input signals and therefore can have many different levels of output unlike the O/I control system. An example of the open loop system is an electric hand drier which takes an input from the hand sensor and activates the drier for as long as the sensor detects your hands, irrespective of the output of the system. The figure below represents the block diagram for an open loop system.

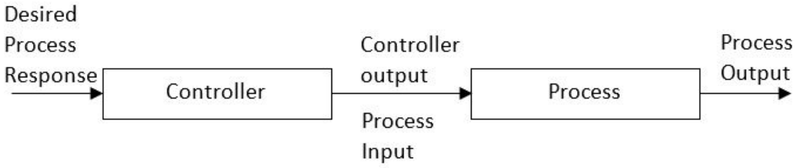


Figure 2.4: Block diagram for an open loop system.

Feed Forward Control

Feed forward control is a control system which is designed to minimise the effect of disturbance on the process. This system works by reading a sensor which detects disturbances or load changes in the process, and the controller calculates any changes that need to be made to the actuator to correct the process (EdgeFX 2019). This means that the controller can correct any disturbance before it can affect the process. An example of the feed forward control system might be a cars cruise control system adjusting a cars speed as it's approaching a hill by measuring the steepness of the hill. A feedback system however would have to wait for the car to slow down before adjusting the cars speed.

Closed loop Control

The closed loop Control System is a feedback-based system where the output signal of the process affects the input signal which creates a feedback loop in the control system (Instrumentation Tools 2019). This system is one of the most widely uses as in can be used to accurately control the system output. The system works by comparing the output signal with a desired or set-point value and adjusting the actuator to minimise the error between the values (EdgeFX 2019). An example of a closed loop system as a thermostat system which adjust the ambient temperature to a desired value and heats or cool the space to keep the ambient temperature as close to the desired value as possible. The following figure represents the block diagram of a closed loop system.

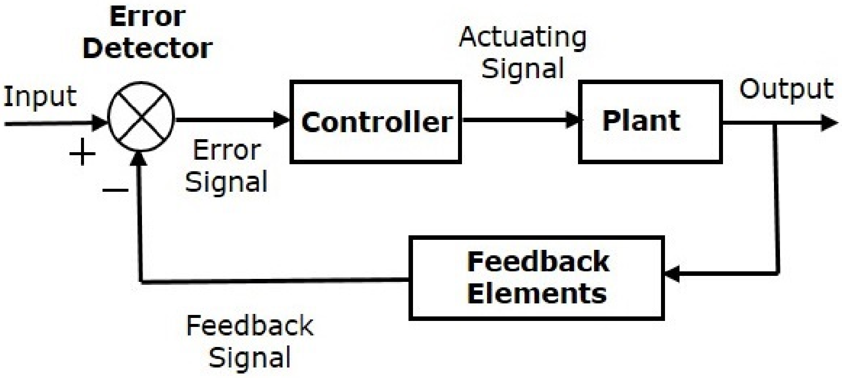


Figure 2.5: Block diagram for a closed loop system (EdgeFX 2019).

2.6.2 Types of control systems

Programmable logic Controllers (PLCs)

Programmable logic Controllers (PLCs) are modular, solid state computers which are programmed for the execution of a specific process or task (EdgeFX 2019). PLCs are useful in control systems as they can be programmed to perform calculations based on a set of input and output a manipulation variable which can be used to alter any attached plant and assets (EdgeFX 2019). A major benefit of PLCs is that they can continuously monitor the inputs meaning that and major changes are guaranteed to picked up by the device, unlike a device which uses sampled data. PLCs are also capable of receiving and transmitting both digital and analogue signals which could be useful for the proposed control system as this will allow for flexible communication methods to and from the generators. Single PLCs are suited to small scale control systems; however, PLCs can be used in conjunction with other control systems for larger scale systems.

Distributed Control Systems (DCSs)

A Distributed Control Systems (DCSs) is a specially designed, automated control system that consists of geographically distributed control elements scattered throughout the plant and/or control area (EdgeFX 2019). DCSs are process orientated systems where data acquisition and control modules are usually located in a confines area separate to other modules. DCSs differ from other control systems as there is no single controller which receives inputs and transmits outputs, but rather each control element maintains control of all the devices connected to it and data is generally shared over a high-speed communications network or bus for use with other control elements (Electrical Technology 2018). DCSs are best suited to large scale manufacturing of processing plants where a large number of control loops need to be controlled and maintained for efficient operation.

Supervisory control and Data Acquisition (SCADA)

A Supervisory Control and Data Acquisition (SCADA) system is a process automation system which collects data from instruments for processing at a central location for monitoring and control purposes (EdgeFX 2019). Based on the sampled data sent from the various sources (sensors, measurement instruments, etc), automated processes and commands can be sent to instruments to control appropriate field devices. SCADA systems usually work by collecting data from and transferring the data to a remote terminal unit (RTU). Multiple remote terminal units can be used on and SCADA system and once data is collected, RTUs transfer data to a communication terminal unit (CTU) or a master terminal unit (MTU) (EdgeFX 2019). The master terminal unit allows for communication with multiple RTUs and passes data to the human-machine interface (HMI). Data for SCADA systems can be collected through both hardware and software and can be easily stored for historical data analysis. SCADA systems also allow for manual interaction through an HMI which allows for manual control over field elements for testing and maintenance purposes.

The following figure shows a common layout of a SCADA system.

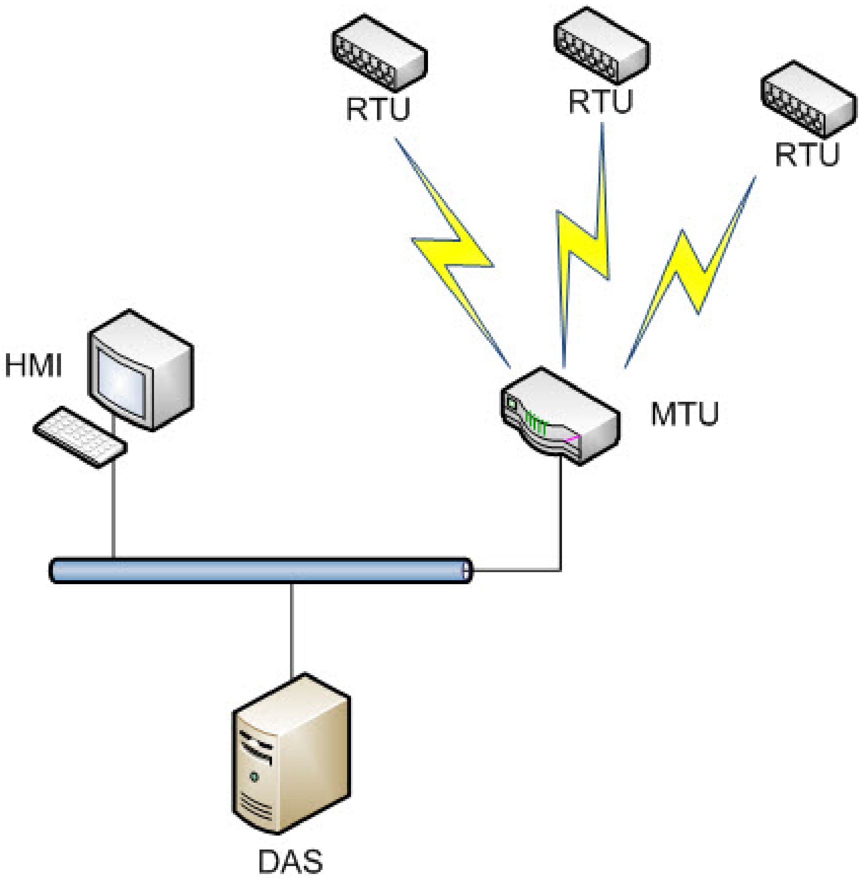


Figure 2.6: Typical layout for a SCADA system (EdgeFX 2019)

2.7 Knowledge Gap

The knowledge gap that was identified in the literature review is that no processes allow for continuous operation of a line higher than the standard operating current but lower than the rated current of the line. The electricity industry is going through rapid change and both the renewable sector and network businesses such as Energy Queensland are responding to these changes. In many cases, legislation, guidelines and standards are still developing however.

Extensive research revealed that while sources suggest that strategies to mitigate the risk factors associated this knowledge gap exist, no research was able to be found concerning the generation of renewable energy between system normal and the limits of the National Electricity Rules. The reviewed literature failed to return many aspects of this topic including: The probability of conditions meeting the upper limits of the National Electricity Rules or the implications of using the total capacity under system normal.

The following statement outlines the overbearing topic which this dissertation will discuss; Is it possible to use the maximum (or near maximum) capacity of a transmission line safely while still following the National Electricity Rules and what place do ramp back schemes play in increasing capacity?

2.8 Chapter Summary

It is intended that this chapter present the relevant information obtained from a diverse range of sources to establish the single resource location which can be referred to as required. The completion of the literature review has facilitation in the completion of objective (1) from the project specification (Appendix A). Achievement of this objective assisted in justification of the project scope, outlined in chapter 1. The major research topics for the literature review were: topics concerning the project scope (Conductor line ratings and types of generators according to AEMO); the national electricity rules; reactive power generation; risks of full capacity operation; and control systems. Additionally, the information contained within this chapter was essential for the completion of the remaining objectives. For these reasons, the literature review forms a critical foundation for the entire dissertation.

Chapter 3

Methodology

3.1 Chapter Overview

Methodology refers to the process which outlines any principles and philosophies undertaken to achieve the objectives of the project outlined in chapter 1 and appendix A. The aim of this chapter is to define and explain the methods used to contextualise and provide detail on the contents of the dissertation.

The specific tasks which outline the dissertation are:

- Research
- Line Capacity Analysis
- Control System Selection, Design and Justification
- Quantification of Results

The following sections will briefly discuss the methods used to achieve each of these tasks. A more in-depth analysis of the methods used each of these tasks can be found the corresponding chapters.

3.2 Research

The purpose of the literature review was to extract information pertaining to the assumptions around the selection and design of and power control method. The information can be found in chapter 2 of the dissertation entitled Literature Review. To summarize, the research was conducted for two major reasons; to gain a better understanding of the problem so as to better define the scope of the project; and to pursue the possibility of implementing some scheme or technology to allow generators to utilize the full capacity of the generator connection lines.

To gain a better appreciation of the literature, the following topics were explored:

- How generator connected lines are rated;
- The national electricity rules that apply to the problem;
- Different methods of overcurrent mitigation;
- Different types of generators (scheduled vs. non-scheduled);
- How reactive power generation affects the capacity of lines;

In general, the review of the literature was successful as it has provided a comprehensive understanding of the overbearing topics associated with the completion of the project.

3.3 Line Capacity analysis

Energy Queensland Have collected data which pertains to the analysis for the generator collected lines. This data is obtained through stored data from Energy Queensland's SCADA system, which constantly monitors load data for substations buses. This data is available to a resolution of 1 second intervals. The data that was supplied was bus voltage, active and reactive power on the bus as well as the generator's control status of the bus for a split bus system within an un-named substation. With this information a line capacity analysis was undertaken to analyse the extent to which generator connected lines were being underutilised. The analysis was conducted using MATLAB and revealed that the was significant underutilisation of the capacity of generator connected lines. The MATLAB code used in this analysis can be found in appendix B.

3.4 Control System Selection, Design and Justification

Subsequent to line capacity analysis the control system selection, design and justification was undertaken. This stage explores the best option to allow for the full utilisation of the capacity of the line. This exploration will involve the selection of a specific scheme or technology, the design of any parameters or code involved in the implementation of the process and a justification as to why the choice best suits the conditions currently in place.

3.5 Quantification of Results

Asset management is important when allowing a process to push the limits of a conductor. The concept of implementing a control system which allowed for full utilisation of assets may be theoretically easy to implement, however, there are many complications which may occur which may hinder the implementation. This stage will aim to ensure that the designed control system operates properly without any unexpected faults.

3.6 Chapter Summary

This chapter has described the processes, techniques and methods employed to successfully complete the objectives of the project. This enabled division of the project into the broad tasks of: research, line capacity analysis; control system selection; design and justification; and quantification of results. Table 3.1 lists each broad task, the chapter/s in which full details are provided and the corresponding project objectives.

Table 3.1: Linkages between the project methodology, dissertation chapters and objectives.

Task	**Relevant Chapter**	**Relevant Objective**
Research	2. Literature Review	(1)
Line Capacity Analysis	4. Data Analysis	(2)
Control System Selection, Design and Justification	5. Control System Design	(3), (4), (5)
Quantification of Results	6. Control System Simulation	(6)

Chapter 4

Data Analysis

4.1 Chapter Overview

To gain an understanding of how the assets are underutilised, and the behaviour of bus variables, historical data was analysed. Energy Queensland's SCADA system supplied the historical real-time data for Bus A and Bus B within Substation X. The dataset consisted of bus voltage, active and reactive components of bus power, and an indicator of whether the connected generator was in control of the bus. The dataset was analysed using MATLAB, and the data was modelled to produce values for the following questions:

- To what extent does bus voltage fluctuate? (annually/daily)
- To what extent does bus power factor fluctuate? (annually/daily)
- To what extent are assets underutilised? (annually/daily)

The following chapter will summarise the findings of the conducted data analysis.

4.2 Real Time Substation Load Data

The data used in this chapter was supplied by Energy Queensland for analysis. The data was pulled from recorded data from Energy Queensland SCADA system and contains the reading from measurement devices from both bus A and B of substation X. Substation

X is a zone substation which connects a solar farm (renewable generator) to both the distribution and sub-transmission networks. The substation is set up in a split bus configuration with a normally open bus tie breaker separating the two buses (A and B). The following figure shows a standard split bus configuration.

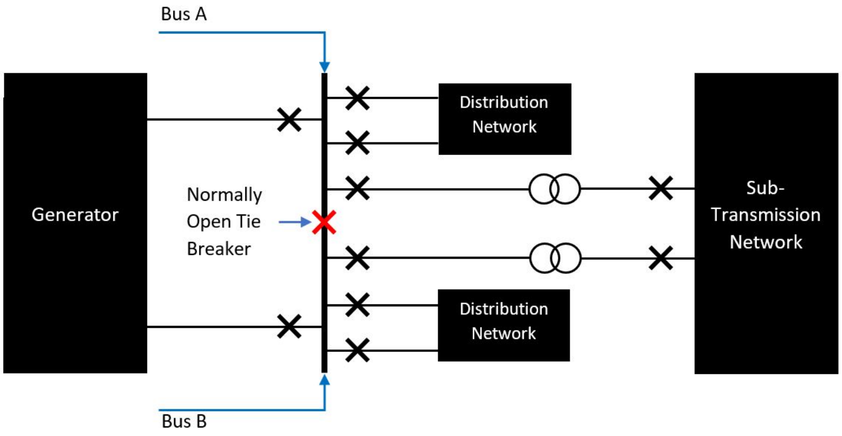
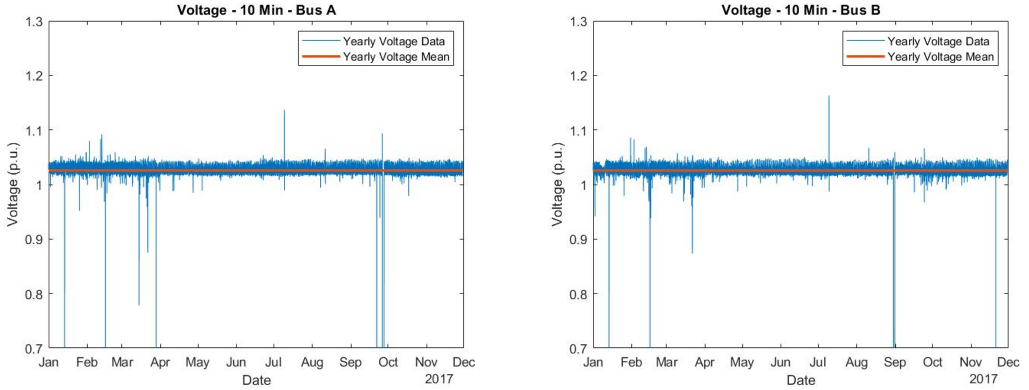


Figure 4.1: Diagramatic representation of a typical split bus substation

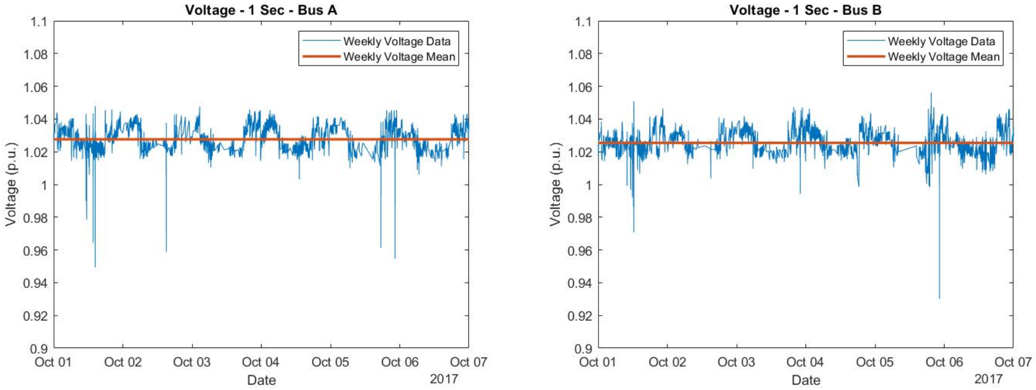
The substation is connected to the generator by 2 radial feeders which are 3-5 Km long. The measurements used in the dataset were taken from on the 2 buses. Two datasets were supplied for use in this dissertation. The first dataset contains data in ten-minute intervals over a year. This data was supplied to identify long term trends in the data while the second set of data contains data in one second intervals over the period of a week. The second dataset was supplied to better understand the general daily activity of the generator.

4.2.1 Voltage Fluctuation Analysis

The data was first analysed to find the bus voltage patterns and fluctuations. The following graphs were obtained by plotting the bus voltage against time:



(a) Yearly Bus Voltage on Bus A (b) Yearly Bus Voltage on Bus B



(c) Weekly Bus Voltage on Bus A (d) Weekly Bus Voltage on Bus B

Figure 4.2: Voltage plots for Energy Queensland supplied data

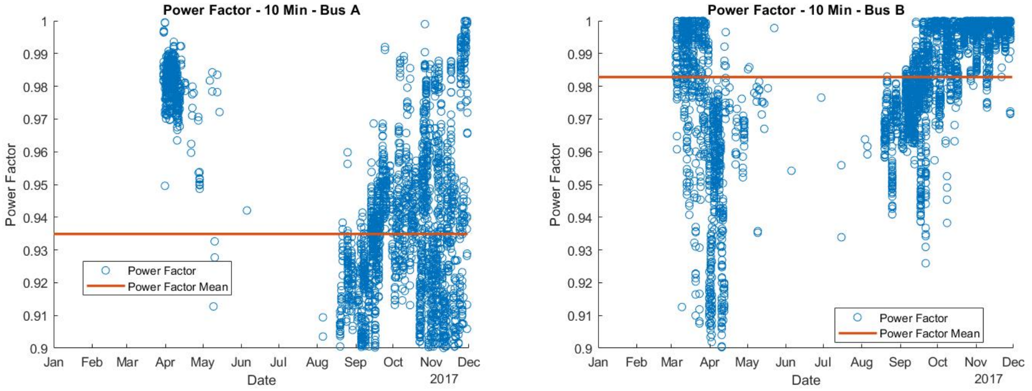
From these plots, it can be seen that the voltage tends to fluctuate above the expected one p.u. voltage, between 1.01p.u. and 1.05 p.u. Volts. It can also be seen that operation below 90% of the rated line voltage is exceedingly rare and generally occurs during major faults which cause tripping of circuit breakers which eliminates any voltage on the line. The weekly data reveals that noticeable drops in voltage can be recorded; however, these drops are compensated for incredibly quickly by using reactive power support. These sudden drops can occur for several reasons such as sudden drops in wind speed for wind farms and cloud cover for solar farms. However, the voltage level drops rarely get to the 90 per cent threshold.

Voltage Fluctuation Analysis using Confidence Intervals

Due to the large sample size used in the yearly data analysis, a 95% confidence interval shows that the true mean of the yearly bus voltage lies between 1.02563572 - 1.02563577 per unit for the voltage on Bus A and between 1.02551905 - 1.02551910 per unit for the voltage on Bus B. Therefore, we can assume a yearly true mean voltage of 1.026 per unit for both Bus A and Bus B. The weekly data uses a larger sample size and therefore the a similar level of accuracy is maintained and a weekly true mean of 1.027 per unit and 1.025 per unit can be assumed for Bus A and Bus B respectively.

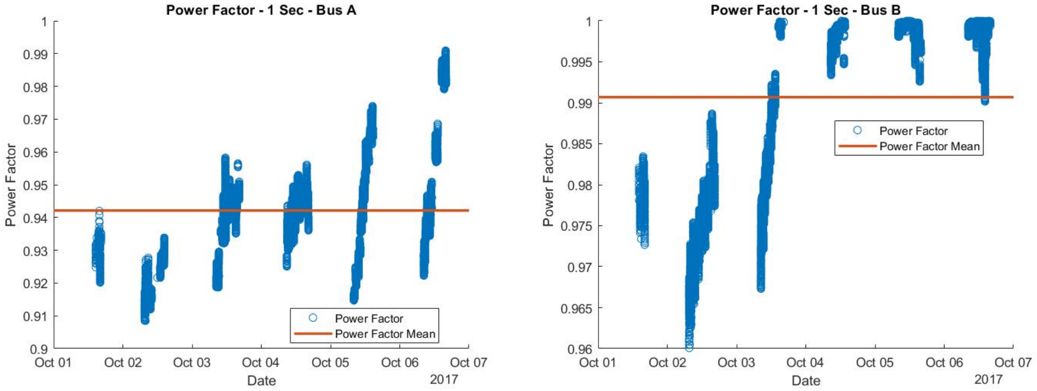
4.2.2 Power Factor Fluctuation Analysis

The second aspect of the data to be analysed was the power factor of the power supplied by the connected generator. The following plots demonstrate the power factor of generated power when active power supplied exceded 95% of the rated power output. The plots only show these values as power factor regulation only need to occur when maximum power generation is met.



(a) Yearly Power Factor when active power is above threshold on Bus A

(b) Yearly Power Factor when active power generated is above threshold on Bus B



(c) Weekly Power Factor when active power is above threshold on Bus A

(d) Weekly Power Factor when active power is above threshold on Bus B

Figure 4.3: Power Factor plots for Energy Queensland supplied data

The data shows that the power factor on the split bus system is inconsistent and is frequently measured below the automatic access standard safe threshold of 0.93. As the provided data is purely data from the generator connected bus, these inconsistencies are possibly a result of factors external to the connected generator. The control system designed in chapter 5 of this dissertation will monitor the generator connected line, and this will not be affected by the same external factors.

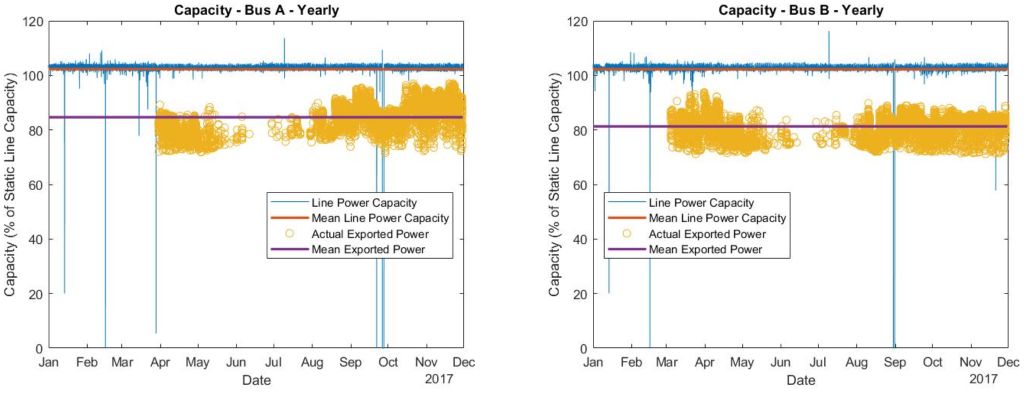
Analysis of power factor on each of the buses highlights the need for better power factor monitoring with any new control system. Warning signals will need to be implemented if the power factor drops below the automatic access standard and control of the bus will need to be relinquished until the power factor of the generator can be corrected.

Power Factor Fluctuation Analysis using Confidence Intervals

Due to the large sample size used in the yearly data analysis, a 95% confidence interval shows that the true mean of the yearly Power factor is accurate to 6 significant figures across both busses. Therefore, we can assume an annual true mean power factor of 0.935 and 0.976 for the data pertaining to Bus A and Bus B respectively. Analysing the weekly data, it can be found that the measurements obtained on Bus A give a confidence interval which is accurate to 6 significant figures while the data from Bus B gives a confidence interval which is accurate to 8 significant figures. From these confidence intervals we can assume a true weekly mean of 0.937 for Bus A and 0.99 for Bus B. The assumed true mean values show the power factor on Bus A is generally lower than that of Bus B, further highlighting the need for power factor monitoring within the control system to ensure that the automatic access standard is appropriately adhered to.

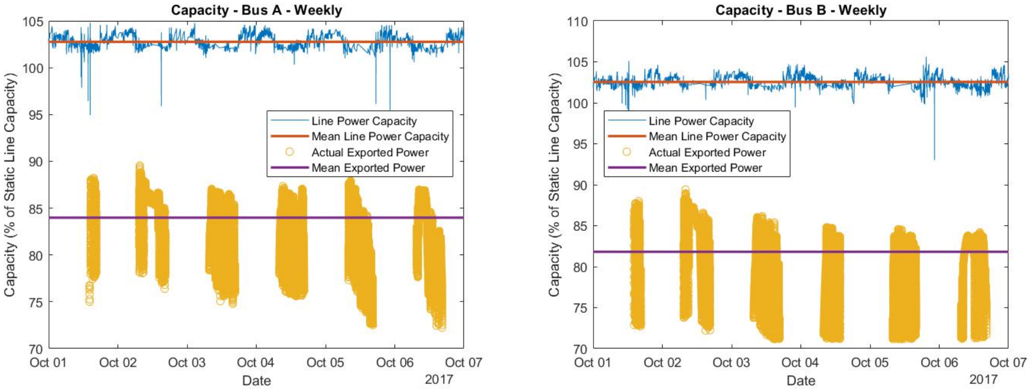
4.3 Available Capacity In The Network

The datasets were next analysed to determine the magnitude to which assets are currently underutilised. The following plots show the power capacity available on the line vs the actual power exported by the generator when the active power generated exceeds 95% of the rated power output.



(a) Yearly capacity Plots on Bus A

(b) Yearly capacity Plots on Bus B



(c) Weekly capacity Plots on Bus A

(d) Weekly capacity Plots on Bus B

Figure 4.4: Capacity plots for Energy Queensland supplied data

From these plots, the following observations can be made. The line connected to Bus A is underutilised by 13.96% to 16.99% depending on which dataset is analysed. The line connected to Bus B is underutilised by 17.86% to 18.51%.

4.4 Chapter Summary

This chapter has presented the findings of a data analysis undertaken on historical substation data provided by Energy Queensland. The data analysis answered the following questions:

- To what extent does bus voltage fluctuate? (annually/daily)
- To what extent does bus power factor fluctuate? (annually/daily)
- To what extent are assets underutilised? (annually/daily)

The outcome of this chapter was to provide insight into the scope of underutilisation on generator connected lines. Based on the provided data it was found that the analysed substation had generator connected lines which were underutilised by 13.96% to 18.51%. The completion of this chapter assisted in the achievement of objective (2) from the project specification (Appendix A). This data assisted in the design of the control system outlined in the following chapter (Chapter 5).

Chapter 5

Control System Design

5.1 Chapter Overview

The purpose of this chapter is to present a viable control system which aims to fully utilise generator connected lines while maintaining compliance with the national electricity rules. The designed system will be based off a case study which uses a specific generator and generator connected conductor to allow accurate timing and thermal values to be obtained. The chapter will delve into general functions of the control system as well as, a voltage support overview and the parameters surrounding the ramp down scheme which was chosen for use within this control system.

5.2 Control System Brief

The chosen control system will be a SCADA based control system which draws real-time data from Energy Queensland's SCADA system. The control system will use a ramp down method to allow the generator to continue exporting even in the case of an overload event. The following sections will cover, in detail, the specifics of the control system.

5.3 Background

A line study will be undertaken to justify the chosen control system. The control system will be a closed-loop system as during the ramp-down phase; the output current will be compared against a threshold until the output current does not exceed the rating of the line. As previously stated, the control system will use SCADA based control to manage the output from the generator. As the generator is assumed to be a non-scheduled generator, scheduling by AEMO will not be necessary, and communication to AEMO for this will not be considered. Communication will be directly between the generator and Energy Queensland for exchanging any ramp down signals. The ramp down scheme will allow the generator to export power, by default, to 2% below the rated current of their generator connected lines (referred to as the overload threshold) unless the generator and Energy Queensland agreed-upon another power level. This small margin should prevent constant fluctuation in current from damaging the conductors.

NOTE: Generally, the generator connected line is rated at or above the automatic access standard calculated current however data was only provided for the MARS type conductor which has a current rating lower than that produced by the generator for the case study of this paper.

5.4 Plant Ratings

The following values were obtained using an Energy Queensland static/dynamic conductor rating calculator.

Table 5.1: Overhead Line Ratings

Voltage (P.U.)	**Limiting Conductor Type**	**Design Temperature (°C)**	**Line Rating [Amps] (% of output MVA)**
1	MARS 7/3.75 AAC 1350	75	[293.04] (111.66)

Table 5.2: Overhead Line Ratings and timings under Full Automatic Access Standards

Element	**Mars conductor parameters**	**Conditions**
Possible conductor temperature rise using standard Climate Parameters	79.48°C	Possible conductor temperature rise under full automatic access standard (313 Amps). Starting temperature of 75 °C
Time to reach conductor temperature if held at automatic access standard current (313 Amps).	442 seconds	Time to reach conductor temperature under full automatic access standard (313 Amps). Starting temperature of 75°C

5.5 General Functions

5.5.1 Safe Limit

The ramp down scheme will utilise a safe limit. The safe limit is used as a power level to which the generator will ramp down to and hold to ensure that no assets are damaged while the ramp down scheme is active.

The safe limit for this control system will be **70% of the contracted output power.**

5.5.2 Generator power plant controller 'Heartbeat' signal

The control system will also utilise a heartbeat signal to ensure that communications failure is registered and adequately handled. The heartbeat signal is an analogue input signal which is sent by the generator to the Energy Queensland remote terminal unit at minimum, every two seconds. The heartbeat will be a simple counter code which will increment in value, to be reset every week or whenever the power plant controller resets. The remote terminal unit will read the signal and compare it to the last known value. If the value has not changed in two scans, then the generator will receive a digital signal to trigger a communications failure protocol until an incremented value can be verified or, in the case of a reset, that communications heartbeat signal is being received.

5.5.3 Communications and RTU Failure

In the case of a communications failure, the generator should follow the ramp down procedures to the safe limit and hold until communications can be verified. Two distinct communications failure situations can occur. The first is the failure of communication equipment on the generator assets, which should be detected by the generator, and the ramp down scheme will be enacted. The second is communications failure on Energy Queensland assets in which a digital signal should be sent to the generator, and the ramp down scheme should be enacted. Should the generator not receive this signal then once the ramp down scheme fails to ramp down the generator the circuit breaker should be tripped, preventing damage to Energy Queensland assets.

5.6 Voltage Support Overview

As stated earlier in the paper, the generator must be capable of supplying voltage support to a power factor of 0.93. Therefore, when ramping down the generator must ramp down active power and allow generation or reactive power to maintain voltage support. If voltage support cannot be provided within the bounds of the automatic access standard (with a power factor higher than 0.93) when ramping down, then control of the bus must be relinquished.

5.7 Ramp Down Scheme

The ramp down scheme will operate by monitoring the generators power output (as separate active and reactive power measurements) from the Energy Queensland side of the substation transformer(s).

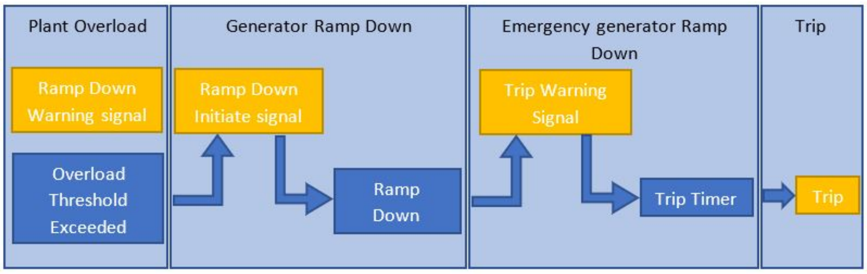


Figure 5.1: Diagramatic representation of the Control System

5.7.1 Ramp Down Warning

If the power output measurement exceeds the overload threshold, a digital signal will be sent to the generator, warning that they are currently exceeding the limits of the control system. When the warning signal activates, the generator shall prepare to ramp down.

5.7.2 Ramp Down Initiate

The ramp down initiate signal will activate when the generator ramp down warning signal is active for 10 seconds continueously, and will trigger the generator to begin ramping down at an agreed ramp rate of 1% per second for this line study. The generator will have 50 seconds to ramp down to the safe limit. If the ramp down is successful, the ramp-down condition will be turned off, and the generator may halt the reduction of power output. The ramp-down hold signal will then be turned on. If the ramp down is unsuccessful, the generator will move to the ramp down failed state, and the system will begin preparation for a generator trip.

5.7.3 Ramp Down Successful

If the ramp down is successful, the ramp-down condition will be turned off, and the generator will finalise the ramp down and enter a hold state. The hold state will prevent the generator from exporting power above the level of the safe limit. The hold state will ensure that any assets which exceeded thermal ratings can recover. After 300 seconds, the hold state will be released, and the generator will be able to resume regular operation.

5.7.4 Ramp Down Failure

If the generator does not ramp down before the ramp down timer expires the scheme will alert the generator and begin a circuit breaker trip timer of 30 seconds. If the generator successfully ramps down before the trip timer expires the trip and ramp-down conditions are turned off, and the generator will follow the successful ramp down procedure. If the generator fails to ramp down before the trip timer expires, the generator will be removed from the network by tripping the appropriate circuit breaker(s)

5.7.5 System Timing

Table 5.3: Control System Timing

Condition	**Overload Threshold Timer (s)**	**Ramp Down Timer (s)**	**Trip Timer (s)**	**Total Time to Trip (s)**
Overload Threshold Exceeded	10	50	30	90

5.7.6 Scheme Error

In the event of a scheme error the generator shall ramp back to the safe limit and hold until the error can be corrected.

5.7.7 Operational Flowchart

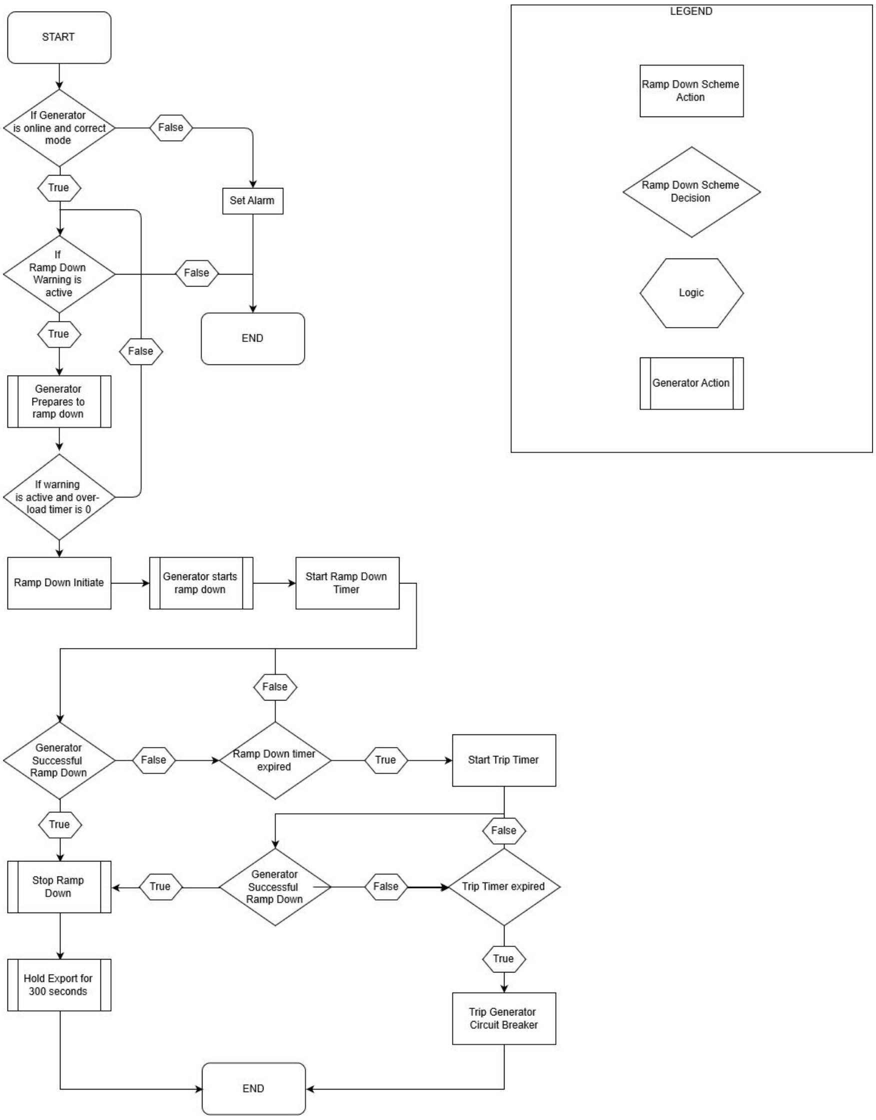


Figure 5.2: Operational Flowchart of the Control System

5.8 Chapter Summary

This chapter has focused on the selection and design of the ramp-back control system. The chapter presents a designed control scheme for a generator of similar size to the generator whose data was used in chapter 4. As the ramp back control scheme parameters would vary depending on the generator size and voltage connection, this chapter focussed on a specific case study. The generator used for the case study was similar in size to the generator whose data was used in chapter 4 and the generator connected line used was a MARS type conductor, which allowed exact values to be for the control system design. General functions of the control system, as well as overcurrent protection measures, timing parameters and an operational flowchart, were provided. The completion of this chapter assisted in the achievement of objectives (4) and (5) from the project specification (Appendix A).

Chapter 6

Control System Simulation Results

6.1 Chapter Overview

The following chapter will aim to present the results from a simulation of the control system logic. A set of expected outcomes will be presented and compared against the findings from the simulation. The second aim of this chapter is to give proof that in the occurrence of a fault the system will prevent the conductor temperature from exceeding 100°C as outlined in chapter 2.

6.2 Simulation Software

In order to test the logic used in the control system a python coded test controller was written using a basic graphical user interface (GUI) to simulate input and output signals. The GUI uses analogue slides to adjust the following input variables; Generated active power, generated reactive power and voltage level (from 90% to 110% of the rated voltage level). The outputs signals were simulated using checkbox indicators as all output signals from the control system are digital. The simulation study uses a 33kV system voltage with an attached 30MW renewable generator. This study produces a rated line current of approximately 627A using equation (2.3) reproduced below for convenience:

Table 6.1: Simulation Situational Inputs

Situation	Active Power (MW)	Reactive Power (MVAR)	Voltage (%)	Ramp Down Rate (% / second)
1	45	0	100	1
2	30	0	100	1 / 0
3	45	0	100	0
4	30	11.85	90	1

$$\text{Rated Current} = \frac{\text{Generator Rated Power}}{0.93 \times 0.9 \times \text{System Rated Voltage} \times \sqrt{3}}$$

Table 6.2: Expected Outcomes of Simulations

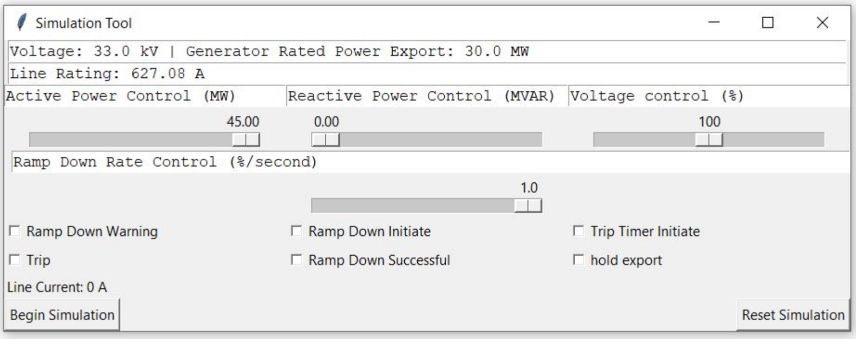
Situation	Description of Expected Outcome
1	The program should show a ramp down warning signal as soon as the simulation begins. 10 seconds later power should begin to ramp down. 50 seconds further the trip warning timer should activate and before the system can activate the trip timer the ramp down should exceed the safe threshold and activate the ramp down successful and hold export signals. After 300 second the hold export and ramp down successful signal should deactivate.
2	No signals should activate.
3	The program should show a ramp down warning signal as soon as the simulation begins. 10 seconds later power should begin to ramp down. 50 seconds further the trip warning timer should activate and after a further 30 second the trip signal should activate.
4	The program should show a ramp down warning signal as soon as the simulation begins. 10 seconds later power should begin to ramp down. Before the ramp down timer expires the system should successfully ramp down and activate the ramp down successful and hold export signals. After 300 second the hold export and ramp down successful signal should deactivate.

6.3 Results of Simulation

The inputs from the above table were table were input into the simulation program and the following results were observed.

6.3.1 Simulation of Situation 1

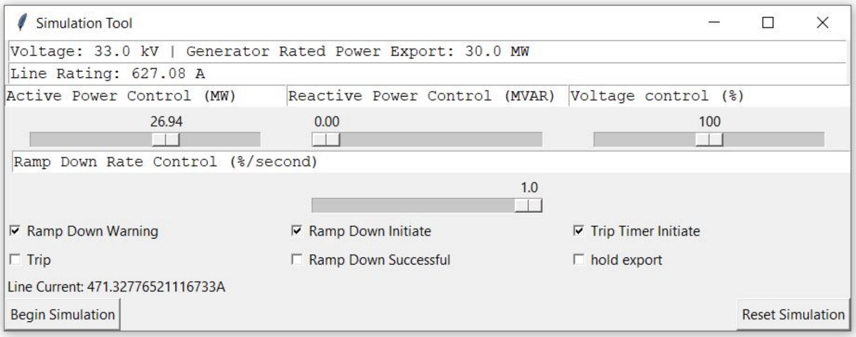
The following figure shows the simulation GUI with the input parameters from situation 1 set up and ready to begin simulation.



Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW
Line Rating: 627.08 A
Active Power Control (MW): 45.00
Reactive Power Control (MVAR): 0.00
Voltage control (%): 100
Ramp Down Rate Control (%/second): 1.0
☐ Ramp Down Warning ☐ Ramp Down Initiate ☐ Trip Timer Initiate
☐ Trip ☐ Ramp Down Successful ☐ hold export
Line Current: 0 A

Figure 6.1: Simulation software with input parameters for situation 1 set and ready for simulation.

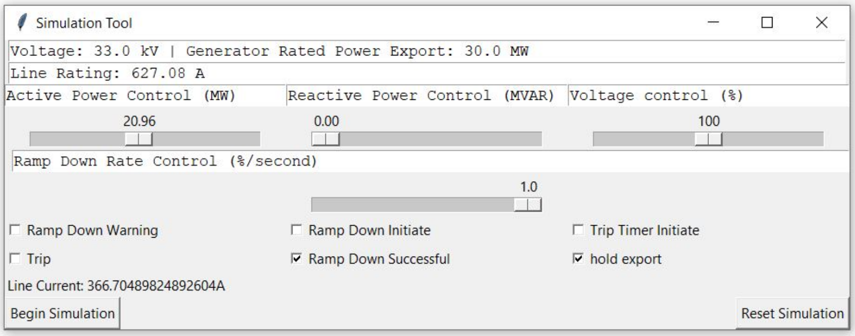
As predicted in (Table) after 60 seconds the trip timer activated due to the simulated output not reaching the safe limit. This can be seen in the following figure:



Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW
Line Rating: 627.08 A
Active Power Control (MW): 26.94
Reactive Power Control (MVAR): 0.00
Voltage control (%): 100
Ramp Down Rate Control (%/second): 1.0
☑ Ramp Down Warning ☑ Ramp Down Initiate ☑ Trip Timer Initiate
☐ Trip ☐ Ramp Down Successful ☐ hold export
Line Current: 471.32776521116733A

Figure 6.2: Simulation software during the simulation of the control scheme.

Before the trip timer expired however the simulated generator successfully ramped down, meaning it entered the hold export state, this is demonstrated in the following figure:



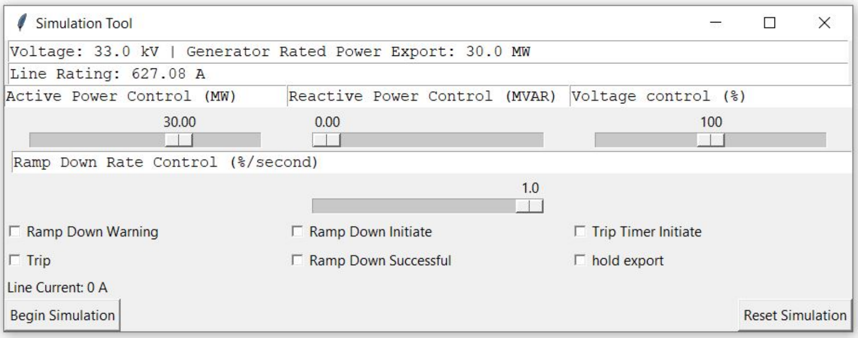
Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW
Line Rating: 627.08 A
Active Power Control (MW) 20.96
Reactive Power Control (MVAR) 0.00
Voltage control (%) 100
Ramp Down Rate Control (%/second) 1.0
☐ Ramp Down Warning ☐ Ramp Down Initiate ☐ Trip Timer Initiate
☐ Trip ☑ Ramp Down Successful ☑ hold export
Line Current: 366.70489824892604A

Figure 6.3: Simulation software after a successful ramp down and in a hold export state.

From the above figures It can be seen that the expected results closely follow the actual results of the simulation.

6.3.2 Simulation of Situation 2

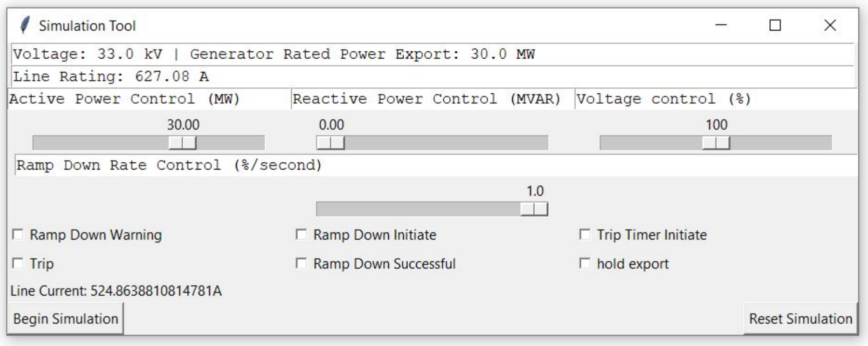
Situation 2 presents a situation in which the control system should not begin a ramp down situation. The following figure shows the simulation GUI with the input parameters from situation 2 set up and ready to begin simulation.



Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW
Line Rating: 627.08 A
Active Power Control (MW) 30.00
Reactive Power Control (MVAR) 0.00
Voltage control (%) 100
Ramp Down Rate Control (%/second) 1.0
☐ Ramp Down Warning ☐ Ramp Down Initiate ☐ Trip Timer Initiate
☐ Trip ☐ Ramp Down Successful ☐ hold export
Line Current: 0 A

Figure 6.4: Simulation software with input parameters for situation 2 set and ready for simulation.

As the input parameters have been set, so as the overload threshold has not been exceeded no change in the parameters have taken place. The following figure shows the software after the simulation of situation 2.



Simulation Tool

Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW

Line Rating: 627.08 A

Active Power Control (MW): 30.00

Reactive Power Control (MVAR): 0.00

Voltage control (%): 100

Ramp Down Rate Control (%/second): 1.0

☐ Ramp Down Warning ☐ Ramp Down Initiate ☐ Trip Timer Initiate

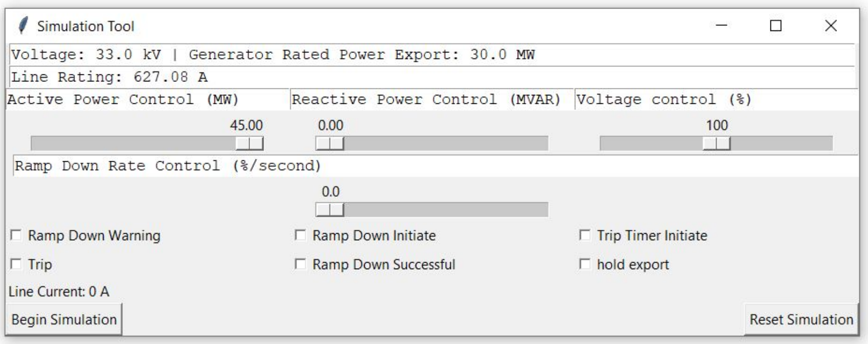
☐ Trip ☐ Ramp Down Successful ☐ hold export

Line Current: 524.8638810814781A

Figure 6.5: Simulation software after simulation of situation 2, showing that if no overload event is recorded then no change will be forced.

6.3.3 Simulation of Situation 3

Situation 3 is a situation in which the generator will not be able to successfully ramp down before the trip timer expires. The following figure shows the simulator with the situation 3 input parameters set.



Simulation Tool

Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW

Line Rating: 627.08 A

Active Power Control (MW): 45.00

Reactive Power Control (MVAR): 0.00

Voltage control (%): 100

Ramp Down Rate Control (%/second): 0.0

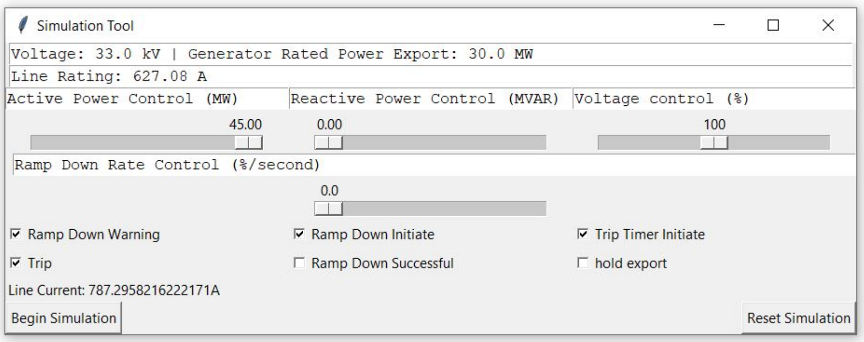
☐ Ramp Down Warning ☐ Ramp Down Initiate ☐ Trip Timer Initiate

☐ Trip ☐ Ramp Down Successful ☐ hold export

Line Current: 0 A

Figure 6.6: Simulation software with input parameters for situation 3 set and ready for simulation.

As the ramp down rate was set to 0 the ramp down phase was unable to successfully ramp down. The following figure shows the simulator after the expiration of the trip timer.



Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW

Line Rating: 627.08 A

Active Power Control (MW) 45.00

Reactive Power Control (MVAR) 0.00

Voltage control (%) 100

Ramp Down Rate Control (%/second) 0.0

☑ Ramp Down Warning
☑ Ramp Down Initiate
☑ Trip Timer Initiate
☑ Trip
☐ Ramp Down Successful
☐ hold export

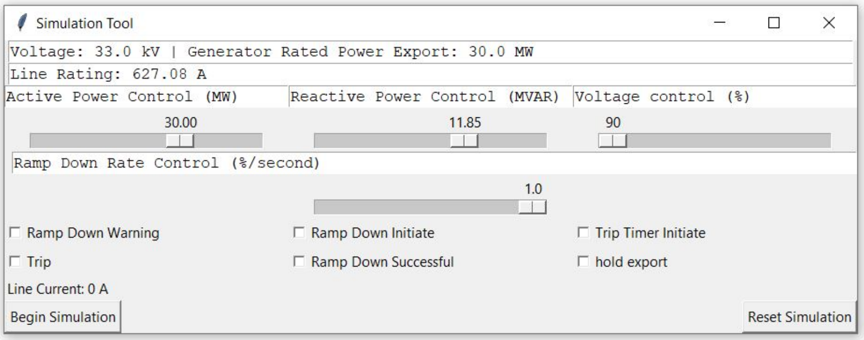
Line Current: 787.2958216222171A

Figure 6.7: Simulation software after simulation of situation 3, showing all expected signals for a failed ramp down are active.

From the above figures it can be seen that the simulation followed the expected result presented in table 6.2.

6.3.4 Simulation of Situation 4

Situation 4 is used to prove that the addition of reactive power does not prevent the control system from operating properly. The following figure shows the simulator with the situation 4 input parameters set.



Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW

Line Rating: 627.08 A

Active Power Control (MW) 30.00

Reactive Power Control (MVAR) 11.85

Voltage control (%) 90

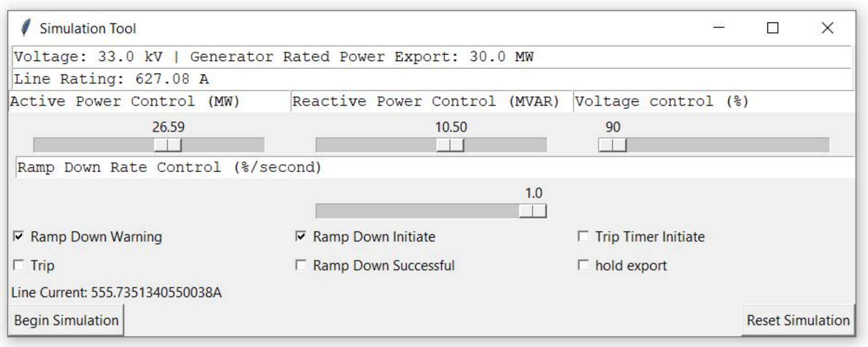
Ramp Down Rate Control (%/second) 1.0

☐ Ramp Down Warning
☐ Ramp Down Initiate
☐ Trip Timer Initiate
☐ Trip
☐ Ramp Down Successful
☐ hold export

Line Current: 0 A

Figure 6.8: Simulation software with input parameters for situation 4 set and ready for simulation.

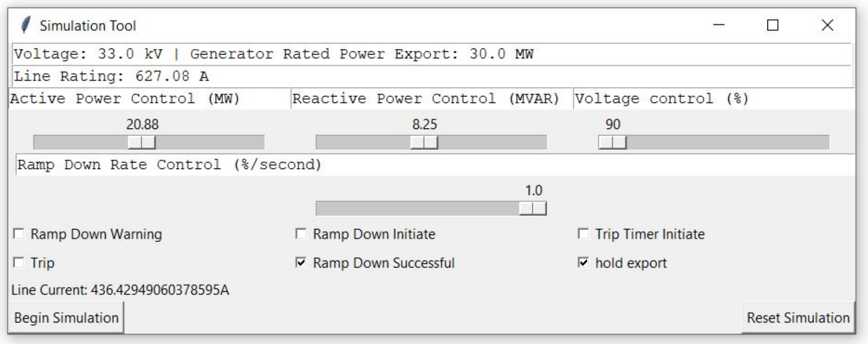
Similar to situation 1, the simulator showed that after 10 seconds the ramp down initiate signal activated and the active power began to ramp down as shown in the figure below.



Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW
Line Rating: 627.08 A
Active Power Control (MW): 26.59
Reactive Power Control (MVAR): 10.50
Voltage control (%): 90
Ramp Down Rate Control (%/second): 1.0
☑ Ramp Down Warning ☑ Ramp Down Initiate ☐ Trip Timer Initiate
☐ Trip ☐ Ramp Down Successful ☐ hold export
Line Current: 555.7351340550038A

Figure 6.9: Simulation software during the simulation of the control scheme showing the ramp down of both active and reactive power.

The generator then successfully ramped down before the ramp down timer expired. The following figure shows the simulator in the ramp down successful / hold export state after a successful ramp down following the simulation of situation 4.



Voltage: 33.0 kV | Generator Rated Power Export: 30.0 MW
Line Rating: 627.08 A
Active Power Control (MW): 20.88
Reactive Power Control (MVAR): 8.25
Voltage control (%): 90
Ramp Down Rate Control (%/second): 1.0
☐ Ramp Down Warning ☐ Ramp Down Initiate ☐ Trip Timer Initiate
☐ Trip ☑ Ramp Down Successful ☑ hold export
Line Current: 436.42949060378595A

Figure 6.10: Simulation software after simulation of situation 4, showing the introduction of reactive power does not affect the operation of the control system.

6.4 Simulator Limitations

As time did not permit simulation within a dedicated SCADA environment the basic simulation designed for testing has some limitations. The first limitation that can be identified is the simulation can only account for one generator connected line. Many generators connect to a split bus substation which uses two generated connected lines, each rated for half the rated output of the generator. The simulator cannot simulate both lines running concurrently but can only simulate one of the lines at a time.

The second identified limitation is that the simulator assumes the power factor is never lower than 0.93 (automatic access standard). This is not necessarily going to be true if implemented for real generators to use.

The third limitation is that in order to simulate two generators connected to different system voltages of different power export rating the source code of the simulator needs to be changed. Time did not permit for future optimisation of the simulator as it was prominently used to test the logic used in the control system.

The fourth identified limitation of the simulator was that it assumes the generator connected line is rated exactly to the automatic access standard of the generator. This will not be the case when connected to real generators and can be fixed through access to Energy Queensland's conductor ratings.

The final identified limitation is that the simulator assumes that the ramp rate is exactly 1% per second. In reality this value may fluctuate, the generator when beginning ramp down procedures may need to build up its ramp rate and when ending ramp down procedures may overshoot and correct to the safe limit.

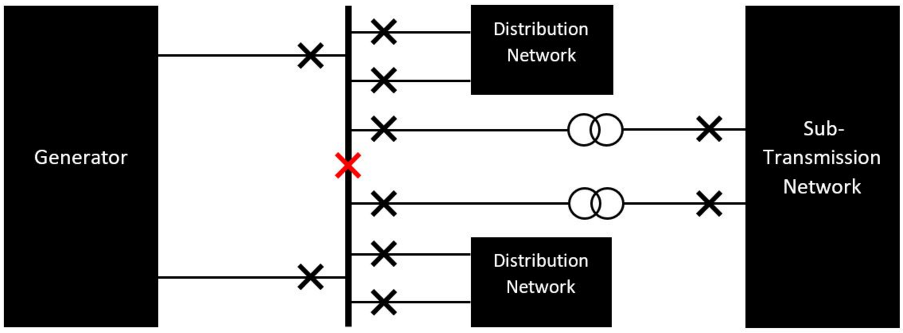
6.5 Fault Case Study

6.5.1 Background

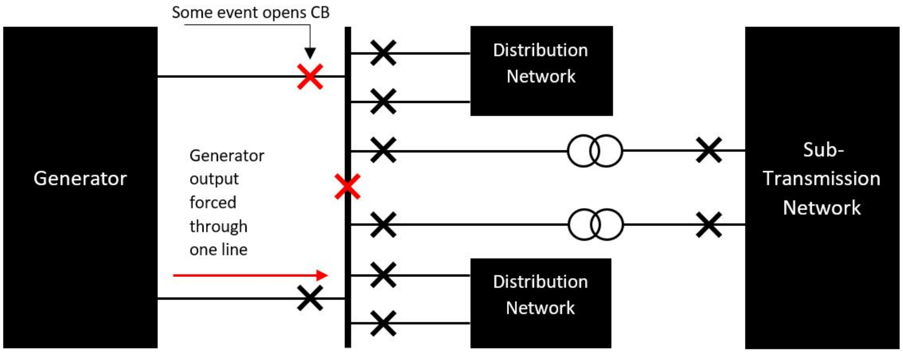
As stated in the literature review, the ccontrol system must be able to limit the conductor temperature to 100°C. The following case study is to show proof that for a large fault the proposed ramp down scheme would prevent generator connected lines from exceeding the 100°C thermal limit.

6.5.2 Large Fault Situation

A common fault situation occurs on a split bus system when a network error occurs causing a disconnection of one of the generators connected lines. Because of this the entire load produced by the generator is forced through a single line. The following line diagrams show the substation before and after the 'fault':



(a) Pre-fault



(b) Post-fault

Figure 6.11: Diagramatic representation of a split bus substation pre-fault (left) and post-fault (right) with an open circuit breaker preventing export to one of the buses.

6.5.3 Study Case Assumptions

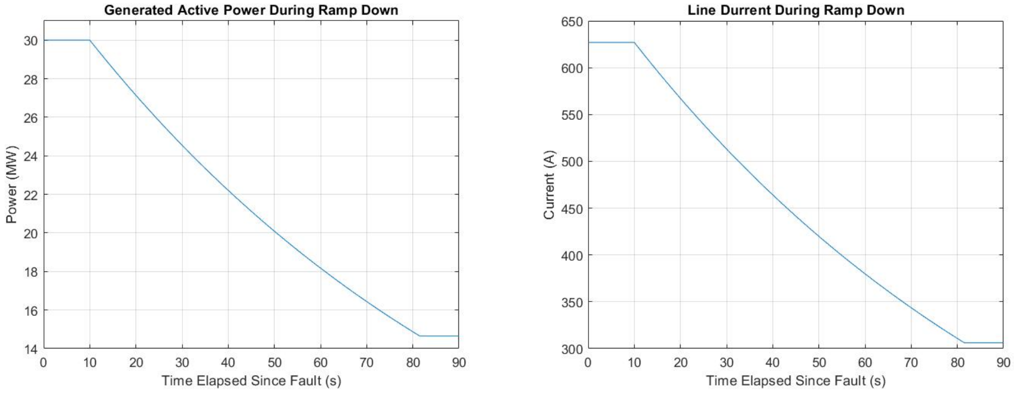
The following assumptions will be made while monitoring the ramp down conditions associated with the fault case study:

- Generator will be operating at the automatic access standard conditions. i.e. 90% of rated voltage, 0.93 power factor and operating at rated active power per line
- 30MW generator connected to a split Bus substation. i.e. 15MW on each Line
- Reactive power Cannot Exceed 0.395 times the active power produced.
- Prior to the occurrence of the fault the line temperature is 75°C (design temperature)

Once the ‘fault’ occurs the full 30MW produced by the generator will flow through a single line. MATLAB was used to simulate the ramp down procedure as the designed simulator does not account for split Bus Systems. The average ramp-down (Amps/Second) was then taken from the MATLAB plots and input into Energy Queensland's static/dynamic Line ratings calculator to identify the thermal characteristics of this situation.

6.5.4 Ramp Down Simulation

The following plots show the operation of the ramp down scheme and track the active power output of the generator and the line current along the operational generator connected line.



(a) Simulated active power export during the control scheme

(b) Simulated line current during the control scheme

Figure 6.12: Ramp down scheme simulation plots

From the plots the average ramp down (Amps/Second) was obtained for use in the static/dynamic Line ratings calculator provided by Energy Queensland. The calculation of the thermal limits was conducted on the MARS type conductor (rated lower than the automatic access standard rating and hence represents a worst-case condition) and showed that the fault would cause a steady state temperature of 94.65°C, this steady state temperature would occur 60 seconds after the occurrence of the fault.

Table 6.3: Fault Study Thermal Calculations

Parameters for Temperature Calculation		
Allowable Temperature	100	(°C)
Time step for time constant	1	(s)
Ramp Back Scheme (A/time period)	4.48	
Temperature Outputs		
Final Conductor temperature	N/A	(°C)
Time to reach allowable temperature	N/A	(s)
Steady State Temperature	94.65	(°C)
Time to reach Steady State	60.00	(s)

This case study shows that a large-scale fault resulting in double the automatic access rated current maintains thermal safety in accordance with Energy Queensland's thermal limiting rules.

6.6 Chapter Summary

This chapter has presented the results from a simulation of the control system logic outlined in the previous chapter (chapter 5). A set of expected outcomes based on a set of specific input were presented as situations, and each situation was set up within the simulator, and the actual results of the simulation were compared with the expected results to provide proof that the control system logic works. Also presented in this chapter was the limitations of the simulator as the simulation did not take place within an actual SCADA environment. The completion of this chapter resulted in the achievement of the optional objective (6) within the project specification document.

Chapter 7

Conclusions and Further Work

7.1 Conclusions

The main objective of the project presented in this dissertation was to determine if a control scheme could be used to fully and safely utilise the capacity of the generator connected lines of renewable generators. It was revealed that the use of a control system in tandem with a ramp down scheme possibly could allow renewable generators to export power to the limit of their generator connected line while still maintain accordance with the national electricity rules. Additionally, timing and tolerance parameters around the design of the control system were presented, and a basic simulation of the control system was undertaken.

In addition to the main objective of the project, a range of other minor objectives were completed and presented within this dissertation via a set of project outcomes. These outcomes include research into the background of the project to identify the most suitable style of control system and management scheme for implementation of the control scheme and a thorough analysis of historical data provided by Energy Queensland to identify relevant trends in the data. This collection of knowledge and the design of the simulation program is of significant value along with the initial design of the control system, as outlined in the main objective.

The control system outlined in chapter 4, if implemented properly, could have a significant effect of Queensland's distribution network. According to the data analysis the control system could allow for a further utilisation of up to 16.51% (after accounting for the 2% capacity tolerance parameter in the design of the control system) on the generator connected line of the analysed generator. This figure is subject to change depending on the size of the generator, connection voltage and/or the static capacity of the line.

7.2 Further Work

Due to time constraints, it was not possible to investigate all avenues identified at the commencement and during the course of the project. As such these ideas become subjects of further work for other students or for industry to investigate. The following list presents these topics as well as a brief explanation of the topic.

1. **Control system which allows for utilisation of dynamically rated generator connected lines**

   The scope of the project was limited to include generator connected lines with a static rating only. Dynamically rated lines allow a more dynamic export dependant on other parameters (generally weather based parameters) which allow a higher rate of export when worst case conditions aren't in play. Therefore, this dynamic rating in combination with the utilisation control system will allow for a much higher export limit.

2. **Control system which allows for utilisation of the generator connected lines of scheduled and semi-scheduled renewable generators**

   The scope of the project was limited to include generator connected lines for non-scheduled generators only. This means that only generators that do not require verification from AEMO so change generation parameters were considered. Therefore, it is a necessary step to ensure that all renewable generators are able to utilise this beneficial system.

3. **Optimisation of tolerance and timing parameters**

   In the design of the control system, tolerance and timing parameters were selected based of control systems currently in use by Energy Queensland and therefor they are not optimised for use in this ramp down control system. This optimisation may be able to potentially be more efficient and further utilise the capacity of the generator connected lines.

4. **Simulation of control system in a SCADA environment**

   The simulation of the control system within the dissertation was written in python to simulate the proposed logic of the control system in order to verify that no parameters of logic decisions were overlooked. However, the control system, if implemented, will run within a SCADA environment and therefore a necessary step before implementation is to verify compliance with the SCADA environment

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Appendix A

Project Specification

ENG 4111/2 (or ENG8002) Research Project

Project Specification

For:	**Michael Scott Elsasser**
Topic:	Optimised renewable generator schemes to improve the utilisation of network assets while maintaining safe operation of primary plant in accordance with the National Electricity Rules.
Supervisor:	Andrew Hewitt
Sponsorship:	Faculty of Health, Engineering & Sciences Energy Queensland
Project Aim:	Propose management scheme(s) which exploit full capacity of conductors, enabling additional renewable generation when system conditions permit. This proposal will include the protection of network assets to ensure thermal limits are maintained as well as any necessary monitoring equipment that would be needed for implementation.

Program:

1. Research the background information on rating methods of generator connected lines and analyse previous management methods for mitigation of congestion on lines.

2. Analyse historical data to determine past trends for system normal operating voltage, power factor and current.

3. Compare potential management schemes and their viability based on the data trends established in (2.).

4. Propose the most viable scheme and determine parameters for the system response times and any protection required.

5. Propose logic for the system which will prevent the system from overloading and/or exceeding other parameters.

If time and resources permit:

1. Simulate the proposed control system under variable conditions to test the viability of the proposed control system.
2. Investigate the response of the proposed control system

Agreed:

Student Name: Michael Elsasser
Date: 15/03

Supervisor Name: Andrew Hewitt
Date: 15/03

Appendix B

Data Analysis Code Listing

The following code was used to analyse historic data provided by Energy Queensland. The code works by importing the data from a Excel spreadsheets and scaling the data to avoid releasing specific substation details. The code then plots and analyses voltage, power factor and line capacity data as shown in chapter 4.

Listing B.1: Data Modeling.

```
%% Initialise
close all;
clc;

load_data = true;
if load_data == true
    clear;
    load_data = true;
end
save_plots = false;
plot_voltage = true;
plot_pf = true;
plot_capacity = true;
plot_misc = false;

%% Create data arrays
if load_data == true
    % Read Ten Min Data from Excel
    data_10_min = xlsread('Substation␣Voltage␣Data.xlsx', "10 min 2017");
    % Read One Sec Data from Excel
    data_1_sec = xlsread('Substation␣Voltage␣Data.xlsx', "1 sec 2017");
end

BUS_power = 10/0.022;
```

```
maximum_power_percentage = 0.85;
max_pow_thresh = BUS_power * maximum_power_percentage;

power_scaling = (22*(10^-3));
voltage_scaling = 22;
% Set yearly data
voltage_bus_1_10_min = data_10_min(:,1)/voltage_scaling;
for z = 1:length(voltage_bus_1_10_min)
    active_power_bus_1_10_min = data_10_min(:,2)/power_scaling;
    reactive_power_bus_1_10_min = data_10_min(:,3)/power_scaling;
end
control_state_bus_1_10_min = data_10_min(:,4);

voltage_bus_2_10_min = data_10_min(:,5)/voltage_scaling;
for z = 1:length(voltage_bus_2_10_min)
    active_power_bus_2_10_min = data_10_min(:,6)/power_scaling;
    reactive_power_bus_2_10_min = data_10_min(:,7)/power_scaling;
end
control_state_bus_2_10_min = data_10_min(:,8);

yearly_voltage_data = [voltage_bus_1_10_min,voltage_bus_2_10_min];
yearly_active_power_data = [active_power_bus_1_10_min,...
    active_power_bus_2_10_min];
yearly_reactive_power_data = [reactive_power_bus_1_10_min,...
    reactive_power_bus_2_10_min];
yearly_control_state_data = [control_state_bus_1_10_min,...
    control_state_bus_2_10_min];

% Set Weekly Data
voltage_bus_1_1_sec = data_1_sec(:,1)/voltage_scaling;
active_power_bus_1_1_sec = data_1_sec(:,2)/power_scaling;
reactive_power_bus_1_1_sec = data_1_sec(:,3)/power_scaling;
control_state_bus_1_1_sec = data_1_sec(:,4);

voltage_bus_2_1_sec = data_1_sec(:,5)/voltage_scaling;
active_power_bus_2_1_sec = data_1_sec(:,6)/power_scaling;
reactive_power_bus_2_1_sec = data_1_sec(:,7)/power_scaling;
control_state_bus_2_1_sec = data_1_sec(:,8);

weekly_voltage_data = [voltage_bus_1_1_sec,voltage_bus_2_1_sec];
weekly_active_power_data = [active_power_bus_1_1_sec,...
    active_power_bus_2_1_sec];
weekly_reactive_power_data = [reactive_power_bus_1_1_sec,...
    reactive_power_bus_2_1_sec];
weekly_control_state_data = [control_state_bus_1_1_sec,...
    control_state_bus_2_1_sec];

datetime_10_min = datetime(2017,01,01,0,0,0):minutes(10):...
    datetime(2017,11,30,0,0,0);
datetime_1_sec = datetime(2017,10,01,0,0,0):seconds(1):...
    datetime(2017,10,07,0,0,0);
```

```
rated_current = 313.54;
%% Plot Voltage Data

if plot_voltage == true
    % Plot Yearly Data
    for a = 1:min(size(yearly_control_state_data))
        for b = 1:length(yearly_voltage_data)
            if yearly_voltage_data(b,a) > 0.9
                voltage_data(b) = yearly_voltage_data(b,a);
            else
                voltage_data(b) = NaN;
            end
        end
        x = zeros(size(datetime_10_min));
        mean_plot = x + (nanmean(voltage_data));
        if a == 1
            name_string = 'Voltage␣-␣10␣Min␣-␣Bus␣A';
        else
            name_string = 'Voltage␣-␣10␣Min␣-␣Bus␣B';
        end
        figure('name',name_string, 'NumberTitle', 'off')
        plot(datetime_10_min,yearly_voltage_data(:,a));
        hold on
        plot(datetime_10_min,mean_plot,'LineWidth',2)
        hold off
        title(name_string);
        xlabel('Date');
        ylabel('Voltage␣(p.u.)');
        legend('Yearly␣Voltage␣Data','Yearly␣Voltage␣Mean')
        ylim([0.7 1.3])

        low_int = nanmean(voltage_data) - (1.96 * nanstd(voltage_data)...
            )/length(voltage_data);
        high_int = nanmean(voltage_data) + (1.96 * nanstd(voltage_data)...
            )/length(voltage_data);

        fprintf('confidence␣interval␣for␣%s␣is␣%4.8f␣-␣%4.8f␣\n', ...
            name_string, low_int, high_int)

    end
    % Plot Weekly Data
    for a = 1:min(size(weekly_control_state_data))
        for b = 1:length(weekly_voltage_data)
            if weekly_voltage_data(b,a) > 0.9
                voltage_data(b) = weekly_voltage_data(b,a);
            else
                voltage_data(b) = NaN;
            end
        end
        x = zeros(size(datetime_1_sec));
        mean_plot = x + (nanmean(voltage_data));
        if a == 1
```

```
            name_string = 'Voltage␣-␣1␣Sec␣-␣Bus␣A';
        else
            name_string = 'Voltage␣-␣1␣Sec␣-␣Bus␣B';
        end
        figure('name',name_string, 'NumberTitle', 'off')
        plot(datetime_1_sec,weekly_voltage_data(:,a));
        hold on
        plot(datetime_1_sec,mean_plot,'LineWidth',2)
        hold off
        title(name_string);
        xlabel('Date');
        ylabel('Voltage␣(p.u.)');
        legend('Weekly␣Voltage␣Data','Weekly␣Voltage␣Mean')
        ylim([0.9 1.1])

        low_int = nanmean(voltage_data) - (1.96 * nanstd(voltage_data))/...
            length(voltage_data);
        high_int = nanmean(voltage_data) + (1.96 * nanstd(voltage_data)...
        )/length(voltage_data);

        fprintf('confidence␣interval␣for␣%s␣is␣%4.8f␣-␣%4.8f␣\n', ...
            name_string, low_int, high_int)
    end
end
%% Plot Power Factor Data
if plot_pf == true
    clear pwr_fact;
    % Plot Yearly Data
    for a = 1:min(size(yearly_control_state_data))
        for b = 1:length(yearly_control_state_data)
            if yearly_control_state_data(b,a)==1 && abs(...
                    yearly_active_power_data(b,a)) > max_pow_thresh
                pwr_fact(b) = cosd(atand(yearly_reactive_power_data(b,a...
                    )/yearly_active_power_data(b,a)));
            else
                pwr_fact(b) = NaN;
            end
        end
        x = zeros(size(datetime_10_min));
        mean_plot = x + (nanmean(pwr_fact));
        if a == 1
            name_string = 'Power␣Factor␣-␣10␣Min␣-␣Bus␣A';
        else
            name_string = 'Power␣Factor␣-␣10␣Min␣-␣Bus␣B';
        end
        figure('name',name_string, 'NumberTitle', 'off')
        scatter(datetime_10_min,pwr_fact);
        hold on
        plot(datetime_10_min,mean_plot,'LineWidth',2)
        hold off
        title(name_string);
        xlabel('Date');
```

```
        ylabel('Power Factor');
        legend('Power Factor','Power Factor Mean','Location','best')
        ylim([0.9 1])

        low_int = nanmean(pwr_fact) - (1.96 * nanstd(pwr_fact))/...
            length(pwr_fact);
        high_int = nanmean(pwr_fact) + (1.96 * nanstd(pwr_fact))/...
            length(pwr_fact);

        fprintf('confidence interval for %s is %4.8f - %4.8f \n', ...
            name_string, low_int, high_int)
    end
    % Plot Weekly Data
    for a = 1:min(size(weekly_control_state_data))
        for b = 1:length(weekly_control_state_data)
            if weekly_control_state_data(b,a)==1 && ...
                    abs(weekly_active_power_data(b,a)) > max_pow_thresh
                pwr_fact(b) = cosd(atand(weekly_reactive_power_data(b,a...
                    )/weekly_active_power_data(b,a)));
            else
                pwr_fact(b) = NaN;
            end
        end
        x = zeros(size(datetime_1_sec));
        mean_plot = x + (nanmean(pwr_fact));
        if a == 1
            name_string = 'Power Factor - 1 Sec - Bus A';
        else
            name_string = 'Power Factor - 1 Sec - Bus B';
        end
        figure('name',name_string, 'NumberTitle', 'off')
        scatter(datetime_1_sec,pwr_fact);
        hold on
        plot(datetime_1_sec,mean_plot,'LineWidth',2)
        hold off
        title(name_string);
        xlabel('Date');
        ylabel('Power Factor');
        legend('Power Factor','Power Factor Mean','Location','best')

        low_int = nanmean(pwr_fact) - (1.96 * nanstd(pwr_fact))/...
            length(pwr_fact);
        high_int = nanmean(pwr_fact) + (1.96 * nanstd(pwr_fact))/...
            length(pwr_fact);

        fprintf('confidence interval for %s is %4.8f - %4.8f \n', ...
            name_string, low_int, high_int)
    end
end
%% Plot Capacity Data

if plot_capacity == true
```

```
clear line_capacity;
clear actual_export;

static_rated_capacity = rated_current * sqrt(3);

% Plot Yearly Data
for a = 1:min(size(yearly_control_state_data))
    for b = 1:length(yearly_voltage_data)
        line_capacity(b) = 100*(rated_current*...
            yearly_voltage_data(b,a)*sqrt(3))/(static_rated_capacity);
        if yearly_control_state_data(b,a) == 1 && abs(...
                yearly_active_power_data(b,a)) > max_pow_thresh
            actual_export(b) = (100*sqrt((...
                yearly_active_power_data(b,a))^2 + (...
                yearly_reactive_power_data(b,a))^2))/...
                static_rated_capacity;
        else
            actual_export(b) = NaN;
        end
    end
    exp_mean = nanmean(actual_export);
    cap_mean = mean(line_capacity);
    blank = zeros(size(datetime_10_min));
    cap_mean_plot = blank + cap_mean;
    exp_mean_plot = blank + exp_mean;
    if a == 1
        name_string = 'Capacity␣-␣Bus␣A␣-␣Yearly';
    else
        name_string = 'Capacity␣-␣Bus␣B␣-␣Yearly';
    end

    dif_mean = cap_mean - exp_mean;
    perc_dif = (dif_mean/cap_mean)*100;

    fprintf(['%s␣shows␣assets␣are␣underutilised␣by␣%4.2f␣percent␣',...
        'of␣the␣capacity␣\n'],name_string,perc_dif);

    figure('name',name_string, 'NumberTitle', 'off')
    plot(datetime_10_min,line_capacity);
    hold on
    plot(datetime_10_min,cap_mean_plot,'LineWidth',2)
    scatter(datetime_10_min,actual_export)
    plot(datetime_10_min,exp_mean_plot,'LineWidth',2);
    hold off
    title(name_string);
    xlabel('Date');
    ylabel('Capacity␣(%␣of␣Static␣Line␣Capacity)');
    legend('Line␣Power␣Capacity','Mean␣Line␣Power␣Capacity',...
        'Actual␣Exported␣Power','Mean␣Exported␣Power',...
        'Location','best')
end
% Plot Weekly Data
```

```
    for a = 1:min(size(weekly_control_state_data))
        for b = 1:length(weekly_voltage_data)
            line_capacity(b) = 100*rated_current*...
                weekly_voltage_data(b,a)*sqrt(3)/static_rated_capacity;
            if weekly_control_state_data(b,a) == 1 && abs(...
                    weekly_active_power_data(b,a)) > max_pow_thresh
                actual_export(b) = 100*sqrt((...
                    weekly_active_power_data(b,a))^2 + (...
                    weekly_reactive_power_data(b,a))^2)/...
                    static_rated_capacity;
            else
                actual_export(b) = NaN;
            end
        end
        exp_mean = nanmean(actual_export);
        cap_mean = mean(line_capacity);
        blank = zeros(size(datetime_1_sec));
        cap_mean_plot = blank + cap_mean;
        exp_mean_plot = blank + exp_mean;
        if a == 1
            name_string = 'Capacity␣-␣Bus␣A␣-␣Weekly';
        else
            name_string = 'Capacity␣-␣Bus␣B␣-␣Weekly';
        end

        dif_mean = cap_mean - exp_mean;
        perc_dif = (dif_mean/cap_mean)*100;

        fprintf(['%s␣shows␣assets␣are␣underutilised␣by␣%4.2f␣',...
            'percent␣of␣the␣capacity␣\n'],name_string,perc_dif)

        figure('name',name_string, 'NumberTitle', 'off')
        plot(datetime_1_sec,line_capacity);
        hold on
        plot(datetime_1_sec,cap_mean_plot,'LineWidth',2)
        scatter(datetime_1_sec,actual_export)
        plot(datetime_1_sec,exp_mean_plot,'LineWidth',2);
        hold off
        title(name_string);
        xlabel('Date');
        ylabel('Capacity␣(%␣of␣Static␣Line␣Capacity)');
        legend('Line␣Power␣Capacity','Mean␣Line␣Power␣Capacity',...
            'Actual␣Exported␣Power','Mean␣Exported␣Power',...
            'Location','best')
    end
end
```

Appendix C

Ramp-back Scheme Simulation Code Listing

The following code was used to simulate the control system logic. It uses the ktinker library to generate a GUI which allows the used to set the input parameters and begin a simulation wich follows the control scheme logic.

Listing C.1: Ramp-back scheme simulation code.

```
from tkinter import *
from math import *
import time
import sys
import os


def run_main():
    system_volt = 33000
    rated_power = 30000000

    line_rating = round(
        (rated_power / (0.93 * 0.9 * sqrt(3) * system_volt)), 2)

    master = Tk()
    master.title("Simulation␣Tool")
    # Code to add widgets will go here...
    text = Text(master, height=1, width=90)
    text.insert(INSERT, "Voltage:␣" + str(system_volt / 1000) +
                "␣kV␣|␣Generator␣Rated␣Power␣Export:␣"
                + str(rated_power / 1000000) + "␣MW")
    text.grid(row=1, columnspan=3)
```

```
text = Text(master, height=1, width=90)
text.insert(INSERT, "Line␣Rating:␣" + str(line_rating) + "␣A")
text.grid(row=2, columnspan=3)

text = Text(master, height=1, width=30)
text.insert(INSERT, "Active␣Power␣Control␣(MW)")
text.grid(row=3, column=0)

w = Scale(master, from_=0, to=(1.5 * (rated_power / 1000000)),
          orient=HORIZONTAL, resolution=0.01, length=250,
          state=ACTIVE)
w.grid(row=4, column=0)

text = Text(master, height=1, width=30)
text.insert(INSERT, "Reactive␣Power␣Control␣(MVAR)")
text.grid(row=3, column=1)

x = Scale(master, from_=0,
          to=0.395 * (1.5 * (rated_power / 1000000)),
          orient=HORIZONTAL, resolution=0.01, length=250)
x.grid(row=4, column=1)

text = Text(master, height=1, width=30)
text.insert(INSERT, "Voltage␣control␣(%)")
text.grid(row=3, column=2)
z = Scale(master, from_=90, to=110, orient=HORIZONTAL,
          resolution=1,
          length=250)
z.grid(row=4, column=2)

text = Text(master, height=1, width=90)
text.insert(INSERT, "Ramp␣Down␣Rate␣Control␣(%/second)")
text.grid(row=5, columnspan=3, sticky=E)

y = Scale(master, from_=0, to=1, orient=HORIZONTAL,
          resolution=0.1,
          length=250)
y.grid(row=6, column=1)

var1 = BooleanVar()
var1.set(False)
a = Checkbutton(master, text="Ramp␣Down␣Warning", variable=var1)
a.grid(row=7, column=0, sticky=W)
var2 = BooleanVar()
var2.set(False)
b = Checkbutton(master, text="Ramp␣Down␣Initiate", variable=var2)
b.grid(row=7, column=1, sticky=W)
var3 = BooleanVar()
var3.set(False)
c = Checkbutton(master, text="Trip␣Timer␣Initiate", variable=var3)
c.grid(row=7, column=2, sticky=W)
```

```
    var4 = BooleanVar()
    var4.set(False)
    d = Checkbutton(master, text="Trip", variable=var4)
    d.grid(row=8, column=0, sticky=W)
    var5 = BooleanVar()
    var5.set(False)
    e = Checkbutton(master, text="Ramp Down Successful",
                    variable=var5)
    e.grid(row=8, column=1, sticky=W)
    var6 = BooleanVar()
    var6.set(False)
    f = Checkbutton(master, text="hold export", variable=var6)
    f.grid(row=8, column=2, sticky=W)

    var = StringVar()
    var.set('Line Current: 0 A')

    l = Label(master, textvariable=var)
    l.grid(row=9, sticky=W)

    button = Button(master, text="Begin Simulation",
                    command=lambda: run_control_system(master,
                                                       system_volt,
                                                       rated_power,
                                                       line_rating, w,
                                                       x,
                                                       y, z, var1,
                                                       var2,
                                                       var3, var4,
                                                       var5,
                                                       var6, var))
    button.grid(row=10, column=0, sticky=W)
    button = Button(master, text="Reset Simulation",
                    command=lambda: restart_program())
    button.grid(row=10, column=2, sticky=E)
    master.mainloop()


def run_control_system(master, system_volt, rated_power, line_rating,
                       w, x, y, z, var1, var2, var3, var4, var5, var6,
                       var):
    seconds_warning = 10
    seconds_ramp = seconds_warning + 50
    seconds_trip = seconds_ramp + 30
    while 1:
        master.update()
        line_current = (sqrt(
            (w.get() * w.get()) + (x.get() * x.get()))) / (
                                system_volt * z.get() * sqrt(
                        3) / 100000000)
        var.set('Line Current: ' + str(line_current) + 'A')
        if x.get() > 0.395 * w.get():
```

```
    x.set(0.395 * w.get())
if line_current > 0.98 * line_rating:
    var1.set(True)
    var5.set(False)
    start = time.time()
    time.process_time()
    elapsed = 0
    while elapsed < seconds_warning:
        line_current = (sqrt((w.get() * w.get()) + (
                x.get() * x.get()))) / (
                               system_volt * z.get() * sqrt(
                           3) / 100000000)
        var.set('Line␣Current:␣' + str(line_current) + 'A')
        if x.get() > 0.395 * w.get():
            x.set(0.395 * w.get())
        master.update()

        elapsed = time.time() - start
        if line_current < 0.98 * line_rating:
            var1.set(False)
        if elapsed >= seconds_warning:
            var2.set(True)
            break
        elapsed_prev = elapsed

    if var2.get() is True:
        while elapsed < seconds_ramp:
            line_current = (sqrt((w.get() * w.get()) + (
                    x.get() * x.get()))) / (
                                   system_volt * z.get() * sqrt(
                               3) / 100000000)
            var.set(
                'Line␣Current:␣' + str(line_current) + 'A')
            if x.get() > 0.395 * w.get():
                x.set(0.395 * w.get())
            master.update()

            elapsed = time.time() - start
            cycle_time_elapsed = elapsed - elapsed_prev
            if cycle_time_elapsed > 1:
                gen_ramp_down(rated_power / 1000000, w,
                              cycle_time_elapsed, y)
                elapsed_prev = elapsed
            if w.get() <= 0.7 * rated_power / 1000000:
                var1.set(False)
                var2.set(False)
                var5.set(True)
                break
            if elapsed >= seconds_ramp:
                var3.set(True)
                break
        if var5.get() is True:
```

```
                    hold_export(master, w, x, var6, var5,
                                system_volt, z, var)

                if var3.get() is True:
                    while elapsed < seconds_trip:

                        line_current = (sqrt((w.get() * w.get()) + (
                                x.get() * x.get()))) / (
                                              system_volt * z.get() * sqrt(
                                          3) / 100000000)
                        var.set('Line␣Current:␣' + str(
                            line_current) + 'A')
                        if x.get() > 0.395 * w.get():
                            x.set(0.395 * w.get())
                        master.update()

                        elapsed = time.time() - start
                        cycle_time_elapsed = elapsed - elapsed_prev
                        if cycle_time_elapsed > 1:
                            gen_ramp_down(rated_power / 1000000, w,
                                          cycle_time_elapsed, y)
                            elapsed_prev = elapsed
                        if w.get() <= 0.7 * rated_power / 1000000:
                            var1.set(False)
                            var2.set(False)
                            var3.set(False)
                            var5.set(True)
                            break
                        if elapsed >= seconds_trip:
                            var4.set(True)
                            break
                    if var5.get() is True:
                        hold_export(master, w, x, var6, var5,
                                    system_volt, z, var)


def gen_ramp_down(rated_power, active_power, scale_time, ramp_rate):
    if active_power.get() > 0.7 * rated_power:
        active_power.set(active_power.get() - (scale_time * (
                ramp_rate.get() / 100) * active_power.get()))
        return True
    else:
        return False


def hold_export(master, active, reactive, hold_signal, success_signal,
                system_volt, volt_cont, string_var):
    start = time.time()
    time.process_time()
    elapsed = 0
    hold_signal.set(True)
    active.config(state=DISABLED, takefocus=0)
```

```
    while elapsed < 300:
        line_current = (sqrt((active.get() * active.get()) + (
                reactive.get() * reactive.get()))) / (
                              system_volt * volt_cont.get() * sqrt(
                          3) / 100000000)
        string_var.set('Line␣Current:␣' + str(line_current) + 'A')
        if reactive.get() > 0.395 * reactive.get():
            reactive.set(0.395 * active.get())
        master.update()
        elapsed = time.time() - start
    hold_signal.set(False)
    success_signal.set(False)
    active.config(state=NORMAL, takefocus=0)


def restart_program():
    """Restarts the current program.
    Note: this function does not return. Any cleanup action (like
    saving data) must be done before calling this function."""
    python = sys.executable
    os.execl(python, python, *sys.argv)


run_main()
```

Appendix D

Risk Assessment

The following Risk assessment was written using the Energy Queensland network risk framework. The network risk framework provides guidance when undertaking risk assessments. The risk framework aligns with the following standards associated with risk management:

- AS/NZS ISO 31000:2018 Risk MAnagement - Principles and Guidelines,
- IEC/ISO 31010 Risk Management - Risk assessment techniques,
- SA/SNZ HB 436:2013 Risk Management Guidelines (Companion to AS/NZS ISO 31000:2018),
- HB 327:2010 Communicating and consulting about risk (Companion to AS/NZS ISO 31000:2018),
- HB158:2010 Delivering assurance based on ISO 31000:2018; and
- IEC/ISO 55000 - Asset Management Standards

Risk Name / Title
Optimised renewable generator scheme to improve the utilisation of network assets while maintaining safe operation of primary plant in accordance with the National Electricity Rules.
Risk Context and Background
The proposed control system will allow Renewable Generators to export power to a level 2% below the rating of their generator connected lines. With this utilisation of network assets, comes added risk which will be discussed in this document. Customer impact, Business Impact, Environmental impacts, Public safety and asset safety will be addressed using a consequence (C) score rated between 1 and 6 (1 Very Low, 6 Very High) as well as a likelihood (L) Score, again rated between 1 and 6 (1 Very Low, 6 Very High).
Considerations and Issues
Proper operation of the control scheme should result in no additional risks, and thus the risk assessment will mostly address risks associated with the failure of the control system; however, the underutilisation of network assets due to not implementing the control system will also be discussed.

Risk Category	Risk Scenario	Risk			Risk Controls / Mitigation
		C	L	Score	
Business Impact	Failure of Control System results in a combined business impact of greater than $500,000 or equivalent	3	2	6 **Low**	Overcurrent protection systems, transformer safety standards and backup rampback systems for system overload

Business Impact	Failure of Control System results in a combined business impact of greater than $100,000 or equivalent	2	3	6 **Low**	Overcurrent protection systems, transformer safety standards and backup ramp-back systems for system overload
Safety	Failure of Control Systems results in plant explosion causing multiple serious injuries	4	1	4 **Very Low**	Transformer safety standards
Business Impact	Failure of Control System results in a compliance breach with the National Electricity Rules	3	1	3 **Very Low**	Overcurrent protection systems
Environmental Impact	Failure of Control Systems results in Plant explosion causing short-term contamination of the environment	4	1	4 **Very Low**	Transformer safety standards and backup ramp-back systems for transformer overload
Customer Impact	Failure of Control Systems results in removal of the generator from the network causing inconvenience to customers	1	1	1 **Very Low**	None

Table D.1: Risk assessment using the Energy Queensland risk framework