University of Southern Queensland

Facility of Health, Engineering and Sciences

Low Load Frequency Support Capability - Collie Power Station

A dissertation submitted by

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Abstract

Energy markets around the world are in a transitional phase, where wind and solar generation are penetrating the markets at unforeseen rates. The desire to decarbonise emissions associated with power generation in Australia, is seen as the first step in meeting our commitments to the Paris Climate Change Agreement. This has had a significant effect upon the electricity grid within Western Australia. The high volume of renewable generation is creating grid instability during times of low demand. This is a result of fluctuations in generation due to the variability of wind and solar. Network strength is no longer as robust because of the loss of synchronous inertia that was behind a grid mainly powered by thermal machines. Many coal fired stations are attempting to become more flexible and change from base load to cyclical operation to assist counteract the irregular nature of wind and solar generation. Collie Power Station is one such station, attempting to improve its operational flexibility. One aspect is the desire that the station move from a current minimum load setpoint of 130MW to 105MW (generated) to assist the station remain dispatched at low load rather than desynchronising it from the grid.

The aim of this dissertation is to model the frequency support capability at 105MW to determine if the station continues to provide frequency support for the grid. The provision of frequency support is an important aspect of grid stability for the West Australian electricity grid. Renewable generation does not currently provide such support service, so the provision must be covered by the reducing number of synchronous machines.

Collie Power Station has been modelled within MATLAB Simulink, with the model successfully verified using the station's historical data. The model has been used to evaluate the frequency support capability at the proposed minimum load set point of 105MW (generated). The results indicate that that the unit can contribute to grid stability when frequency deviations occur. This low load capability enhances the stations ability to support the grid as the transition to even higher levels of renewable generation continues.

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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.

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Glossary of Terms

Ancillary Service	Generation services used by the AEMO to manage the power system safely, securely and reliably in accordance with key technical requirements. The frequency control service is the main service applicable to this dissertation.
Capacity Factor	A measure of a power station's generated output over a given period compared to that of 100% continuous output over the same period.
Dead Band	The sum of increase and decrease in power system frequency before a measurable change in the generating unit's active power output.
Dispatchable Generator	A generating unit that can be dispatched at the request of the market operator according to the market needs.
Frequency Support	Governor response of generation unit to system frequency disturbance to assist restore system frequency to nominal.
Load Rejection	Power station capability to very quickly reduce generation output after a significant over frequency event.
Non-dispatchable Generator	A generating plant that cannot be turned on or off, or regulated to match market requirements (notably wind and solar power).
Paris Agreement	United Nations agreement made in 2016, dealing with greenhouse gas emission mitigation.
ProControl	ABB control system version used at Collie Power Station
Spinning Reserve	Additional power generation that can be made available to the grid to assist stabilise the system, usually during an under-frequency event.
Steam Bypass	An arrangement used to safely divert steam flow from the turbine into the cold reheat steam line.
Thermal Station	Gas turbine or coal fired power station.

Abbreviations

AEMO	Australian Energy Market Operator
DCS	Distributed Control System
ESS	Energy Storage System
LFAS	Load Following Ancillary Services
ICV	Intercept Control valve
MCR	Maximum Continuous Rating
MCV	Main Control Valve
MW	Megawatts
NEM	National Energy Market
OEM	Original Equipment Manufacture
POS30	Process Operator Station (DCS Interface)
PPP	Private Power Provider
PV	Photovoltaic
SWIS	South West Interconnected System
VWO	Valves Wide Open
WEM	Wholesale Energy Market (Applies to the SWIS)

Chapter 1
Introduction

1.1 Introduction

The topic of low load frequency support for Collie Power Station is an employer sponsored research project, which has arisen from changes to the energy market in Western Australia over recent years. The rapid uptake in renewable energy (photovoltaic) by households and the expansion of windfarms by government and private companies has changed the energy market considerably. Solar and wind generation currently have dispatch priority over traditional thermal generation. To compete in the market and facilitate grid stability, it is necessary for thermal units to frequently cycle to low load and cycle off-line when extreme renewable output combines with very low customer demand.

1.2 The Problem

Coal has been the backbone of power generation for many countries over the past 100 years. However, the environmental concern surrounding greenhouse gas reduction is providing motivation for the transition to purely renewable power generation. History has shown that notable engineering achievements occur when the impetus for change is significant. Social and political pressure to meet the targets set by the Paris Climate Change Agreement are providing such motivation.

Currently, there are some challenges associated with large scale renewables that must be resolved as their penetration into the market continues to expand. The unpredictable nature of wind and solar, along with the loss of synchronous inertia, has influenced grid stability in recent years. Concerns for the West Australian network authority include, excess reactive power, excessive voltage levels and frequency stability. Frequency support service requirements are now calculated and scheduled to meet the minimum requirements, whereas these were consistently provided by the multitude of synchronous machines before inverter-based systems commanded such a presence in the energy market.

The uptake in domestic solar has occurred at a rate far beyond that at which the state-owned distribution authority (Western Power) predicted. The network that covers Perth and the South West is known as the SWIS (South West Interconnected System) and is represented in the map shown in Figure 1.1.

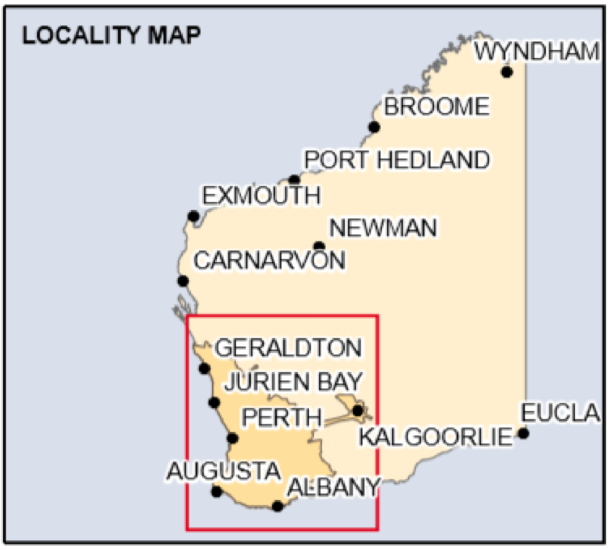

Figure 1.1 The SWIS Boundary (Enhanced Information Service Team 2013)

The SWIS is not connected to the National Energy Market (NEM) and therefore operates as an island. Voltage and frequency stability from interstate generators during times of high renewable input and relatively low demand is therefore unavailable. Traditionally the SWIS has been serviced by medium sized thermal generators remotely located to the main load being the city of Perth. The SWIS is a relatively small grid, with a peak summer demand of approximately 3600MW (AEMO 2019, p. 3).

Typical minimum demand of 1200MW occur in the months of April/May and September/October (known as the shoulder periods) where heating and cooling systems are not in use due to the mild weather. This grid minimum demand value is continuing to drop as the growth in photovoltaic continues to grow. According to Ford (2019, p. 5) current roof top photovoltaic (PV) capacity in the SWIS is at 1.2GW. With an installation rate of 200MW per year, 2GW of capacity will be reached in 2024 (Ford 2019, p. 5). In addition to the domestic contribution of PV's, there are large scale solar and wind projects under construction in Western Australia. The Clean Energy Council Project Tracker (Clean Energy Council 2020) reports, two significantly sized projects are the Warradarge Wind Farm and the Yandin Wind Farm which have generation capacities of 180MW and 214MW respectively. Projects such as this will continue to displace the thermal generation that currently provides system security for the SWIS through the rotation of high mass rotors at synchronous speed.

As an example, the daily penetration of solar into the market is shown in Figure 1.2. The shutting down of thermal generators (gas and coal) to facilitate solar's heavy midday contribution is shown. The rate at which thermal units must start and ramp-up at is significant. This steep power gradient is due to the evening peak demand occurring just as solar output is rapidly declining at sundown.

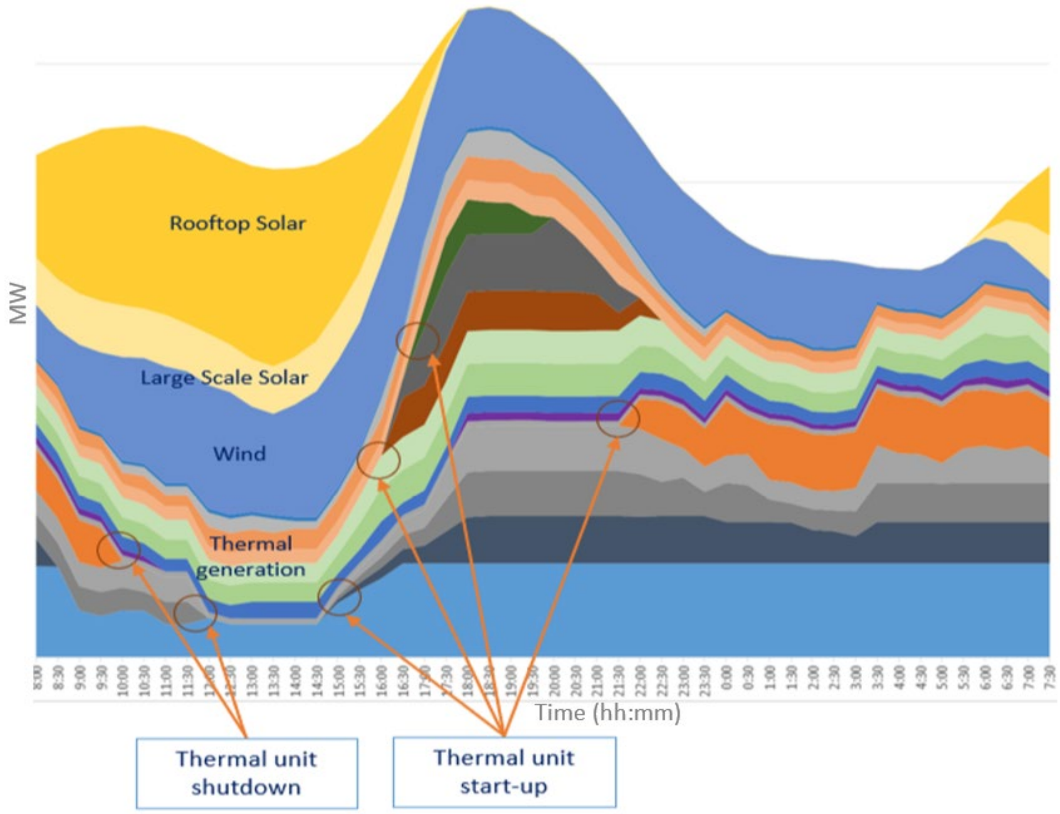

Figure 1.2 24 Hour Dispatch Profile (Ford 2019, p. 6)

Davis (2019) states that the market operator (AEMO) has pointed to a looming risk to supply security for the SWIS. That risk arises because at 700MW of minimal operational demand the voltage in the South West Interconnected System (SWIS) cannot be kept within technical limits. The state is expected to hit that demand level in three to five years (Davis 2019).

At low level of demand, the market operator is unable to keep the required level of synchronous generation on the grid to provide system stability unless a portion of the renewable generation is curtailed (Kirk, A 2020, pers. comm., 17 June). In May 2019, the West Australian Government appointed an Energy Transformation Taskforce to oversee the planning and implementation of renewable infrastructure projects (WA.gov.au 2019). In addition, the task force is to ensure the SWIS remains reliable during the renewable transition and in the long term. The state-owned coal fired stations have a requirement to become more flexible in operation to facilitate stability as part of this transition plan.

1.3 Description of Collie Power Station

Collie Power Station was first proposed in 1991 by the West Australian Government as a 600MW station consisting of two 300MW units. At this time only two coal fired stations existed within Western Australia, Muja - 8 units, (with 1040MW total capacity) and Kwinana 4 units, (640MW total capacity). By 1993 it was decided to build the Collie Power Station to facilitate two units in the medium term but limit the initial build to one.

Collie 'A' was commissioned in December 1999, with a Maximum Continuous Rating of 330MW. The station was built by a joint venture consortium between ABB and Itochu (Boylen and McIlwraith 1994, p. 94).

ABB built most of the station with its own brand of electrical and control equipment whilst Itochu provided the boiler. Collie B was never progressed despite subsequent offers from ABB-Itochu. Collie A was uprated to 340MW in 2006, which required operation with the governor valves wide open (VWO). Minor changes to the soot blower system, rotary air heater and outlet temperature control were made to improve unit efficiency (Lye, H 2020, pers. comm., 23 April).

Whilst owned by the West Australian government, Collie Power Station has been operated and maintained (including engineering) under contract since construction. TW Power Services have held the contract since 2006. Collie Power Station is a highly automated station. Only two operators are present on weekends and nightshift. Low manning levels, high automation, proximity coal mines and a typical net unit efficiency of 35% has traditionally made Collie the cheapest generator on the SWIS. However, cycling to lower load reduces this efficiency and cost effectiveness. Operation at Collie's current minimum load setpoint of 130MW reduces the efficiency to 32%. The unit is displayed in Figure 1.3.

Figure 1.3 Collie Power Station Turbine Generator

Typical capacity factors of 70% - 80% have been observed for the first 17 years of operation. In 2019 this factor reduced to approximately 45%. This trend is shown in Figure 1.4. Plant historical data shows that the annual coal usage has dropped from 1megatonne per year to approximately 500 kilotonnes.

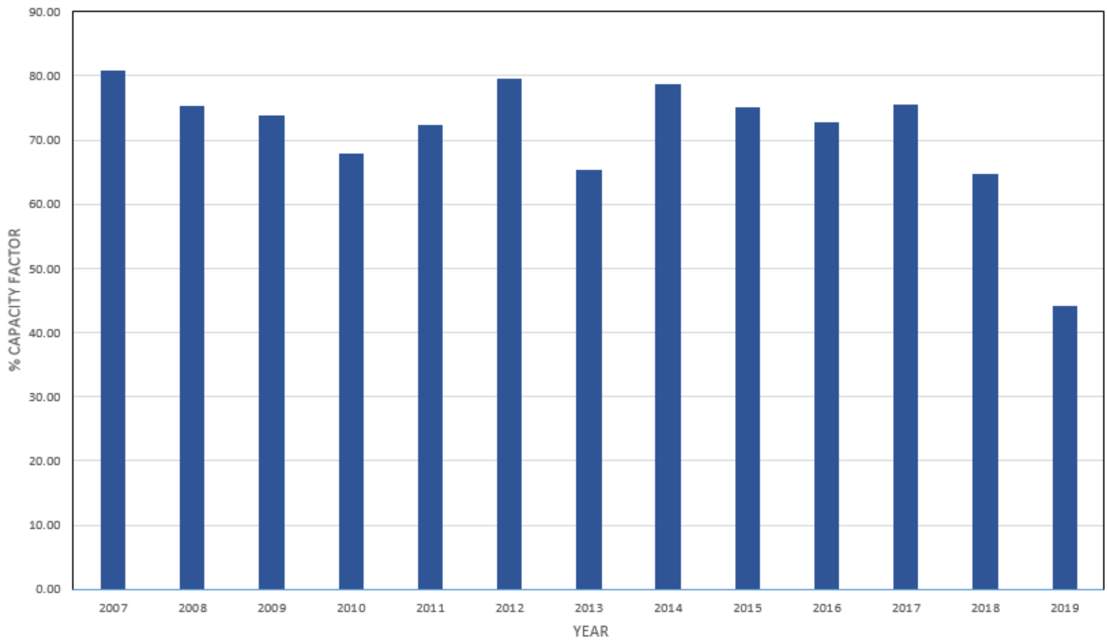

Figure 1.4 Trend of Station Capacity Factor (since 2007)

Inversely to the capacity factor, the number of starts per year has changed from an average of 8 to 23. The proposed number of starts for 2020 is currently 29, with 50 starts estimated for subsequent years. This change in operation is represented in Figure 1.5.

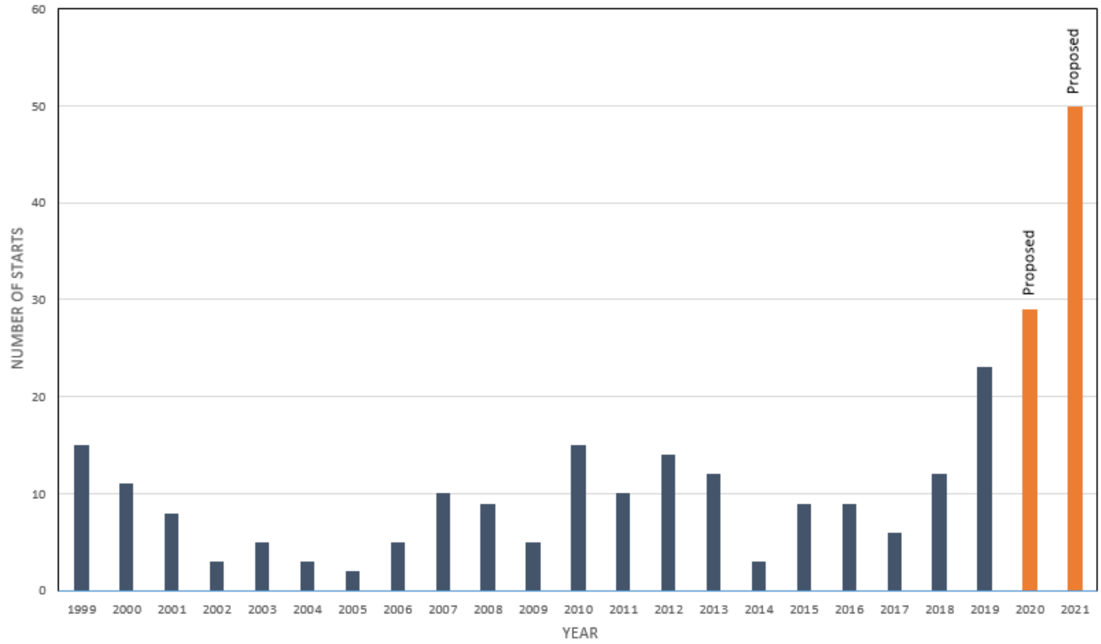

Figure 1.5 Number of Station Starts per Year (since 1999)

Whilst Collie has served the SWIS for approximately 20 years as a base load station, the growth in renewable energy has changed the operational intent from high output baseload to highly cyclical with the majority of time at low load. It is expected that the imposed flexibility requirements will continue to increase, particularly over the coming two to three years.

The requirements to become more flexible includes the following short-term aspects:

- Reduced start up duration
- Reduced start up fuel costs
- Increased ramp rates during load change requests
- Reduction in minimum load setpoint
- Improved frequency support service provision

1.4 Research Objective

This research project is associated with the two final points above. It is proposed that Collie's minimum load setpoint (generated) will be reduced from 130MW to 105MW. This will provide 90MW onto the SWIS as 15MW is consumed by station in-house load. The minimum load set point defined by the OEM was 150MW (45% of original MCR). This was reduced to 130MW (40% of original MCR) in 2017. The turndown of 40% is a typical value for thermal stations so no analysis was conducted, other than a physical trial so that station operational parameters could be evaluated. However, reducing the minimum load to an even lower setpoint of 105MW (30% of MCR) requires engineering analysis of various parameters and equipment to ensure the unit is not adversely affected.

Whist the efficiency of operating Collie at 105MW is reduced to 29.5%, these losses are outweighed by the reduction of thermal stresses when compared to an additional stop/start. Keeping the unit online through short term periods (four to eight hours) of high solar contribution is still preferred, despite the negative trading price of generation which typically occurs when midday solar floods the market.

The effect of operation at 105MW for extended periods upon boiler equipment is currently being evaluated. The boiler OEM - Mitsubishi Hitachi Power Services has been engaged to conduct a study on the boiler to determine the effect of low load upon aspects such as drum life, reheater and superheat tubing, blockages within coal delivery piping, coal burner nozzles and fireball positioning. A study will also need to be performed to determine the minimum safe steam flow for the low-pressure turbine as last row blades are susceptible to overheating when steam flow is minimised.

With a small number of thermal units on the SWIS during these times of low demand and high solar contribution, it is important that these remaining units provide the frequency support services required for grid stability. The aim of the research is to model the support capability at this proposed minimum load setpoint to predict if the unit can provide the support service following a grid frequency disturbance.

1.5 Conclusion

The aim of this research project is to model the ancillary support capabilities at the proposed 105MW, such that the information gained can be utilised as a basis and justification to conduct physical testing. If it is determined that Collie cannot provide frequency support at suitable levels (at 105MW), gas turbines will also need to be dispatched onto the grid to provide the service. This defeats the purpose of allowing Collie to remain dispatched due to the additional fuel costs associated with the gas and running lightly loaded machines in parallel. The knowledge of load rejection and spinning reserve values at low load are just as important as the proposed minimum load setpoint, when the Market Operator is scheduling ancillary support services for the SWIS.

It is expected that the level of load rejection supplied by Collie will be minimal at 105MW, however, a high portion of the current spinning reserve capacity is anticipated. The information gained from the model will be used with the turbine and boiler studies being conducted outside this dissertation, to progress towards physical testing at low load. The final goal is to determine if 105MW is a safe operating setpoint for Collie Power Station and the SWIS.

Chapter 2
Literature Review

2.1 Introduction

The purpose of this research project is to identify the frequency support capabilities in terms of spinning reserve and load rejection for Collie Power Station at low load operation. The requirement to determine these capabilities has transpired due to the impact of renewable energy upon the stability of the SWIS. Photovoltaic panels were not available for domestic consumers at the time of Collie Power Stations construction. At that time, the fuel allocation was primarily coal, gas and a very small amount of wind. This meant that the coal fired stations operated in a base load manner where load changes were slow and predicable. Load rejection and spinning reserve requirement were shared by many thermal machines. With Collie Power Station being the largest single unit on the grid, total spinning reserve requirements for the SWIS usually matched it's output, with a Maximum Continuous Rating (MCR) of 340MW. The large number of synchronous machines could easily share the reserve requirement as it typically equated to a small percentage of their respective MCR ratings. At the time of Collie's commissioning, eight coal fired units were in service at Muja power station and six units at Kwinana. With Collie's contribution, the total generating capacity of coal fired stations (owned by the government) was 2290 MW (Boylen and McIlwraith 1994, p. 56). Current coal fired generation with the SWIS varies between 500MW and 1500MW, which is a significant decrease.

Collie Power Station is not alone in the desire to make the unit operation more flexible. Many thermal stations throughout Australia and around the world are faced with the same issues imposed by the transition to renewable generation. The current energy market in Western Australia requires that the government energy provider (Synergy) supply the Load Following Ancillary Services (LFAS) for the SWIS (Economic Regulation Authority 2020, p. 173). If Synergy cannot meet the service requirements, the market operator can enter into a contract with alternative providers. As the Synergy fleet is primarily responsible for this requirement, the capability of their generation units need to be known (Economic Regulation Authority 2020, p. 173). This includes the capability of individual machines, rather than overall power stations, and must cover all load setpoints (within their normal load profile of each unit).

Whilst the aim of this research focuses on low load spinning reserve and load rejection capabilities, the literature review has been broadened to determine if similar research has previously been conducted. The following are the primary areas of interest:

1. AEMO and Western Power documentation
2. Changes in operation of thermal power stations due to renewable generation
3. Modelling of governor control systems
4. Load rejection and spinning reserve modelling and testing

Significant volumes of literature identify the requirement for coal fired stations to become more flexible in their operation and the issue of grid instability associated with the high-volume penetration of solar and wind generation. Literature was also identified that discussed modelling of load frequency control and load rejection capability.

2.2 Legislation

Firstly, it is necessary to review the legislation and rules that apply to the electricity generation within Western Australia. Of interest are the sections that describe the requirements for frequency support and ancillary services and the differences between these services. At the time of writing this paper, the following documents applied:

1. **Electricity Industry Act**
   The Act is the principle Act which sets out the broad principles used to govern the operation and regulation of the Electricity Industry in Western Australia. (Electricity Industry Act 2004)
2. **Electricity Industry (WEM) Regulations**
   These regulations are subsidiary legislation that outlines how the Act is to be managed, principally defining the different bodies involved in the electricity industry and their responsibilities.
   (Electricity Industry (Wholesale Electricity Market) Regulations 2004)
3. **WEM Rules**
   These rules are subsidiary legislation that provides the commercial rules by which the wholesale energy market operates.
   (Wholesale Electricity Market Rules 2020)
4. **Western Power Technical Rules**
   The rules provide the technical requirements that must be met by Western Power (as the transmission and distribution authority) and all users of the Western Power network.
   (Western Power 2016).

Section 122 of the Electricity Industry Act 2004 provides principle objectives of the electricity market within Western Australia. This section stipulates that the objectives of the market are:

(a) to promote the economically efficient, safe and reliable production and supply of electricity and electricity related services in the South West interconnected system; and

(b) to encourage competition among generators and retailers in the South West interconnected system, including by facilitating efficient entry of new competitors; and

(c) to avoid discrimination in that market against particular energy options and technologies, including sustainable energy options and technologies such as those that make use of renewable resources or that reduce overall greenhouse gas emissions; and

(d) to minimise the long-term cost of electricity supplied to customers from the South West interconnected system; and

(e) to encourage the taking of measures to manage the amount of electricity used and when it is used.

(Electricity Industry Act 2004, p. 117)

From these objectives, it can be seen that the West Australian Government is aligned with the reduction in greenhouse emissions, creating competition in the market, the encouragement of new technology, minimising cost to customers and reliable supply. This has encouraged new market participation from Private Power Providers (PPPs) over the last decade.

WEM Regulations

Under the Electricity Industry Act 2004, the Electricity Industry (Wholesale Electricity Market) Regulations 2004 dictate how the provisions of the act are applied to the electricity industry. Functions are defined for governing authorities, market participants, the rule change panel and system management. General market rule provisions are described which are principle based, without specific technicalities. (Electricity Industry (WEM) Regulations 2004, Section 17 p.11).

WEM Rules

Section 3.9 of the Wholesale Electricity Market Rules outlines the requirements for what is called ancillary services. The AEMO also explains ancillary services within the Guide to Ancillary Services in the National Electricity Market (AEMO 2015). The components of ancillary services that apply to Collie Power Station are spinning reserve and load rejection.

From section 3.9 of the Wholesale Electricity Market Rules the definitions are:

Spinning Reserve Service is the service of holding capacity associated with a synchronised Scheduled Generator or Interruptible Load in reserve so that the relevant Facility is able to respond appropriately in any of the following situations:

(a) to retard frequency drops following the failure of one or more generating works or transmission equipment; and

(b) in the case of Spinning Reserve Service provided by Scheduled Generators to supply electricity if the alternative is to trigger involuntary load curtailment.

Spinning Reserve response is measured over three time periods following a contingency event. A provider of Spinning Reserve Service must be able to ensure the relevant Facility can:

(a) respond appropriately within 6 seconds and sustain or exceed the required response for at least 60 seconds; or

(b) respond appropriately within 60 seconds and sustain or exceed the required response for at least 6 minutes; or

(c) respond appropriately within 6 minutes and sustain or exceed the required response for at least 15 minutes,

for any individual contingency event. (Economic Regulation Authority 2020, p. 170)

Load Rejection Reserve Service is the service of holding capacity associated with a Scheduled Generator in reserve so that the Scheduled Generator can reduce output rapidly in response to a sudden decrease in SWIS load.

Load Rejection Reserve response is measured over two time periods following a contingency event. A provider of Load Rejection Reserve Service must be able to ensure that the relevant Facility can:

(a) respond appropriately within 6 seconds and sustain or exceed the required response for at least 6 minutes; or

(b) respond appropriately within 60 seconds and sustain or exceed the required response for at least 60 minutes,

for any individual contingency event.
(Economic Regulation Authority 2020, p. 170)

The ancillary service that Collie Power Station aims to provide is that of type (a) for both spinning reserve and load rejection. Therefore, the response must be delivered within 6 seconds and maintained for a minimum of 60 seconds. The level of support required is outlined within the Western Power Technical Rules.

Western Power Technical Rules (1st December 2016).

These rules were the only compliance document that power generators had to abide by at the time of Collie's commissioning in 1999. At that stage, Western Power was the generation authority, distribution authority and the governing body.

Section 3.3 of the Rules provides the technical requirements for connection of generating units. 3.3.4.4 describes the frequency control requirements, including the control range.

For dispatchable generating units:

The overall response of a dispatchable generating unit for power system frequency excursions must be settable and be capable of achieving an increase in the generating unit's active power output of not less than 5% for a 0.1 Hz reduction in power system frequency (4% droop) for any initial output up to 85% of rated output. (Western Power 2016, p. 52).

A dispatchable generating unit must also be capable of achieving a reduction in the generating unit's active power output of not less than 5% for a 0.1 Hz increase in system frequency provided this does not require operation below the technical minimum (Western Power 2016, p. 52).

However, additional requirements are imposed upon thermal generating units which extend beyond that required above:

Thermal generating units must be able to sustain load changes of at least 10% for a frequency decrease and 30% for a frequency increase if changes occur within the above limits of output (technical minimum up to 85% of MCR) (Western Power 2016, p. 52).

For dispatchable thermal power generators, it is necessary that 90% of the response is delivered within 6 seconds and must be maintained for a minimum of 10 seconds (Western Power 2016, p. 52). There are no time specifications within which 100% of the response needs to be delivered.

From the WEM Rules and Western Power Rules, the difference between frequency support and ancillary services (for thermal generators) can be defined, along with their respective deliverable measures.

Frequency Support (under frequency event): Generator output increase of 10% MCR, 9% MCR delivered within 6 seconds and sustained for 10 seconds.

Frequency Support (over frequency event): Generator output decrease of 30% MCR, 9% MCR delivered within 6 seconds and sustained for 10 seconds.

Frequency support is compulsory for all generators. If the above criteria cannot be met, an exemption must be applied for from the Market Operator (Western Power 2016, p. 52).

Spinning Reserve (under frequency event): Generator output increase of 10% MCR, 9% MCR delivered within 6 seconds and sustained for 60 seconds.

Load Rejection (over frequency event): Generator output decrease of 30% MCR, 9% MCR delivered within 6 seconds and sustained for 60 seconds.

Ancillary Services are paid resources that extend beyond that of frequency support. Collie is currently paid for spinning reserve and load rejection capabilities. The initial governor response for frequency support and ancillary service is the same as can be seen in the definitions mentioned above. As this research is focused on the initial response, the terms frequency support and ancillary service may be used interchangeably.

2.3 Application of the Rules to Collie Power Station

Applying the WEM regulation (ancillary service rules) to Collie Power Station, the unit should be capable of delivering the response in Table 2.1:

Table 2.1 WEM Ancillary Services Requirements

System Frequency Deviation	**100% Response**	**90% Response (within 6 seconds)**	**Limitation**
Increase	99 MW Load Reduction	89 MW Load Reduction	Gen Output remains > Technical Minimum
Decrease	33 MW Load Increase	29.7 MW Load Increase	Up to initial load of 280.5 MW

Load Rejection is beyond that which Collie Power Station can currently provide. Current rating is 7.5%, within a load range of 180 to 270MW. Whilst technically insufficient (according to the WEM Rules), the AEMO has approved this level of service for Collie Power Station. Figure 2.1 outlines the service capability for that described by the WEM Rules, Collie's current capacity and the realistic capacity (if 105MW can be achieved as the new minimum load setpoint).

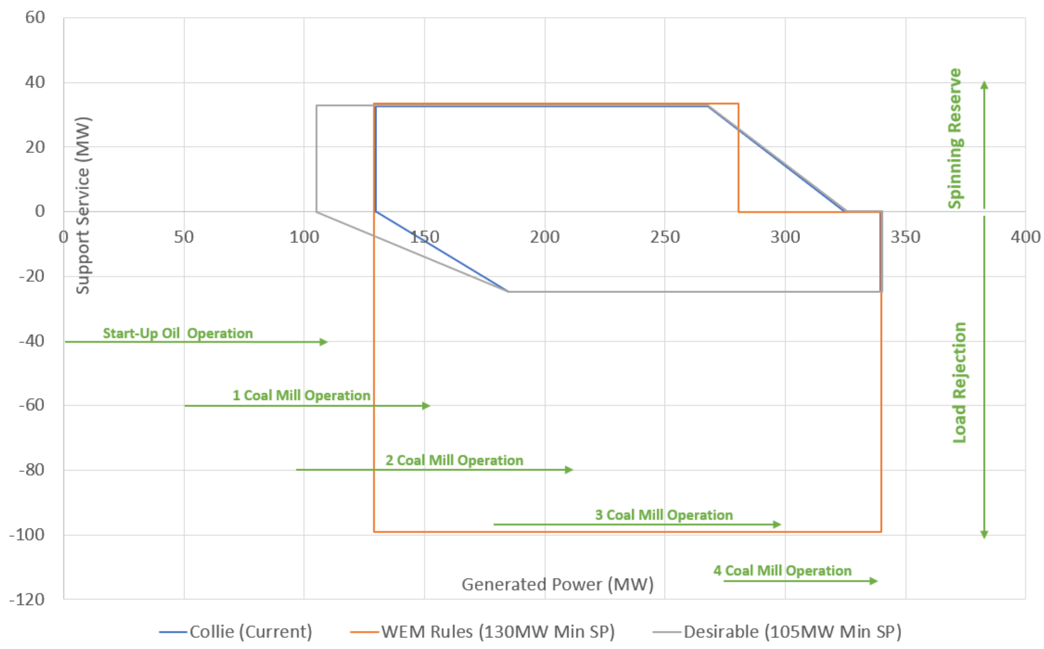

Figure 2.1 Existing Ancillary Service Capability

Figure 2.1 displays the limitations in both spinning reserve and load rejection when measured against the WEM Rules. The limitation is that observed for load rejection. 24.75 MW observed over most of the range is far short of the 99MW required by the WEM rules. This is due to the unit not having a steam bypass to facilitate the rapid disposal of steam.

2.4 Applicable Research

Gorzegno et al.(1983, p. 551). suggest that load rejection capabilities of 50% load can be achieved without the installation of a bypass system but it does result in the lifting of superheater outlet safety valves and potentially drum safety valves. The cost associated with safety valve leakage and refurbishment is significant. Collie Power Station places a high emphasis on avoiding the lifting of safety valves. This has been accomplished through boiler combustion and control system tuning. As the Collie unit does use sliding pressure, the likelihood of lifting safety valves at low load is reduced.

Inoue et al. (2006, p. 1442). explains that load frequency control is an important part in the reliable operation of electric power systems. They continue with a description of slow and fast components as the terms used to describe frequency regulation in Japan. If comparing to the ancillary services described by the West Australian WEM regulations, these are the load following service and the frequency support service respectively.

For the fast component (frequency support action) they suggest that turbine governor response, turbine load reference control and steam pressure change due to valve movement need to be considered in a dynamic model for a thermal power generator (Inoue et al. 2006, p. 1442). These influences are considered in the MATLAB model used for the purpose of this dissertation. As is frequently suggested in thermal power station literature, Inoue et al (2006 p. 1442) defines 40% MCR as the minimum load setpoint. Frequency support requirements to sustain grid stability are not discussed within the paper.

Much research has been identified that discusses the negative impact of cycling coal thermal stations (both in load and dispatch). The consequences of repetitive thermal fatigue are well understood. This is especially so within the USA, where a similar situation occurred when base load coal fired station were displaced by nuclear in the 1970's (Cochran 2013, p. 41). The exacerbated thermal stress and corrosion created by the cycling increased the average Forced Outage Factor (FOF) for North American Coal Generating Stations from 6.4% to 32% (Cochran 2013, p. 41). The key finding from CGS was the ability to cycle on and off and run at lower output (below 40% of capacity) requires limited hardware modifications but extensive modifications to operational practice (Cochran 2013, p. 41). The main operational change was the minimisation of ramp rates to curtail the thermal fatigue (Cochran 2013, p. 43).

Unfortunately ramp rates for Collie Power Station cannot always be minimised due to the response required to counteract the uncontrolled and often dramatic change in renewable generation rates. Cochran also reports that flexibility to very low outputs at CGS's stations were provided by utilising gas ignitors for flame stability. Again, this is not an option at Collie as start-up is performed on diesel oil and the current environmental licence does not allow the burning of oil at times other than station start-up or coal mill transitions to provide flame stability (Environmental Licence L6637/1995/15 Collie A Power Station 2014). The consideration of grid frequency support in CGS's case would not have been required because the coal fired units were displaced by nuclear stations, which are also synchronous machines and capable of frequency provision. In addition, the size of the grid in North America would have been of much greater size than that of the SWIS.

2.5 Conclusion

Collie Power Station finds itself in an unprecedented position. The high levels of solar and wind generation on an islanded grid are making the scheduling of essential support services difficult for dispatch controllers. Not only is it desirable for Collie to increase its flexibility to a 30% MCR turn-down ratio, but it is also desirable that it provide some degree of ancillary services at this new minimum load. The modelling conducted under this dissertation is the first step in identifying the unit's frequency support capability at this anticipated setpoint.

Chapter 3

Methodology

3.1 Introduction

The desire to constrain carbon within the energy market has had a significant effect upon grid strength and stability within Western Australia. As the transition to a renewable market continues, it is important that the existing conventional thermal stations support this significant transformation by changing from base load operations to flexible entities that can quickly respond to the fluctuations created by the currently uncontrolled renewable generation systems. The AEMO reports that renewable technologies that connect to the SWIS via inverters do not inherently provide all the previously unvalued yet essential system support services with the characteristics provided by synchronous generation (AEMO 2019, p. 13). One aspect of this imposed flexibility requirement is the reduction in minimum load setpoint. Collie Power Station is proposing to reduce is minimum generated setpoint from 130MW to 105MW. Whilst this does not seem a significant change, Collie is in an unprecedented position due to the relatively small size of the SWIS. Collie currently provides ancillary services for the SWIS, which is important for grid stability. 105MW has been proposed for Collie as it is the set point at which the station operates on two coal mills with each just above the minimum coal feed rate of 22.5 tons/hour. Two mill operation provides some security in terms of flame stability, reducing the likelihood of a unit trip due to flameout. The level of ancillary support at a generation setpoint of 105MW is currently unknown and is thus the purpose of this research.

3.2 Options Available to Collie Power Station

The determination of frequency support capabilities for Collie Power Station could be determined in several ways. The options available to Collie Power Station include:

1. Determination by low load trials
2. Determination by governor response testing
3. Modelling via engagement of the generator OEM or control system engineer
4. Modelling within a suitable software package by an undergraduate

Each option has advantages and disadvantages, that will now be discussed:

Determination by low load trial - This appears to be the simplest method as the unit could simply be reduced to the 105MW generation setpoint. However, it would then be necessary to wait for a suitably sized frequency excursion to occur so that the response can be evaluated. The unknown timing of a grid frequency event could require extensive periods of operation at low load.

This makes Collie unavailable for full load during times of high demand and means that the station is operating at reduced efficiency for an extended duration.

In addition, the effect of extended operation at low upon the boiler and turbine is yet to be determined. Low steam flow through a turbine can overheat rear stage blading and result in failure. Catastrophic failure of turbine blades in this manner can result in instant retirement of the unit. Low steam flow demand from the boiler also results in low exhaust temperatures.

This can also cause rapid fouling of air heater, electrostatic precipitators and exhaust duct steelwork. In addition, coal pulverises have a minimum safe throughput. Below this setpoint, there exists the potential for table to roller contact from the loss of sufficient coal bed. Coal mills can explode as a result of this minimal flow and metal to metal contact creating an ignition source within a dust laden environment.

Determination by governor response testing - This requires liaison with the AEMO to schedule testing. An outline of the proposed tests must be submitted to the AEMO for approval prior to the testing. Simulation of frequency deviation would need to be performed in incremental steps to ensure unit stability does not cause a unit trip as a result of the testing. The time required for this is estimated at 8 – 10 hours, which is still an extended duration and exposes the unit to the same potential damage mentioned above.

Modelling via engagement of the generator OEM - The generator and turbine/governor control system were manufactured and commissioned by Asea Brown Boveri (ABB). ABB sold the generator/turbine division to Alstom which has since been purchased by General Electric (GE). ABB Switzerland still maintain support for Collie's turbine control system (ABB ProControl P13). However, over the past 10 years, it has been noted that much of the engineering expertise associated with the system have retired since Collie was commissioned in 1999. The P13 system is also the only one of its type within Australia. Therefore, local OEM support is not available. An alternative is the engagement of a consultant control system engineer whom is familiar with turbine control systems.

Modelling within a suitable software package by an Undergraduate - A safer strategy than determination by trial, is to have the governor-turbine-generator modelled so that the frequency support capabilities can be estimated. A number of software packages exist that could be used: MATLAB, DIgSILENT PowerFactory, GNU Octave or Scilab xcos. The station does have a DigSILENT model for the high voltage network (from the station design documents in 1997), however it does not include a governor model. A current version of the DIgSLIENT software is not owned by the station to facilitate running of this model or utilising it for the addition of the governor system. The experience gained by completing the research was considered significant enough to allow it to be performed by an undergraduate.

MATLAB was utilised for USQ subjects through the author's bachelor and was thus considered as the best option due to being the most familiar. MATLAB Simulink was originally proposed to mimic Collie's governor control logic, using function blocks. However, the use of MATLAB pre-defined models for the steam turbine and governor system (power_thermal.slx) were suggested by the USQ project supervisor (Ahfock, T 2020, pers. comm., 23 April). The use of MATLAB provides repeatability for similar USQ research projects, due to the availability of the student version.

Modelling of the unit using MATLAB Simulink provides a cost-effective method of identifying the potential support capabilities, which can then be used to assess if progression to physical testing is warranted.

3.3 Model Validation

Software modelling requires that the model be suitably validated to ensure suitability and accuracy. The method by which the MATLAB model will be validated is by comparing simulated frequency excursions to those captured by the stations ABB historian database - Plant Generation Information Manager (PGIM). The main signals that will be used for the response comparison are:

1. Frequency
2. Generator Output
3. Main Control Valve position (MCV1 – 4)

As the station uses the KKS system for equipment and control system identification, the signal tags in Table 3.1 apply:

Table 3.1 Validation Signals & KKS

Signal Name	KKS Tag Name
Calculated Frequency	11MAY01DU110 XJ51
Generator Output (Gross)	11BAC10CE300 XQ21
MCV1 Position	11MAA11CG012 XJ01
MCV2 Position	11MAA12CG012 XJ01
MCV3 Position	11MAA12CG011 XJ01
MCV4 Position	11MAA11CG011 XJ01

By using the PGIM database, a significant number of frequency excursions can be considered over the past few years. PGIM facilitates the comparison of frequency events at various load setpoints between generation outputs of 130MW to 340MW. This reduces the amount of field work required as part of the research phase as data does not need to be collected by external measuring equipment. It also provides a safer option, as it removes the requirement to enter the unit measurement panels for the connection of metering equipment to capture frequency excursions. Exposure to Voltage Transformer (VT) voltages of 110V AC are avoided. The risk of station trip or transducer damage due to incorrect metering connections are also circumvented.

3.4 Data Analysis

Once the model is validated using the PGIM history for high load generation setpoints, it can be used to estimate the unit's performance at 105MW. Correlation of results below 130MW may also be used to confirm the model results.

PGIM historian can provide signal data in trend form, or it can be extracted into Microsoft Excel using the ABB built PGIM add-in. Both Excel and PGIM trends can be used to compare the model results for the validation phase. Limits of acceptability in the comparison must be defined to provide confidence in the model. As this is the first time that the MATLAB model (power_thermal.slx) has been customised to represent the turbine/generator at Collie Power Station, a wider window of acceptance is considered warranted. For the purpose of this research, the following measures are defined for "goodness of fit" in the validation phase:

0% > Model error < 5%	Excellent validation accuracy
15% > Model error < 5%	High validation accuracy
25% > Model error < 15%	Acceptable validation accuracy

Where the % error is defined:

$$\%\ error = \mp \frac{(PGIM\ signal\ response\ at\ 6\ sec - Model\ signal\ response\ at\ 6\ sec)}{signal\ measurement\ range}$$

and time is measured from the start of the deviation event.

25% error may appear to be too wide for acceptance. However, the model does not currently utilise a function to account for the pressure variation observed when MCV positions react to the excursion. The boiler pressure within the steam turbine function block is a constant 1 PU. PGIM has revealed that pressure loading (or loss) of the boiler drum during a reasonable frequency excursion is typically 1 to 1.5MPa which approximates 0.1 PU. This has a dynamic effect upon the turbine mechanical input power and thus the governor valve setpoints. For this reason, the 6 second response has been selected for the validation.

This calculation will be applied to all signals mentioned in Table 3.1.

An example of a frequency deviation event is shown on the PGIM trend (Figure 3.1). The frequency dip is observed (trend line 6). MCV1 and MCV3 are wide open (trend lines 1 & 3), with MCV 2 and 4 "kicking" in response (trend lines 2 & 4). The response of the generator MW is represented (trend line 5). The initial response and the sustain time for the deviation can be evaluated for each deviation.

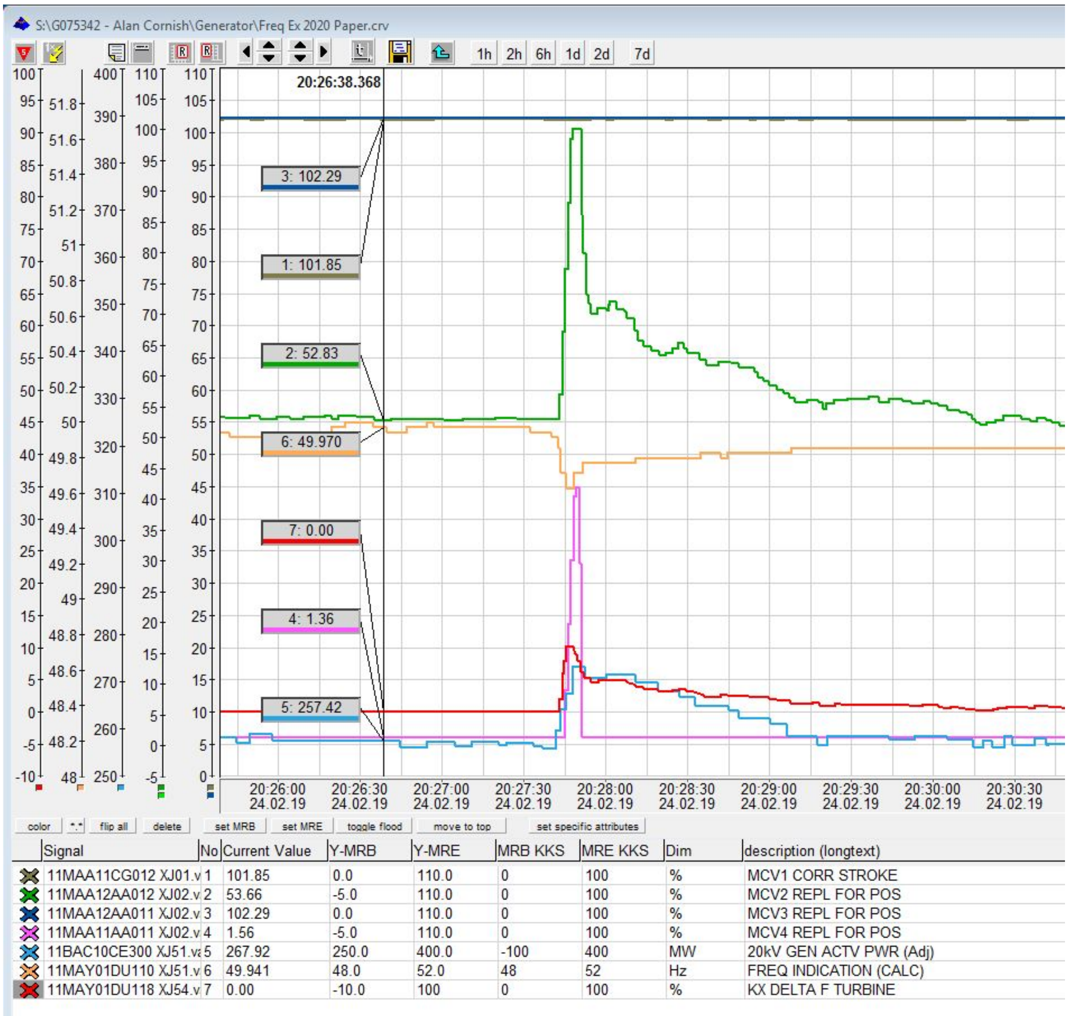

Figure 3.1 Frequency Event 24th February 2019

Frequency deviations have increased over the past few years as the amount of synchronous inertia on the SWIS has reduced. This means that the past two years of PGIM history should be suitable for the comparative analysis. Events times for recorded grid frequency deviations can be identified by utilising the analogue signal: Frequency Inflection K*Delta*F (11MAY01DU112 XJ03). By using the PGIM Excel addin, the analogue can be filtered to determine when frequency deviations have occurred. A table of frequency deviations has been recorded using this function and is contained within Appendix D - Table D.1.

3.5 Key Assumptions

A number of assumptions have been made in the proposed methodology. These are now discussed.

The MATLAB Simulink model (power_thermal.slx) will be used as the template for building the station model. It is assumed that the power_thermal.slx s is suitably engineered and representative of coal fired thermal power station response. The parameters associated with the model are assumed to be appropriately flexible and not limited by constraints that inhibit suitable entry of Collie Power Station's specific parameters. It is also assumed that the defined parameters within the MATLAB model will be available within the ABB OEM manuals, such that Collie's characteristics can be appropriately programmed into the model.

Because the (power_thermal.slx) model is principally designed to evaluate sub-synchronous resonance, it is assumed that resolution will be suitable for analysis of frequency deviation. The presumption has also been made that logic blocks available within MATLAB Simulink (2020a student version) will be suitable to represent logic within the ABB P13 ProControl governor logic (if changes are required to better customize the model). In a similar manner, it is also assumed that logic blocks within the P13 ProControl system are not customized by ABB such that they cannot be understood.

As PGIM will be used to collect the unit response to past frequency deviations, it is assumed that the data will be suitable for evaluation, both in resolution, deviation size, and the signal availability (not all P13 ProControl signals report to the historian). Signal resolution is discussed further in Chapter 4 – Model Design Considerations.

A significant assumption has also been made by presuming that validation at high load generation setpoints means that the model will be valid at the low load setpoint of 105MW. However, this is an accepted method of qualitative validation in both industry and research applications. Physical testing that follows this dissertation will confirm the results obtained and may facilitate refinement of the model for research that builds upon the results of this research.

3.6 Ethical Considerations

World governments and the energy industry and are facing mounting pressure from social and environmental bodies and activists. The mining of coal can be damaging to the environment, with factors such as ground water contamination and land clearing often experienced. Whilst the mining leases within Western Australia are well regulated and the station has environmental emission limits, there remains an obligation to minimise pollution and strive for a renewable energy market. The West Australian Government is actively seeking to do this.

By making Collie Power Station more flexible, the proportion of SWIS power derived from the renewable sector can continue to rise. Specifically, the low load aspect of this flexibility requirement means that Collie Power Station is contributing to the reduction in greenhouse gases from SWIS coal fired units. In addition to reducing annual coal consumption, the station can reduce the number of times that the unit has to by cycled off-line for momentary periods ranging between 4 and 12 hours. This will reduce the annual volume of diesel burned to fire the boiler from flame off condition. The burning of diesel during start-up has a visual impact as carbon residue cannot be captured by the electrostatic precipitators. The current emission licence (Environmental Licence L6637/1995/15 Collie A Power Station 2014) ignores emission limits during start-up as the combustion is considered as abnormal. By minimising the number of start-ups these periods of abnormal emissions can be reduced.

Collie Power Station is a significant asset to the West Australian Government with considerable remnant life. A responsibility to balance Collie's return on investment with the desire to decarbonise the power sector with a safe transitional strategy is therefore essential. As power storage methodologies improve, the requirement to have ancillary service provision from synchronous machines will reduce. In the short term, the transition to renewable energy must be made in a manner that does not jeopardise the security of a modern society that is heavily reliant upon electrical power. The cost of the state-wide blackout in South Australia in September 2016 was reported by the ABC news at $367m (Harmsen 2016). With the SWIS being an island, the restoration of the grid from a total blackout could be more complicated than that experienced by South Australia and must be avoided.

3.7 Conclusion

The combined use of MATLAB Simulink and the PGIM historian for this research provides a cost-effective and safe approach to estimate the unit response to frequency deviation. PGIM offers significant volumes of quality data for the model validation and eliminates the requirement for field instrumentation to record frequency deviation events. In addition, the use of Excel to filter frequency deviation timestamps further simplifies the data collection phase significantly. This approach provides a justified method of evaluating the level of ancillary support and is a critical step in the process of making Collie Power Station more flexible in the changing energy market.

Chapter 4
Model Design

4.1 Introduction

The original proposal was to model the governor logic programmed into the ProControl system within MATLAB. To accomplish this, a simplified logic diagram was constructed to provide a basis of design. This included the ProControl P14 unit control logic, ProControl P13 automatic control logic and the ProControl P13 base controller logic. This diagram combines many pages of logic across the ProControl systems to represent the frequency regulation and deviation logic. To simplify the logic diagram, two assumptions were made:

1. The unit is in Load Operation Mode.
2. The unit controller is selected to Boiler Follow Mode.

Following the completion of this diagram, the USQ Project Supervisor. suggested that a predefined turbine-governor model would provide a suitable basis for the research (Ahfock, T 2020, pers. comm., 23 April).

This suggestion was accepted as a better option for the modelling process. However, the diagram remained useful in the modelling process and provided understanding of the interconnection of the ProControl P14 and P13 Automatic and Base Controllers. The constructed overview diagram is displayed in Figure 4.1. Logic associated with the frequency dead band and the droop control settings are represented at grid coordinates D5 of the diagram. The function blocks are generally self-explanatory; however, block descriptions are available within the ABB P13 Basics and Applications Training Manual (ABB 2010).

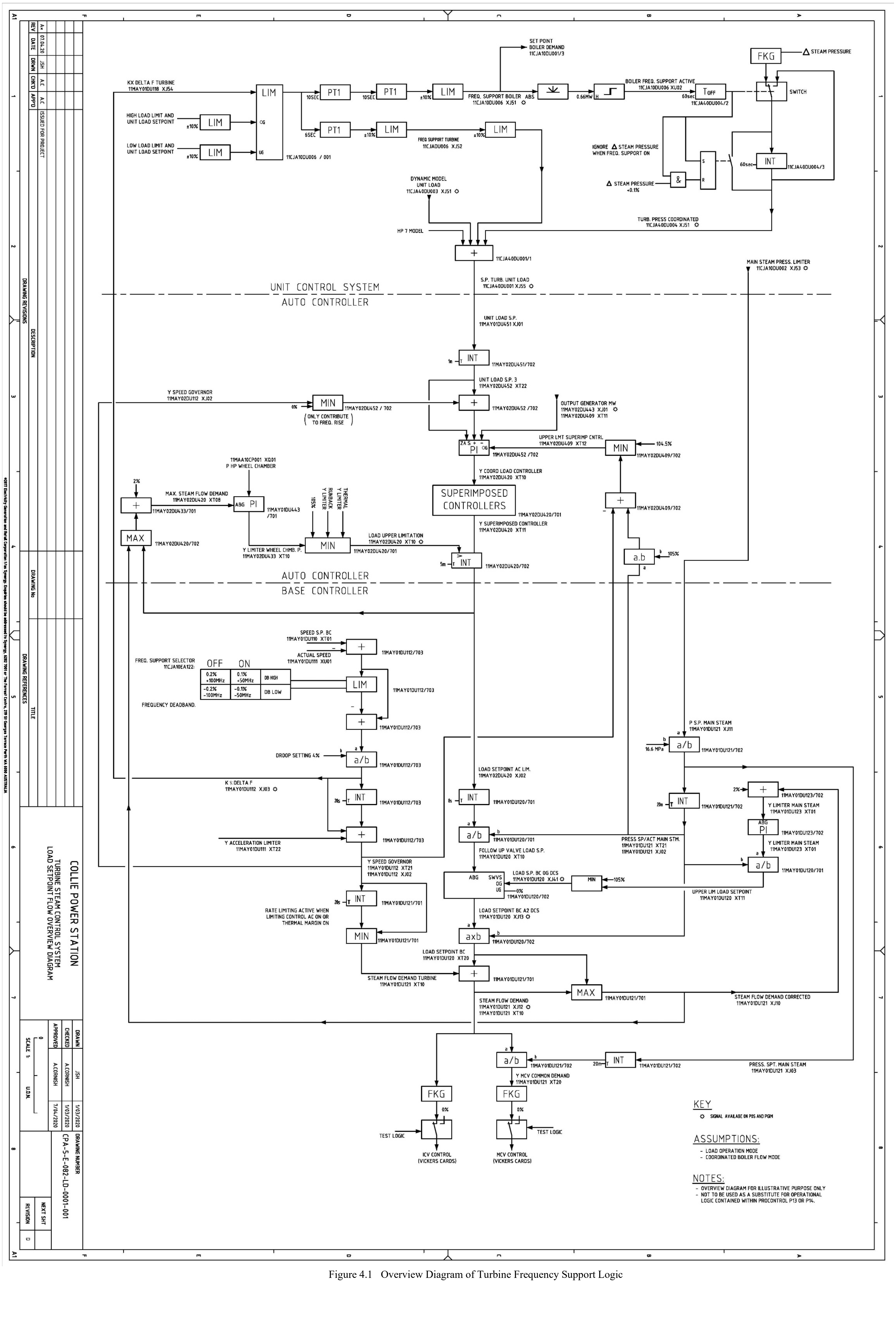

Figure 4.1 Overview Diagram of Turbine Frequency Support Logic

4.2 Signal Resolution

The resolution of signals used in the analysis is an important aspect to consider. Historian systems are renowned for lower resolution, which is intentional in saving server memory. Regarding PGIM, the resolution also varies between signals. This is due to resolution of field instrumentation and the resolution of the DCS through which the instrumentation feeds the data to the historian. Figure 4.2 displays a minimum step change of 29mHz for the generator frequency, when it is displayed in PGIM. Note that the frequency is calculated from the turbine speed.

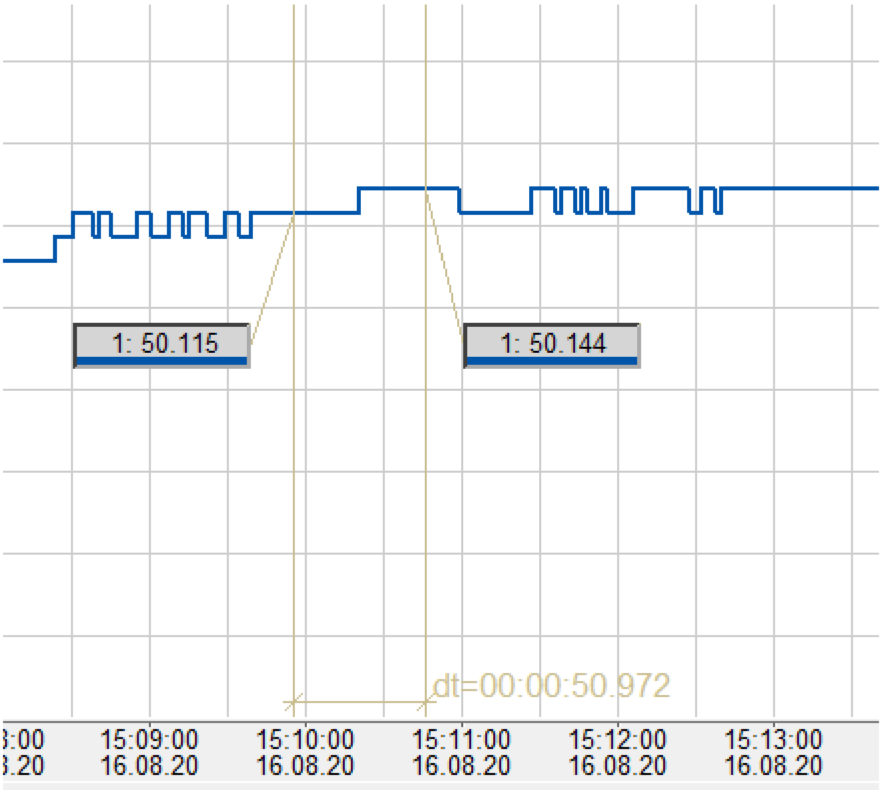

Figure 4.2 PGIM Resolution of Frequency Signal 11MAY01DU110 XJ51

In this instance, the DCS is the limiting factor. Many of the turbine control signals are passed between the turbine control system (ABB ProControl P13) to the main DCS (ABB ProControl P14). This is done to accommodate the Operator Interface Called POS30 (Process Operator Station, Version 30), which operates via the P14 System. Figure 4.3 is a representation of the speed probe measurement from the speed sensors to the DCS, through to the historian. Note that the turbine droop controller has a resolution of nine bit for the speed signals, which is much higher than that which is transferred to the historian. Governor response to the turbine valves are therefore appropriately responsive.

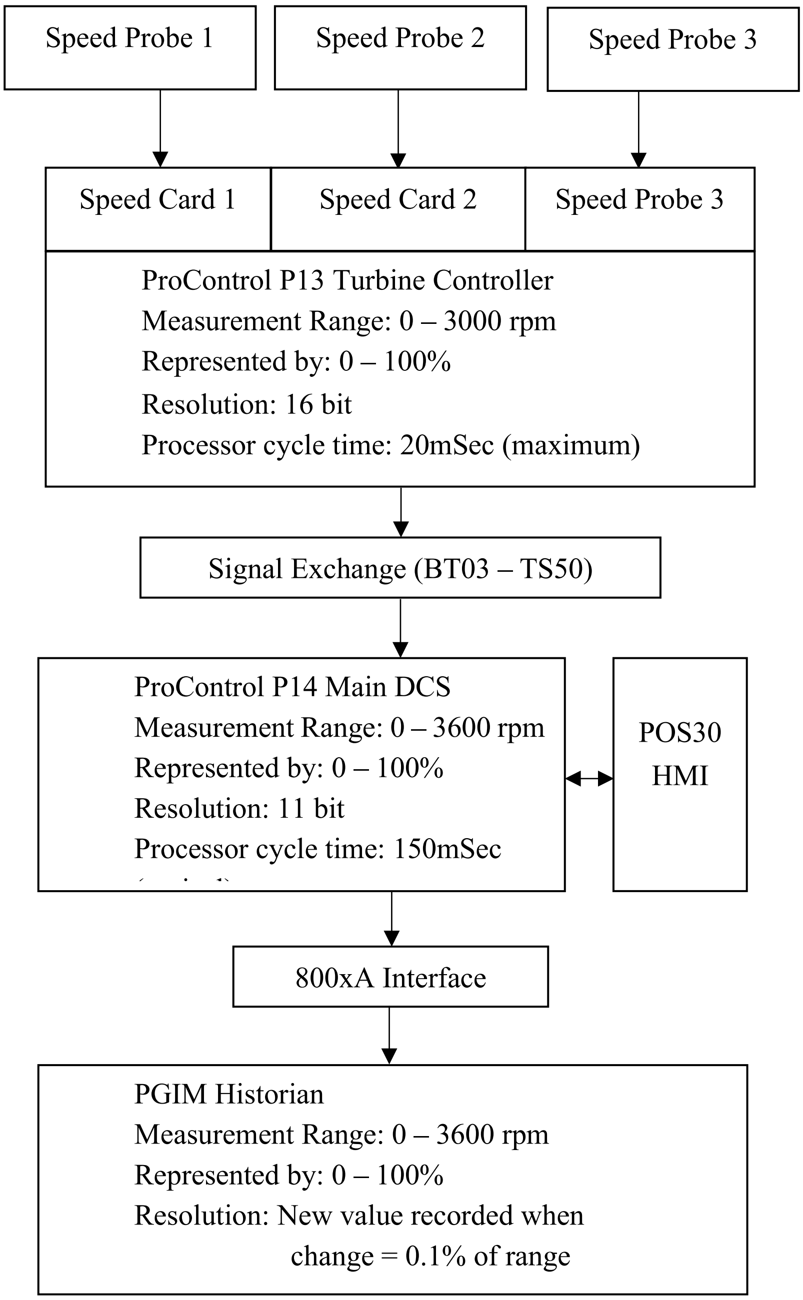

Figure 4.3 Speed Signal from Probe to Historian

The P14 DCS resolution of 11 bits over a range of 0 to 3600 rpm:

$$Resolution = \frac{3600}{2^{11}} = 1.75\,rpm$$

Considering resolution in frequency:

$$Resolution = \frac{1.75}{60} = 0.029Hz$$

This is equal to the step size observed in the PGIM trend of Figure 4.2.

MCV position feedback and generator output resolutions are suitable for this research. Whilst the frequency signal is acceptable for evaluation of frequency deviation under this dissertation, the resolution may be too coarse for other research such as that involving transient response. Consideration of signal resolution for all signals is necessary, as it must meet the research requirements. If deemed unsuitable, external high-resolution equipment may require physical connection.

4.3 MATLAB Model Customisation

The original model (from the MATLAB library) uses a speed regulator for the governor position control as shown in the LHS of Figure 4.4.

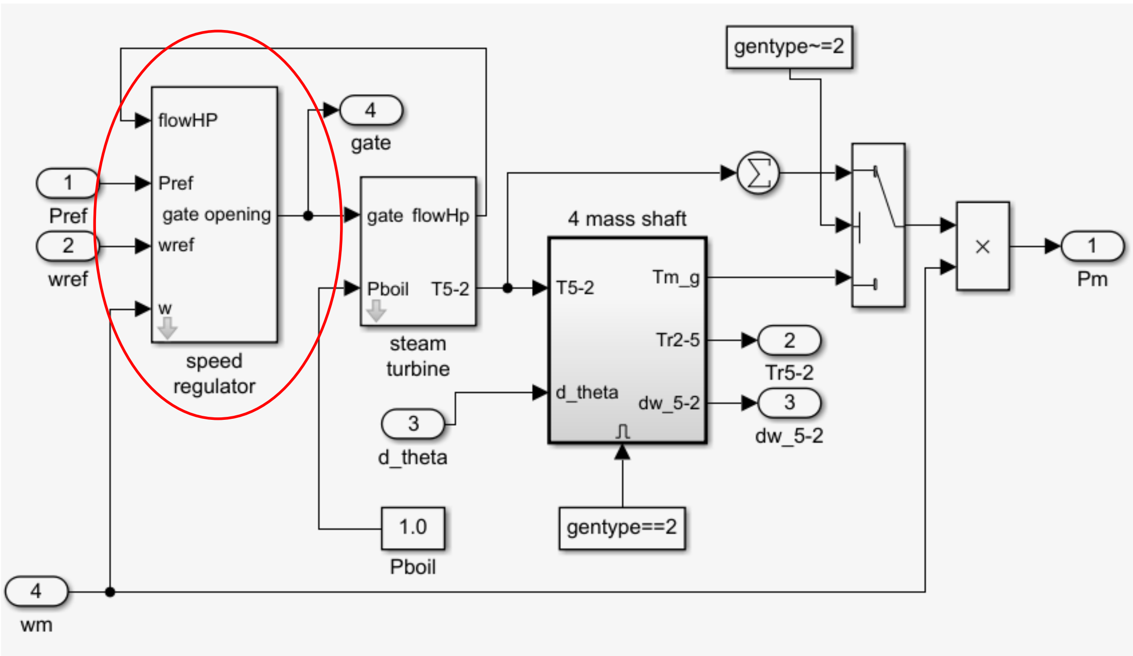

Figure 4.4 MATLAB Model Governor Logic Diagram

This speed regulator block has been replaced with logic blocks that replicate that programed within the ProControl P13 turbine governor controller. Several function blocks are under the mask called Governor in Figure 4.5.

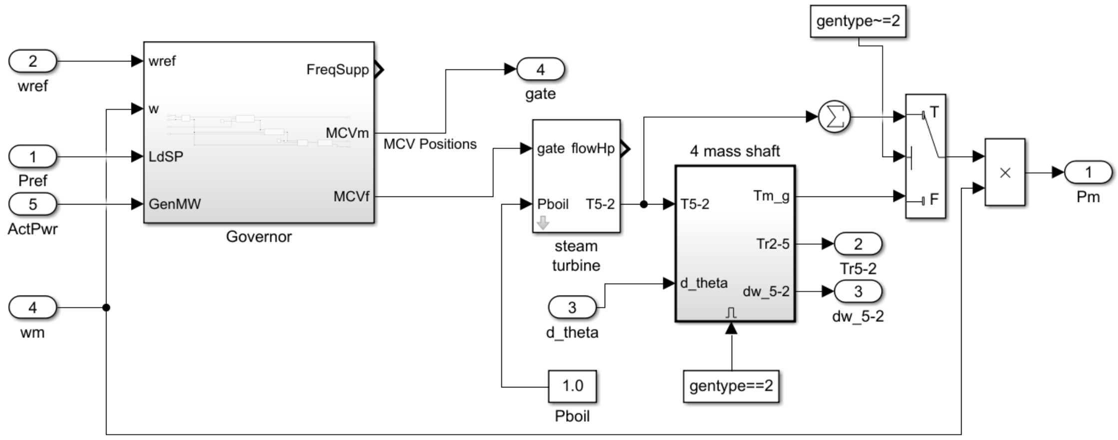

Figure 4.5 Modified Governor Controller

The MATLAB model and associated masked components (programmed under the Governor block) are displayed in Appendix C. By customizing the model to represent the governor logic programmed at Collie Power Station, the individual Main Control Valve (MCV) positions can be used to evaluate the model response to frequency deviation.

Unfortunately, the addition of the main control valve characterization blocks significantly impacted the processing time of the model. This characterisation is displayed in Figure C.7 within Appendix C. As a result, it was decided that the acceleration limiters that restrict valve movement should be left out of the customisation, to avert further increased processing time.

4.4 PGIM History

The prevalence of frequency deviations observed by the station's control system and recorded by PGIM have increased in recent years. Upon analyzing these events it was found that whilst the number of deviations had increased, the number that provided useful data were few. Many of the significant deviations were slow drifts in frequency rather than due to an instantaneous loss of load or generation. Frequency deviations (below 50Hz) that had occurred whilst Collie was at or near rated output also meant that the response of the governor valves could not be used to compare actual event with the model.

To provide higher validity to the data used from PGIM, it was decided to use history gained during testing that was performed under another site project. In July 2020, load swing testing was performed at 190MW and 270MW to improve boiler fuel response logic. Several tests were performed over three days of testing as shown in Figure 4.6. The trend displays the generator frequency as calculated from the turbine speed.

Progressive changes were made to the logic in the process of this testing, which did change the unit response over the three days. However, the information gained over these three days provided data at two initial load setpoints, which improved repeatability in measurement. The load swings also provided step responses, whereas some grid-based frequency excursions displayed deviations that were progressive in action.

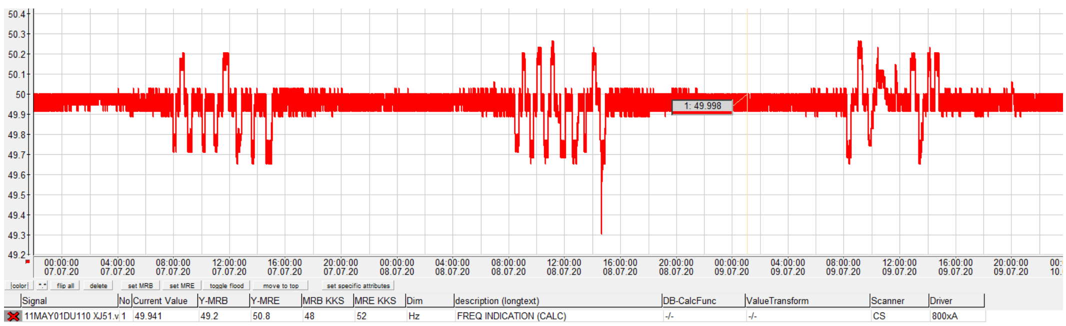

Figure 4.6 Calculated Frequency During Boiler Response Testing 7th - 9th July 2020

Whilst the spikes in Figure 4.6 suggests that the grid frequency changed due to these tests, this is not the case. The injected offset is added to the turbine speed prior to the droop controller such that the governor valves respond to the simulated step in turbine speed. The calculated frequency (shown in Figure 4.6) is therefore simulated and the turbine-generator remains locked into the grid frequency of 50Hz. That being said, Collie is a large unit on a small grid and often provides more than 10% of the SWIS demand. Due to the significant contribution from Collie, the testing over these three days did show that large load steps do cause frequency deviations on the SWIS. This is shown in Table D.2 of Appendix D, where the modulating valve movement is very similar for dead bands of 50 and 100mHz. The 50mHz dead band should result in greater valve movement but has been limited by the system frequency changing as a result of the test itself. It is imperative that such testing is coordinated with the AEMO and Western Power System Control so that the SWIS is not placed at risk.

A summary of the valve movement for respective load swings (steps) are contained in Table 4.1

Table 4.1 Summary of MCV Movement per Load Swing (at 6 seconds after event)

Load Setpoint (MW)	Dead band (mHz)	Step (mHz)	Step (MW)	Average of Valve Movement for Test (%)			
				MCV 1&3		MCV 2	
270	50mHz	-200	+24.75	Test Not Performed			
	100mHz		+16.5	100	100	47	69
	50mHz	+200	-24.75	100	100	47	32
	100mHz		-16.5	100	100	47	33
	50mHz	-250	+33	100	100	47	73
	100mHz		+24.75	100	100	47	72
190	50mHz	-200	+24.75	73	100	0	48
	100mHz		+16.5	72	100	0	25
	50mHz	+200	-24.75	73	60	0	0
	100mHz		-16.5	73	61	0	0
	50mHz	-250	+33	73	100	0	56
	100mHz		+24.75	73	100	0	42

The consistency in the initial MCV positions for each load swing can be observed. This provides a good basis to verify the MATLAB Simulink model outputs. The +/-5% load swing data (as provided within Appendix D) has been ignored for the purpose of the verification table as the main areas of interest are the regions beyond +/-7.5%.

4.5 Conclusion

The history captured under simulated frequency deviation testing proved more suitable for the model analysis than actual grid frequency deviations. However, the use of the ABB PGIM historian to validate the MATLAB model still proved to be a suitable methodology for the research. Further enhancements could be made to the model to match the response of the ICVs associated with the Collie unit.

Chapter 5

Model Validation

5.1 Introduction

The use of a computer model to predict an outcome requires that the model accuracy be defined. The model can only be validated if the results can be compared against repeated experimental evidence or observational assessment. Fortunately, the station historian (PGIM) already contained generator and NCV position history that could act as authentication for the model predictions.

5.2 Model Validation Results

Following customisation of the MATLAB Simulink model, the results were compared to PGIM trend history for frequency events where large load swings had occurred. Generator output and main control valve movements were recorded for these events and are displayed in Table 5.1 below. For each parameter, the following defines the recording:

1. Initial – Recorded value immediately prior to excursion event
2. 6 Second – Recorded value 6 seconds after excursion event
3. 12 Second – Recorded value 12 seconds after excursion event

For each validation test, the % error displays the difference between the PGIM history and the MATLAB model for the 6 second response.

Section 3.4 of the Methodology defined proposed accuracy regions for the model validation. The criteria setpoints are repeated:

Model error < 5%	High validation accuracy
15% > Model error < 5%	Good validation accuracy
20% > Model error < 15%	Marginal validation accuracy

Referring to Table 5.1, deviation percentages highlighted in yellow are those that are beyond 15%, which was defined as the error margin for good validation accuracy. Whilst MCV2 and MCV4 received marginal accuracy in some test, the Generator Output Power and MCV1&3 displayed high and good accuracy validation respectively.

The lower accuracy of MCV4 was not unexpected as the valve is the last utilised in the sequence when the governor is controlling in partial arc mode. In this mode, MCV1 and 3 operate in parallel and are the modulating valves up to 60% load. MCV2 then controls the load up to 90% output. MCV4 then acts to control the last 10% output. 100% valve movement to control 10% of the unit output means that this valve is very responsive to small load changes and thus pressure variation. What was defined as marginal validation accuracy in Section 3.4 – Data Analysis is considered reasonable for the level of model refinement progressed thus far.

Table 5.1 Model Validation Table

MODEL VERIFICATION

Load Setpoint	Sliding Scale Pressure	Validation Test Number	Dead Band	Frequency Step	Expected Output Response		Generator Output Power			MCV1&3			MCV2			MCV4			Test Data Reference
							Initial	6 Second	12 Second	Initial	6 Second	12 Second	Initial	6 Second	12 Second	Initial	6 Second	12 Second	
MW	Mpa		mHz	%	MW		MW	MW	MW	%	%	%	%	%	%	%	%	%	
270	16.6	**1**	+/-100	-0.4	286.5	**PGIM History**	270	285	289	100	100	100	47	63	62	0	0	0	Test 7/07/20 10:55
						MATLAB Simulink	270	282	286	100	100	100	55	73	72	0	0	0	Test 9 20200919
						% Error		**0.9**	**0.9**	**0.0**	**0.0**	**0.0**	**-8.0**	**-10.0**	**-10.0**	**0.0**	**0.0**	**0.0**	
		2	+/-100	+0.4	253.5	**PGIM History**	270	255	255	100	100	100	47	31	33	0	0	0	Test 7/07/20 08:30
						MATLAB Simulink	270	240	238	100	100	100	55	41	41	0	0	0	Test 10 20200919
						% Error		**4.5**	**5.2**	**0.0**	**0.0**	**0.0**	**-8.0**	**-10.0**	**-8.0**	**0.0**	**0.0**	**0.0**	
		3	+/-100	-0.5	294.75	**PGIM History**	270	287	297	100	100	100	47	86	64	0	15	5	Test 7/07/20 12:30
						MATLAB Simulink	270	290	296	100	100	100	55	100	100	0	38	23	Test 11 20200919
						% Error		**-0.9**	**0.3**	**0.0**	**0.0**	**0.0**	**-8.0**	**-14.0**	**-36.0**	**0.0**	**-23.0**	**-18.0**	
190	15.35	**4**	+/-50	-0.4	214.75	**PGIM History**	190	213	215	73	100	100	0	48	38	0	0	0	Test 8/07/20 13:26
						MATLAB Simulink	190	214	216	79	100	100	7	41	37	0	0	0	Test 12 20200922
						% Error		**-0.3**	**-0.3**	**-6.0**	**0.0**	**0.0**	**-7.0**	**7.0**	**1.0**	**0.0**	**0.0**	**0.0**	
		5	+/-50	+0.4	165.25	**PGIM History**	190	168	166	73	59	60	0	0	0	0	0	0	Test 9/07/20 14:32
						MATLAB Simulink	190	167	165	71	61	61	7	0	0	0	0	0	Test 13 20200919
						% Error		**0.3**	**0.3**	**2.0**	**-2.0**	**-1.0**	**-7.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	
		6	+/-50	-0.5	223	**PGIM History**	190	220	224	73	100	100	0	57	44	0	0	0	Test 9/07/20 13:23
						MATLAB Simulink	190	221	228	79	100	100	7	50	44	0	0	0	Test 14 20200922
						% Error		**-0.3**	**-1.2**	**-6.0**	**0.0**	**0.0**	**-7.0**	**7.0**	**0.0**	**0.0**	**0.0**	**0.0**	

Validation for generator and MCV1 & 3 (at 6 seconds) are represented in Figure 5.1. As MCV1 and MCV3 are the only valves used at low load, the validation is considered acceptable to progress the modelling at the proposed setpoint of 105MW.

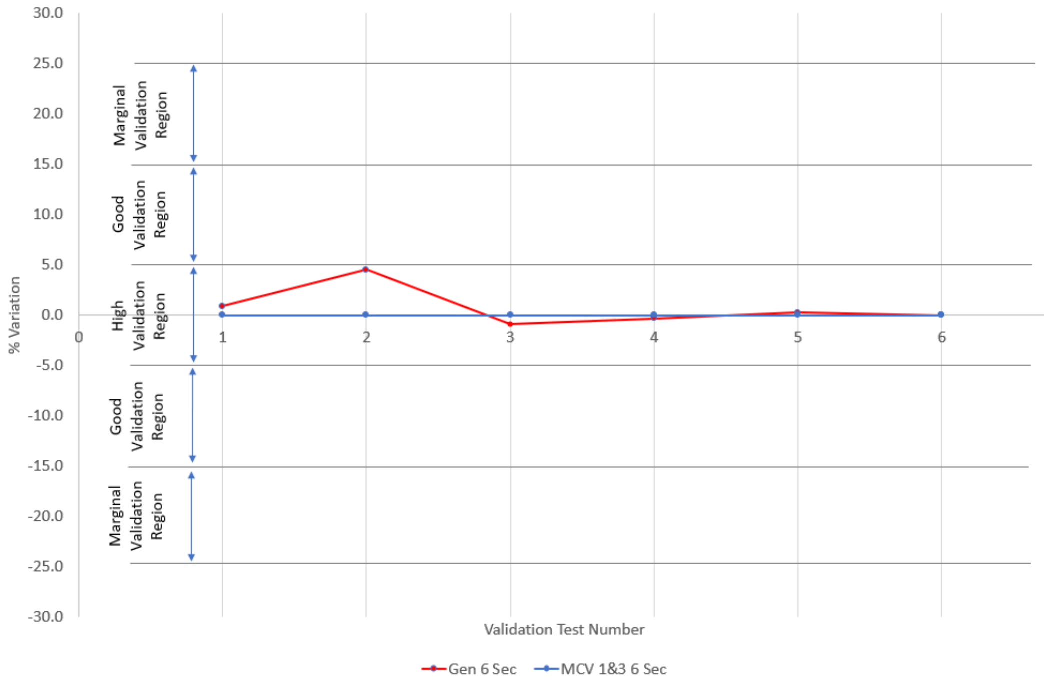

Figure 5.1 Model Validation Error (Generator and MCV1&3)

The validation has been performed at the 6 second response as this is the initial response period of the ancillary service for which Collie is contracted to supply.

Whilst the 6 second governor valve and the generated output response have been the main measurements used for validation and evaluation of the model, Figure 5.2 is an example of a trend comparison between the PGIM history and the MATLAB Simulink model (at a one second sample rate).

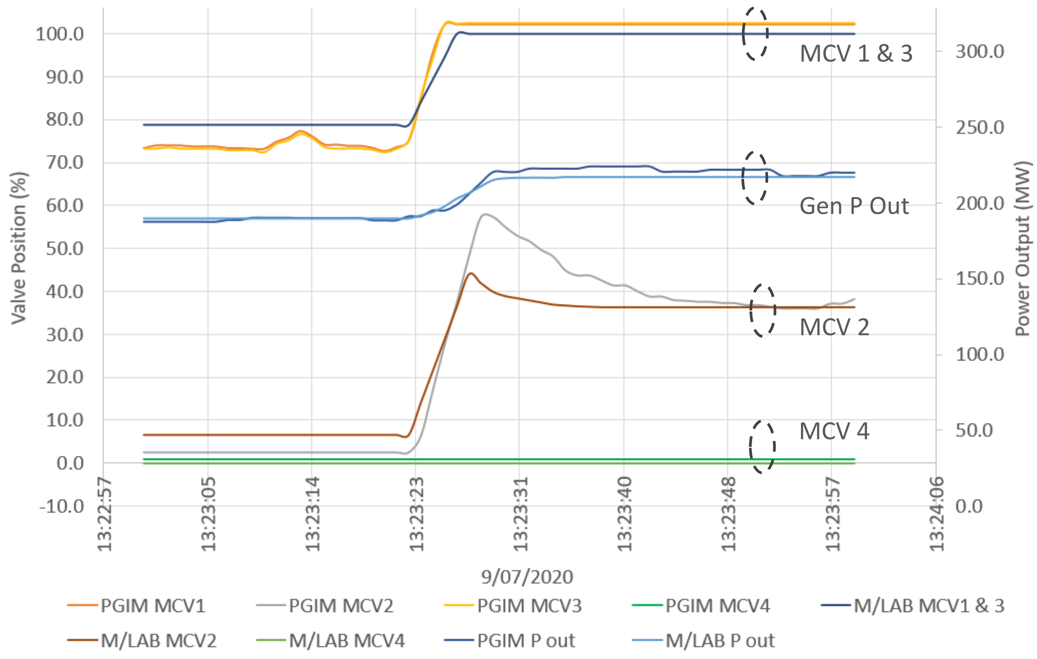

Figure 5.2 PGIM vs MATLAB Simulink Results

Whilst some variation is observed, the comparison shows the relative accuracy and supports the model validation. This information relates to and correlates with validation test number 4 on Table 5.1.

5.3 Conclusion

The comparison of history captured by the PGIM historian and the MATLAB model proved high validation for the Generator output and governor valves 1 and 3 (MCV1&3) at 190MW and 270MW. This was not only for the 6 second response, but also the 12 second result.

Further model refinement could be performed to improve validation of MVC2 and MCV4. This would include boiler drum pressure components. However, the model has proven valid and is therefore suitable to represent the unit response to frequency deviation at a generation setpoint of 105MW.

Chapter 6

Model Results

6.1 Introduction

The aim of this research project is to model the frequency support capabilities at the proposed new minimum load setpoint of 105MW (generated). The model has been successfully validated in preparation for simulation at low load.

6.2 Results

Running of the model at 105MW indicates that the unit can provide frequency support (in terms of spinning reserve) at 10% MCR as required by Section 3.3.4 of the Western Power Technical Rules (Western Power 2016, p.52) The model also indicates that the unit can sustain the support as required by generation units employed to provide ancillary services (Wholesale Electricity Market Rules 2020, p. 167). As the AEMO require that Collie operate at 50mHz dead band, the model was run with this setting. The results are shown in Table 6.1. Graphical representation of the results are shown in Figure 6.1. Frequency reduction of 200mHz and 250mHz (which results in load increase) are shown in the first and third bar graph sets.

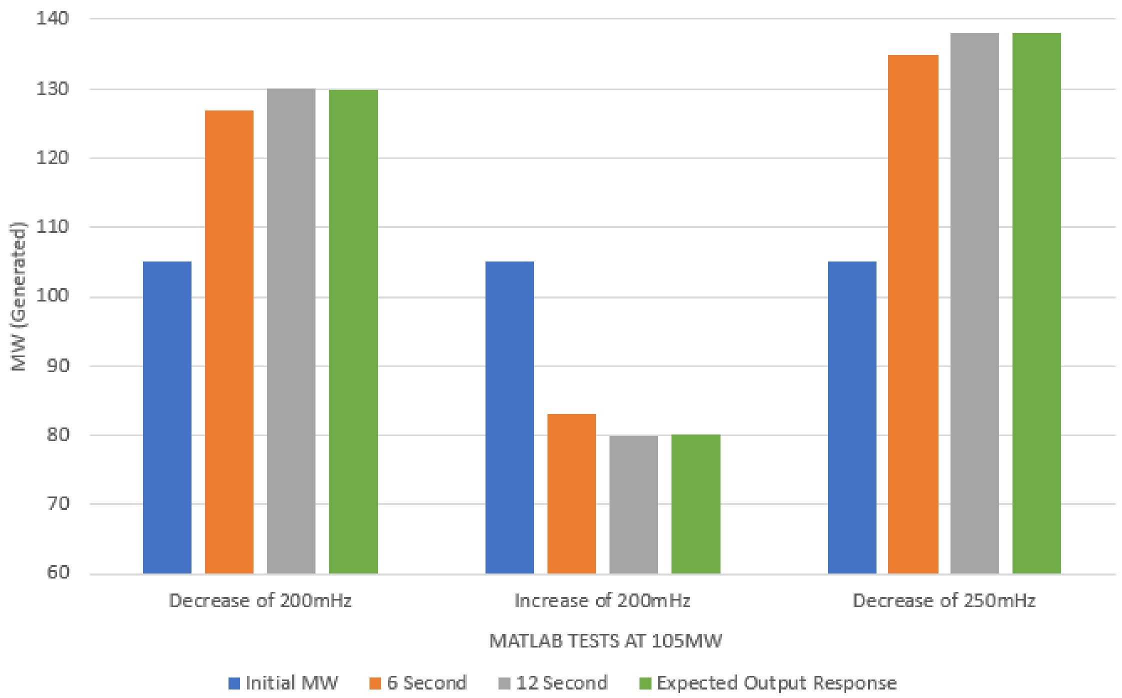

Figure 6.1 Model Response from SP of 105MW (generated)

Figure 6.1 also displays the modeled load rejection capability in the center bar graph set. Whilst it does not meet the Technical Rules requirements of 30% MCR, it is in line with the 7.5% MCR rating that Collie currently operates with (between 130 – 340 MW generated).

Table 6.1 Model Results at 105MW (Generated)

MODEL RESULTS AT 105MW (GENERATED)

Load Setpoint	Sliding Scale Pressure	MATLAB Test Number	Dead Band	Frequency Step	Expected Output Response		Generator Output Power			MCV 1&3			MCV2			MCV4			Reference
							Initial	6 Second	12 Second	Initial	6 Second	12 Second	Initial	6 Second	12 Second	Initial	6 Second	12 Second	
MW	Mpa		mHz	%	MW		MW	MW	MW	%	%	%	%	%	%	%	%	%	
105	10	**1**	+/-50	-0.4	129.75	MATLAB Simulink	105	127	130	49	54	54	0	0	0	0	0	0	Test 15 20200919
		2	+/-50	+0.4	80.25	MATLAB Simulink	105	83	80	49	43	43	0	0	0	0	0	0	Test 16 20200919
		3	+/-50	-0.5	138	MATLAB Simulink	105	135	138	49	56	55	0	0	0	0	0	0	Test 17 20200919

The information gained from the model has been used to define a proposed capability envelope as displayed in Figure 6.2. The extension of the envelope from the minimum load setpoint of 130MW to 105MW is represented. The 24.75 MW (7.5% MCR) load rejection capability at 105MW is not displayed in Figure 6.2. The load rejection line tapers from -24.75MW support at 160MW generated, to 0MW support at 105MW generated. This is due to the logic associated with the minimum load setpoint contained in ProControl P14 Unit Load Control function 11CJA40DU001 and Frequency Support Correction function 11CJA10DU006. A frequency deviation (in the positive direction) at the minimum load setpoint (105MW) will cause the governor valves to respond (close in), as displayed by Test 2 of the MATLAB Simulink model in Table 6.1. However, the P14 logic will quickly restores the governor valve positions to that commanded by the minimum load setpoint. This is important logic as it ensures that the coal mills are not driven below their safe minimum flow rate. It also prevents the unit from tripping due to a boiler flame-out created by the sudden loss of fuel on two mill operation.

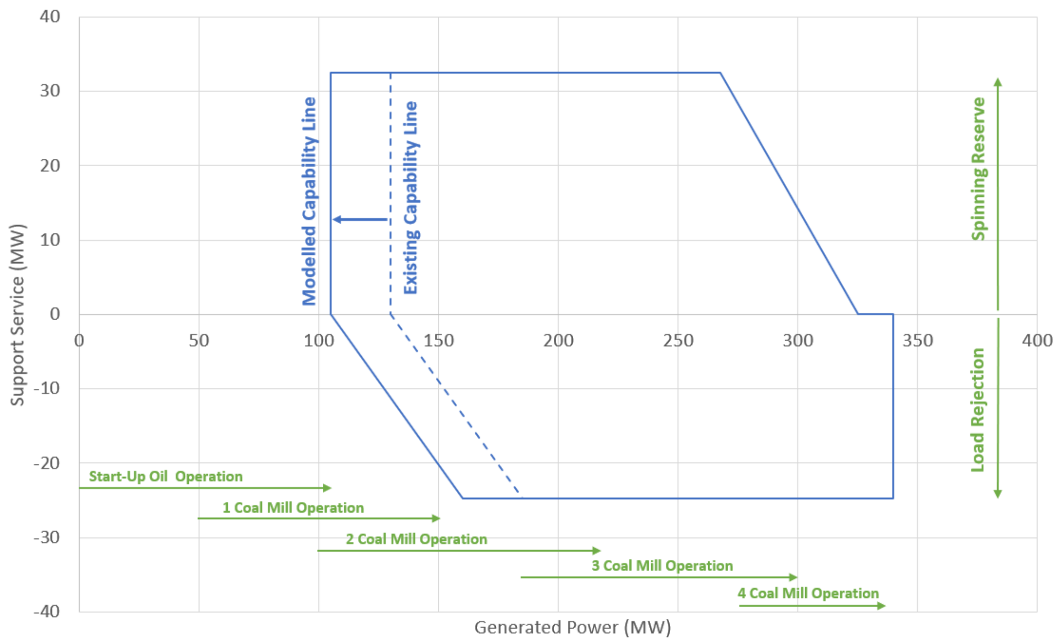

Figure 6.2 Proposed Support Capability Chart

The capability envelope represented in Figure 6.2 is slightly different to that initially proposed in Section 2.3 - Figure 2.1. The load rejection support capability of -24.75MW was not expected to extend from 180MW down to 160MW (generated). The parallel shift of the load rejection line was identified through examination of the logic that makes up the control system.

6.3 Conclusion

The model results indicate that the unit can provide the same level of ancillary service at 105 MW (generated) as that which the unit provides at 130MW. Operation at 105MW is at the lowermost fuel flow for two coal mill operation. The limitation of load rejection at low load is important to ensure boiler combustion stability through a frequency deviation. Further model refinement could be performed to match the output to that recorded within the PGIM history.

Chapter 7
Conclusion

The research under this dissertation set out to analyse the frequency support capability for Collie Power Station at a load setpoint well below that at which the unit currently operates. The desire to operate the unit at lower load has been borne by the changing energy market within Western Australia. The transition to a renewable energy market currently requires that grid stability be provided by thermal synchronous units. However, the high level of renewables penetrating the sector has made it difficult to keep the required level of thermal machines on-line. By operating Collie Power Station at a lower generation output, the unit is more likely to remain in-service during times of high renewable generation.

The modelling performed within MATLAB Simulink has indicated that Collie Power Station can provide both spinning reserve and load rejection capabilities at the proposed minimum load set point of 105MW (generated). The modelled levels of support match those currently provided at 130MW (generated). Verification of the model at 190MW and 270MW against the station historian has substantiated the model accuracy. However, before the ancillary support capability chart (as displayed in Figure 6.2) can be adopted as operational, it must be further validated by physical testing. This will be arranged with the AEMO and Western Power System Control in 2021.

Whilst Collie Power Station is a large machine on a relatively small grid, the flexibility requirements imposed on SWIS thermal generators will likely be faced by thermal generators in the NEM over the coming years. The model constructed under this dissertation could be further customised to determine ancillary capability for these machines as the constraints currently observed in the SWIS intensify on the east coast.

Chapter 8

Recommendations for Further Work

The aim of this dissertation was to model the frequency support capability of Collie Power Station when operating at a generator setpoint of 105MW. This has been successfully completed and the results shown that the Collie unit should be capable of providing 10% MCR spinning reserve and 7.5% MCR load rejection.

Confirmation of these results by physical testing is now required. This can only proceed once the low steam flow observed at 105MW is deemed acceptable for extended periods of operation and does not damage the unit or place components at risk of failure.

The inclusion of the acceleration limiters (as programmed within the ProControl P13 base Controller) would further enhance the accuracy of the model. This would require the industrial license version of MATLAB Simulink to facilitate greater processing capability. The logic within ProControl P14 which limits the load rejection response within the capacity of the current coal mill configuration could also be included within the MATLAB model.

Since starting this dissertation, Synergy have proposed to model all Synergy-owned SWIS generators within PowerFactory-DIgSILENT. The information compiled under this dissertation could be useful in building and validating the model for Collie Power Station made within PowerFactory. The customised MATLAB Simulink governor model could be easily written within PowerFactory and would provide greater simulation accuracy for Collie power Station.

The proposed modelling will be done in preparation for the WEMR (Wholesale Energy Market Reform). According to Energy Reform WA, the aim of the market reform is to deliver several improvements to the WEM:

- To enable efficient dispatch of energy and ancillary services in order to deliver least cost electricity to customers.
- To ensure system security and reliability arrangements are able to accommodate an increasing penetration of renewable energy generators and changes to the profile of electricity consumption.
- To ensure an effective market power mitigation regime, limiting the potential for distortion of market outcomes to the detriment of electricity consumers.
- To facilitate a more responsive capacity pricing regime, delivering clear signals for the efficient entry and exit of capacity to the market.

(Energy Policy WA 2018)

The second of these market reform improvements is aligned exactly with the outcomes of this dissertation. The operation of Collie Power Station at a lower minimum load set-point and the provision of frequency support assists ensure system security and reliability as the penetration of renewables continues to expand.

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Legislation

Electricity Industry Act 2004 (WA)

Electricity Industry (Wholesale Electricity Market) Regulations 2004 (WA)

Environmental Licence 2014 L6637/1995/15 Collie A Power Station (WA)

Wholesale Electricity Market Rules (2 July 2020) (WA)

Appendix A
Project Specification

ENG 4111/2 Research Project

Project Specification

For:	Alan Christian Cornish
Topic:	Auxiliary Services Capability at Low Load Operation – Collie Power Station
Supervisors:	T. Ahfock
Sponsorship:	Faculty of Health, Engineering & Surveying
	TW Power Services – Collie Power Station
Project Aim:	To investigate the load rejection and spinning reserve capabilities of Collie Power Station at low load operation. To compare the results with the requirements imposed by the WA Technical Rules and the AEMO.

Program:

1. Research the auxiliary services minimum requirements imposed by the WA Technical Rules.
2. Research the auxiliary services minimum requirements imposed by the AEMO.
3. Build a model of the governor and fuel control system (using MATLAB Simulink).
4. Test the model using the station historian data from previous frequency deviation events (130MW to 340MW)
5. Use the model to analyse the auxiliary services capability at the proposed low load setpoint (90MW)
6. Compare the results to the requirements set by the above authorities.
7. Utilise the model to propose new tuning parameters / logic at low load operation to improve the capability.

As time and resources permit:

1. Engage control system consultant engineer to verify results obtained in Simulink model.
2. Design and verify parameter / logic changes within the station control system.
3. Perform the parameter / logic changes if a station outage permits.
4. Arrange frequency step testing with Western Power System Control and the AEMO.
5. Perform frequency step testing to verify new parameters and logic.
6. Provide a report to the AEMO detailing the results of the tests.
7. Seek from the AEMO, a statement approving the new auxiliary services capability.

Appendix B

Equipment Information

The following nameplates and OEM information is used within the MATLAB Simulink Model to customise parameters.

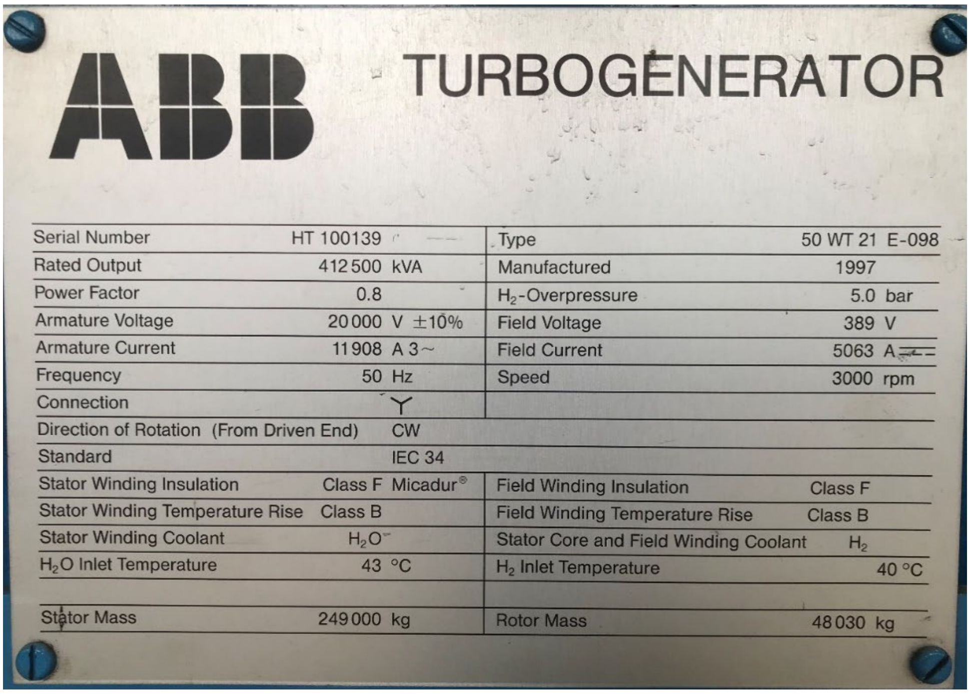

Figure B.1 OEM Generator Nameplate

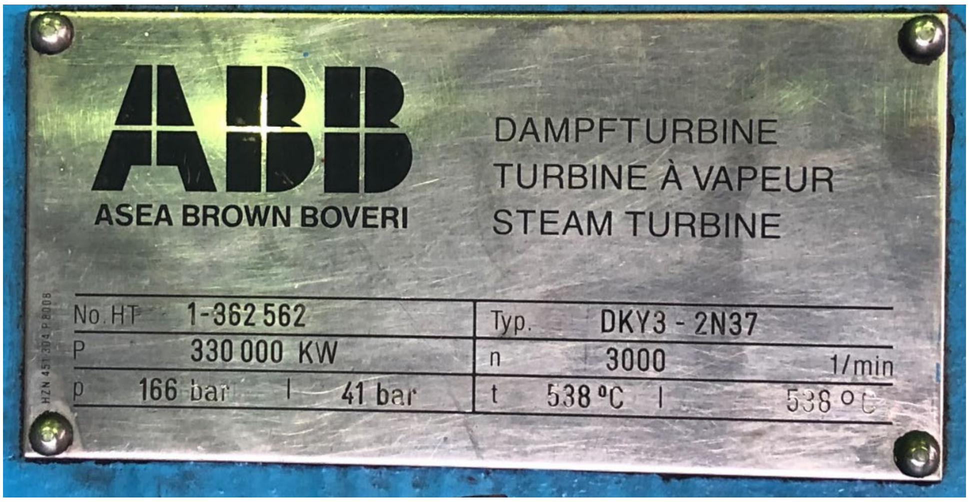

Figure B.2 OEM Turbine Nameplate

Generator Type **50WT21E–098**
Serial No. **HT100139**

Rating data

Rated output	:	412.5	MVA
Max. output (at cos phi = 0.8)	:	428.5	MVA
Rated voltage	:	20	kV
Variation from rated voltage	:	± 10	%
Rated current	:	11.9	kA
Power factor (cos phi)	:	0.8	-
Rated frequency	:	50	Hz
Variation from rated frequency	:	± 3	%
Number of poles	:	2	-
Number of phases	:	3	-
Rated speed	:	50	s^{-1}
Connection	:	⅄	-
Direction of rotation (viewed from DE)	:	clockwise	-
Rated field voltage	:	389	V
Field voltage at max. output	:	403	V
Rated field current	:	5 063	A
Field current at max. output	:	5 245	A
Short-circuit ratio	:	0.51	-
Efficiency at rated output (Standard)	:	98.5	%

Standards

Standards	:	IEC34	-

Figure B.3 Generator Datasheet (ABB Itochu Ltd 1999, p. 115)

Time constants (calculated values)

Direct-axis transient short-circuit time constant	T'_d	:	0.89	s
Direct-axis subtransient short-circuit time constant	T''_d	:	0.03	s
Direct-axis transient open-circuit time constant	T'_{do}	:	5.9	s
Armature winding short-circuit time constant	T_a	:	0.35	s

Resistances and capacitances (calculated values)

Stator winding resistance per phase (at 20 °C)	:	1.79	mΩ
Rotor winding resistance (at 20 °C)	:	0.06	Ω
Stator winding capacitance (all phases connected)	:	0.47	µF
Rotor winding capacitance to ground	:	0.75	µF

Short-circuit

Sudden short-circuit current:

– Peak value based on full-load excitation and rated voltage (calculated at three-phase short-circuit)	:	142000	A
Max. short - circuit torque	:	8000	kNm

Substained short-circuit current:

– (Calculated at three-phase short circuit with rated field current)	:	19400	A

Reactances (based on rated output and voltage, calculated values)

Direct-axis synchronous reactance (unsaturated)	X_d	:	2.1	
Quatrature-axis synchronous reactance (unsaturated)	X_q	:	2.0	
Direct-axis transient reactance (unsaturated)	X'_d	:	0.31	
Direct-axis subtransient reactance (saturated)	X''_d	:	0.25	p.u.
Quatrature-axis subtransient reactance (unsaturated)	X''_q	:	0.26	
Negative-sequence reactance (unsaturated)	X_2	:	0.25	
Zero-sequence reactance (unsaturated)	X_0	:	0.10	
Stator leakage reactance (unsaturated)	X_l	:	0.22	

Insulation

Insulation class (stator and rotor)	:	F	-
Temperature rise, max. (stator and rotor),class	:	B	-
Test voltage (duration 1 minute):			
– Stator	:	41	kV
– Rotor	:	3.89	kV

Figure B.4 Generator Datasheet (ABB Itochu Ltd 1999, p. 116)

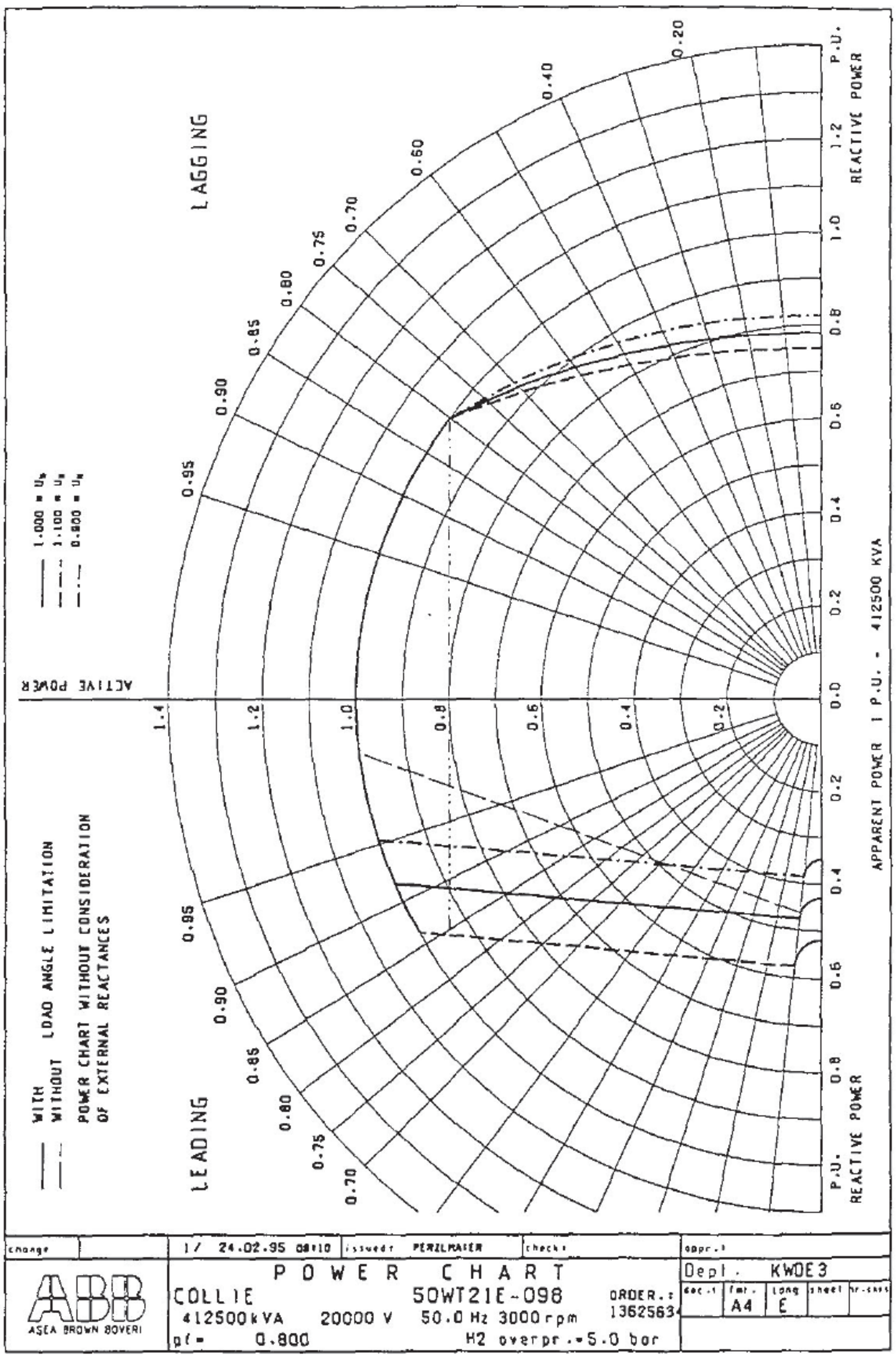

Figure B.5 Generator Capability Diagram (ABB Itochu Ltd 1999, p. 134)

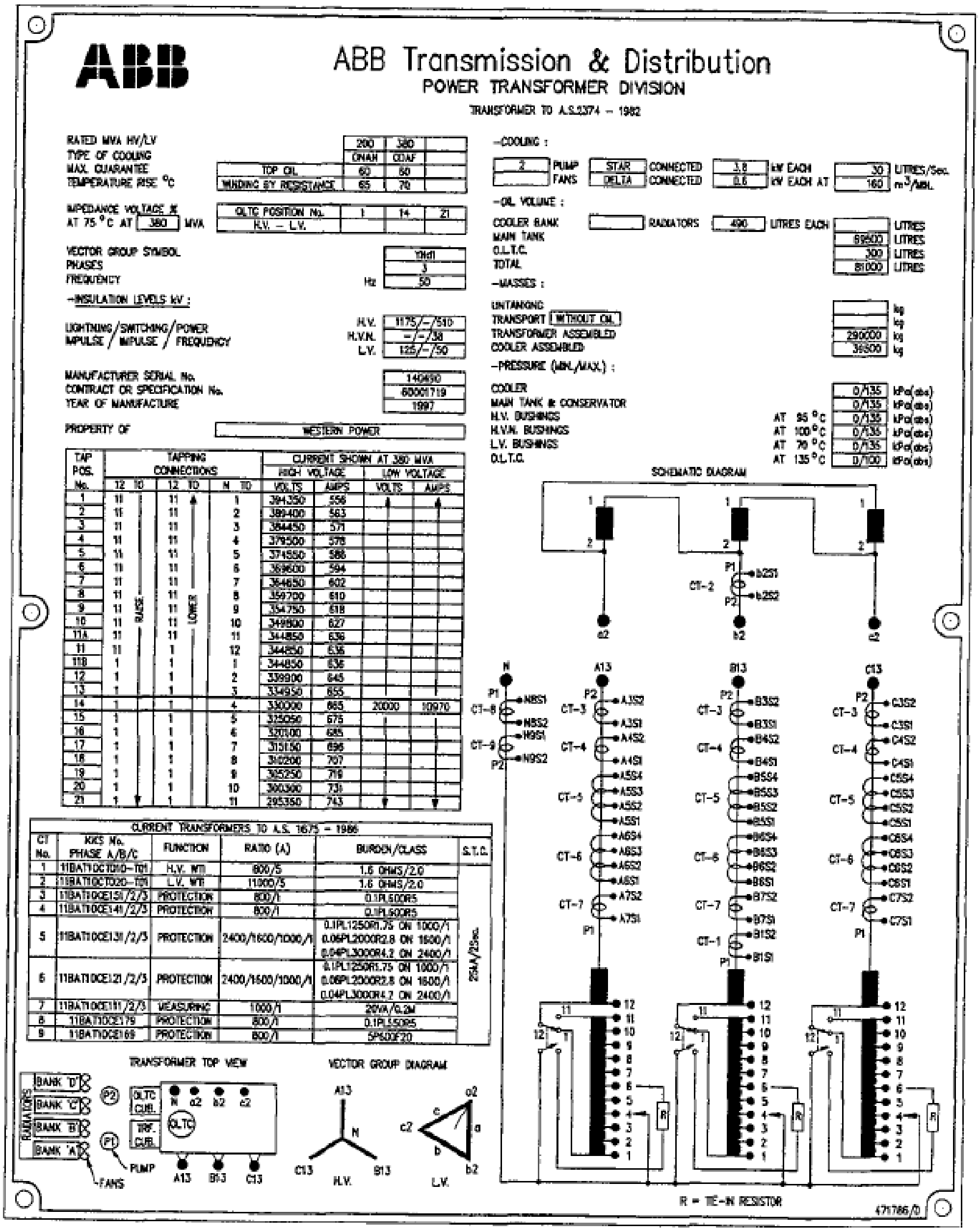

Figure B.6 GSUT Rating and Diagram Plate (ABB Itochu Ltd 1999, p. 77)

Appendix C

Model Diagrams

The model has been built using the MATLAB Simulink library model called Steam Turbine and Governor System – Subsynchronous. This is available under MATLAB Examples - Simscape Electrical – Specialised Power Systems. – Motors and Generators. The model has been modified to include equipment and system parameters for Colie Power Station. In addition, the governor logic has been enhanced to mimic that with the ABB ProControl P13 Turbine Controller at Collie Power Station. The customised governor logic is represented on Figure C.1 through to Figure C.7.

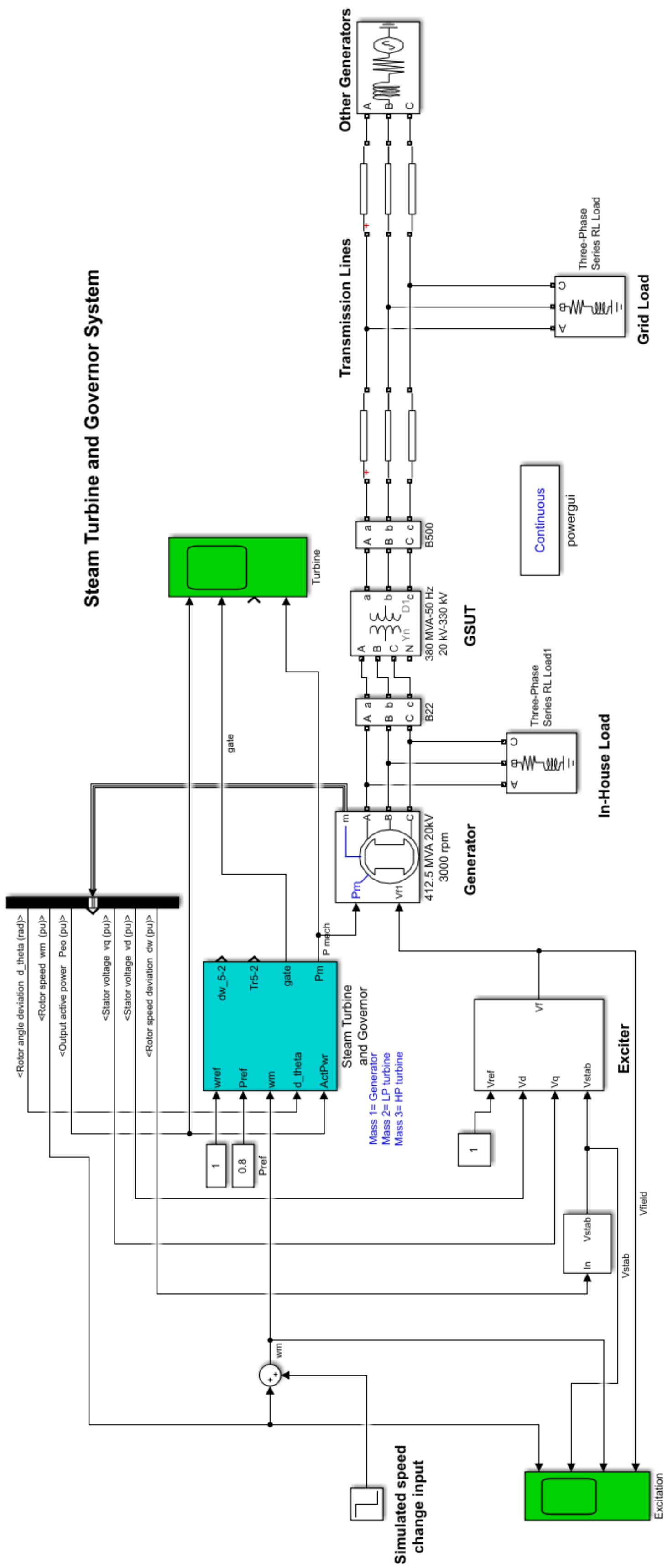

Figure C.1 MATLAB Model (Main Overview)

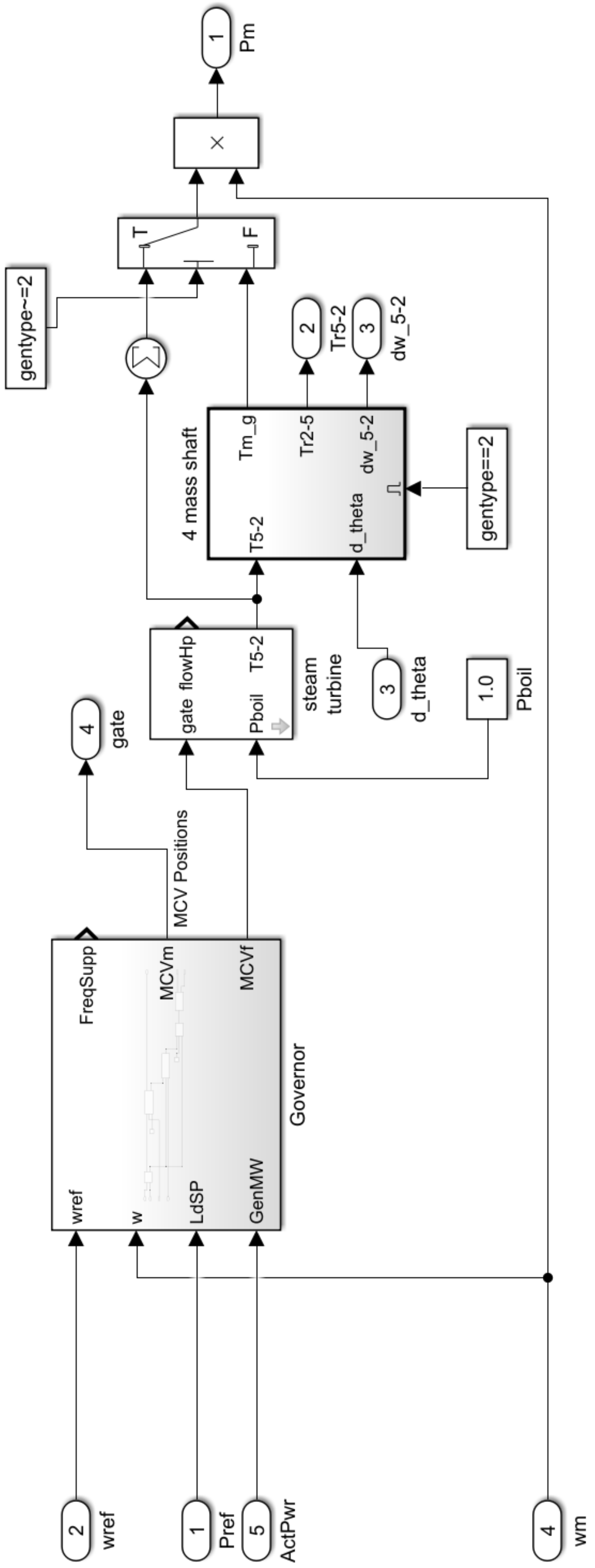

Figure C.2 MATLAB Model (Under Model)

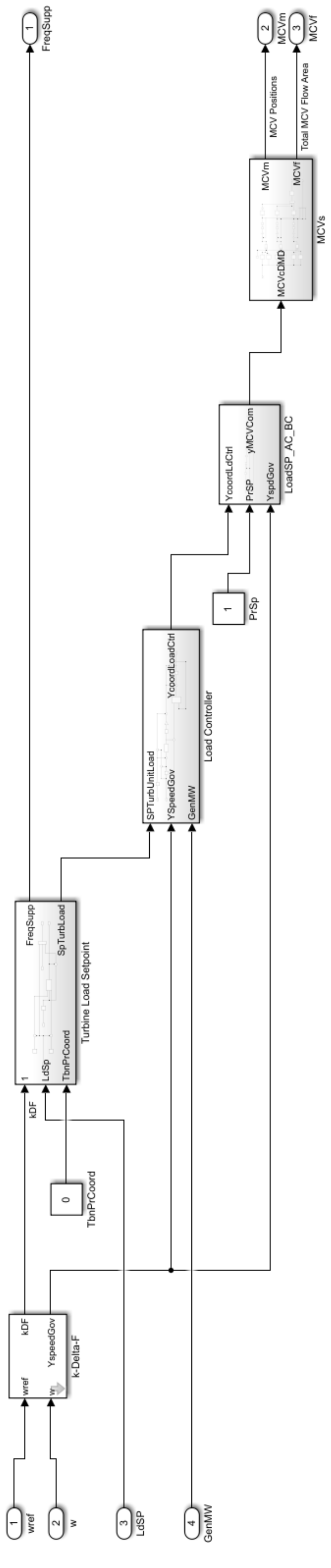

Figure C.3 MATLAB Model (Under Governor)

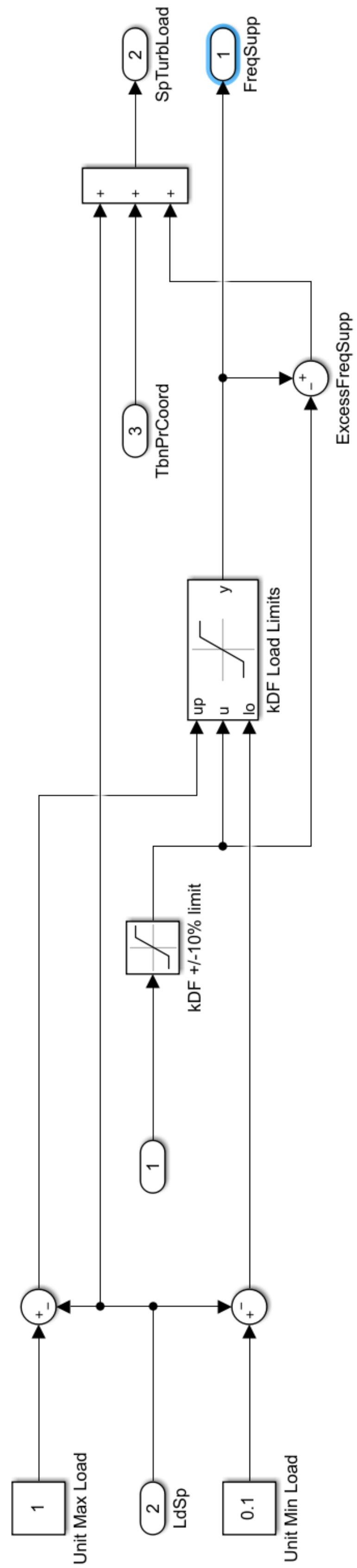

Figure C.4 MATLAB Model (Under Turbine Load Setpoint)

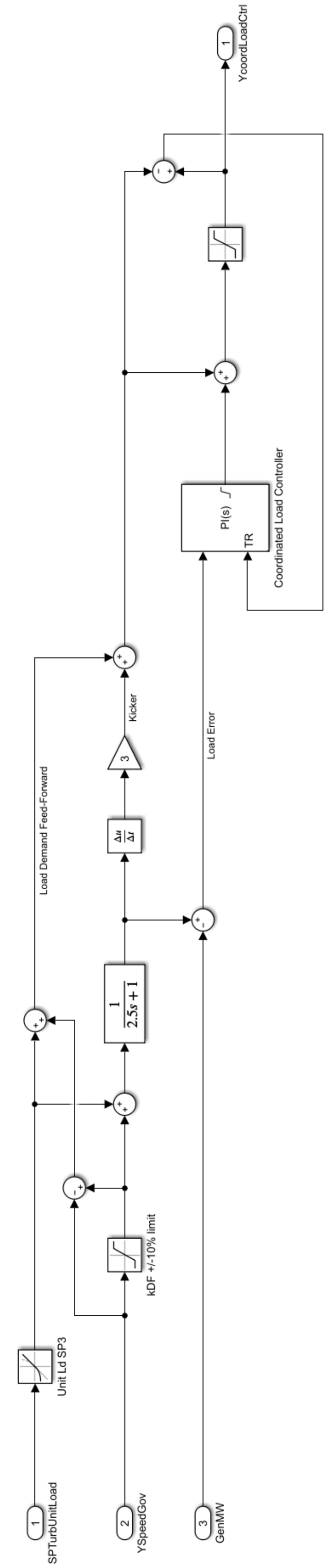

Figure C.5 MATLAB Model (Under Load Controller*)*

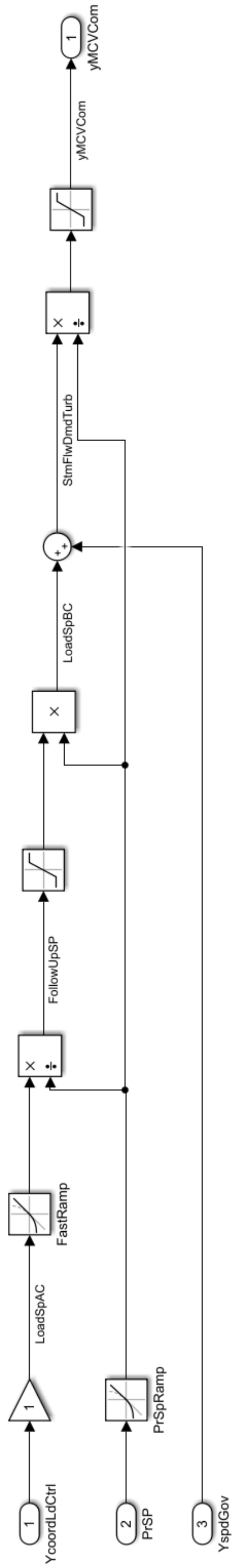

Figure C.6 MATLAB Model (Under LoadSP_AC_BC)

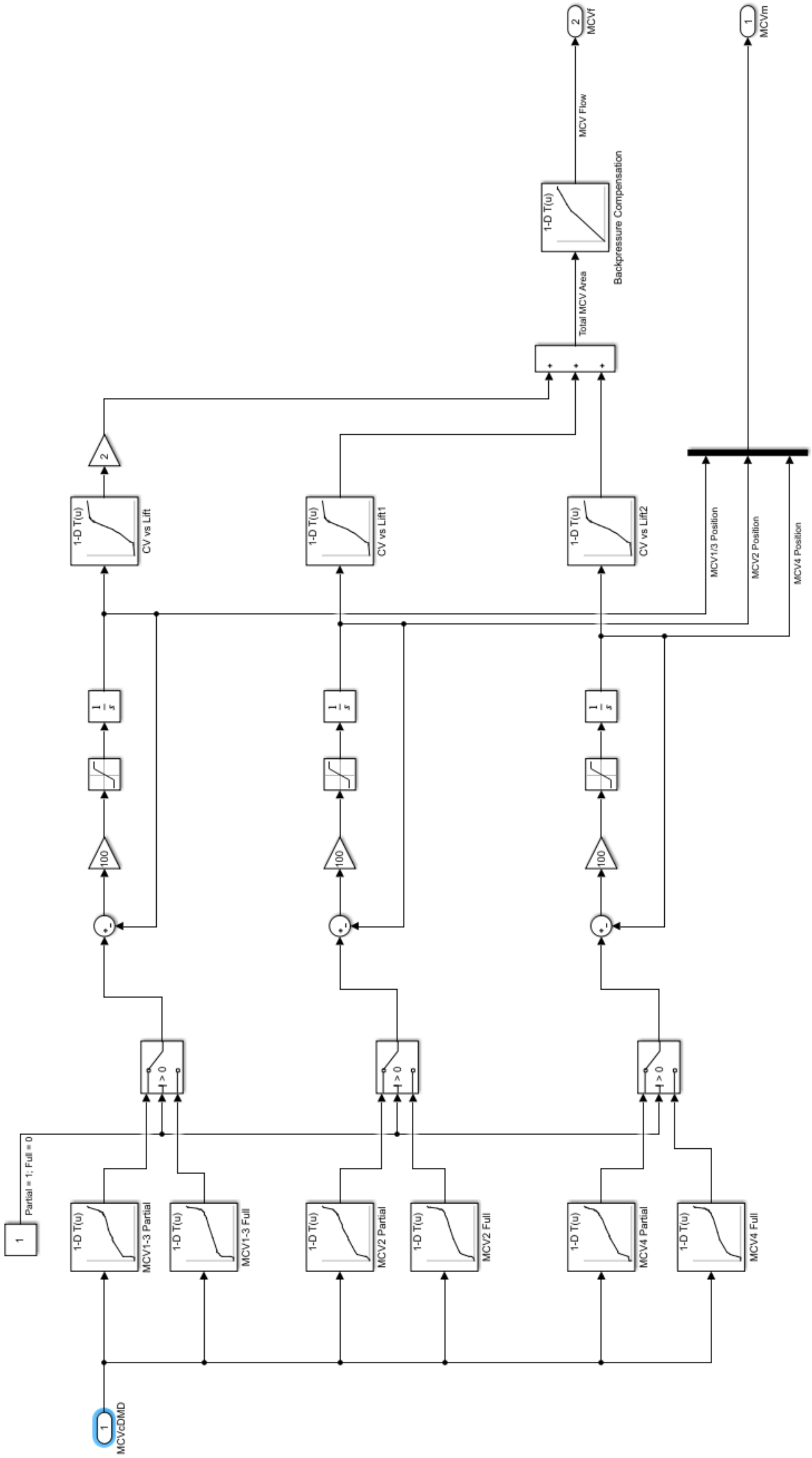

Figure C.7 MATLAB Model (Under MCVs)

Appendix D

Frequency Excursion Events

Table D.1 has been collected from PGIM data using K Delta F as a filter to eliminate smaller frequency disturbances.

Date of collection: 31 August 2020

KKS Tag: 11MAY01DU112 XJ03

Period of query: 01/01/2019 – 23/08/2020

Criteria: K-Delta F > +/-1.5%

Table D.1 PGIM History of Frequency Excursions since 1st January. 2019

Date	Time	K Delta F (%)	Gen SP (MW)	Gen Response (MW)	Step Response (MW)	Freq Nominal (Hz)	Freq Abs Peak (Hz)
28/08/2020	10:25	12.74	134	155	21	49.97	49.564
25/08/2020	9:36	6.29	203	213	10	49.998	49.709
24/08/2020	20:11	4.34	302	305	3	49.94	49.796
16/08/2020	17:22	3.75	291	306	15	49.882	49.796
16/08/2020	15:08	-3.5	160	150	-10	49.941	50.144
16/08/2020	12:06	-3.8	160	150	-10	49.998	50.144
16/08/2020	11:06	-3.71	160	150	-10	50.056	50.144
16/08/2020	9:32	1.66	130	135	5	49.853	49.824
9/08/2020	18:13	5.07	337	337	0	49.998	49.824
6/08/2020	9:40	-1.9	206	200	-6	49.998	50.085
5/08/2020	11:34	-2.78	136	127	-6	50.056	50.115
3/08/2020	1:12	5.02	327	338	11	49.998	49.767
3/08/2020	17:38	3.9	340	340	0	49.998	49.796
25/07/2020	11:15	-2.25	136	126	-10	5.027	50.115
25/07/2020	10:02	2.05	172	176	4	49.912	49.824
20/07/2020	17:25	3.66	345	345	0	49.912	49.796
19/07/2020	16:58	9.17	334	339	5	49.941	49.767
17/07/2020	12:30	-2.73	180	171	-9	49.912	50.056
17/07/2020	9:33	-2.29	339	334	-5	49.998	50.556
9/07/2020	14:31	-6.83	189	167	-22	49.998	50.201
9/07/2020	14:00	-5.22	188	170	-18	49.912	50.115
9/07/2020	13:23	11.3	189	223	34	49.912	49.650
9/07/2020	12:47	-6.05	192	175	-17	49.912	50.115
9/07/2020	11:41	-3.17	270	261	-9	49.941	50.085
9/07/2020	10:22	-5.12	271	255	-16	49.97	50.144
9/07/2020	9:47	6.68	274	291	17	49.998	49.767
9/07/2020	9:00	-5.12	272	254	-18	49.912	50.173

Date	Time	K Delta F (%)	Gen SP (MW)	Gen Response (MW)	Step Response (MW)	Freq Nominal (Hz)	Freq Abs Peak (Hz)
9/07/2020	8:12	8.3	272	289	17	49.941	49.738
8/07/2020	14:35	7.03	188	214	26	49.998	49.767
8/07/2020	14:00	-4.73	190	175	-16	50.912	50.115
8/07/2020	13:26	7.66	192	214	22	49.912	49.707
8/07/2020	12:35	10.64	190	221	31	49.912	49.679
8/07/2020	11:45	8.34	189	212	23	49.97	49.679
8/07/2020	11:16	4.88	170	187	17	50.173	49.941
8/07/2020	10:03	4.68	188	174	-14	49.97	50.144
8/07/2020	9:30	7.91	189	217	28	50.144	49.970
8/07/2020	8:30	3.07	190	200	10	49.998	49.796
7/07/2020	14:35	7.12	268	289	21	49.97	49.740
7/07/2020	13:30	-5.12	270	283.5	13.5	49.998	49.767
7/07/2020	12:30	6.68	268	289	21	49.97	49.679
7/07/2020	11:34	-3.8	267	257	-10	49.97	50.144
7/07/2020	10:55	5.46	269	283	14	49.97	49.738
7/07/2020	10:05	5.12	268	282	14	49.941	49.738
7/07/2020	9:02	7.08	269	289	20	49.912	49.709
7/07/2020	8:32	-5.12	270	253	-17	49.97	50.173
7/07/2020	8:00	6.1	269	289	20	49.882	49.709
5/07/2020	19:00	-5.2	341	327	14	49.97	50.173
27/02/2020	6:07	-11.13	300	288	-12	49.941	50.200
25/02/2020	17:00	-8.2	247	224	-23	49.97	50.200
2/02/2020	17:43	5.32	340	340	0	49.882	49.767
19/12/2019	3:14	3.17	219	225	6	49.941	49.700
6/12/2019	8:30	9.47	253	275	22	49.941	49.679
11/11/2019	21:08	14.67	334	334	0	49.912	49.593
31/10/2019	15:48	6.34	185	207	22	49.912	49.738
22/10/2019	21:35	3.67	254	263	9	49.998	49.796
30/08/2019	22:09	-5.46	239	221	18	49.97	50.201
30/08/2019	7:31	2.78	312	323	11	49.941	49.796
14/05/2019	13:38	15.08	138	158	20	49.998	49.564
24/02/2019	20:30	10.05	258	271	13	49.97	49.623
8/02/2019	12:17	7.71	206	220	14	49.97	49.679

Table D.2 has been built from load swing test information (performed between the 7th to 9th July 2020) and PGIM history:

Table D.2 Load Swing Step Testing Results (July 2020)

			Settings			Expected Results					Actual Results													
Date	Time	Test	Deadband (mHz)	Step (%)	Setpoint (MW)	Target Load (MW)	Load Direction	90% Target (MW)	Load Change (%)	Load Change (MW)	Load Change within 6 Seconds (MW)	+/- 6 Second Expectation	6 Second Ancillary Service (MW)	Max Load Change	+/- Expectation	Ancillary Service (MW)	Duration of Maximum Load Change (seconds)	MCV 1/3 Initial (%)	MCV 1/3 Post (%)	MCV 2 Initial (%)	MCV 2 Post (%)	MCV 4 Initial (%)	MCV 4 Post (%)	k Delta Factor (%)
7/07/2020	8:00:03	1.01	100	-0.40%	269	285.5	▲	283.9	5.0%	16.5	286	2.1	17.0	289	3.5	20	9	100	100	46	69	0	0	6.68
7/07/2020	8:30:21	1.02	100	0.40%	269	252.5	▼	254.2	-5.0%	-16.5	255	-0.8	-14.0	255	-2.5	-14	6	100	100	47	31	0	0	-5.12
7/07/2020	9:02:39	1.03	100	-0.40%	269	285.5	▲	283.9	5.0%	16.5	288	4.1	19.0	290	4.5	21	12	100	100	47.6	82	0	0	7.08
7/07/2020	10:04:29	1.04	100	-0.40%	269	285.5	▲	283.9	5.0%	16.5	279	-4.9	10.0	281	-4.5	12	12	100	100	48	63	0	0	5.12
7/07/2020	10:55:07	1.05	100	-0.40%	269	285.5	▲	283.9	5.0%	16.5	285	1.1	16.0	289	3.5	20	17	100	100	47	63.5	0	0	5.46
7/07/2020	11:34:04	1.06	100	0.40%	269	252.5	▼	254.2	-5.0%	-16.5	255	-0.8	-14.0	257	-4.5	-12	7	100	100	47	36	0	0	-3.8
7/07/2020	12:30:03	1.07	100	-0.50%	269	293.8	▲	291.3	7.5%	24.75	287	-4.3	18.0	297	3.3	28	70	100	100	47	86	0	15	7.6
7/07/2020	13:34:21	1.08	100	-0.50%	269	293.8	▲	291.3	7.5%	24.75	280	-11.3	11.0	292	-1.8	23	25	100	100	47	63	0	0	5
7/07/2020	14:35:51	1.09	50	-0.50%	269	302.0	▲	298.7	10.0%	33	285	-13.7	16.0	290	-12.0	21	12	100	100	48	76	0	0	7.3
8/07/2020	8:28:36	2.01	100	-0.40%	190	206.5	▲	204.9	5.0%	16.5	198	-6.8	8.0	210	3.5	20	40	72	100	0	25	0	0	2.7
8/07/2020	8:58:43	2.02	100	0.40%	190	173.5	▼	175.2	-5.0%	-16.5	173	2.2	-17.0	173	0.5	-17	6	73	61	0	0	0	0	-2.83
8/07/2020	9:30:00	2.03	100	-0.50%	190	214.8	▲	212.3	7.5%	24.75	204	-8.3	14.0	210	-4.8	20	15	73	100	0	34	0	0	5.4
8/07/2020	10:03:26	2.04	100	0.50%	190	165.3	▼	167.7	-7.5%	-24.75	170	-2.3	-20.0	170	-4.8	-20	4	73	61	0	0	0	0	-4.6
8/07/2020	10:32:43	2.05	100	-0.50%	190	214.8	▲	212.3	7.5%	24.75	205	-7.3	15.0	213	-1.8	23	14	73	100	0	42	0	0	6.34
8/07/2020	11:02:19	2.06	100	0.50%	190	165.3	▼	167.7	-7.5%	-24.75	176	-8.3	-14.0	172	-6.8	-18	15	73	62	0	0	0	0	-4.8
8/07/2020	11:45:16	2.07	100	-0.50%	190	214.8	▲	212.3	7.5%	24.75	208	-4.3	18.0	212	-2.8	22	8	73	100	0	50	0	0	8.34
8/07/2020	12:35:34	2.08	50	-0.50%	190	223.0	▲	219.7	10.0%	33	221	1.3	31.0	221	-2.0	31	6	72	100	0	56	0	0	10.6
8/07/2020	13:26:19	2.09	50	-0.40%	190	214.8	▲	212.3	7.5%	24.75	213	0.7	23.0	215	0.3	25	15	73	100	0	48	0	0	7.7
8/07/2020	14:00:00	2.10	50	0.40%	190	165.3	▼	167.7	-7.5%	-24.75	175	-7.3	-15.0	177	-11.8	-13	6	73	60	0	0	0	0	-4.73
8/07/2020	14:35:00	2.11	50	-0.50%	190	223.0	▲	219.7	10.0%	33	200	-19.7	10.0	214	-9.0	24	12	76	100	0	7	0	0	7.5
9/07/2020	8:12:00	3.01	100	-0.50%	270	294.8	▲	292.3	7.5%	24.75	284	-8.3	14.0	292	-2.8	22	12	100	100	47	67	0	0	6.2
9/07/2020	9:00:00	3.02	100	0.50%	270	245.3	▼	247.7	-7.5%	-24.75	257	-9.3	-13.0	254	-8.8	-16	12	100	100	47	31	0	0	5.2
9/07/2020	9:47:00	3.03	50	-0.50%	270	303.0	▲	299.7	10.0%	33	289	-10.7	19.0	293	-10.0	23	15	100	100	47	70	0	0	6.7
9/07/2020	10:22:00	3.04	50	0.40%	270	245.3	▼	247.7	-7.5%	-24.75	253	-5.3	-17.0	253	-7.8	-17	3	100	100	47	32	0	0	-5.2
9/07/2020	11:41:00	3.05	50	0.30%	270	253.5	▼	255.2	-5.0%	-16.5	262	-6.8	-8.0	261	-7.5	-9	12	100	100	47	36	0	0	-3.15
9/07/2020	12:47:00	3.06	50	0.40%	190	165.3	▼	167.7	-7.5%	-24.75	174	-6.3	-16.0	171	-5.8	-19	28	73	59	0	0	0	0	-6
9/07/2020	13:23:00	3.07	50	-0.50%	190	223.0	▲	219.7	10.0%	33	220	0.3	30.0	224	1.0	34	15	73	100	0	57	0	0	11.3
9/07/2020	14:00:00	3.08	50	0.40%	190	165.3	▼	167.7	-7.5%	-24.75	173	-5.3	-17.0	171	-5.8	-19	12	72	60	0	0	0	0	-5.2
9/07/2020	14:32:00	3.09	50	0.40%	190	165.3	▼	167.7	-7.5%	-24.75	168	-0.3	-22.0	166	-0.8	-24	14	73	58	0	0	0	0	-6.83

Appendix E

Resources

This research project is primarily a desktop study conducted using MATLAB. The student version of MATLAB 2020a has been used (purchased via USQ Bookshop-Omnia Books & Beyond), which does have some limitations when compared to the licenced version for industry use. The functions block used to characterise the governor valves became processor burdensome and required significant durations to produce an output.

Access to logic as programmed into the ProControl P13 turbine controller, ProControl P14 distributed control system was made at Collie Power Station. PGIM history data was accessed via the PGIM Engineering Station. Physical access to the station Electrical Control Centre (Level 4) was provided by TW Power Services as this was an industry sponsored dissertation.

Appendix F

Risk Assessment

To assist define the risks associated with the research performed under this dissertation, the following categories are described:

Project Risk – A risk that an event or condition that, if it occurs, may have a detrimental effect on one or more of the project deliverables.

Safety Risk – A risk that an event or condition that, if it occurs, may cause injury to personnel or station equipment.

For both categories, known and unknown risks are listed as subcategories. The Covid19 pandemic was an unknown risk as the potential was not known when the research project was defined. An example of a known risk is the potential for an outage extension beyond the scheduled 7th June for return to service. The two categories of project and safety risk are captured within the risk assessment sheets displayed in *Figure F.1*and *Figure F.2* respectively. The TW Power Services risk Assessment Sheet as used at Collie Power Station have been utilised. Note that the risks are described, recognising the risks going into semester 2 (ENG4112).

TW POWER SERVICES

PROJECT RISK ASSESSMENT WORKSHEET

Risk Assessment No.:

Revision :

Activity : Research Project – Project Risk

Approved by : Alan Cornish

Date Approved : 30/06/2020

Categories
1 Commercial
2 Financial
3 Legal / Compliance
4 Strategic / Business Development
5 People
6 Occupational Health and Safety
7 Rail Safety
8 Environmental and Sustainability
9 Quality
10 Client / Stakeholder Relations
11 Project Management
12 Detail Design
13 Procurement and Sub Contracting
14 Mobilisation / IT and Knowledge Systems
15 Construction
16 Hand-Over and Commissioning
17 Operations and Maintenance
18 Asset Stewardship

Consequence (C)
1. Insignificant
2. Minor
3. Moderate
4. Major
5. Catastrophic

Likelihood (L)
1. Rare (1-5%)
2. Unlikely (%)
3. Moderate (30-59%)
4. Likely (60-89%)
5. Almost Certain (≥90%)

Risk Matrix

Likelihood (L)					
5	E	E	E	H	H
4	E	E	H	H	M
3	E	E	H	M	L
2	E	H	M	L	L
1	H	H	M	L	L
	5	4	3	2	1
	Consequence (C)				

Risk Rating (R)
E = Extreme
H = High
M = Moderate
L = Low

Control Effectiveness

Development of Process (D of P)
A Fully developed (100%)
B Substantially developed (75%)
C Partially developed (50%)
D Limited development (25%)
E No Process (0%)

Implementation of Process (I of P)
A Fully implemented (100%)
B Substantially implemented (75%)
C Partially implemented (50%)
D Limited implementation (25%)
E No implementation (0%)

Risk Treatment Options
1 Avoid the Risk
2 Transfer the Risk
3 Accept the Risk
4 Reduce the Consequence
5 Reduce the Likelihood

Category	Identify Potential Risks / Hazards	Worst Foreseeable Outcome	Initial Risk Analysis			Identify Management Controls	Current Control Effectiveness		Current Risk Analysis			Risk Treatment Options
			L	C	R		D of P	I of P	L	C	R	
11	Turbine Governor Model not successfully developed	Unable to model frequency support characteristics at low load	3	3	H	Re-establish update meeting with USQ Supervisor	A	B	2	3	M	5
						Appoint Perth Control System Engineer as external supervisor to assist model progression	C	B	2	3	M	5
						Utilise annual leave to ensure enough time is spent on research project	A	A	2	3	M	5
17	Extended station breakdown interrupts time available for research project	Unable to complete research or write-up dissertation	2	4	H	Employer management made aware of situation, so that after hours electrical and control support is only requested when absolutely necessary. Electricians used for call out support as much as possible.	A	A	1	4	M	5
4	Research project not completed	Collie Power Station frequency support characteristics unknown at low load target. Project delayed.	3	3	H	Unit continues to be removed from service if generation below 130MW is required by the AEMO.	A	A	3	3	H	3

Risk Assessment Completed by: Alan Cornish	**Next Approval Date:**	**Next Review Date:**
Stakeholders: Alan Cornish, Collie Power Station, Tony Ahfock, Matthew Witney	**Reviewed By:**	**Actual Review Date:**

Figure F.1 Risk Assessment for Project Aspect

TW POWER SERVICES

SAFETY RISK ASSESSMENT WORKSHEET

Risk Assessment No.:

Revision :

Activity : Research Project – Safety Risk

Approved by : Alan Cornish

Date Approved : 30/06/2020

Categories
1 Commercial
2 Financial
3 Legal / Compliance
4 Strategic / Business Development
5 People
6 Occupational Health and Safety
7 Rail Safety
8 Environmental and Sustainability
9 Quality
10 Client / Stakeholder Relations
11 Project Management
12 Detail Design
13 Procurement and Sub Contracting
14 Mobilisation / IT and Knowledge Systems
15 Construction
16 Hand-Over and Commissioning
17 Operations and Maintenance
18 Asset Stewardship

Consequence (C)
1. Insignificant
2. Minor
3. Moderate
4. Major
5. Catastrophic

Likelihood (L)
1. Rare (1-5%)
2. Unlikely (6-29%)
3. Moderate (30-59%)
4. Likely (60-89%)
5. Almost Certain (≥90%)

Risk Rating (R)
E = Extreme
H = High
M = Moderate
L = Low

Risk Matrix

Likelihood (L)					
5	E	E	E	H	H
4	E	E	H	H	M
3	E	E	H	M	L
2	E	H	M	L	L
1	H	H	M	L	L
	5	4	3	2	1
	Consequence (C)				

Control Effectiveness

Development of Process (D of P)
A Fully developed (100%)
B Substantially developed (75%)
C Partially developed (50%)
D Limited development (25%)
E No Process (0%)

Implementation of Process (I of P)
A Fully Implemented (100%)
B Substantially Implemented (75%)
C Partially Implemented (50%)
D Limited Implementation (25%)
E No Implementation (0%)

Risk Treatment Options
1 Avoid the Risk
2 Transfer the Risk
3 Accept the Risk
4 Reduce the Consequence
5 Reduce the Likelihood

Category	Identify Potential Risks / Hazards	Worst Foreseeable Outcome	Initial Risk Analysis			Identify Management Controls	Current Control Effectiveness		Current Risk Analysis			Risk Treatment Options	Risk Action Plan
			L	C	R		D of P	I of P	L	C	R		
6	Site access and movement	Personal injury	2	3	M	Site inductions, site policies and standards	A	A	1	2	L	4, 5	
						Compliance with TW Power Mandatory Safety Rules	A	A	1	2	L	4, 5	
						Industry experience	A	A	2	3	M	5	
17	Turbine controllers and the Distributed control system (DCS) are live systems	Potential logic changes whilst viewing could result in unit trip, loss of control or loss of protective function	2	5	E	Control system training for respective systems and devices	A	A	1	4	H	4, 5	
						Utilise view only mode for DCS (ProControl P14) Utilise pdf copies of turbine control (ProControl P13) logic when possible	A	A	1	1	L	4,5	
16	Logic changes proposed by research project are not suitable	Unit instability during a frequency excursion, causing a unit trip	1	3	L	Proposed changes (if identified) to be validated by control systems engineer, approved for implementation and tested in incremental steps.	D	A	1	1	L	4	

Risk Assessment Completed by: Alan Cornish	**Next Approval Date:**	**Next Review Date:**
Stakeholders: Alan Cornish, Collie Power Station, Tony Ahfock, Matthew Witney	**Reviewed By:**	**Actual Review Date:**

Figure F.2 Risk Assessment for Safety Aspect

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