

University of Southern Queensland
Faculty of Health, Engineering & Sciences

**Energy Efficiency Improvement in Coal Fired Power Plant
through Operational Optimisation**

A dissertation submitted by

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Abstract

Energy consumption is a significant cost to all business with the countries large industrial plants consuming 75 % of all energy produced in Australia. This cost is not only a financial burden but it has an environmental cost. The energy consumption within coal-fired power stations that is directly associated with generation is called auxiliary power. Approximately 10 % of all power produced is used to drive power stations internal auxiliary power needs. It is the auxiliary power consumption at Tarong Power Station that is the focus of this dissertation.

This dissertation first seeks to understand the stations energy consumption through a comprehensive review of auxiliary power issues worldwide and the creation of control system tracking logic. The next stage of the dissertation then models that consumption in MATLAB and finally proposes ways in which to reduce that consumption without capital investment.

The auxiliary power consumption within Tarong Power Station is recorded by two energy meters per unit on the main high voltage unit transformer feeds. The energy consumed is then reported each week as a percentage of unit generation. It is at this high level that the consumption is currently understood. This project has created energy tracking logic in the unit control system, a Siemens T3000 installation, to provide additional usage knowledge. A number of MATLAB models have been produced. The first of these reproduces the energy usage map of a running unit. The final Simulink model allows modification of the major component loading to trial energy reduction options. Using this model a reduction of 10 % at low loads has been achieved. The accuracy of the energy tracking logic and models created is proven to be within 2 % of the field energy metering.

This dissertation has concluded that meaningful energy efficiency improvement can be obtained through operational improvement at Tarong Power Station.

ENG4111/2 *Research Project*

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JASON LANG

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Acronyms & Abbreviations

AEMO	Australian Electricity Market Operator
AP	Automation Processor
ASD	Adjustable Speed Drives
AVR	Automatic Voltage Regulation
BFP	Boiler Feed Pump
CEP	Condensate Extraction Pump
CPU	Central Processing Unit
CT	Current Transformer
CW	Circulating Water
DA	Deaerator
DC	Direct Current
DCS	Distributed Control System
DF	Displacement Power Factor
DOL	Direct on Line
EPRI	Electric Power Research Institute
ESP	Electrostatic Precipitator
FD	Forced Draft
FIFO	First In First Out
GOC	Government Owned Corporation
GT	Gas Turbine
HMI	Human Machine Interface
HP	High Pressure
HP5	HP heater 5

HP6	HP heater 6
hr	Hour
HV	High Voltage
I&C	Instrumentation and Control
ID	Induced Draft
IEEE	Institute of Electrical and Electronics Engineers
I/O	Inputs/Outputs
MV	Medium Voltage
IP	Intermediate Pressure
JSEA	Job Safety and Environmental Analysis
kW	Kilowatt
LP	Low Pressure
MV	Medium Voltage
MW	Megawatt
MWhr	Megawatt hour
NGERS	National Greenhouse Energy Reporting Scheme
NOX	Nitrite Oxide
PID	Proportional Integral Derivative
P&ID	Process and Instrumentation Drawing
PA	Primary Air
PF	Pulverised Fuel
PF	Power Factor
PIMS	Process Information Management Solutions
PLC	Programmable Logic Controllers
QEC	Queensland Electricity Commission
SCADA	Supervisory Control and Data Acquisition
SISO	Single Input Single Output
Stanwell	Stanwell Corporation
Tarong	Tarong Power Station
THD	Total Harmonic Distortion
VT	Voltage Transformer

Chapter 1

Introduction

This chapter aims to introduce the project, its drivers, its key aims, objectives and how they are proposed to be achieved.

In an ever more energy hungry austere world the way in which energy is produced and consumed is under constant scrutiny. Every Megawatt (MW) produced in a coal fired power station consumes valuable finite resources, coal and oil. The production of electricity emits pollution into the atmosphere leaving an indelible footprint on the landscape and atmosphere. This carbon footprint, as it is known, that the Tarong Power Station (TPS) leaves is larger than most energy consumers in Australia. TPS is ranked in the top ten Australian polluters and as such is always under pressure to improve its environmental performance. TPS is run by Stanwell Corporation (Stanwell), a Government Owned Corporation (GOC). As such it is owned by the people of Queensland and while environmental performance is important so is financial sustainability. Couple these two factors with global downturns, market oversupply and low price in the electricity market you have a business that is always actively looking to reduce costs. Time and energy is spent to improve fuel burn returns, reduce water usage, implement reduced manning practices, improve market share and reduce the cost of maintenance work. One of the last major cost influences, auxiliary power consumption, has only been lightly touched on during the recent stakeholder driven cost reduction exercises. It is this cost of internal energy consumed through auxiliary power consumption that is the focus of this project.

1.1 Project Outline

This section outlines some further detail on the issue of auxiliary power consumption to give context to the project direction. It will also detail the projects aims, scope and objectives.

Auxiliary energy consumption is a large contributor to the cost of power production. Within Tarong Power Station it is not fully understood, that is, it is understood to a basic level. It is known that of the energy produced at TPS approximately 10 % is required to run in house auxiliaries and therefore cannot be exported for sale. This auxiliary energy usage is a significant cost to the business and adds to the cost of producing one MW of electricity. This auxiliary power usage is metered on each unit and is reported on each month. If a unit has an increased energy usage at the end of the month not only is it accepted and unchallenged but there is no easy way to understand the underlying cause. Therefore there is no way to prevent a future high energy usage occurrence of the same nature. Since the usage is metered at a high level, unit level, there is also no reasonable way to assess the usage and implement changes to the plant to reduce the usage. It can also be noted that the energy usage whilst visible is generally lost in the other concerns of the station.

The major contributors to the auxiliary energy consumption are already broadly known and loosely understood. It is the plants large high voltage (HV) motors which consume a huge amount of electricity to produce the motive forces required by the electricity generation process. Reducing this consumption via major plant upgrade would require enormous capital investment and plant redesign. Further to this it is widely accepted that the current level of unit energy consumption, as part of the designed efficiency figure, is the minimum achievable usage. It is essentially viewed as unavoidable byproduct of the process requirements. The plant was designed in the mid 1970's with a strong reliability focus. To ensure high plant availability the plant design included many redundant and oversized drives. The station was also designed to be a base load 350 MW unit. The energy consumption across the full load range of the plant was not the primary focus of the design phase of the station. Peak efficiency at 350 MW was the primary aim of the station design.

1.1.1 Aims

The questions that this project seeks to address are two stage, firstly can the auxiliary energy consumption of unit at Tarong Power Station be fully understood? Secondly can this energy usage be reduced solely through control optimisation? That is to reduce the auxiliary energy consumption without capital investment and solely by control system logic modification. This leads to the creation of the aims of this project. The first primary project aim is to better understand the auxiliary energy consumption at Tarong Power Station. Once understood the second primary aim of reducing the usage through control optimisation can be addressed.

In building the tools to understand the stations auxiliary usage the project will create valuable data in T3000. The created logic will be able to monitor and report on usage for the project and into the future. This had led to a secondary aim of leaving in place lasting a energy information source.

These aims are summarised here for reference.

Primary Aim 1 To understand the auxiliary consumption within Tarong Power Stations 350 MW coal fired units;

Primary Aim 2 Identify potential control based energy reduction strategies;

Secondary Aim 1 To leave in place energy consumption information that the station can utilise into the future.

Notes The primary aims are those that drive the project objectives. The secondary aims are those that will be achieved through the primary aims.

1.1.2 Objectives

The project objectives drive how the project aims will be achieved. This leads to the project and the associated dissertation having four primary objectives. The first is to understand the associated project topics more deeply and uncover any existing work that can be used to assist the completion of this project. This will be achieved through a wide ranging literature review. The next two objectives will be to model the auxiliary energy usage of a 350 MW coal fired unit using MATLAB and to create energy tracking logic in

the T3000 Distributed Control System (DCS). Using this model and T3000 data the final primary objective is to propose control changes to reduce the internal electrical energy consumed to produce electricity. Proposed changes will be implemented in the MATLAB model to confirm the energy impact. The secondary objectives of this project are to utilise the T3000 simulator and the TPS generating plant to implement the proposed control changes. The achievement of these secondary objectives will depend heavily on the outcomes of the first stages and the risk assessment of any proposed changes. These secondary aims are an extension to the primary stated objectives and will be proven theoretically if implementation is not possible.

Primary Objective 1 Complete a literature review of issues pertinent to the project;

Primary Objective 2 Create a SIMULINK model, in MATLAB, of the energy profile of a single unit;

Primary Objective 3 Create energy tracking logic in the T3000 Digital Control System;

Primary Objective 4 Identify potential control based energy reduction strategies and propose changes to the operational plant;

Secondary Objective 1 Trial energy reduction options on the T3000 Unit simulator;

Secondary Objective 2 Implement energy reduction strategy on an operational Unit.

Note Primary objectives are those that drive this project and the secondary objectives are extension tasks if time and plant risk assessment permit.

1.1.3 Scope

The scope of this project is limited to the Unit Auxiliary energy usage. Specifically the energy usage on the 350 MW coal fired units location at Tarong Power Station, Queensland, Australia. The Power Station Ancillary energy usage ie Coal Handling Plant, Tarong North, Administration areas and Meandu mine energy usage is excluded from this project.

1.2 Overview of the Dissertation

This dissertation is organised as follows:

Preface has a list of abbreviations that will be used throughout the dissertation;

Chapter 1 is an introduction to the problem of auxiliary energy usage in coal fired power stations;

Chapter 2 is a background information on the various facets of this project;

Chapter 3 is a discussion of the existing knowledge on the dissertation topic and is presented through discussion of existing literature;

Chapter 4 discusses the methods utilised in the completion of this project;

Chapter 5 presents the results of the created T3000 logic and MATLAB models;

Chapter 6 analyses and evaluates the data collected from all sources;

Chapter 7 discusses the reduction options and presents the results of these options implemented using the MATLAB models;

Chapter 8 concludes the dissertation with a concise presentation of the project achievements and suggests further work that could be undertaken in the area of ‘energy modeling and reduction in the power station environment’.

1.3 Conclusion

In this chapter the project overview was explored from many perspectives to allow a solid understanding of the drivers for this project, its aims and the final outcomes it will produce. The next chapter will provide the background information required on auxiliary power usage within Tarong Power Station to allow the reader the basis on which to better understand the future project outputs.

Chapter 2

Background - Tarong Power Station

This chapter is to provide background information that relates to the topic. The majority of the information within this chapter is a summary of the Operations and Maintenance manuals for the Tarong Power Station plant (Hitachi 2003). Further detail is based on the experience of the project author Jason Lang who has 20 years experience in the electricity generation industry (Lang 2015).

2.1 History

This section outlines the brief history of Tarong Power Station from construction through to current day.

Tarong Power Station construction started in 1979 after it was commissioned to be built as part of 10 coal fired units in Queensland by then Queensland Premier Sir Joh Bjelke-Peterson. Tarong had four 350 MW units fully commissioned by November 1986 with Unit 1 in full operation during 1981. These units were designed to be base load for Queensland for 25 years. The units design efficiency was 28 % at 350 MW and were installed with the best technology available at the time (Brady 1996) (Thiess 2015).

Move forward to the modern day, Tarong is past its design life and there have been many evolutions in the Queensland Electricity Industry. Larger, more efficient units have

been built, the industry is partly deregulated and gas is now a significant factor in the marketplace. Tarong has established itself in the middle of the Australian Electricity Market Operator (AEMO) trading dispatch order of merit. The Queensland electricity market has been depressed with state load reducing, an oversupply and solar all impacting price and load profiles. To extend the station life and to remain a competitive force Tarong Power Station has undergone a major capital works program. These include a full control systems refit, field device upgrade, burner front upgrade to low Nitrite Oxide (NOX), major turbine refurbishment program and generator rewinds (Australia 2015).

The half-life refit work has significantly improved the underlying long term life on the plant but has only slightly improved the efficiency factor. TPS is also no longer a base load station with the plant being regularly requested to load ramp. This mode of operation is outside of the original plant design specification and therefore not the most efficient plant operation. To return to base load the overall cost to produce one MW of energy needs to be reduced to allow the plant to be bid in lower in the market dispatch order.

2.2 Production Costs

This section outlines the cost of producing one MW of electricity at TPS. The cost of this electricity production process has many contributing factors. Tarong Power Station's major contributing factors are the cost of fuel, water, overhaul maintenance, auxiliary energy consumption, ancillary energy consumption and fixed overheads. The estimate of the breakdown of the cost contributions to each MW are shown in table 2.1.

Cost Contributor	Contribution
Fuel	30 %
Water	30 %
Overhaul Maintenance	20 %
Auxiliary Energy Usage	15 %
Ancillary Energy Usage	4 %
Fixed Overheads	1 %

Table 2.1: Cost Contribution of Major Factors to the Cost of Producing 1 MW (Breda 2014).

The fuel and water costs are fixed by long term contract and therefore cannot be readily

reduced. However the amount of fuel and water consumed can be reduced through efficient practices. Overhaul costs are strongly linked to long term asset strategy which are locked down by multiple year strategy. Moves to reduce this overhaul cost are possible but hold a high level of risk to plant performance and reliability. Auxiliary energy usage costs are those directly associated with the energy required to generate power. This power usage is wide spread from control system power requirements, through to High Voltage Drives and generator excitation. This cost is considered to be fixed during the initial design process but is monitored. Ancillary energy usage costs are those associated with common processes like coal handling plant, air compression, demineralised water production, chemical plants and water distribution. The fixed costs are those support items that a company generating electricity requires. All manner of costs make up this factor including head office, payroll, market and trading, procurement, operations, maintenance, and engineering. These fixed costs are a small percentage of the overall cost of 1 MW but are relatively easily influenced by plant management. They are therefore under constant scrutiny and downward pressure (Economy 2013).

Key parameters are reported on each month to track the items that affect the amount and cost of the saleable product, in this case electricity exported to the grid. These key parameters align with the key cost contributors above. Figure 2.1 is a sample of the data presented in monthly reports.

The data shows, per unit, the energy and performance results for the month. While they are all impacted by the unit load profile they also indicate other unit qualities which are explored briefly below. Megawatt hours (MWhr) produced or generated energy exported is metered at the 275 kV level as the power is leaving the unit transformer to meet the grid. Auxiliary energy usage is a measure of the electricity used to produce the MWhrs exported in the month. It is metered at the unit 20 kV to 6.6 kV transformers that feed the majority of energy consuming devices on the units. Capacity factor is an indication of how the plant is loaded in relation to its full capacity. Efficiency and heat rate shows how effectively the coal consumed is utilised. It is a combination of many factors including coal quality, ash content, moisture content, mill grind quality, air leakage etc. Availability is the measure, in percentage, of the amount of time the unit is available to meet the demands of the market. Availability is impacted by breakdowns, plant trips and outages. Solid long term maintenance practices and underlying plant design influence this figure.

The grid and export requirements are managed by Australian Electricity Market Opera-

		February 2015 Performance Summary											
		1 Unit Tarong	2 Unit Tarong	3 Unit Tarong	4 Unit Tarong	TPS Station / Gas Turbine	Tarong Power Station	1 Unit Tarong North	Tarong North Power Station	Tarong Site			
Energy	Generation												
	Generated MWh	156,698	-	148,783	148,933	-	454,414	194,303	194,303	648,717			
	Auxiliaries MWh	13,409	-	12,870	13,265	7,552	39,544	10,698	10,698	50,242			
	Net Generation MWh	143,289	-	135,913	135,668	(7,552)	414,870	183,605	183,605	598,475			
Market	Auxiliaries Consumption %	8.6%	-	8.7%	8.9%	-	8.7%	5.5%	5.5%	7.7%			
	Sold (Sent Out) MWh	143,289	-	135,913	135,668	-	414,870	183,605	183,605	598,475			
	Purchased MWh	-	-	-	-	3,163	3,163	-	-	3,163			
	Net Market MWh	143,289	-	135,913	135,668	(3,163)	411,707	183,605	183,605	595,312			
Performance Parameters	Installed Capacity MW	350	-	350	350	-	1,050	443	443	1,493			
	Period Hours h	672	-	672	672	-	672	672	672	672			
	Capacity Factor (Generated) %	66.6%	-	63.3%	63.3%	-	64.4%	65.3%	65.3%	64.7%			
	Generation Hours h	672	-	672	672	-	2,016	672	672	2,688			
	Service Factor %	66.6%	-	63.3%	63.3%	-	64.4%	65.3%	65.3%	64.7%			
	Heat Rate (Sent Out) GJ/MWh	10.45	-	10.82	10.86	-	10.70	10.34	10.34	10.59			
	Efficiency (Sent Out) %	34.5%	-	33.3%	33.2%	-	33.6%	34.8%	34.8%	34.0%			
	Number of Trips	-	-	-	-	-	-	-	-	-			
	Number of Starts	-	-	-	-	-	-	-	-	-			
	Possible Generation MWh	235,200	-	235,200	235,200	-	705,600	297,696	297,696	1,003,296			
	Forced Lost Generation MWh	-	-	-	-	-	-	-	-	-			
	Maintenance Lost Generation MWh	-	-	-	-	-	-	-	-	-			
	Planned Lost Generation MWh	-	-	-	-	-	-	-	-	-			
	Availability %	100.00%	0.00%	100.00%	100.00%	-	100.00%	85.78%	85.78%	85.78%			
	Forced %	0.00%	0.00%	0.00%	0.00%	-	0.00%	0.00%	0.00%	0.00%			
	Planned %	0.00%	0.00%	0.00%	0.00%	-	0.00%	14.22%	14.22%	4.22%			
	Maintenance %	0.00%	0.00%	0.00%	0.00%	-	0.00%	0.00%	0.00%	0.00%			

Figure 2.1: Monthly Report is a Snapshot of the Data Produced to Track Unit Performance (Sands & Blake 2015).

tors (AEMO). The unit load, its available capacity and metered energy is communicated in real time to AEMO. The station transformer's usage is measured and read by Ergon Energy and Stanwell is billed for its use. The station transformer energy is used to run the ancillary services of the station like administration buildings, coal handling plant drives, air compression and water treatment. The station boards also link to each unit to assist in unit start-up until it can sustain its own load. Tarong also has a 15 MW Gas Turbine (GT) connected to the station switchboards which is used for start-up power during black start operations. This is a situation when the state grid is unable to supply the station power. The GT can also be used to generate back to the grid. All metering is audited and certified by a third party at routine intervals to ensure transparency.

2.3 Electricity Generation Process

This section outlines the power generation process or what is known as the cycle. The Tarong Power Station is a closed cycle regeneration sub critical thermal unit utilising coal as its primary fuel source. The cycle consists primarily of 11 major components. A broad understanding of these components will assist to better understand the future discussion this project will undertake.

Cooling Water Cycle: Used to convert the steam back to condensate once it has passed through the low pressure turbine, heat absorbed is removed by the associated cooling towers.

Condensate and Feedwater System: Collects the condensate and transports it through the heater stages to the boiler drum;

Steam Cycle: This cycle converts the preheated feedwater to steam and superheats it to precise pressure and temperature require by the turbine. The steam cycle also includes supplying heat to the low and high pressure heaters.

Turbine System: Produces the mechanical motive force required to drive the generator through conversion of steam energy;

Generator System: Produces power via a 6 pole generator with a stationary stator and rotating DC field. The generator output is 20 kV which is stepped up for transmission and stepped down for internal unit auxiliary power usage.

Fuel System: This system supplies the fuel for the boiler flame via oil supply, coal pulverisers and associated burner fronts.

Boiler: Produces the heat required for steam generation and consists of multiple stages of tubing.

Air and Gas: Forced Draft, Induced Draft, Primary Air and Air Heaters all combine with dampers to supply the necessary air for the mills and boiler operation.

Control System: Servers, processors, control cabinets, field power supplies, field devices, unit control desks and operator workstations that are required to monitor and control the unit.

HV/LV Distribution; Switchboards, cabling and circuit breakers that control the distribution of electricity for the unit;

Chemical: Chemical instrumentation, wettrucks, chemical dosing, and condensate polishing plants required to monitor and maintain the unit cycle chemistry.

Figure 2.2 is a realtime capture of the TPS Unit 4 HMI overview page which shows the major processes that combine to generate power in a thermal unit.

The cycle is considered closed as once the steam energy is utilised by the Low Pressure (LP) turbine it is then recondensed and used in the cycle again. Fresh demineralised water is only required to be added to the system to make up for losses. The paragraphs below explain the cycle operation in more detail.

The Cooling Water, Condensate and Feedwater Cycle

Cooling water is used in the condenser to recondense the steam into water. The cooling water picks up heat during this process; this heat is then removed by circulation through the natural draft cooling towers. This circulation is achieved by Circulating Water (CW) Pumps. The condensed steam is then considered condensate and is extracted from the condenser hotwell by the Condensate Extraction Pumps (CEPs). The CEPs transport the condensate through the gland seal condenser and three low pressure heaters. The condensate picks up heat as it passes through each heater. This heat is supplied by gland seal steam and steam picked off the LP turbine stages. Once the condensate has

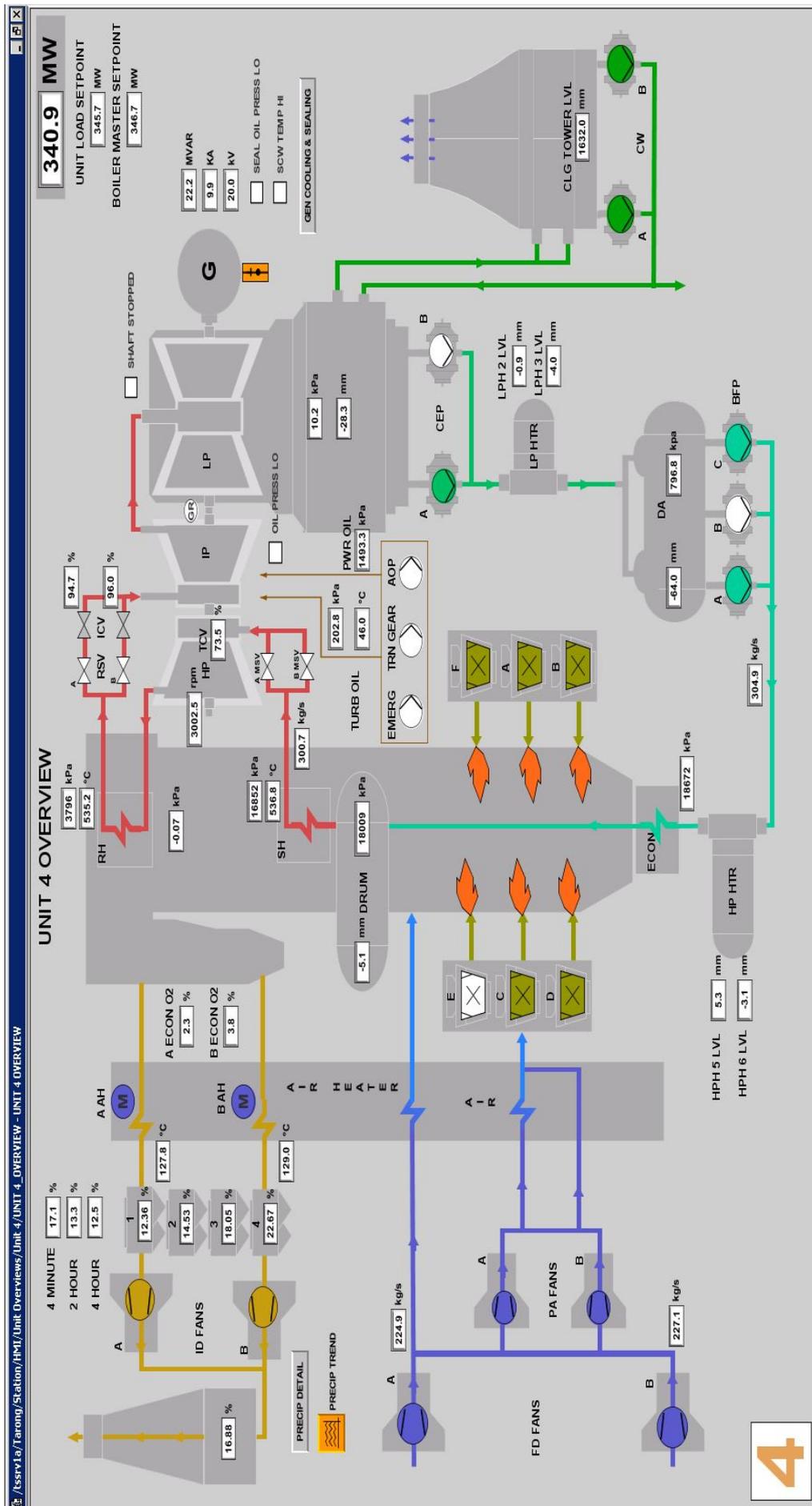


Figure 2.2: Unit 4 T3000 Overview - Screen Capture from Tarong Power Station DCS (Siemens 2015).

passed through the LP heaters it arrives in heater 4 or a vessel better known as the Deaerator (DA). It is known as the Deaerator as part of its function is to remove any CO_2 from the condensate as it enters the vessel. The Boiler Feed Pumps (BFPs) draw their feed water from the DA then transport it through two high pressure (HP) heaters and economiser tubing into the boiler drum. Through this part of the cycle the water is known as feedwater and picks up further heat. The heat for HP heater 5 (HP5) and 6 (HP6) is supplied by steam tapped off the higher temperature Intermediate Pressure (IP) turbine stage and the cold reheat line respectively. The economiser tubing heat is supplied by the waste heat extracted from the boiler air as it makes its way to the chimney stack. From the boiler drum the feedwater is converted to saturated steam and enters the steam cycle. The steam builds enthalpy as it works its way through the primary, secondary and tertiary superheater stages to arrive at the HP turbine at $535^\circ C$ and 17 MPa. The steam drops pressure and temperature as its stored energy is imparted on the HP turbine. The steam is then fed back into the boiler as cold reheat steam to boost the pressure and temperature again in the reheat boiler stages. Once the temperature has reached $535^\circ C$ and 3.8 MPa it returns as hot reheat steam to drive through the intermediate and low pressure turbine into the condenser to complete the cycle.

The Boiler, Air and Gas Cycle

The boiler flame is supported by the fuel, air, and gas systems. The air and gas cycle consists of two Forced Draft (FD) Fans, two Induced Draft (ID) Fans, two Primary Air (PA) Fans, two Air Heaters, Electrostatic Precipitator (ESP) and the chimney stack. This air and gas system supplies air to the boiler and pulverisers. The fuel system consists of six coal pulverisers and the interconnecting pipework to take the Pulverised Fuel (PF) to the six burner fronts. There is 3 to 5 of these 6 pulverisers in service at any point in time depending on load requirements. The Tarong pulverisers are ball grinding mills that grind the coal to fine dust to be transported by the $100^\circ C$ PA to the burner front. The PF enters the boiler and is lit off by either the existing flame or by gas ignition supported oil flame. The rate of PF added supports the floating boiler flame to provide the required heat to the boiler tubing transporting the steam. The boiler requires large amounts of air to feed the flame and to carry away ash from the combustion process. This air is supplied from two FD fans drawing in fresh air and two ID fans drawing air out through the precipitator then expelling it through the chimney stack. The precipitators

are located between the boiler and the stack. The ESP removes particulate matter via attraction to plates with pulsed direct current (DC).

Minor Auxiliary Systems

There are many other smaller systems that contribute to the Tarong thermal cycle. Below are some of the smaller systems;

Condensate Polisher: Chemically cleans the unit cycle water;

Flame Detector Cooling Fans: Supplies cooling air to burner front flame detectors;

Oil Systems: Supplies oil for bearings, hydraulic equipment and burner front ignition needs;

Coal Feeders: Controls the feed rate of coal into pulverisers;

Stator Cooling Water: Supplies water for generator cooling.

2.4 Unit Energy Requirements - Auxiliary Consumption

This section outlines the major items of energy use within the unit cycle that are deemed to be auxiliary. The major energy consuming devices are those associated with the major functions of the unit. They are condensate and feedwater, fuel supply, air supply, cooling water and generator excitation. Primarily these are large Direct on Line (DOL) 6.6 kV motor driven devices.

The functions of the units boiler are to combine the fuel, air and heat required to sustain combustion thus providing heat to the boiler tubing. This combustion process requires large amounts of air which is supplied by two 2.95 MW 6.6 kV motor driven Forced Draft Fans through an air heater into the boiler. The fuel is supplied to the boiler by coal pulverisers or mills. Each mill is driven by a 200 kW 415 V motor to drive the grinding table via a speed reduction gearbox. The coal is supplied into each mill via a coal feeder driven by a smaller 4 kW variable speed motor. Once ground the coal is picked up and transported to the boiler by the air supplied by two 0.9 MW 6.6 kV motors that drive the Primary Air Fans. Some of this air is heated by the air heater, hot PA, and some

is cold PA. The hot and cold PA are then combined to ensure the optimal combustion temperature is maintained. All of this air needs to be removed from the boiler at the correct rate to ensure a vacuum is always maintained in the boiler enclosure. This is achieved by two 4.55 MW motors that drive the Induced Draft Fans. These fans draw air and non-combusted waste material out of the boiler through the air heater and over the economiser tubing. The air then passes through the electrostatic precipitator, which remove particulate matter before discharging the air out of the chimney. The boiler tubing requires water which is converted to driving steam energy of a thermal sub critical power plant. This boiler water is fed up to the boiler drum by pump units in two stages. During the first stage water is extracted from the hotwell with one of two 1.1 MW 6.6 kV motor driven condensate extraction pumps. The CEP then pushes the water through the LP heaters into the DA. The second stage is two of the three 5.65 MW 6.6kV motor driven boiler feed pumps deliver the feedwater at the correct rate through the economiser into the boiler drum. The rate of feedwater is controlled by the variable speed nature of the pump section of the BFPs. An actuated scoop element controls the oil flow inside the fluid coupling to link the DOL motor to the pump element. Cooling water is circulated through the condenser and out to the cooling tower for heat removal. This is achieved by two 1.35 MW 6.6 kV motor driven circulating water pumps. The final large consumer of energy is the generator excitation system. This system uses an excitation transformer to reduce the 6.6 kV to 700 V AC which in turn is fed into the Automatic Voltage Regulation (AVR) system to convert to high current DC. The current level of this DC is varied and applied to the rotor of the generator (Hitachi 2003).

Table 2.2 is a listing of the major drives and their ratings as discussed in the section above.

Many other smaller loads contribute to the total auxiliary power usage of a unit including control system power supplies, flame detection cooling fans, lube oil pumps, stator cooling water pumps, air heater drive motors, polisher booster pumps and deaerator booster pumps.

Drive	Rating
Force Draft Fan	2.95 MW
Induced Draft Fan	4.55 MW
Primary Air Fan	0.9 MW
Boiler Feed Pump	5.65 MW
Circulating Water Pump	1.35 MW
Condensate Extraction Pump	1.1 MW
Automatic Voltage Regulator	1.1 MW

Table 2.2: Major Drives as summarised from Hitachi Operations and Maintenance Manuals (Hitachi 2003).

2.5 Energy Monitoring

This section outlines the way in which energy has been and is currently monitored on the Tarong Power Station site.

In the year 2000 the station was approaching the end of its design life. It was still part of the Queensland Electricity Commission (QEC) and a move to a deregulated electricity market was being proposed. As part of this change the state government was looking at breaking up the generators to ensure they were competitive when they moved to the market environment. This network evolution was an important step as the electricity generators now would be treated as a business and would be required to return profit. Up until then they had been solely government controlled and were treated as an essential service. Being solely government owned their primary drivers were long-term availability rather than profit. Once this breakup began Tarong Power Station ultimately became part of Tarong Energy as a standalone business in the electricity market (Australia 2015). Hence Tarong Energy wanted to better understand its business costs and part of this was the need to understand its in-house electricity usage. Below is an outline of the level that Tarong Energy and now Stanwell Corporation understand their internal energy usage. It will start with an overview of the stations electrical distribution.

Figure 2.3 is a high level single line diagram showing the electrical distribution of a single unit.

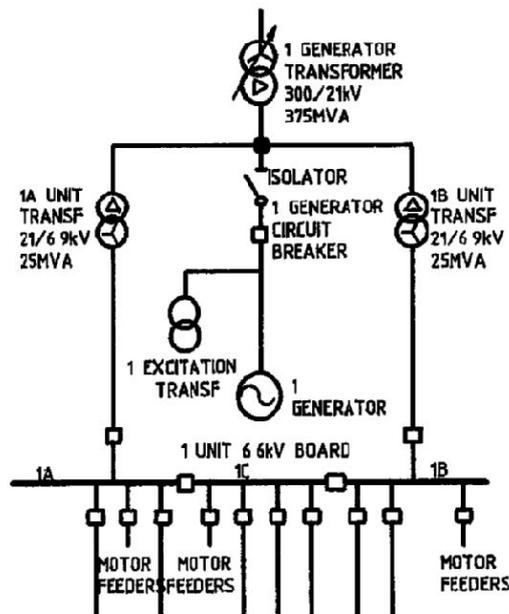


Figure 2.3: Unit 1 Distribution Overview (Hitachi 2003).

It can be seen that the Unit 6.6 kV switchboards are fed from the step-down transformers connected to the generator output. These are the A and B Unit Transformers and together they supply all the major drives and auxiliaries for a single unit. The station ancillary supplies are shown in figure 2.4. Some of the station supplies are coal handling, air compression, administration, water treatment and ashing.

The four unit generator transformers feed into the grid and also supply their own in house auxiliary energy requirements via 25 kV/6.6 kV step down transformers, the unit transformers. The ancillary services common to all units are supplied by the station transformers A and B which draw their power directly from the grid. The station transformer also can be linked to the unit 6.6kV switchboards to assist in unit start-up until it can supply its own auxiliaries. Each of the four generator transformers and eight unit transformers have an energy meter installed. It is these meters that are directly connected to AEMO for market purposes. These meters have been updated routinely as part of the stations network connection agreement. The then Tarong Energy implemented metering on the major drives across one unit, Unit 4, and all primary feeds on the station switchboards. The approach would give them a good picture of site usage on which to base future strategy. Some additional meters have been added to individual areas such as ash and chemical plants loads. Administration building supplies had more metering installed in recent years under the government reporting guidelines of the National Greenhouse Energy Reporting Scheme (NGERS). Each segment of the energy metering was connected

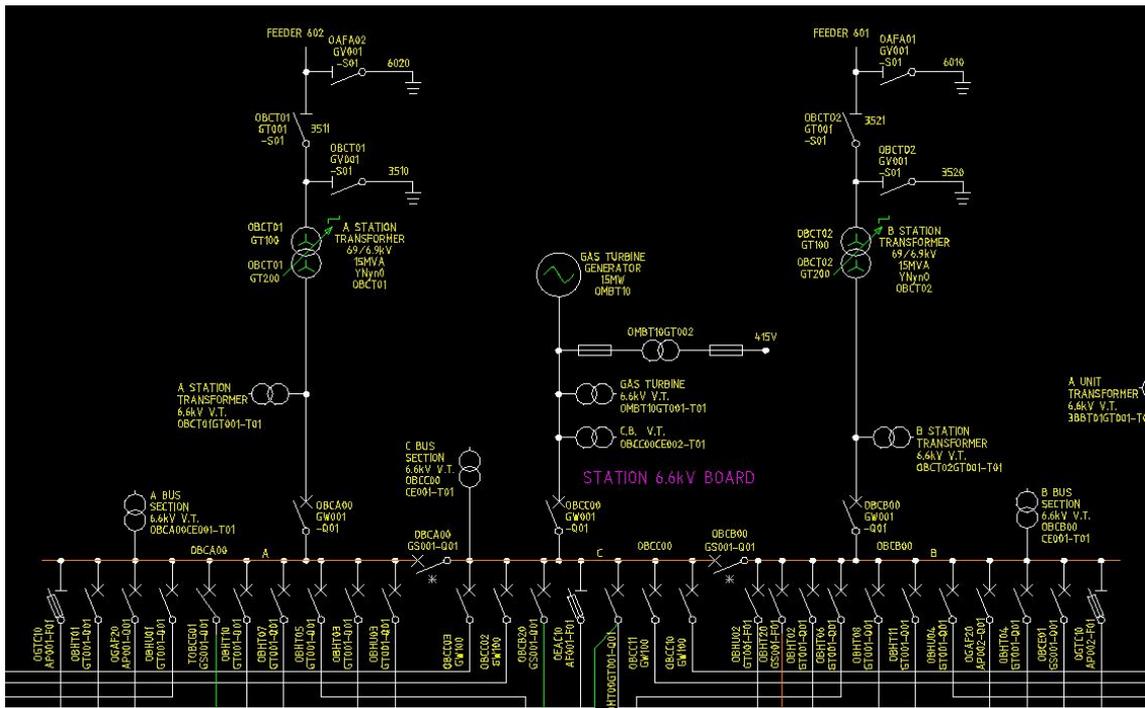


Figure 2.4: Station Ancillary Distribution Overview (Hitachi 2003).

to the station Supervisory Control and Data Acquisition (SCADA) system via local Momentum Programmable Logic Controllers (PLCs). The local PLC polls the individual meters to retrieve the blocks of relevant data from the energy meter via RS-485. This data includes current, voltage, power factor and running totalisers. All data retrieved is then read out of the PLC's by the plant data historian.

2.6 Control System

This section outlines an overview of the Tarong Power Station site control system and some of its features that will assist this project.

The control system is central to all industrial plants. In this way Tarong is no different. The control system allows a high level of automatic responses to the raw signal inputs from the field. It is this automated system that enables the plant operators to oversee and run the plant. The control system and associated data historians allows engineers to monitor, improve and optimise the plant. Tarong is now 30 years old and is operating past its design life. The original Hitachi control system has been upgraded to the Siemens T3000 Distributed Control System (DCS). The majority of plant's, station and units based, now

run on T3000 with a project currently running to migrate the remaining plants across to T3000.

T3000 is Siemens flagship product that allows both logic and Human Machine Interface (HMI) creation to occur whilst the plant processes are running. Operators can continue to monitor and control the plant while engineering staff work on the system (Ltd 2015). It is a powerful all in one product with hundreds of individual blocks available from which to create screens, logic and sequences. T3000 can be easily altered, optimised or expanded up to the resource limitation of each individual Central Processing Unit (CPU).

The unit plant energy usage is the focus of this project so the T3000 structure for one unit will now be briefly described; this description is true for all units. The unit T3000 architecture consists of a central server and two major buses. The first bus is the automation bus which looks after communications between the Automation Processors (AP). The second bus is the application bus which handles the communication from the plant APs to the operator workstations and other services that requires plant data access. The central server is a multiple slice high redundancy server that sits between the two buses and runs the T3000 processes. There are eight APs on a unit application bus to handle the large number of Inputs/Outputs (I/O) required to safely and affectively manage the running the unit, around 7000 I/O in total. Each AP handles a specific area of plant to reduce the level of inter AP communication required. For example AP 3 is Fuel and AP 1 is Turbine. There are separate high integrity I/O for Safety System control loops. An additional virtual AP exists in the central server. In this virtual AP logic can be created without consuming resources. At TPS the logic space that this virtual machine provides is used to run plant performance calculation and other functions that are not directly related to plant functionality.

Some of the I/O relate to the control and monitoring of drives. These drives are a variety of valves, dampers, pumps and fans. The drive data that exists within T3000 is position, status, current, voltage and power factor when available. The data from this I/O is ported from T3000 through to the data historians. It is this drive data around auxiliary energy consumption devices that will be utilised during this project.

2.7 Conclusion

In this chapter the background and operation of Tarong Power Station was explored. Both a brief history and a plant overview builds a picture of the current plant status. It demonstrates the need to understand the unit auxiliary energy consumption and the control system tools available for use during the project. This overview of the energy information assists in understanding the gaps that this projects outcomes aim to fill, and the drivers behind them. The next chapter reviews the existing literature related to the project aims.

Chapter 3

Literature Review

This chapter reviews relevant literature that is key to understanding previous work that has been completed in the field of the project. The review will focus on the outcomes of previous work to uncover any gaps and learning that can be utilised during this project. The standards and best practice required in the field measurements of energy calculation inputs will also be reviewed to assess Tarong Power Stations energy practices. Power calculations, control optimisation and power station modeling techniques round out the chapter.

3.1 Auxiliary Power Usage and Reduction

This section reviews the knowledge base of auxiliary power usage and the ways in which auxiliary power reduction has been approached around the world. While there are some common themes in the approach to energy reduction, each country has developed a unique focus. Their focus is directed by the current issues that are seen to be the top contributors to the problem.

The first steps in any attempt to reduce power usage is to understand the energy consumption within a plant. This understanding often takes the form of an energy audit. A Chinese study of energy auditing and its coal-fired power plant application by the Jilin Province Science and Technology Department states that the concept of energy audit is to inspect, examine and analyze the physical, financial and other high-energy using units.

This study continues to state the targets of energy audit are investigating problems and weaknesses in using energy, tapping of energy-saving potential, finding rectification measures and formulating saving goals (Li, Wang, Jiang & Zhang 2009). This project, whilst not framed as an audit, will address the shortfalls in Tarong Power stations current levels of energy usage knowledge. This current lack of knowledge is a primary barrier to achieving meaningful energy reduction at TPS.

United States of America Network Experience

The 2011 Technical Report published by Electric Power Research Institute (EPRI) (EPRI 2011) focuses on the opportunities to enhance electric energy efficiency in the production and delivery of electricity. The pertinent sections of the report are the chapters that focus on electricity used for power plant auxiliaries. The report is centered around power stations in the American grid. The discussions in this paper by EPRI are significant as the American power industry, whilst considerably larger, is at a similar evolutionary state as Australia. The report states that 11 % of electricity produced is used in delivering the electricity to the customer of that 40 % is consumed in power production. The figure 3.1 shows some of the typically uses of auxiliaries or so called “parasitic loads” in thermal power plants. EPRI states that “These auxiliaries are designed based on maximum performance and environmental compliance, not on minimum use of in-house electricity use.” (EPRI 2011). It is this statement which demonstrates that past design focus leaves room for energy improvement which will be explored by this project. The paper discusses that many auxiliaries have an opportunity to improve on their energy consumption due to factors such as oversized auxiliaries, use of modulating mechanical mechanisms, design trade offs between efficiency and cost, and tuning based on a particular parameter. It is also noted that as is the case with Tarong the auxiliary load is monitored but not generally considered separately as there are greater efficiency opportunities possible in the boiler and turbine plant. EPRI consider plant auxiliaries as part of heat rate and they contribute approximately 90.8 kHJ/kWh to the overall average heat rate of 1000 kHJ/kWh. This linkage may help lift the profile at Tarong. EPRI continue to say that this amounts to 5-10 % of total generation depending on unit size, fuel type and ambient temperature. This is a figure that is reflected in Tarong’s monthly reports. These reports show that between 7.3 and 10.3 percent of generated energy is consumed by in house auxiliary loads. These monthly figures are presented in table 3.1 (Sands & Blake 2015).

- Electric motors used to power:
 - Pumps
 - Gas booster compressors
 - Fans
 - Air compressors
 - Material handling (conveyors, coal mills, crushers, limestone slurry feed, etc.)
 - Gas turbine starters
 - Soft starters for hydro turbines and synchronous condensers
- Electric pre-heaters
- Environmental controls
- Building uses sometimes called house uses such as:
 - Lighting
 - Air conditioning
 - Food service
 - Domestic water heating
 - Information technology (computers, monitors, Supervisory Control and Data Acquisition Systems (SCADA), etc.)

Figure 2-1 illustrates the components of a typical steam-driven electric power plant. These auxiliaries are designed based on maximum economic performance and environmental compliance, not on minimum use of in-house electricity use.

Figure 3.1: Typical Auxiliary Loads in Coal Fired Power Plant (EPRI 2011).

Two facts that EPRI presented which are of particular relevance to the TPS situation. The first was that the more base loaded and therefore higher capacity factor of the plant the lower the internal usage. The second fact revealed by the figures is that age of the plant is not as relevant as once thought. This is partly due to the additional of overall auxiliary plant load by emission control equipment. The EPRI data is considered high quality as it was collected over a 5 year period across 350 fossil fuel power stations.

World Comparison

The level of auxiliary energy consumption recorded in America by EPRI (EPRI 2011), of 5-10 %, is reinforced as an average level of consumption through the findings of Mandi (Mandi et al. 2012) and India (Cornerstone 2014) in Indian power grid. Mandi reported that within Indian sub-critical power stations, 30-500MW, an average auxiliary consumption of 9.5 % existed. Mandi continued to state that this figure offers ample room for improvement. This auxiliary energy usage level is also reflected in the recorded European auxiliary energy consumption. ABB's European productivity group states that between 7 and 15 % of coal-fired power generation is consumed in-house by auxiliary systems (Boveri 2015). These figures reflect the levels recorded at Tarong Power Station in their monthly reports (Sands & Blake 2015). Tarong's Monthly reports over the last 12 months show a range of 7.3 % to 10.3 % depending on the load profile of the month. Below in table

Month	Unit 1	Unit 2	Unit 3	Unit 4	Tarong Total
August 2015	7.7%	offline	7.9%	8.0%	7.9%
July 2015	8.1%	offline	7.9%	8.2%	8.1%
June 2015	8.8%	offline	8.0%	8.3%	8.3%
May 2015	8.1%	offline	7.3%	8.0%	7.8%
April 2015	8.1%	offline	8.2%	8.2%	8.2%
March 2015	8.7%	offline	8.7%	9.1%	8.8%
February 2015	8.6%	offline	8.7%	8.9%	8.7%
January 2015	8.9%	offline	8.9%	9.8%	9.2%
December 2014	9.0%	offline	9.1%	9.3%	9.1%
November 2014	8.8%	offline	10.3%	10.3%	9.7%

Table 3.1: Auxiliary Energy Usage Figures in Percentage by Unit for the Last 10 Months (Sands & Blake 2015).

3.2 is a summary of the results uncovered from different countries. This identifies a key point, which is that Tarong's auxiliary energy consumption is consistent with recorded levels of internal power usage in coal fired power stations around the world.

Location	America	India	Europe	TPS
Auxiliary Energy Usage Level	5-10 %	9.5 %	7-15 %	7.3 - 10.3 %

Table 3.2: A Sample of Auxiliary Energy Consumption figures from Around the World. (EPRI 2011) (Mandi et al. 2012) (Boveri 2015) (Sands & Blake 2015)

Figure 3.2 shows the breakdown of the auxiliary power consumption for a typical coal fired power plant (EPRI 2011). The EPRI figure shows that the BFP group is the primary power consumer at approximately 37 % of the total load. The CW and ID fans make up the next 30 %. This breakdown will be compared to the results found during this project and will be used to drive the investigation portion of this project. The EPRI report also presents some suggested methods for auxiliary power consumption reduction. Its primary recommendation are the installation of adjustable speed drives (ASD) this is also a recommendation made by ABB European Division (EPRI 2011) (Boveri 2015). This is a major capital works investment but can, particularly at lower loads, deliver large savings of up to 85 % reduction in drive power. The investigation of the application of

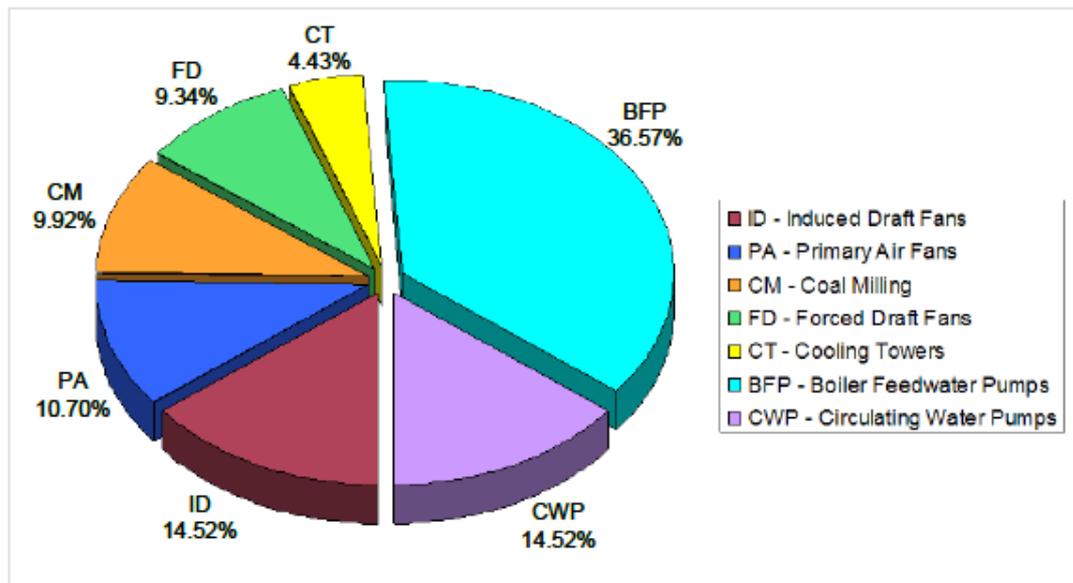


Figure 2-4
Auxiliary Power Consumption – Typical Coal-Fired Power Plant (Source: EPRI 1017546)

Figure 3.2: Typical Auxiliary Loads and their Breakdown of Usage in Coal Fired Power Plant (EPRI 2011).

this innovation to Tarong plant is outside of the scope of this project. Though it should be noted that while drive replacement is not to be investigated by this project the idea has merit and should be investigated by Tarong in the future. This project will instead consider control optimisation of the high usage drives to reduce energy consumption.

Indian Network Experience

The concept of reducing the auxiliary power usage of coal fired power stations was explored in Indian power stations by Rajasheker, Mandi, Udaykumar and Yaragatti. The focus was how to reduce auxiliary power usage without major capital investment. Their study was undertaken across twenty three 210 MW sub-bituminous coal fired power stations giving a large base for data collection and comparisons (Mandi et al. 2012). The data within the paper is closely representative of the Tarong units as the cycle, depicted in figure 3.3, is very similar to the Tarong cycle previously outlined. This study is highly relevant to the Tarong Power Station situation as Mandi discusses that the Indian power stations are routinely requested by the network controller to run at sub-optimal partial load. As discussed previously this is routinely the case for TPS as it is no longer always

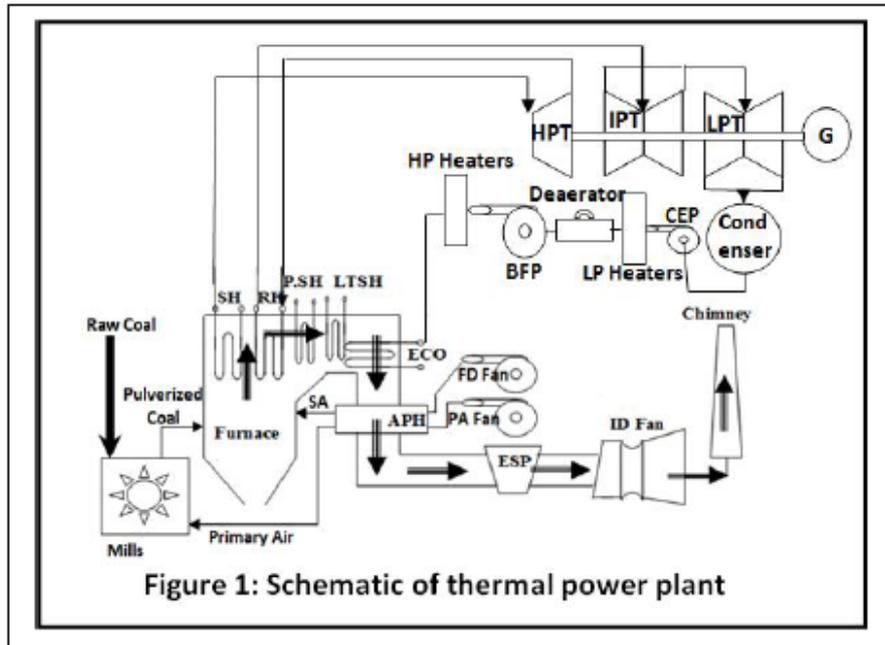


Figure 3.3: 210MW Coal Fired Power Plant Cycle (Mandi et al. 2012).

a base load station in the AEMO dispatch order of merit.

The major contributors to auxiliary power usage are the BFPs, IDs, FDs, PAs, Mills, CW pumps and CEPs. Mandi's work showed a strong link between plant load factor and auxiliary power usage. Load factor is the actual running power level versus the peak running power level expressed as a percentage. The work undertaken by Mandi and associates show that when the plant is running at higher loads all major drives are operating at a high load factors. This leads to the plant operating more efficiently and is reflected in the overall reduction of auxiliary power usage (Mandi et al. 2012). The graph in figure 3.4 is extracted from the study which shows the positive impact of load factor on each major power contributor.

Mandi's concludes that the auxiliary power consumption within the Indian power generation plant is on the high side compared to other developed countries and that low load factor is a primary cause of running with higher auxiliary power usage than the benchmark (Mandi et al. 2012). The Tarong monthly reports reflect this occurrence as when running at higher unit loads, therefore higher load factor, TPS shows lower recorded auxiliary power usage (Sands & Blake 2015). Mandi lists the following Indian specific factors that affect load factor: Coal quality, lack of equipment optimisation, excess steam and water flow, hesitation to upgrade equipment, as well as poor initial design with many oversized drives. All of these factors, coupled with inefficient controls, have a degrading effect on

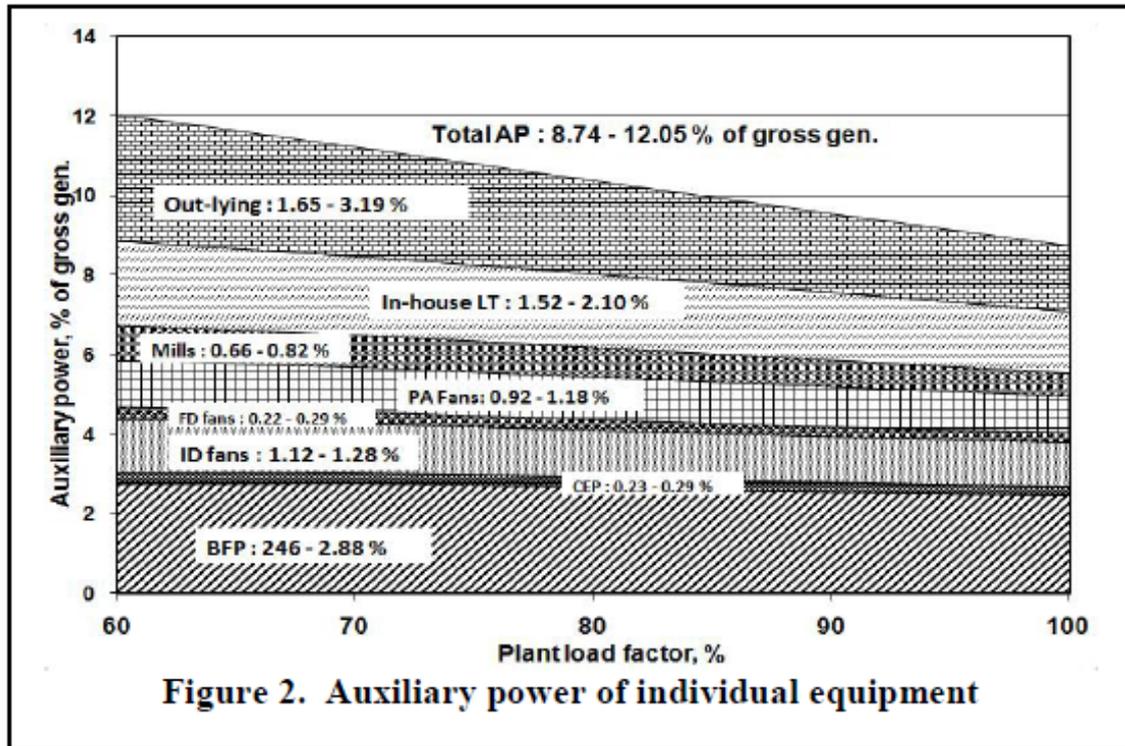


Figure 3.4: Auxiliary Power Consumption Against Load Factor in Coal Fired Power Plant (Mandi et al. 2012).

the plants overall power factor. There are many reasons presented for the lower power factor of the units across India. Mandi gives reasons like inadequate coal supply, poor coal quality, ID fan erosion, inadequate PA supply and non-availability of mills are all related to the low level of development in the Indian power generation industry (Mandi et al. 2012). These factors are largely not present within Tarong Power Station. If these do occur i.e. intermittent lower coal quality, which does occur in the form of high iron or ash content coal, it is well prepared for and effectively managed. During these lower coal quality periods the plant does show downgrading effects. Some other factors they discuss are still a large concern within the Tarong plant, however it should be mentioned that they are more quickly and effectively addressed due to the developed nature of the Queensland electricity industry. Factors such as poor electrostatic precipitator performance (ESP), poor condenser vacuum, air leakage in the air heater and duct system, inadequate circulating water temperature and less demand in the power grid all negatively influence the efficiency of the Tarong Power Station and Stations worldwide. Many of these factors are also identified in the 2011 EPRI report on American power generation as negative influences on auxiliary energy usage levels (EPRI 2011). This suggests that the case Mandi puts forward of these being solely Indian specific factors is somewhat overstated.

The Indian paper also presents some methods to improve plant load factor for each of the major drive groups. Primarily Mandi focuses on health and capacity adequacy of major auxiliaries, especially the Mills and ID fans (Mandi et al. 2012). This focus is interesting and leaves out the major contributor to the auxiliary load and that is the BFP units. The BFP influence and potential reduction will be explored more during this project.

The majority of energy conservation measures Mandi suggested to improve load factor are already in place within Tarong to some extent or are not relevant due to local factors. They are however relevant for discussion. In the paragraphs below each of the factors discussed by Mandi are broken down by plant group. They are then reviewed for potential relevance to this current project and Tarong in general.

Coal Pulveriser Improvement

Suggested mill group improvement factors, including improvements to coal quality, coal grind sizing quality and raw coal sizing are all in place at Tarong. Coal quality is continually monitored but is limited by the available mine coal quality and contractual obligations. The station's overall design is linked strongly to the station's Meandu mine coal characteristics. Trials of different coal quality have caused high heat pick up and ash build up problems proving that TPS cannot cope with higher calorific value coal. The coal at Tarong is sent through sizers to ensure that only coal under 25 mm diameter enters the mills. As noted by Mandi the size of the coal entering the mill has a profound effect on the mill group power consumption. The coal grind quality is monitored at Tarong and the classifiers are a fixed design with regular inspections to ensure that the adjustment and wear rates do not degrade the mill performance to greatly. Mandi suggests that hi-chrome liners, wear plates and ball ring sets be utilised to reduce wear rates and improve mill performance. This suggestion has merit within the broader mill management at Tarong as wear rates and material review is continuous but is not in the scope of this paper. The measure of periodic purging of mills to enhance the capacity and reduce auxiliary power usage is a concept that has potential merit at Tarong and is in the scope of this project as it can be fully implemented with control system modification (Mandi et al. 2012). This being the case it will be fully investigated to evaluate the potential energy reduction value in the Tarong environment.

Induced Draft Fan Improvement

Most measures identified by Mandi to improve the ID fans capacity factor are strongly linked to coal quality and plant overhauls (Mandi et al. 2012). As with the suggested mill factors, most ID fan factors the Indian paper suggest are already in place at Tarong. Reducing ash content in the coal, reducing pressure drops across the Precipitator and Air Heaters, reducing furnace ingress and air ingress in flue gas ducts, improvement of electrostatic precipitator performance and air heater performance are all in place on Tarong units in some form (Hitachi 2003). Improving Ash content of coal through washing the coal has always been a key part of the Tarong coal management strategy. It is achieved through passing the coal through a wash plant on the mine site prior to being sent to the Tarong stockpile. As noted by Mandi the ash content can be reduced through washing which reinforces the Tarong practice. This reduction of ash content assists in the reduction of pressure drops across precipitator and air heaters. Coupled with good soot blowing, ashing and overhaul processes the pressure drop is addressed in these important high wear portions of the process.

Another factor in ID fan energy usage is reducing furnace and air heater air ingress, tramp air. This is managed at Tarong through O_2 monitoring and the overhaul routines. This is a major factor in ID fan performance and is largely out of the day to day control of the operator. There is little that can be done from a control system perspective in relation to tramp air. Mandi suggests that hard facing of the ID fan impellers to reduce the erosion rate and enhance the capacity the ID fans (Mandi et al. 2012). This has merit within the broader air management at Tarong as wear rates and material review is continuous but is not in the scope of this project.

Another item raised by Mandi is the dosing of ammonia into the flue gas to assist the ESP to collect particulate matter, this also has potential gains at Tarong but is not within the scope of this project. There are no clear control system optimisation recommendations for the ID fan group in the Indian paper (Mandi et al. 2012). This will be explored further during this project as the ID fans are a significant contributor to auxiliary power load of the coal fired stations.

General Improvements

The remaining plant areas were viewed by Mandi under the section on other measures to improve load factor. The improvements were very broad based wide reaching statements that apply to all thermal plants but without any specific examples that could be directly utilised during this project. Some improvements listed were improve boiler efficiency, improve turbine efficiency, maintain circulating water temperature through cooling tower maintenance, maintain regenerative heaters, use higher calorific value low ash coal, reduce specific steam consumption and fuel consumption (Mandi et al. 2012). One improvement suggestion that has control optimisation merit is to maintain generator performance by enhancing cooling systems. This will be explored further during this project.

Whilst the majority of the auxiliary power reduction options explored by Mandi cannot be realised without capital investment the concept of reduction through improving plant load factor, operational optimization, adoption of advance control techniques and implementation of energy conservation techniques is certainly a target worth spending time investigating as the repayment is considerable (Mandi et al. 2012). Most of the suggestions within this key paper will not be pursued in the form raised. These suggestions will be instead explored from the angle of capital free control modification.

Europe and South American Experience

ABB Europe suggests there are many ways that a reduction in auxiliary power can be addressed. Primarily their focus is on installation of Medium Voltage (MV) variable speed electrical drives. They claim a significant reduction in power consumption is possible if the power required to drive the fans and pumps is generated in the right way. This however requires significant capital outlay, whilst this may be repaid it is a major works program to achieve (Boveri 2015). This has potential on the Tarong site but will not be explored during this project.

In Brazil the focus of one research group into the reduction of auxiliary power in coal fired plants was to investigate the influence of displacement power factor (DF) and total harmonic distortion (THD) (Schwanz, Silva, Leborgne, Bretas & Gaidzinski 2014). The paper concludes that the ESP section of the plant was the main source of THD and that the major drive induction motors are the source of low power factor. They propose that

these two factors combined are a source of energy consumption that could be addressed through filters and capacitor banks. As Tarong has a similar pulsed DC precipitator and multiple large induction motor loads it is a strong possibility that these two situations exist within the TPS plant. This means that there is a potential to reduce power usage at TPS with the capacitor and filter banks. This is outside of the scope of this project and will not be explored further.

Auxiliary Power Usage and Reduction Conclusion

The literature discussed in this section has demonstrated that the auxiliary power is a worldwide issue that causes the industry considerable problems each year. The EPRI report suggests that if the auxiliary load in America could be reduced by just 5 % the industry could delay the need for building new coal fired power plant by 10 years (EPRI 2011). There is clearly a need and incentive for this project and continuing research to assist the industry move forward.

3.2 Power Calculations

This section outlines the theoretical background information that relates to power measurement in a 3 phase AC system. Primarily all drives that relate directly to the auxiliary energy consumption of the Tarong Power Station are 3 phase AC and generally are 6.6 kV or 415 V DOL drives.

When a load is connected to an AC power source it draws current. This current varies sinusoidally depending on the load requirements and will lead or lag the voltage depending on the load. The voltage supply system maintains the sinusoidal supply voltage that originates at the generator. In a power generation environment, such as Tarong, it can be noted that the voltage supply system is very robust being fed directly from the generator output and a system of low impedance transformers. The other note is that loads within the power generation environment tend to be inductive with a lagging current.

The information in this section is summarised from the text “Introductory Circuit Analysis” Chapters 14 and 19 (Boylestad 2003). There are 6 major concepts that need to be comprehended in order to understand the power calculations. This understanding is

required to enable the in-depth exploration of auxiliary power usage of a power station.

These are:

1. Average or Real Power;
2. Power Factor;
3. Apparent Power;
4. Reactive Power;
5. Power Triangle;
6. Wattmeters.

Each of these 6 will be mathematically explained in the sections below.

3.2.1 Average or Real Power

(Boylestad 2003) shows that Average or Real Power is defined as

$$p = vi \quad (3.1)$$

Where

$$v = V_m \sin(\omega t + \theta_v) \quad (3.2)$$

$$i = I_m \sin(\omega t + \theta_i) \quad (3.3)$$

Once manipulated using trigonometric identities the following represents the power delivered to a network.

$$p = \left(\frac{V_m I_m}{2} \cos(\theta_v - \theta_i) \right) - \left(\frac{V_m I_m}{2} \cos(2\omega t + \theta_v + \theta_i) \right) \quad (3.4)$$

It can be noted that the first portion of equation 3.4 is fixed i.e. not time varying and the second portion varies with time t . This can be extended that the time varying portion of equation 3.4, over a period of one AC cycle, will be equal to zero. Therefore the first

portion of equation 3.4 is referred to as the average or real power delivered to the load. This fixed portion becomes equation 3.5 below.

$$p = \frac{V_m I_m}{2} \cos(\theta_v - \theta_i) \quad (3.5)$$

As the difference between the angle of the voltage and the angle of the current is defined as

$$\theta = |\theta_v - \theta_i| \quad (3.6)$$

Therefore the average power calculation becomes

$$P = \frac{V_m I_m}{2} \cos \theta \quad (3.7)$$

The symbol for real or average power is P. Since the effective voltage and current equations are

$$V_{eff} = \frac{V_m}{\sqrt{2}} \quad (3.8)$$

$$I_{eff} = \frac{I_m}{\sqrt{2}} \quad (3.9)$$

Therefore the average power calculation can also be written as

$$P = V_{eff} I_{eff} \cos \theta \quad (3.10)$$

Where

P - is the average power in watts [W];

V_{eff} - is the effective voltage applied to the load in volts [V];

I_{eff} - is the effective current drawn by the load in amperes [I];

$\cos \theta$ - is the displacement angle between the voltage and current waveforms [degrees].

It is worth noting that if the load is purely resistive the voltage and current are in phase. In this situation the phase angle is $\theta = 0$ therefore $\cos \theta = 1$ and the average power is the product of voltage and current. If the load is purely inductive the voltage and current are in 90° out of phase. Since the i lags v by 90° the phase angle θ is -90° therefore $\cos \theta = 0$ and the average power is zero. If the load is purely capacitive the voltage and current are 90° out of phase. Since the i leads v by 90° the phase angle θ is $+90^\circ$ therefore $\cos \theta = 0$

and the average power is zero. In situations where all components are not ideal the phase angle will rarely reach $+/- 90^\circ$

Within Tarong it is the average or real power reading that is utilised to measure auxiliary power consumption.

3.2.2 Power Factor

From 3.2.1 it can be seen that the displacement angle $\cos \theta$ causes significant impact on the final power value and it is therefore known as the power factor.

$$PowerFactor = PF = \cos \theta = \frac{P}{V_{eff}I_{eff}} \quad (3.11)$$

Where

PF - is the power factor which is either leading or lagging [dimensionless];

θ - is the displacement angle between the voltage and current waveforms [degrees];

P - is the average power in watts [W];

V_{eff} - is the effective voltage applied to the load in volts [V];

I_{eff} - is the effective current drawn by the load in amperes [I].

The terms leading and lagging power factor are used to describe if the current leads the voltage or lags it. Capacitive loads have a leading power factor and an inductive loads have a lagging power factor. As the auxiliary power consumption at Tarong is primarily inductive loads it is expected the system power factor would be lagging.

3.2.3 Apparent Power

Is the result of the applied voltage and current without the influence of power factor. This apparent power is generally used as equipment power rating in VA. The equation for apparent power is shown below in equation 3.12.

$$S = VI \quad (3.12)$$

Where

S - is the apparent power [VA];

V - is the voltage applied to the load in volts [V];

I - is the current drawn by the load in amperes [I].

3.2.4 Reactive Power

The reactive power is the peak value of power that produces no net power transfer, either in an inductive or capacitive load, during a complete cycle. The formula for reactive power is shown in equation 3.13.

$$Q = VI \sin \theta \quad (3.13)$$

Where

Q - is the reactive power [VAR];

V - is the voltage applied to the load in volts [V];

I - is the current drawn by the load in amperes [I];

θ - is the displacement angle between the voltage and current waveforms [degrees].

While the net value of this power is zero it is significant in that the load must be supplied power every half cycle and return the power source during the other half cycle. This reactive power calculation influences the peak level of power required to be supplied to the network.

3.2.5 Power Triangle

Average power, Reactive power and Real power relate together in the vector domain as in the equation 3.14 below

$$S = P + Q \quad (3.14)$$

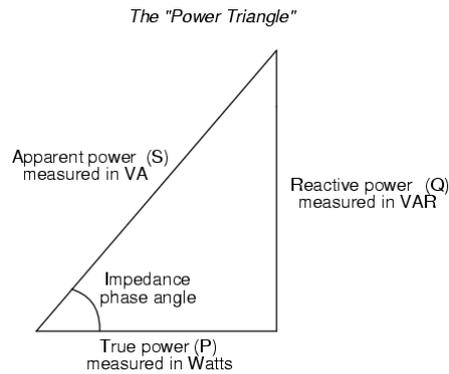


Figure 3.5: The Power Triangle relates Apparent, Reactive and Average Power with Power Factor (Boylestad 2003).

The power triangle is shown in figure 3.5. It visually displays the vector relationship between the three powers and the power factor.

The individual power components of separate loads can be summated in the vector form to give an overall resultant power vectors. If one quantity is not known then Pythagorass theorem can be applied to the system to solve for the missing quantity. This is possible as the real power and reactive power vectors always form a right angle.

$$S^2 = P^2 + Q^2 \quad (3.15)$$

It is also noted that from the power triangle the power factor can be found and vice versa as

$$PF = \cos \theta = \frac{P}{S} \quad (3.16)$$

3.2.6 Wattmeters/Watthour Meters

A wattmeter is a type of meter that measures the number of watts consumed by a load in a measure of time. The meter inputs are the voltage and current relating to the load. The meter also measures the displacement angle between the two waveforms. It utilises these three measurements to calculate the forms of power required to be displayed. Typically the units of measure of this style of meter is kWhr or kilowatts consumed in an hour. The meters normally totalise the kW consumed to allow billing or other monitoring to occur. It is typical for the modern version of this style of meter to be connected to a remote system to record and/or display consumption data.

The mathematical representation of this meter is

$$E_{Wh} = P_W t_h \quad (3.17)$$

Where

E_{Wh} - is the average or real power consumed by the load in watt hours [W/hr];

P_W - is the instantaneous power consumed by the load in watts [W];

t_h - is the time in hours over which the measurement is taken [hr].

3.3 Practical Industrial Power Measurement

This section outlines the way in which power measurement is undertaken in industrial plants and more specifically the way in which it is measured within Tarong Power Station unit auxiliary plant.

From the late 1970's until the turn of the century the primary means of achieving both electrical drive protection and load metering was via a meter involving an analogue device generally an induction disk type. These meters function by utilising the magnetic field generated by passing a sample of the circuit load current through a coil which in turn spins the induction disk. The field strength increases with increased current flow which in turn spins the disk faster. In drive protection once the disk is moved far enough the relay will trip the feeder. In energy measurement the speed of the disk can be used to meter the loads energy consumption. Today the primary method installed in new plant is digital based metering. These use the load voltage and current measurements together with digital sampling times to calculate power flow. The meter than can process this data in many ways to perform protection functions or measurement recording (IEEE 2013).

The key inputs to calculate power are voltage, current and power factor or the magnitude of the phase angle θ . The measurement of these will now be discussed.

The first key measurement is the supply voltage to the load of interest. This voltage measurement is difficult to measure directly in most cases as the supply voltage is high voltage. It is generally too high for direct measurement or input into electronic components. This being the case the voltage that is required to be measured is stepped down to

a safe level. In most cases the voltage is reduced to 110 V AC and is achieved by step down transformers commonly known as a voltage transformer or VT. These transformers have a primary winding that is connected to the higher level voltage and the secondary winding is connected to the energy metering device or control system interface module. VT's have a fast response and high resistance to saturation with fuses to provide protection from over voltage or failure events (IEEE 2013).

The next key measurement of interest is the load current. Similar to load voltage the value of the current is normally too high for safe measurement without an interface device. The interface device in the case of current is a current transformer or commonly known as a CT. The CT is directly wrapped around the conductor of which the measurement is to be made. This conductor can be a core of a supply cable or in higher current situations it is common to be a busbar. This CT steps the high current value down to a lower value that can be directly fed through an energy meter or control system interface module.

The final measurement is power factor and this is not measured as such, it is extracted from the voltage and current measurement. It is the displacement angle between the two measurements.

The accuracy of measurement is a combination of the accuracy, repeatability and linearity of the pickup devices, namely CTs and VTs and the quality of the energy meter being utilised to totalise the measurement. CT's come in different classes, protection, metering and general purpose. Protection class CT have a high saturation level as they are required to accurately measure high current under fault conditions. Metering CTs are high accuracy and have good linearity in the region of interest. General purpose CTs have an average level of accuracy across a wide operating range and are generally used for control system feedbacks (IEEE 2013).

An article produced by Power Logic in conjunction with the University of Missouri-Columbia describes the way in which energy metering can be combined with local Programmable Logic Controller (PLC) and computer based data historian to create a power measurement network (Asumadu, Devaney, Wallis & Bond 1990). This is precisely the way that energy metering data is collected at Tarong. Tarong Power Stations unit auxiliary power usage is recorded by two primary meters per unit, one on each of the two unit transformer feeds into the unit 6.6 kV switchboards. It is these two meters that totalise the auxiliary power usage on the unit. The meters are Power Logic model DM6200 which

get their voltage and current inputs from the metering class CTs and VTs mounted in the unit switchboard 6.6 kV incoming cubicle. These power logic meters are then connected to the plant data historian via Modbus over ethernet. The unit power meters are in good working order and are regularly certified. It is the readings from these meters that are used to report on the unit auxiliary usage each week, month and for annual reporting.

On Unit 4 additional metering devices are installed on each 6.6 kV drive and the major 415 V drives. These meters are Electrex brand and are connected together on a RS-485 network whose data communications is controlled by a local PLC. This PLC is then connected to the plant data historian via ethernet. The individual drive data network has been left decay. The local meters are generally operational but the communications network to retrieve data from the meters has failed. This has in the past been related to individual meter failures dragging a segment of the RS-485 network down. Attempts to repair this system are current underway but are unlikely to be completed by the end of this project.

This section has summarised some of the key points of industrial power measurement.

3.4 Standards

This section outlines the standards relating to the measurement of energy metering.

The most relevant standard uncovered during the literature review was IEEE Standard 3001.8 - IEEE Recommended Practice for the Instrumentation and Metering of Industrial and Commercial Power Systems (IEEE 2013). This standard covers Instrumentation and Metering. It outlines the importance of metering including considerations to apply the latest metering technology. It discusses examples of ideal installations, instruments, permanent and portable meters, recording instruments and auxiliary devices such as CT's and VT's. The standard provides guidance on the class of CT's and VT's for reliable measurement.

As this project will utilise data from an existing metering network the standard has been used to review the metering network and its overall capacity for accurate readings as compared to the standards recommended practice. The TPS installation conforms well to the standards outlined in IEEE 3001.8 - 2013. The majority of installation practices

are closely aligned with the example installations given in the standard. In particular the class of CT being utilised is better than recommended, the VT's limit the voltage and have the relevant fuse protection recommended by the standard. The digital power meters themselves are integrated into the industrial plant supervisory system as recommended in the previous section, though current plant failures need to be addressed (IEEE 2013). The device used for DCS feedback do not comply with the metering class standard outline in IEEE standard. The devices accuracy combined with the 100 ms sampling time of the control system makes them accurate to approximately 1 % meaning that they comply with the standard expected accuracy under IEEE 3001.8.

As a result it is confirmed that the readings available in the TPS DCS are of a reasonable standard from which to base calculations but will have a level of inherited error.

3.5 Control Optimisation

This section outlines the control optimisation and the recent research in the field.

Control optimisation is defined as the process of tuning a process to give an ideal response in relation to a specific parameter. In the power station environment the units control is optimised or tuned to give the optimum energy return for the coal being fed into the boiler. This involves multiple loop tuning with the end aim being the lowest amount of coal required to deliver the high pressure steam at the ideal temperature and pressure to the turbine. During this tuning process the level of energy consumption is not monitored or reviewed in any way. It is considered a byproduct of running the unit efficiently. Simon and associates discuss in their 2010 control conference paper that primarily industrial control and specifically power station control is based on multiple Single Input Single Output (SISO). Often these loops are Proportional Integral Derivative (PID) that require independent tuning even though they all influence the same final overall system output (Simon et al. 2010). Simon's focus was on adding in an overall controller to coordinate the effort of the multiple SISO loops in achieving the steam temperature at minimum coal input.

A simplified control scheme of a coal-fired power plant is shown in Figure 3.6. It visually displays the primary inputs and outputs of the overall power station control system. This simplified system shows the final drivers on which normal power station control

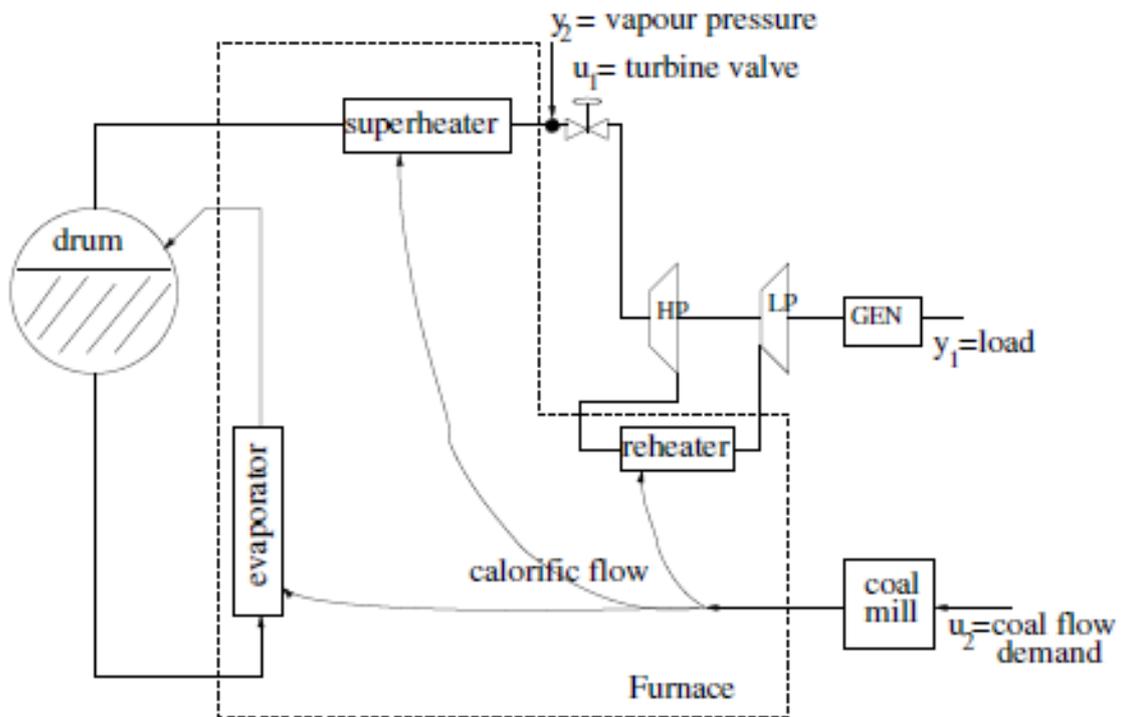


Fig. 1. Simplified scheme of a coal-fired power plant.

Figure 3.6: The Simplified Control Scheme of a Coal-fired Power Plant (Simon et al. 2010).

optimisation is focused.

3.6 Power Station Modelling

This section outlines the styles of modelling recently utilised to represent power station processes for the means of research or investigation. This project will require a robust MATLAB model of auxiliary energy usage to be created. This model will be used to not only better understand the energy consuming devices on the Tarong coal-fired units but also to trial any possible reduction options that will be generated later in the project. The intention of this section is to review the information known about power station modeling techniques.

In 2011 a paper was presented to a Mechatronics seminar in China which gave an overview of modelling and simulation of thermal power plant (Changliang, Hong, Jinliang & Chenggang 2011). This paper was reviewed as a starting point to understanding the challenges of modelling power plant. The paper firstly reviews thermal process and

its modelling. It acknowledges that whilst approaches are widespread from step-response models to predictive control models there is always a large gap between the model output and the reality of the plant process. This is primarily due to the complexity of the thermal process. Zhen and associates next cover simulation of the thermal plant through Distributed Control System (DCS) interface. These simulators use the actual DCS logic and learned values from running the logic in the simulation environment to create a simulator that can be driven in real-time. Tarong Power Station has just such a simulator for their 350 MW units based on the T3000 DCS platform. It is proposed as part of this project to use this simulator to test in near real-time any proposed energy saving modifications to confirm the control system response. The paper discusses the fact that whilst many solid modelling results have been achieved there are many challenges to be resolved. The primary issue is achieving a model that accurately reflects the real plant. Another is how to best use the abundance of operational data that is stored by the plant historians. The final challenge presented is how to best control access to the data to allow simulation development to continue. The balance between open access to data and secure access still needs to be addressed.

The creation of a non-linear model in Simulink for a 300 MW coal-fired unit is discussed in a paper presented to the IEEE Industrial Electronic Society Conference in 2004 (Changliang, Jizhen, Yuguang & Xiuzhang 2004). The basis of the model is to break down the power production process into smaller systems in the complex S-plane environment and then combine as a total model. The model is heavily reliant on parameter adjustments to ensure the model closely reflects the running plant. It also required large amounts of development to get a relatively close working model before parameter tuning can begin. They concluded that much future work is required to develop usable models.

With a considerable amount of data tracked and stored in the modern era it is a natural progression that this data is utilised as the basis of models (Yang, Wang, Zhang & Chen 2010). The Beijing University paper explores this potential by focusing on the real-time data collected at 600 MW coal-fired units in China to produce a model that focuses on determining energy-saving potential in the plant. They explain that as the power generation process is complex and non-linear environment the creation of models which accurately reflect the real plant is extremely difficult. This leads to the creation of models that only focus on individual equipment items or on steady state process as the dynamic nature of power generation process cannot be reflected accurately. Their

modelling efforts extract data from the plant historian and then apply rules to classify and correlate the data to provide theoretical guidelines for energy conservation within coal fired power generation. Chen and associates use the cleansed data through a Spatial-temporal Distribution Model of Energy Consumption based on Support Vector Regression algorithm. Their conclusions were that the process of data mining can support real-time or historical review of power generation process under many possible algorithms setup to reflect the user requirements. They propose that it could be linked to real-time plant data to reflect the current status of the plant energy consumption. The modelling technique based on data mining holds particular interest as the modern control system at TPS hold vast quantities of data that can be readily accessed. The data is not only available in realtime though data links to T3000 but historical data is able to be accessed, via the plant data historian PIMS which holds the last 6 years data.

This section has reviewed a cross section of literature relating to potential modeling techniques that the could be utilised in achieving this projects aims. The discussion has highlighted the challenges of ensuring that the final model matches the actual plant response. This was identified as being particulary challenging in the complex non-linear power station environment with many modelling techniques requiring multiple parameter tuning to achieve any decent level of accuracy. The key discovery of the literature review on power station modelling was that the environment lends itself to models based on plant data. This data based model technique has many advantages, the main one is the link ensures that the model inputs are actual plant data not calculated or estimated. This real data input basis means that when constructed properly the final model outputs have strong ties to the actual plant.

3.7 Conclusion

In this chapter the literature related this project has been explored. The use and importance of energy monitoring was reviewed with the main finding that monitoring and reporting is a key step to reduction of energy usage.

It has been demonstrated that auxiliary energy consumption in power stations worldwide is an issue which remains largely unresolved. Many of the solutions proposed require capital works to achieve energy reduction. These solutions, as with all unproven capital

works programs, come with risks. The primary risks are that the outlay does not yield the return expected, along with project cost and time over runs. Potential short and long term plant issues associated with changes to an isolated section of the plant design also pose a creditable risk. These reasons combine to mean most plant owners are reluctant to take on large scale plant changes in the pursuit of energy reduction. This lends support to undertaking projects such as this that look at ways to reduce energy consumption without capital investment.

Energy metering calculations were covered as these will form the backbone of this projects outcomes. The way in which practical industrial measurement is achieved was explored. Confidence was gained that the energy input measurements made in the Tarong Power plant are reliable. This is an important point as it is these DCS inputs that will be utilised for both the creation of energy tracking logic in T3000 and to prove the MATLAB models.

The IEEE energy measurement standard was reviewed with respect to the installed equipment and this showed that the installed measurement devices are suitable on which to base calculations. The chapter was concluded with a discussion on the possible power station modeling techniques. These were explored and the conclusion was that using data mining as the model basis is not only robust but the ideal way to represent the complex non-linear environment of power generation processes.

The next chapter will explore the project methodologies employed to achieve the project aims.

Chapter 4

Methodology

This chapter will outline the methodology utilised to reach the project aims. It will begin with a justification of the project methodology selection then move onto detail of how each of the methods were achieved. Being a highly dynamic power station environment the method chosen must be able to be compared to the installed energy meters to give the confidence needed to propose long term plant change.

4.1 Selection

This section will outline the development of the project methodology. The methodology was completed after analysing the literature review, the available plant data and the required outputs from this project. The use of both MATLAB modelling and T3000 energy tracking logic was decided upon after investigation of other methodologies. This method allows both a calculated and real world insight into the auxiliary power usage of the power station. The dual approach will allow robust confirmation of the MATLAB models as there will be a running total, on the actual plant, to compare it against.

The primary method chosen is the creation of plant data based MATLAB models that will reflect the actual plant energy consumption throughout the model running period. MATLAB models of the auxiliary energy consumption of the power station electricity generation process will be created. This method will assist with both understanding the high usage items and in testing of potential energy reduction options. MATLAB has been

selected as the software in which to develop the required models due to its flexibility and common use in engineering environments. It is a proven software that is known to perform this function well and is regularly referenced in power station modeling IEEE papers found during the literature review (Yang et al. 2010). This will align with Objective 2 to “Create a SIMULINK model, in MATLAB, of the energy profile of a single unit”. These models will be valuable tools for achieving project Primary Aims 1 and 2 being “To understand the auxiliary consumption within Tarong Power Stations 350 MW coal fired units” and to “Identify potential control based energy reduction strategies”.

The approach of creating a purely mathematical based model in MATLAB was discounted as not being linked strongly enough to the running plant to enable justification for change in the control system on the actual plant. It also became obvious during the literature review that the power generation process is extremely dynamic making the creation of an accurate model very difficult. Most modeling paper outlined previously discussed concerns that the end product was unlikely to reflect the actual plant. The process of creation of a plant data based model is seen to be more robust and fit for purpose (Yang et al. 2010). One of the secondary objectives of this project is to achieve real energy reduction on the running plant and therefore the method chosen needed to reflect the requirement to be able to present data to Stanwell management in support of any proposed change. Another method that was considered was solely utilising the historical data in the plant historian to create trends and graphs of the usage in certain situations. This method may have been robust in giving some resultant data to work with and base potential improvement options on but it lacks the ability to be able to test the impact of any proposed changes. Therefore the data available will still be assessed as part of the project process as it can assist in guiding the creation of potential energy reduction options. Data stored in the plants historical databases, Process Information Management Solutions (PIMS) and InSQL, will be extracted to explore the plants energy usage under different operational conditions. The data extracted from the historian was used as an input into the MATLAB models created.

The second primary method will be the creation of real time energy tracking logic within T3000. This project methodology will utilise the real time plant current and voltage measurements available in the T3000 DCS to calculate power usage on all drives related to auxiliary power usage. The field measurements have been confirmed as suitable for use in this method. The literature review confirmed that the measurement devices comply

with standard expected accuracy levels. The digital control system sampling rate and CPU cycle rate whilst high will still have a low level of sampling error. This method will align with Objective 3 - “Create energy tracking logic in the T3000 Digital Control System”. The tracking logic will calculate and totalise the power usage of auxiliary power devices with available feedback. This data can then be summated in a number of ways to assist in investigation of usage under certain conditions. This will create valuable data for achieving project Primary Aims 1 and 2 being “To understand the auxiliary consumption within Tarong Power Stations 350 MW coal fired units” and to “Identify potential control based energy reduction strategies”. Another driver for creation of the T3000 tracking logic was creating something that can be used during this project and into the future. This logic will progress toward the Secondary Aim 1 “To leave in place energy consumption information that the station can utilised into the future”. Once the tracking logic is created it can forever be used by the plant owners engineering staff to look at short and long term energy usage of individual drives across all units. This tracking logic can potentially assist in short term rectification of high power consumption events and in long term planning to reduce the overall level of auxiliary energy consumption. There is the potential to setup alarms based on this logic to warn the operator of the unit of a high energy consumption event. This would allow operator assessment and response to occur during the event rather than solely reviewing the data at the end of each week or month.

The tracking logic and MATLAB modeling will be validated against the limited installed energy metering which strengthens the method selection. The tracking logic will be installed on Tarong Unit 4 initially and the MATLAB models will represent one units auxiliary energy consumption. The tracking logic will be installed on the other 3 Units once confirmed as correct and functional.

This MATLAB model and T3000 tracking logic findings will complement the comprehensive literature review that focused on energy calculations, coal fired power plant auxiliary energy usage, auxiliary power reduction techniques, relevant standards and control optimisation. The literature review had a broad approach to uncover as much relevant information as practical.

Building on this the methodology selected is shown below

Primary Method 1 Extract the mechanical and electrical parameters from the data

historian e.g. vane positions, scoop positions, current, voltage and power factor data;

Primary Method 2 Create MATLAB models based on the extracted data. The first group of models summate the voltage and current data to ensure it matches the monthly energy meter reported value. The second group of models will be able to alter vane and scoop position to alter the energy consumption pattern;

Primary Method 3 Collate all potential energy reduction strategies and assess the resulting strategies utilising the MATLAB model;

Primary Method 4 Create energy tracking logic in T3000 for all drives where field measurements are available;

Primary Method 5 Compare T3000 energy tracking and MATLAB model results against the installed energy metering;

Primary Method 6 Propose advantageous low risk changes to the operational plant;

Secondary Method 1 Test proposed changes to the operational plant on the unit simulator;

Secondary Method 2 Implement proposed changes on the operational plant;

Secondary Method 3 Create HMI and reporting based on the T3000 tracking logic.

Note The primary methods are those that are required to complete the project primary objectives. The secondary methods are those that will achieve the projects secondary aims if time and risk assessment permits.

The next sections will describe the process of implementation of the chosen methods. Firstly a section discussing the mechanics of the initial data gathering exercise will be presented. This then leads into discussions of the MATLAB model and T3000 logic creation processes. These processes are laid out in order of completion to build a picture of how the validity of the created outputs was confirmed.

4.2 Initial Data Gathering

The first stage of the design process comprised exploration and collection of data. This required a multifaceted approach to locate any data that was loosely or specifically re-

lated to the auxiliary energy consumption at TPS. The approach was to first collate the information then later sort for relevance and decide on whether inclusion was warranted.

The primary sources that were consulted were

1. Drawings - Electrical, Mechanical and Process Instrumentation(P&ID);
2. Operations and Maintenance Manuals - Boiler, Turbine and Generator;
3. Energy Meter Data - Manual, InSQL data and PLC code of the site energy metering;
4. T3000 - PIMS Data and I/O relating to energy usage;
5. Plant Performance Reports - Weekly and monthly editions.

Each of these areas will now be expanded on in the sections below. It should be noted that each area was revisited as new information or path of enquiry became available.

4.2.1 Drawings

Mechanical, Electrical and P&ID drawings exist for the majority of TPS plant areas. The majority of drawings were supplied with the construction contract. These drawings have been progressively expanded and modified to reflect the current installation as changes have occurred on the plant. Each drawing has a revision number or letter to track the revisions as they occur. Majority of the drawings accessed have had minimal revision and reviewing the revision detail blocks show that the changes have not changed the original design intent. These drawings are stored in electronic form within a software package called Projectwise, a Bentley drawing management package. A smaller selection of electrical drawings are stored in hard copy form in drawing libraries across the site. These two locations were searched to locate relevant drawings. The drawings located were in two main categories, heavy power and instrumentation and control (I&C).

The unit auxiliary power is measured at the unit transformer level. The heavy power electrical drawings of the power feeds radiating from these transformers were located. From there drawing detailing of the size and type of loads was determined. Interconnections between boards were identified for later use in models and tracking logic. A sample of identified drawings is listed in Appendix G.

Below in table 4.1 all of the auxiliary loads that emanate from the unit 6.6 kV transformers are listing including there key rating data.

Load	Rating	Duty	Voltage	Ampere	Power Factor
A Primary Air Fan	990kW	1 of 2	6.6kV	103A	0.6-0.85
A Forced Draft Fan	2950kW	1 of 2	6.6kV	311A	N/A
A Induced Draft Fan	4550kW	1 of 2	6.6kV	503A	N/A
A Unit 415V Transformer	2000kVA	1 of 1	6.6kV	175A	N/A
A Precipitator Transformer	2500kVA	1 of 2	6.6kV	220A	N/A
A Condensate Extraction Pump	1100kW	1 of 2	6.6kV	116A	N/A
A Circulating Water Pump	1350kW	1 of 2	6.6kV	158A	0.7-0.75
A Boiler Feed Pump	5650kW	1 of 3	6.6kV	550A	0.65-0.87
C Boiler Feed Pump	5650kW	1 of 3	6.6kV	550A	0.65-0.87
Bunkering Transformer	1000kVA	1 of 1	6.6kV	88A	N/A
C Unit 415V Transformer	2000kVA	1 of 1	6.6kV	175A	N/A
B Primary Air Fan	990kW	1 of 2	6.6kV	103A	0.6-0.85
B Forced Draft Fan	2950kW	1 of 2	6.6kV	311A	N/A
B Induced Draft Fan	4550kW	1 of 2	6.6kV	503A	N/A
B Unit 415V Transformer	2000kVA	1 of 1	6.6kV	175A	N/A
B Precipitator Transformer	2500kVA	1 of 2	6.6kV	220A	N/A
B Condensate Extraction Pump	1100kW	1 of 2	6.6kV	116A	N/A
B Circulating Water Pump	1350kW	1 of 2	6.6kV	158A	0.7-0.75
B Boiler Feed Pump	5650kW	1 of 3	6.6kV	550A	0.65-0.87

Table 4.1: Auxiliary Load - Detail of all Loads that Contribute to the Auxiliary Power Consumption of the Unit (Alstrom 1981). Note N/A (Not Available) Power Factors were Unable to be Located.

The second part of the drawing review was a search for signals relating to the power calculations. It was found the majority of drives had a current feedback but there was limited voltage and power factor feedback. These I&C drawings show the T3000 loop from the field device through to the analogue input card. The drawings located are also listed in Appendix G.

4.2.2 Operation and Maintenance Manuals

When TPS was constructed the contract included the supply of multiple sets of operations and maintenance manuals. The manuals were supplied with each contract area. The primary areas of interest for auxiliary power consumption are the Boiler, Turbine and Generator Operations and Maintenance manuals. The operations sections of these manuals describe to the plant operator the way the plant process works and how to drive each of the individual components. The maintenance sections of the manuals detail the individual plant devices spare parts, recommended maintenance schedules, fault finding information, and the manufacturers literature at the time of installation. These manuals have been updated and expanded as the plant has been modified or as the plant has been made redundant. The manuals also contain the initial commissioning and testing results for the plant drives.

Where available, manufacturer data on the major auxiliary energy consuming motors, pumps and fans were gathered from the respective manuals. This was found to be limited with data being unavailable for many drives. The operational descriptions of each of the items identified from the drawings were also obtained and reviewed. These describe the preferred operational limits and plant configurations for each system. In the vast majority of cases this is still how the plant is operated. Discussions were held with operations staff and the plant control logic was reviewed to confirm the plant function. This occurred during data gathering with a view to understand the plant limitations and operational practices to be considered during the creation of any proposed energy reduction options.

4.2.3 Energy Metering Data

A specific energy metering manual was located during the data gathering exercise. This manual contains details of the installation of Electrix meters onto the Unit 4 and Station 6.6 kV switchboard feeders (Godsmark 2001). A full list of drives and CT sizes was located. This is included in Appendix H along with some installation drawings. This manual showed the detail of the RS485 and PLC network that was installed. The available registers that were setup to be retrieved from the energy meters is shown, a sample of this is included in Appendix H.

InSQL is the oldest plant data historian that exists on the Tarong site for SCADA/PLC

data collection. Using the detail found in the energy metering manual a review of available data in InSQL was then carried out. It was hoped that this would yield recorded data for the Unit 4 auxiliary energy drives. It was found that the Station 6.6 kV energy meter installation was active with large amounts of data available. The Unit 4 system has fallen into disrepair as the only figures being actively reported on are the high level unit transformers which have their own communications network. The unit data has only recorded null values for many years with old data being written over. This has meant no meaningful data relating to the auxiliary energy consumption was able to be collected from the InSQL system.

4.2.4 T3000

T3000 is the very broad title given to the DCS monitoring and controlling the majority of the plant within TPS. The T3000 monitors and actively drives all of the loads that consume auxiliary power on the units. Within the T3000 function block code there is an archiving function that stores selected values at the rate of the solve of the block involved. The archive data is stored on the T3000 application server. This storage is finite and only three years available within the system at any point in time. Each month the oldest data is archived off onto DVD. There also exists a plant historian PIMS which accesses and logs points of data from within the T3000 code. This then allows long term retrieval and viewing of plant data without needing to access historical DVD data.

During the drawing collection and analysis process I/O was identified that pertain to the flow of energy on the plant. These are listed in Appendix G and are primarily voltages and currents within the power system. These I/O were then investigated in T3000 to see if they were archived. Any points archived are then read out and stored in PIMS. All points identified in the drawing review were found to be archived at 200 ms in T3000. The PIMS archive settings for these points set to record at 1 second intervals. This means that rapid changes in T3000 will not be recorded in PIMS. This will give a low level of sampling error in the PIMS data as it is being archived. It is worth noting that as data is retrieved by the PIMS interface, interpolation of stored data will occur if the data requested is not available at the point in time requested.

As it was now identified that the energy calculation data was available the next stage was to locate those points within the process that effect the load on the auxiliary drives. These

include damper, vane and valve positions that affect the air and water flows within the unit processes. While it is a highly dynamic process that is influenced by multiple functions the points identified are the primary influence and for the purposes of this project are suitable for MATLAB data input. The identified process points were investigated to confirm the T3000 and PIMS archiving rates. All points identified in the process review were found to be archived at 100 ms in T3000. The PIMS archive settings for these points set to record at points were investigated to look at T3000 and PIMS archiving rates. All points identified in the process review were found to be archived at 50 ms intervals.

Once all relevant PIMS points were identified 24 hour blocks of information were requested of PIMS. These blocks were chosen to reflect the varying loads and situations that the plant is routinely requested to perform. The blocks of data were requested from PIMS with an interval of 1 second. This gave output excel files of 86402 rows of data which 2 rows of header data showing the PIMS tag name and the tag description. A sample of this data is located in Appendix F.

4.2.5 Plant Performance Reports

Performance of the TPS is always under constant scrutiny as small changes in performance can cause large variations in running costs. To effectively collate and disseminate the plant performance data the responsible engineer creates a weekly report highlighting the key performance indicators. This weekly report is a short 2 page presentation of data relating to capacity factor, availability, coal consumed, fuel oil consumption, generated MWhrs, exported MWhrs (AEMO), auxiliary energy MWhrs, efficiency and fuel oil stock levels. Graphs relating to water, fuel and emissions round out the report. The plant performance engineer also prepares a far more detailed 35 page monthly report which rolls up all of the details of the weekly reports and dissects them further. The auxiliary energy usage is presented here as an overall figure per unit in MWhrs and in percentage of generation.

The level of information contained in these reports is of use to the project aim of understanding the unit auxiliary energy consumption. Twelve months worth of these reports has been collected and the key factors summarised for later reference. These summaries are analysed in the results and data analysis chapter 5.

4.3 T3000 Energy Tracking Logic Creation

This section details the way in which the T3000 energy tracking logic was created. The creation of energy tracking logic in T3000 was addressed in a staged approach to build confidence in the accuracy of the logic before applying it to all loads of interest.

As discussed in the sections above it was identified that the majority of drives had realtime current feedback available. There is limited voltage feedback into the DCS with realtime voltages available at the 20 kV and 6.6 kV level but none at the 415 V level. The power factor readings are very limited with only the 2 available. They are read out of the unit transformer energy meters at a slow poll rate.

The first item that was built in T3000 was a set of test logic to implement equation 3.10, real or average power. It is repeated here for convenient reference.

$$P = V_{eff}I_{eff} \cos \theta \quad (4.1)$$

This formula was implemented using basic blocks from the T3000 library such as add, multiply and divide blocks. This logic was then tested by simulating the input parameters with known values. Applying these simulation values allowed a known current, voltage and power factor to be input into the logic. This allowed the logic accuracy to be confirmed against the result of manual calculations. This allowed testing of a variety of function blocks to reduce the logic complexity to a minimum. This initial test logic is shown in figure 4.1.

Once this test logic was confirmed as functional a page of logic was created for the A Unit Transformer. This drive was chosen as it has a functional energy meter whose value also exists in T3000. This allowed comparison logic to be created for logic confirmation. The test logic was copied and the real plant 20 kV level power factor, voltage and current inputs were connected to the blocks in place of the simulated test inputs. The realtime power reading from the energy meter was then compared to the realtime calculated reading generated from the logic. The initial logic instantaneous power matched the energy meter realtime power reading. The same logic was then created using the voltage and current readings on the 6.6 kV side of the A Unit Transformer. As there is no 6.6 kV level power factor reading the same 20 kV power factor has been utilised. These two reading were

the compared to confirm accuracy. The accuracy of the calculated logic was found to be within 1 % of the the 20 kV energy meter reading.

The next stage of the tracking logic creation was to expand on the realtime calculated logic to include blocks for totalisation of the energy consumption. The T3000 integration blocks were utilised as part of the totalisation function to implement equation 3.17, watthour meter. This was then fed into a series of first in first out (FIFO) and addition blocks to allow daily, weekly and monthly figures to be captured. Resets and progression of these blocks required the connection of logic to a “Time” block that has realtime links to the application server clock. Since this meter is one of the two meters utilised for reporting there is a daily, weekly and monthly totalised figures to which the tracking logic can be compared. The logic shown in figure 4.2 shows the final configuration of the logic blocks required to achieve the MWhr totalisation. This stage of the project took some weeks to achieve the required accuracy. This was primarily because the multiple delays required between the FIFO blocks took many iterations to achieve the required reset order. After each logic change the logic was tested using the simulation function but a full 24 hour, midnight to midnight block, was required to confirm the function. Often the results reflected in testing by simulation were not reflected in the actual logic response to the change of day. This was due to the speed of applying simulations is different to the speed of input changes during realtime solve of the blocks.

The accuracy of this A Unit Transformer logic was proven to be within 2 % of the energy meter readings for a period of two weeks. Then a page of logic was then created for the B Unit Transformer at the 20 kV and 6.6 kV level. This was chosen to be the second drive as it also has field energy metering that exists in T3000. Once B Unit Transformer 24 hour readings were proven logic pages were then created for each feed on the unit 6.6 kV switchboards.

The naming conventions of the current readings in the T3000 caused some confusion as to which voltage level the current reading was being measured. The confusion was unable to be clarified by drawings as the poor T3000 naming convention exists on the drawings also. Physical inspection of the plant was possible in some cases and this assisted in identifying the current measurement location. This situation mainly occurred on the current readings on the transformer feeds as it was unclear as to which side of the transformer they were being taken. The final calculated results guided the final current reading designation.

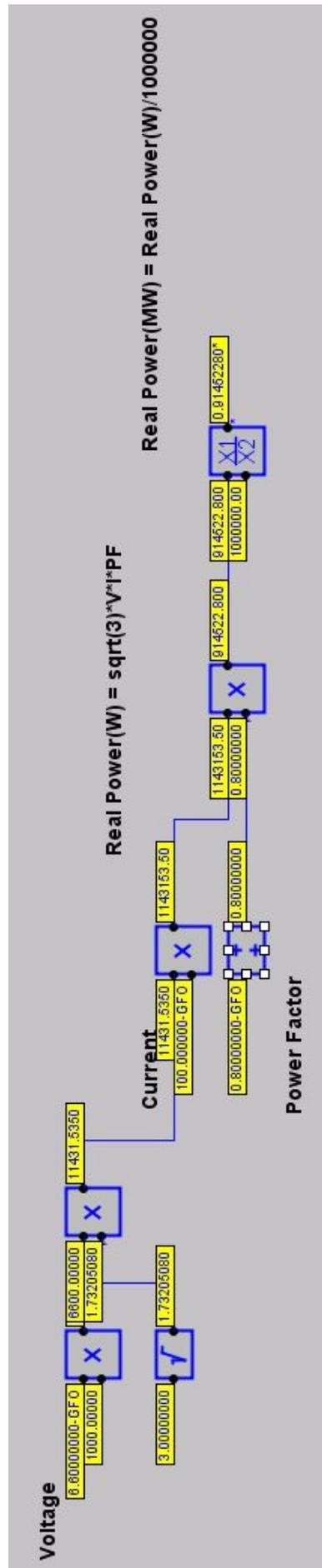


Figure 4.1: Initial Test Real Power Calculation Logic - Screen Capture from Tarong Power Station DCS (Siemens 2015).

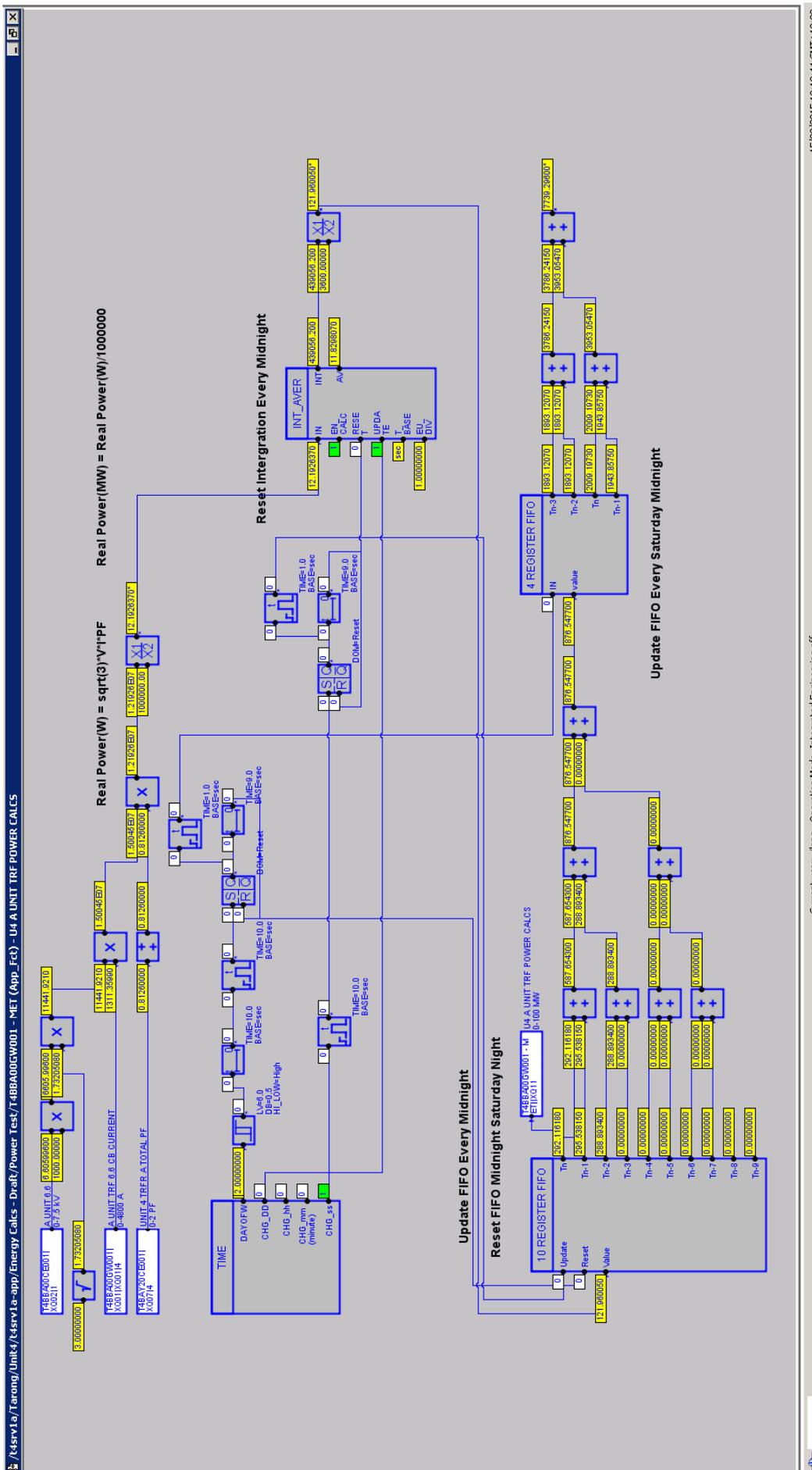


Figure 4.2: Unit 4 A Unit Transformer Energy Tracking Logic - Screen Capture from Tarong Power Station DCS (Siemens 2015).

At this point a new page of logic was created to compare the daily totals from the different sources. The aim of this logic was to ensure that all the calculated data across the drives is accurate. Once the data was initially summated a large discrepancy existed between the final sum and the real energy metering reading. Two main reasons for this existed. The first was that some current readings assumed to be taken at the 6.6 kV level were actually measured at the 415 V level. This was resolved by replacing the 6.6 kV voltages with fixed 415 V levels. The second was that no allowance for the switchboard bus ties existed. To resolve the bus tie error, logic had to be added to account for the status of the C 6.6 kV bus interconnection to either A or B 6.6 kV bus. The bus tie statuses have been used to modify the addition of the C bus energy consumption to the correct bus total. The logic shown below in figure 4.3 is the final configuration of this code for A bus connected to C bus. Similar logic exists for the B bus. The logic compares the 24 hour total from the energy meters with the calculated values at the 20 kV level. On the same page all of the auxiliary loads that feed out of the 6.6 kV unit switchboards are summated together and then compared with the unit transformer energy meter reading that feeds them. The summation of the MWhr totals of each bus section agreed with the overall supply energy meters with an error of under 2 %.

When this tracking logic was complete all energy consuming loads at the layer below the official auxiliary energy meters were being monitored. This was a major milestone of the project as data was now available to achieve the aim of understanding the auxiliary energy usage on a TPS unit.

4.4 MATLAB Models Creation

This section details the way in which the MATLAB models were created. The end aim of the MATLAB model creation process is to have a model that firstly, accurately represent the auxiliary energy consumption of a running unit across a wide range of loads. Secondly it must display the individual load contribution to enable full understanding of the energy consumption and finally it must be able to be manipulated to test energy reduction options later in the project.

The order in which the MATLAB models were created was to ensure that the accuracy of the models was confirmed at every stage of development.

4.4.1 Conceptional MATLAB Script Creation

The first stage of the MATLAB model creation process was to create a small script that would firstly import the voltage, current and power factor data from the 24 hour PIMS Excel export. The script, InitialAuxPower.m then calculates the daily auxiliary energy total. In this case the 7th of July was used as both PIMS and T3000 energy tracking data was available.

Once the data has been imported the script next manipulates the data into separate vectors to allow power usage calculations to be performed. Array multiplication using element-by-element multiplication is then used to implement equation 3.10, real or average power. This calculation gives an output array, for each drive, that contains a second by second energy consumption value. The script next totals each drive array to give a overall energy consumption for the 24 hour period. These drive totals are then added together to give an overall bus total. To prove the script accuracy the result was then compared to the T3000 tracking logic total and the energy metering total for the 7th of July. The full script and its output from the 7th of July input file are in Appendix B. The final values from the July 7th script outputs and the actual plant energy meters are included below for reference in table 4.2. The table shows that there is only a small error between the created MATLAB script and the real plant energy meter the percentage difference is shown in brackets to be at worst 1 %. This confirms the accuracy of the script for future use in cross checking the accuracy of any future models created.

Plant	Energy Meter Total	Tracking Logic Total	MATLAB Script Output
A Bus	239.04	234.10 (-2 %)	240.37 (+1 %)
B Bus	225.08	223.65 (-0.6 %)	226.39 (+0.5 %)
Aux Total	464.12	457.76 (-1 %)	466.76 (+0.6 %)

Table 4.2: Auxiliary Energy Usage Figures Comparison between Plant Energy Meter, Tracking Logic and the MATLAB Script Output. Totals are in MW/hr and the Percentage Error in Presented in Brackets.

The methodology selected was to utilise a data input based model in MATLAB. One challenge was that 24 hour periods of running at a fixed load do not occur in the TPS plant. TPS units are constantly tracking the AEMO dispatch requirements after the bidding process is complete. Stanwell units are no longer the top of the dispatch order

due to running cost and are more often at partial load rather than full load. Therefore it was decided to take samples of data from the plant at different loads to determine the state of the process at various loads. This data was then used as the basis to create 24 hour fixed load files.

The next step in the process was to then create multiple import files for the different load profiles. Data was retrieved from PIMS for loads between 140 MW and 365 MW. A row of data at 13 separate load points across the range were selected out of the data. These rows of data were used to create Excel files of a 24 hour length at those 13 load points. These files represent the voltage, current and power factor of the plant if it was to remain locked at a fixed load for the 24 hour duration. It should be noted that when the PIMS data was reviewed there were small variations in all parameters at the same load. This is due to the dynamic nature of power production and in particular the continual small variations in heat generated through the combustion process. That is no two kilograms of coal consumed by the process are the same. The data around the load points was reviewed and an average response was selected to be expanded out to a full 24 hour file.

These 13 load files were then fed through the initial import and manipulation script discussed above. The outputs of the script at the 13 load points will later be used to compare the to the output of the SIMULINK models to be created at the next stage of the MATLAB creation process. This was essentially a baseline to use as a comparison when the SIMULINK models were created. The results are presented below in table 4.3.

Plant	140MW	150MW	175MW	190MW	200MW	225MW
A Bus	193	196	210	211	216	223
B Bus	172	173	182	199	206	212
Aux Total	363	369	396	416	423	437

Plant	250MW	275MW	300MW	310MW	325MW	350MW	365MW
A Bus	237	253	269	271	282	297	303
B Bus	228	243	259	265	266	282	289
Aux Total	474	510	538	545	548	579	592

Table 4.3: MATLAB Script Output - Auxiliary Energy Usage Figures at the 13 Load Points.

The next stage was to create a MATLAB SIMULINK model of the auxiliary energy usage process for a single unit.

4.4.2 SIMULINK Auxiliary Power Model Creation

The SIMULINK creation process started with implementing equation 3.10, real or average power for a single drive. This was achieved using the basic maths blocks in SIMULINK to solve the power calculation. The result of this calculation gives an instantaneous power value for the drive in watts. This instantaneous power value is then divide by a constant 1000000 to convert it from watts to megawatts. This instantaneous MW value is then integrated up over the time of the model simulation, in this case 86401 seconds or 24 hours 1 second, midnight to midnight. The integrated figure is then divided by the number of seconds in one hour to convert it to MWhrs. In an approach similar to the T3000 test tracking logic creation the voltage, current and power factor inputs were set to fixed values to allow testing to occur. Once the testing was successful test logic for a full drive was completed. In this case the drive selected was A ID Fan. Shown in figure 4.4 below is the initial test SIMULINK model of A ID Fan at 190 MW. The resulting SIMULINK energy consumption for the 24 hour period was 52.49 MWhrs with the MATLAB script result being 52.4854 MWhrs. This proved the concept in SIMULINK and gave a much better visual display of both the instantaneous and total energy usage with a much reduced model running time.

Next a lookup table was added to allow selection of the input current value based on a one dimensional lookup table that cross references the generator load set point, in MW's, with the current of the drive. The lookup table contents were obtained from the PIMS data Excel files. Figure 4.5 below shows the test SIMULINK model of A ID Fan at 190 MW utilising the lookup table to select the correct current required. The resulting energy consumed was 52.49 MWhrs which proved the accuracy of the lookup table concept.

With the concept of utilising SIMULINK and lookup tables proven the next task was to create a model of the full unit. The concept was to be expanded to have all voltages, currents and power factors selected from lookup tables based on the required load set point. All table data was extracted from the 13 load files created from PIMS data.

The full unit model was created based on the A 6.6kV bus being tied to the C 6.6 kV bus. This was the state of the 6.6 kV boards when the data was exported from PIMS. Creating code to select which bus is tied together was not created as it was assessed as adding no value to achieving the overall project aims. The model was laid out in sections for clarity and to avoid high levels of crossed lines or repetition in the model structure.

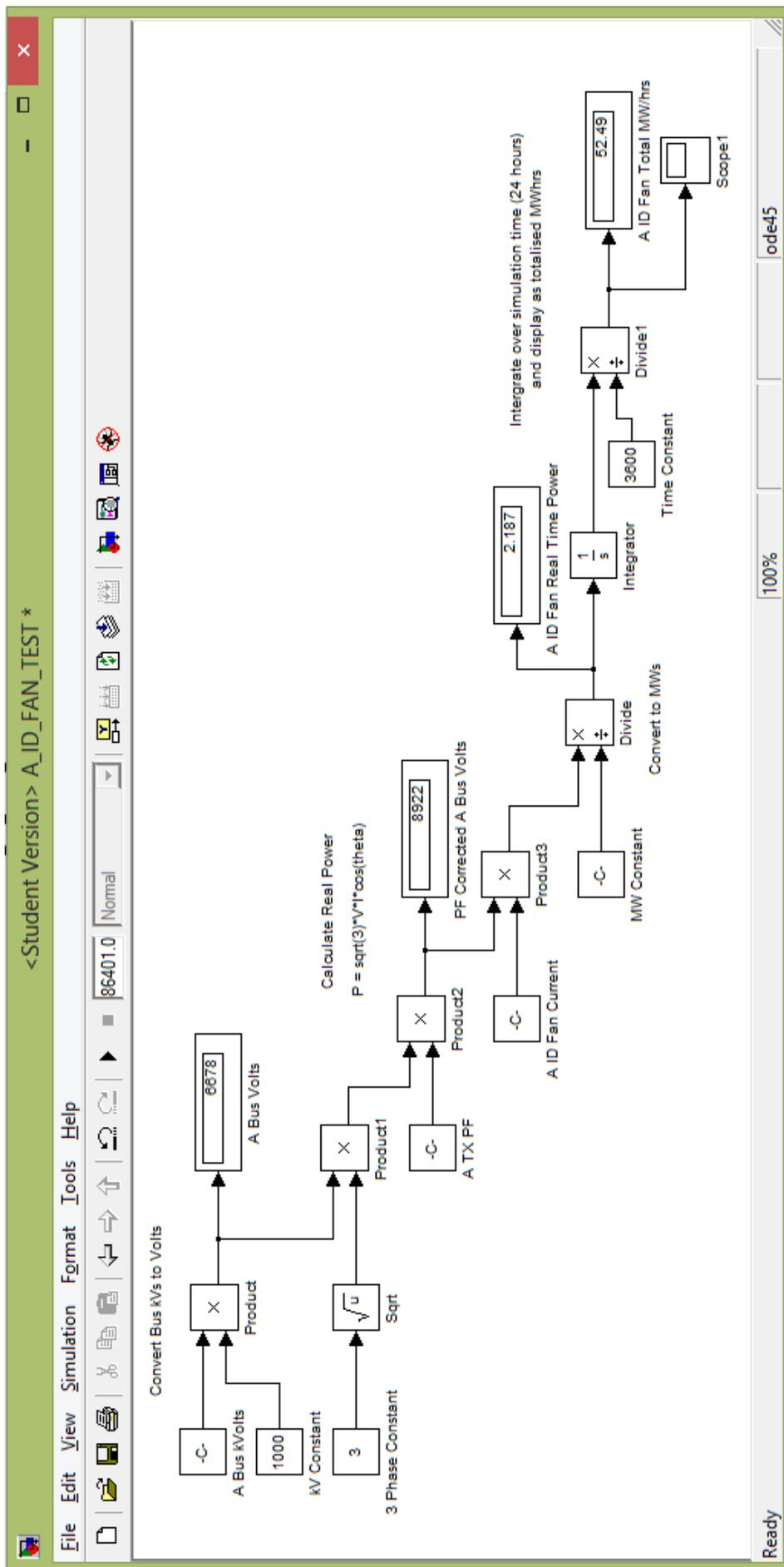


Figure 4.4: Initial SIMULINK model of Induced Draft Fan - Basic Concept Version.

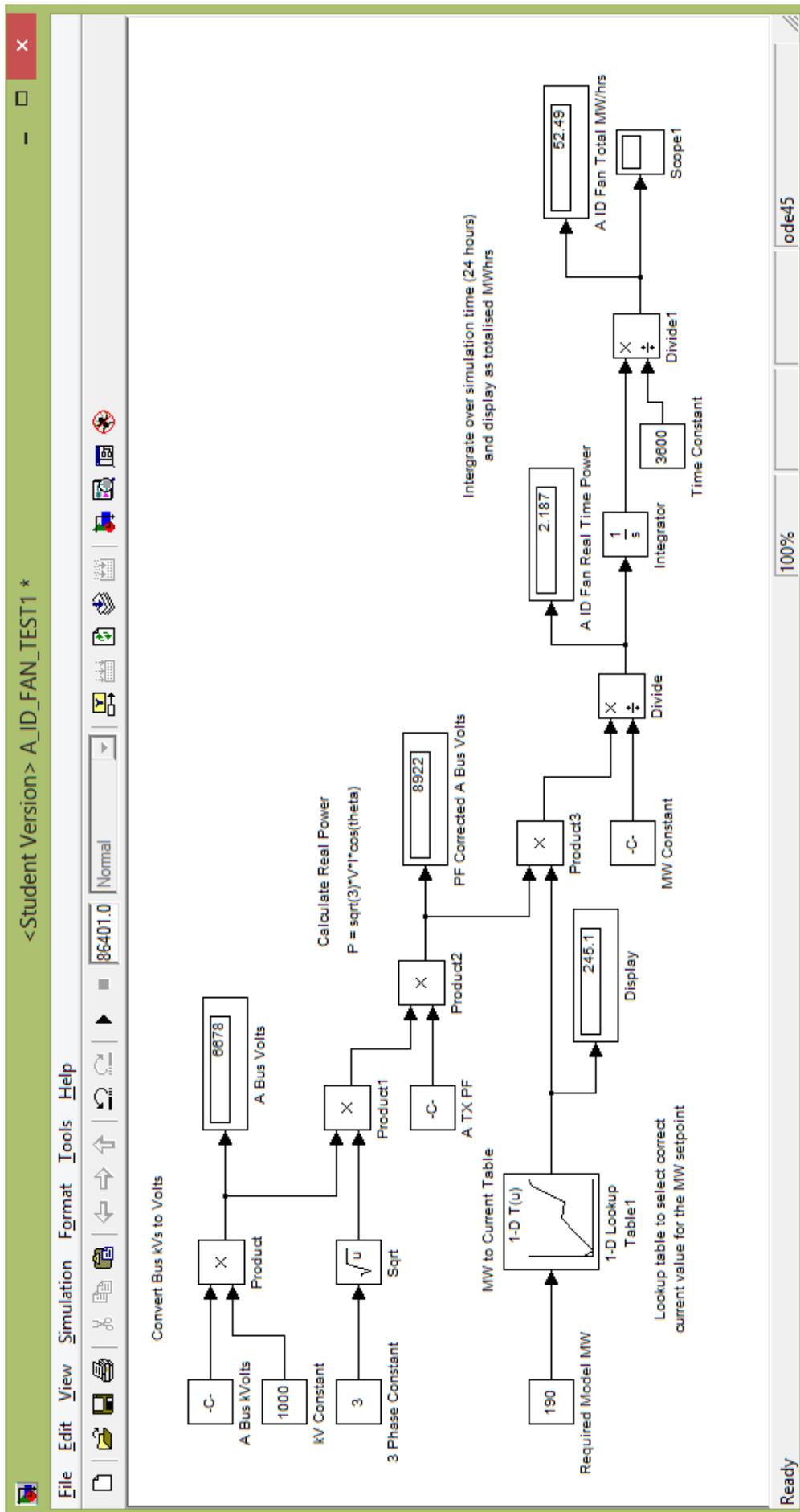


Figure 4.5: Initial SIMULINK model of Induced Draft Fan - Lookup Table Concept Version.

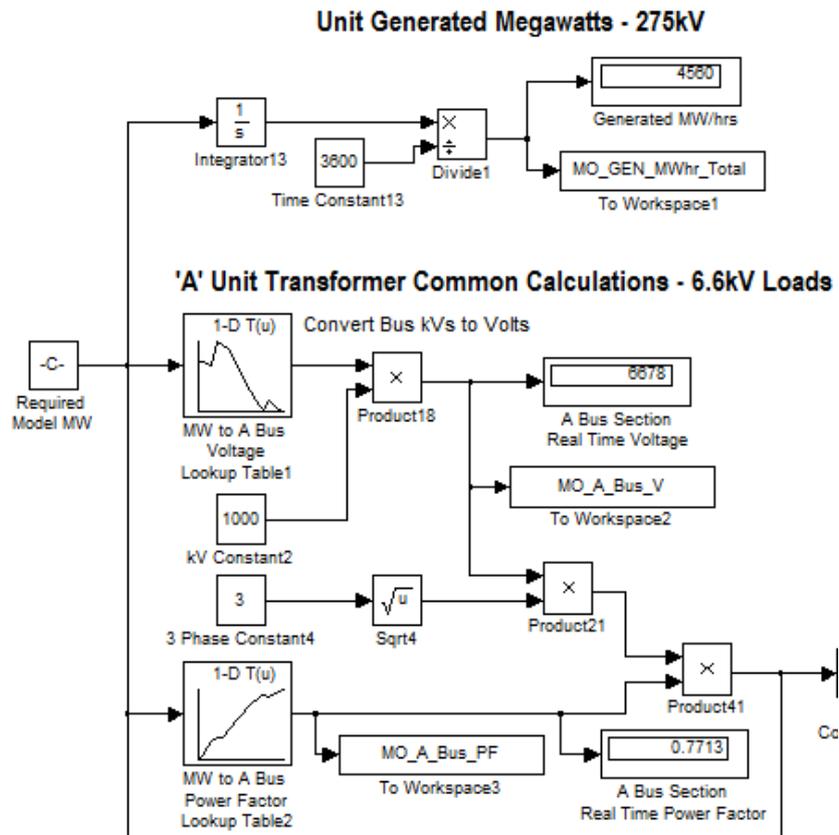


Figure 4.6: Auxiliary SIMULINK Model - Power Version of Full Unit - A Bus Common Calculations.

A common power supply section was first setup for each bus section. Figure 4.6 is the power supply calculations for A 6.6 kV bus. Note that the bus voltage and power factor are selected from one dimensional lookup tables. The same code was used for B 6.6 kV bus and both A and B 415 V bus. As discussed in previous sections the 415 V bus power supply calculations require the use of a fixed value of 415 V as no field measurement is available to create a lookup table.

Beneath each of the common power supply sections the drives that are fed from that particular bus section were laid out in order. Each drive then takes the corrected bus voltage feed from the common calculations section. This bus voltage is then multiplied with the current output from the MW to current lookup table to give an instantaneous energy consumption reading in watts. This is then converted and totalised to give MWhrs in the same way as the trial model. All loads on the one bus section are then summated to give an overall energy consumption for the bus. The two bus section energy consumption figures are then added together to give a total MW/hr usage for the 24 hour period at that load set point. Data links to the workspace were added to allow results to be more

easily accessed and reviewed. Below in Figure 4.7 is a section of the power model showing a couple of the A bus load calculations and the load totals. The data for the MW to current, voltage and power factor lookup tables was taken from the plant PIMS data utilised during the concept script creation stage of the project. Each table spans the 140 MW and 365 MW load range.

Table 4.4 below contains part of the results data from the power model at 190 MW. The result from the script at 190 MW has also been included. It shows that there is only a small discrepancy, about 200 kW(0.04 %), between the load sum calculations from the script and the load sum calculations from the model. This proves the accuracy of the SIMULINK power based model as the script accuracy was previously proven against the plant energy meter reading. There is a slightly larger discrepancy between the total power and the supply transformer sum of about 6 MW(1.5 %). This discrepancy also occurs in the T3000 tracking logic with the load summation being slightly different to the transformer calculation and the transformer calculation being closest to the energy metering measurement. The fact that the power factors are only measured at these transformers leads to the comment the transformer calculation is more accurate. It is surmised that the same error is apparent in both the T3000 logic and the model because the same common power factor, raw current and voltage values are being used therefore the error is very similar.

Plant	Power Model Load Sum	Script Load Sum	Script Transformer Sum
A Bus	210.55	210.65 (0.05 %)	214.89 (2.02 %)
B Bus	199.22	199.28 (0.03 %)	201.51 (1.14 %)
Aux Total	409.77	409.93 (0.4 %)	416.39 (1.5 %)

Table 4.4: Auxiliary Energy Usage Figures Comparison between the MATLAB Script Output and the Power Based Model Output at 190 MW. Totals are in MWhrs and the Percentage Error in Presented in Brackets.

Below are some assumptions and additional notes that are relevant to the use of the power model. The assumptions were required as not all drives were in service when the PIMS data was captured, that is there were some drives with missing data. The additional notes guide the user and outline the limits of the model. The full power model is located in Appendix C.

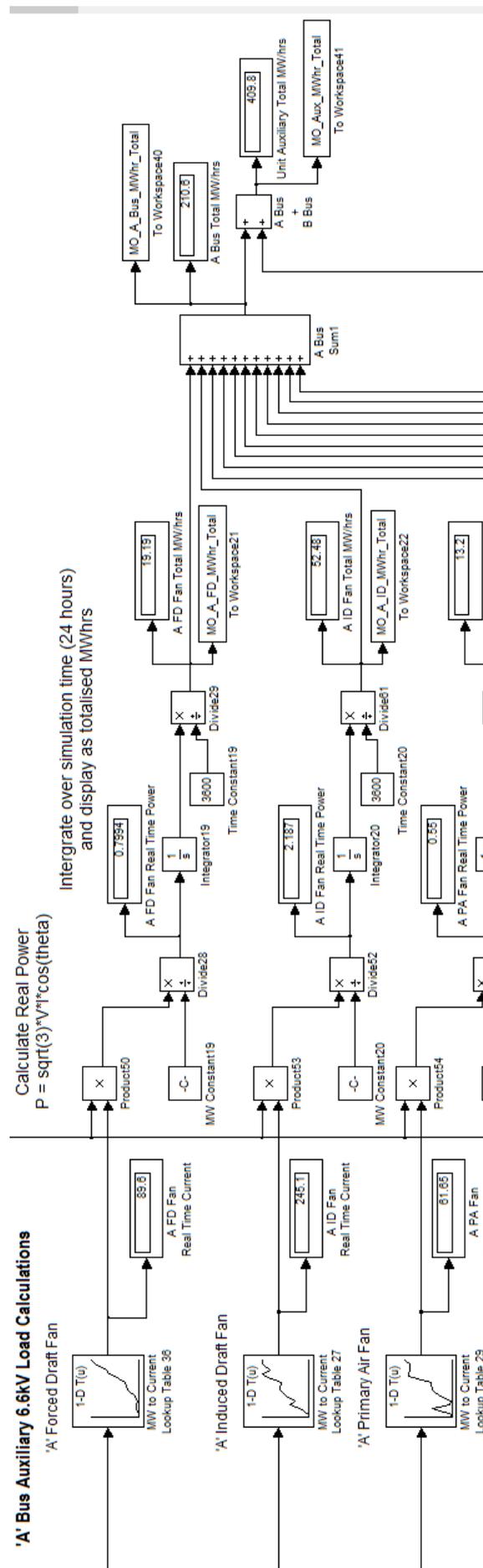


Figure 4.7: Auxiliary SIMULINK Model - Power Version of Full Unit - A Bus Load Calculations.

Model Setup - Duty Pump Sections and Generator Load Set Point need to be setup using file AuxModel_Setup_Results.m for a single load set point or AuxPowerMW-Step.m to step through a range of loads;

Model Limits - The Load Range of the model is 140 MW to 356 MW, which reflects the operational range of the plant;

Model Outputs - The Model Outputs the Total MW/hrs from each drive and overall totals to the workspace as arrays;

CEPs - A CEP load table is a copy of B CEP as B was duty during data capture, only one pump is in service at any time, both motor and pump arrangements are identical;

BFPs - A BFP load table is an average of B BFP and C BFP as B-C were duty during data capture, two of the three pumps are in service at any time, all three motor and pump arrangements are identical;

415V Loads - No field 415 V level voltage measurement available in PIMS so a fixed voltage used, 415 V;

CW Pumps - CW Pump switch inserted to allow isolation of 1 drive below a selected MW level;

Pulverisers - Pulveriser loads are under the 415V transformer loads. There are 3 to 5 mills are in service across the load range.

The auxiliary power usage SIMULINK model based on the drive power consumption was found, that while accurate, was limited in its application for investigating potential energy reduction options. This was due to only one drive set being able to be freely manipulated, this being the CW pumps. This could be achieved through modification of the generator load at which the model utilises one or two pumps. The next step was seen to be the creation of a model that included the position of the drive load elements such as vanes, dampers, scoops and valves. The next section is an outline of the modifications to the power model that were made to include both the load element positions and bias inputs to allow load modification.

4.4.3 SIMULINK Auxiliary Position Model Creation

Firstly all of the loads were assessed to see if a direct link could be made between them and a variable load element. This assessment included if the manipulation of these elements then allowed load to be shifted to another drive without disrupting the overall power generation process. It did not assess any potential long term plant impacts from the load shifting. The load assessment is shown below in table 4.5.

Plant Area	Drive Element	Plant Configuration	Capable of Load Share
A FD Fan	Outlet Vane	1/2 of 2	Yes
A ID Fan	Inlet Vane	1/2 of 2	Yes
A PA Fan	Outlet Vane	1/2 of 2	Yes
A CEP	Outlet Valve	1 of 2	No
C BFP	Scoop Thruster	2/3 of 3	Yes
A BFP	Scoop Thruster	2/3 of 3	Yes
A CW Pump	Outlet Valve	1/2 of 2	Yes
A Precip	DC Pulse	2 of 2	No
Bunkering	Multiple Motors	1 of 1	No
A 415V Bd	Multiple Motors	1 of 1	No
C 415V Bd	Multiple Motors	1 of 1	No
B 415V Bd	Multiple Motors	1 of 1	No
B FD Fan	Outlet Vane	1/2 of 2	Yes
B ID Fan	Inlet Vane	1/2 of 2	Yes
B PA Fan	Outlet Vane	1/2 of 2	Yes
B CEP	Outlet Valve	1 of 2	No
B BFP	Scoop Thruster	2 of 3	Yes
B CW Pump	Outlet Valve	1/2 of 2	Yes
B Precip	DC Pulse	2 of 2	No

Table 4.5: Assessment of Auxiliary Load Drive Elements, Plant Configuration and there Capacity for Load Share.

Once it was established which drives could load share, time was then spent to find PIMS data on the controlling element for those drives. These elements positions were found to archived in both T3000 and PIMS. The PIMS data for the load elements was exported

for the same periods of time that the load data was exported. From this data, look up tables were built to allow selection of load element position at different loads. These look up tables were added to the SIMULINK power based model in front of the existing MW to current tables. This meant that for those elements that were assessed as being able to load share the look up tables were then split into two parts. Firstly a MW to position table and secondly a position to current table. This split allowed a point at which bias inputs could be added. The bias inputs were added in such a way that if load was removed from one drive it is automatically added to the corresponding drive with whom it can load share. In this way it was proposed that the overall motive load would remain the same. An example is if the “A” FD fan load is increased by 10 % of vane position then the “B” vane position is decreased by 10 %. Below in Figure 4.8 is a section of the position model showing a couple of the drive load calculations with the split look up tables and the bias inputs to allow load variation. The setup script was expanded to add the bias inputs which allows the plant configuration to be modified before the running of the model. The script also outputs the key figures for the plant loads to allow later interpretation. The same assumptions and application notes from the power model apply to the position model. The full position model is located in Appendix D.

The investigation of the auxiliary load manipulation through bias of load elements was found to be accurate and assisted in building a clearer picture of unit auxiliary load consumption. The model was found to be limited in the sense that while load element position was able to be manipulated it was not clear whether transferring the same position change to another load element would give the same drive capacity to the other drive. To give an example if the scoop position on one BFP was reduced by 10 % and the scoop position of another BFP was increased by 10 % would the net feedwater flow required by the unit remain the same? If all element responses were linear this would be the case but this is unlikely with the known characteristics of the elements involved. It was decided to create a SIMULINK process based model. The process of creating the process based model will be presented in the next section.

4.4.4 SIMULINK Auxiliary Process Model Creation

Firstly, all of the loads previously identified as being able to load share were assessed to see which process measurement would best reflect a change to the load element. The load

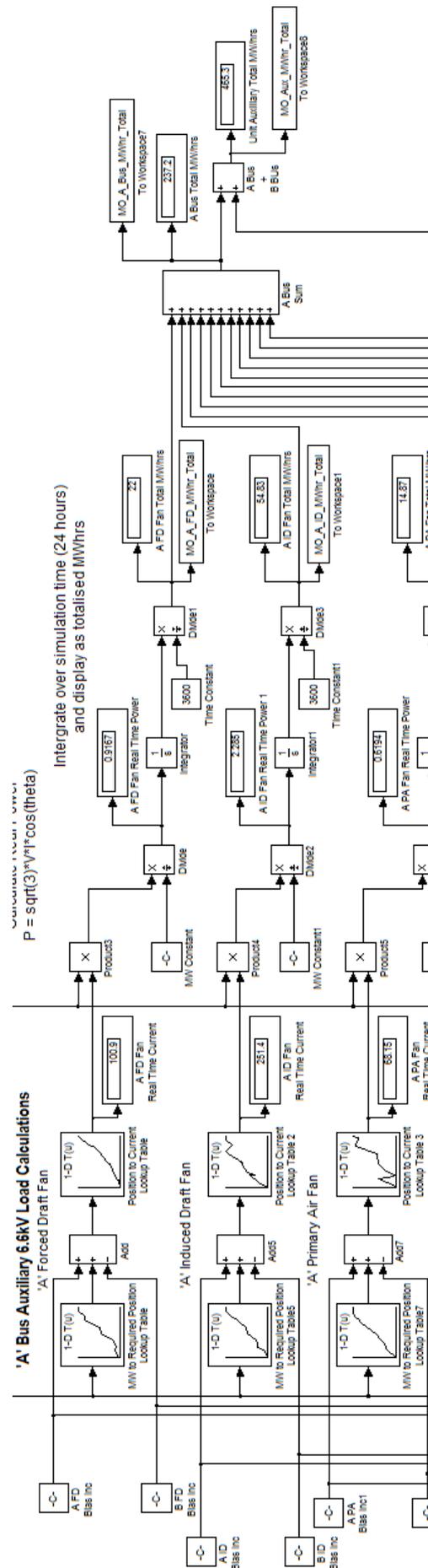


Figure 4.8: Auxiliary SIMULINK Model - Position Version of Full Unit - A Bus Load Calculations.

assessment in shown below in table 4.6 only includes those that can load share.

Plant Area	Drive Element	Process Measurement	Capable of Load Share
A FD Fan	Outlet Vane	Air Flow	Yes
A ID Fan	Inlet Vane	Furnace Pressure	Yes
A PA Fan	Outlet Vane	Bus Pressure	Yes
C BFP	Scoop Thruster	Suction Water Flow	Yes
A BFP	Scoop Thruster	Suction Water Flow	Yes
B FD Fan	Outlet Vane	Air Flow	Yes
B ID Fan	Inlet Vane	Furnace Pressure	Yes
B PA Fan	Outlet Vane	Bus Pressure	Yes
B BFP	Scoop Thruster	Suction Water Flow	Yes

Table 4.6: Auxiliary Loads and their Identified Process Measurement.

Once the loads were assessed and the process measurement identified, the data relating to those processes was exported from PIMS. The data was then processed and points were identified that reflected the state of the process across the load range of the model. Specifically at the same 13 load points utilised in the power model. The SIMULINK position based model was used as the basis of the creation of the SIMULINK process based model. The position model was modified to replace the position data with process data. This meant that the split look up tables then became MW to process and then process to current. This then allowed the auxiliary power usage profile to be modified by the bias blocks by sharing process flow. The model was then able to reflect the impact of the load sharing on the running processes required by the unit to ensure load generation was not interrupted. This was not possible with either the power or position models. The same bias names were used so no modification of the setup script was required. The use of the bias input then changed from 0-100% to the process scale for example the feedwater flow 0-566 kilograms per second.

The same assumptions and application notes from the power and position model apply to the process model with the relevant additional assumptions below. The additional assumptions were required as not all the process measurements being modified exist in the field as measurements. The full process model is located in Appendix E.

ID Fans - There is no available flow measurement to assist in process sharing of this

plant group, control is to furnace pressure but flow is the loading factor of the ID fan. Hence position sharing was left in place for these drives;

PA Fans - There is no direct PA fan flow measurement to assist in process sharing of this plant group, control is to PA bus pressure but flow is the loading factor of the PA fan. Air flow readings where PA enters the mills are available and these are combined in T3000 to give a total PA flow reading. This has been assumed as being equally shared between the PA fans. Hence the total PA flow reading was halved and used for the lookup table points.

This SIMULINK process based model was found to be robust model with which to explore the possible energy reduction possibilities. Figure 4.9 shows a section of the process model showing a couple of the drive load calculations with the split look up tables and the bias inputs to allow load variation.

4.4.5 Model Comparison Data

Table 4.7 below shows the comparison of the results between the MATLAB script and the three SIMULINK models.

Plant	MATLAB Script Model	SIMULINK Power Model	SIMULINK Position Model	SIMULINK Process Model
A Bus	210.65	210.18	210.65	210.08
B Bus	199.29	199.22	198.45	205.08
Aux Total	409.93	409.77	408.63	415.15

Table 4.7: Auxiliary Energy Usage Figures Comparison between the Three SIMULINK Models at 190MW. Totals are in MWhrs.

4.5 Conclusion

This chapter presented the detail of the methodology selected. The selection of the multifaceted approach of literature review, data based MATLAB modeling and T3000 logic

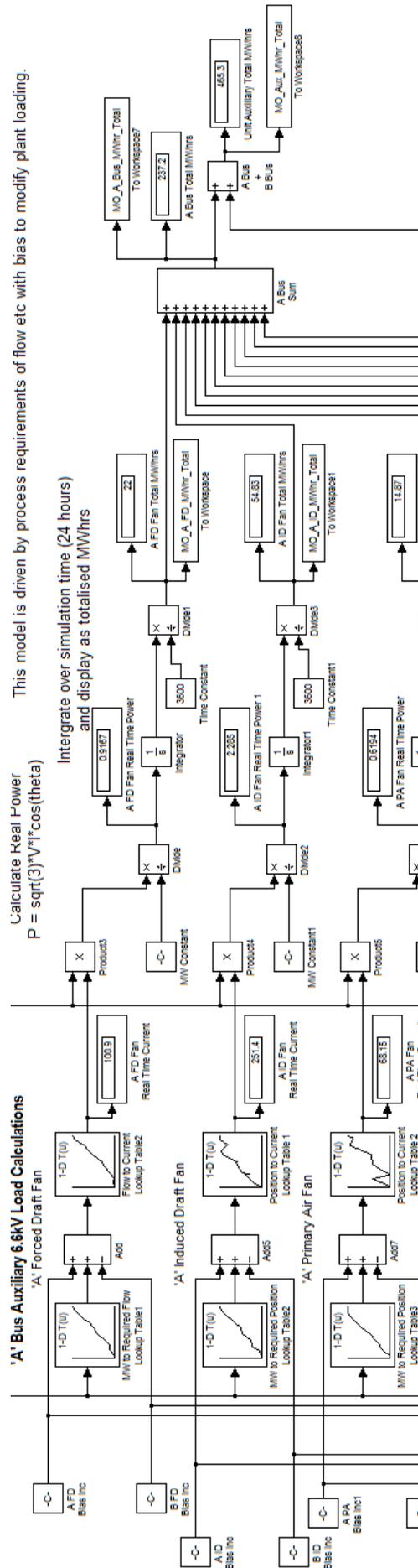


Figure 4.9: Auxiliary SIMULINK Model - Process Version of Full Unit - A Bus Load Calculations

creation approach was justified as being required due to the project outcomes secondary aims to alter the running plant. Being a highly dynamic power station environment the dual approach and comparison to the installed energy meters gives the confidence needed to propose long term plant change. The steps taken to implement the methodology were presented in the order undertaken to develop the understanding of the underlying processes behind the high level methods. The next chapter will present the results of the method outputs.

Chapter 5

Results and Data Analysis

This chapter presents in raw form the results from the T3000 tracking logic and the MATLAB models.

This chapter is to analyse the data collected from all sources and evaluate for future use. The validity of both the T3000 tracking logic and the MATLAB models will be explored to assess their suitability for use in proposing and testing reduction options. A total cost to the business and the environment will also be presented.

5.1 Performance Reports Data

This section presents the data collected from the weekly and monthly Tarong Power Station performance reports for Unit 4. This unit has been presented as it was the first to have T3000 tracking logic installed. The other units show very similar results. The data shows the generated MWhrs of the unit along side the auxiliary MWhrs consumed and the financial impact of the consumption. The average August Queensland pool price of \$55 per MWhr has been used for the financial impact value. (Zecevic & EEUAA 2015) The environmental impact is also included to show the influence of the additional generation required to run auxiliaries. If auxiliary usage was reduced then the additional generation would not be required therefore reducing emissions and running costs. This additional available generation could alternately be sold to the market. The Stanwell corporation figure of 3.664 tonnes of CO_2 per one tonne of coal consumed has been used as the

environmental impact figure. (Sands & Blake 2015)

The data table below 5.1 below is an extract of the vital statistics from the monthly TPS performance reports that relate to auxiliary energy consumption. An additional column for the estimated financial cost of this auxiliary energy usage has been added. This table then gives a complete snapshot of the financial and environmental impact of the auxiliary energy consumption requirements of the Tarong Power Station Units.

Unit 4	Aux Usage	Aux %	Aux Cost	Coal	CO ₂
Sept 15	19071 MWhr	7.8 %	\$1,048,905	8915 t	32664 t
Aug 15	18499 MWhr	8.0 %	\$1,017,445	8679 t	31799 t
Jul 15	16586 MWhr	8.2 %	\$912,230	7883 t	28883 t
Jun 15	15839 MWhr	8.3 %	\$871,145	8083 t	29616 t
May 15	17632 MWhr	8.0 %	\$969,760	8242 t	30198 t
Apr 15	16197 MWhr	8.2 %	\$890,835	7318 t	26813 t
Mar 15	14474 MWhr	9.1 %	\$796,070	6792 t	24889 t
Feb 15	13265 MWhr	8.9 %	\$729,575	6234 t	22844 t
Jan 15	12993 MWhr	9.8 %	\$715,615	6425 t	23544 t
Dec 14	13847 MWhr	9.3 %	\$761,585	7162 t	26244 t
Nov 14	12022 MWhr	10.3 %	\$661,210	5917 t	21682 t

Table 5.1: Auxiliary Energy Usage Figures - Unit 4 for the Last 10 Months (Sands & Blake 2015)

This Unit 4 auxiliary energy usage figures shown in table 5.1 that the monthly cost both in financial and environmental terms is significant and that even small reductions could give tangible returns to the business. The auxiliary energy required for the month is given in both MWhrs and as a percentage of total generation. The effect discussed in the literature review chapter of overseas power station requiring less auxiliary energy, as a percentage, when the plants are running at a higher load factor can be seen within these figures. That is during months that the plant runs at a higher load profile the required auxiliary energy, as a percentage of total generation, is reduced. For example in September 2015 the average load of the unit was 339 MW and the cost of running the auxiliaries was over \$1 million dollars but the percentage of generation was 7.8 %. Whereas during November 2014 the market was depressed with a lower load profile leading to an average unit load of 162 MW. During this month the percentage of generation required to run the auxiliaries

was 10.3 %. These figures show a clear link between the unit load profile and the unit auxiliary energy usage efficiency.

5.2 T3000 Daily Auxiliary Total Data

This section presents a selection of the data collected from the T3000 tracking logic created during this project. This data is then analysed.

The data table 5.3 at the end of this section is a selection of daily totals from the Unit 4 T3000 energy tracking logic created as part of this project. The dates selected represent a cross section of the average generator load set points since the T3000 logic was made active. The averages have been in the mid to high load range for the units. The table also includes the real 24 hour totals from the plant installed energy meters, marked as (Real), for comparison to the tracking figures.

The Unit 4 figures confirm that there is only a small difference between the calculated and metered energy figures. The data shows that there are some plant area contributions that can be considered as negligible. The precipitator, bunkering and unit 415V boards, which the mills are a part of, only contribute a relatively small amount of load to the overall total. The PA fans and CEP contribute a medium amount of load to the overall total. With the higher contributing loads being the CW pumps, BFP's, FD fans and ID fans. The load contributions of each plant area change over the load range of the generator but the four major auxiliary load consumers do not change.

This leads to the question "How does the load distribution of TPS's auxiliary energy consumption compare to other stations?" The load distribution of American power stations was presented in the literature review chapter and will be used again now for comparison. The figure 5.1 shows two pie charts, the first is the typical distribution of auxiliary power consumption within American coal fired power plant (EPRI 2011). The second chart is the average auxiliary load distribution at TPS. The load distribution shown here is based on the average of results from the created T3000 energy tracking logics daily 24 hour totals. The distribution shows that the four major contributors in America equate to approximately 75 % of the total load and are the BFP, CW pumps, ID fans and PA fans. When this is compared to the TPS result it can be seen that the four highest contributors are the BFP's, ID fans, CW pumps and FD fans. Together their contribution equates

to approximately 80 % of the total auxiliary load. Whilst there is some differences the primary contributor in both results is the BFP group. With the CW pumps and ID fans being the next largest contributors, all be it in the reverse order.

The pulverisers or mills contribute approximately 9-10 % of the total load and as such the project created T3000 tracking logic to monitor and totalise the mills energy usage. The data table 5.2 below is a selection of daily totals, for the 415 V pulverisers, from the T3000 energy tracking logic. It can be seen that generally the load is shared evenly between the mills that are in service.

Date	6/07/2015	8/07/2015	28/07/2015	6/08/2015	8/10/2015
A Pulv	11.67	6.39	6.78	6.89	6.44
B Pulv	0	6	6.66	6.56	6.43
C Pulv	9.22	6.1	0	0	5.42
D Pulv	8.76	5.61	6.4	6.41	5.89
E Pulv	3.25	6.17	6.6	6.57	6.24
F Pulv	0	0	0	0	0

Table 5.2: Auxiliary Energy Usage Figures in MWhrs - Pulverisers - Output from T3000 Energy Tracking Logic Daily Totals.

This section has presented an overview of the data collected from the Unit 4 T3000 energy tracking logic at TPS created during this project. This has shown that the major contributors and the load distribution of auxiliary energy consumption is comparable to other stations around the world. The data has also identified that only four plant areas, or nine major drives, contribute 80 % of the total auxiliary load consumption.

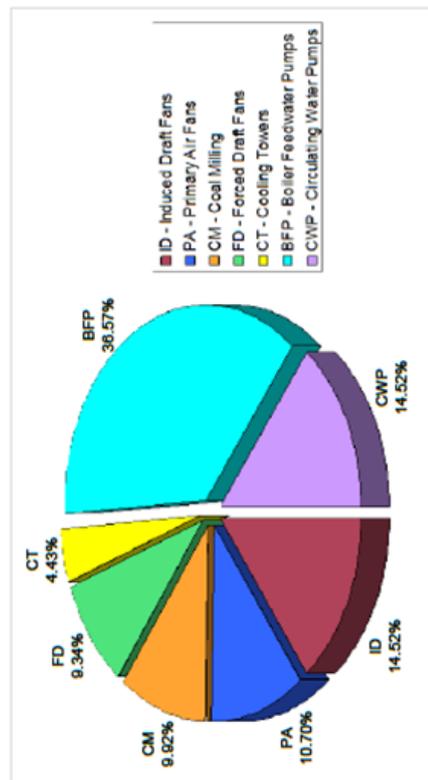
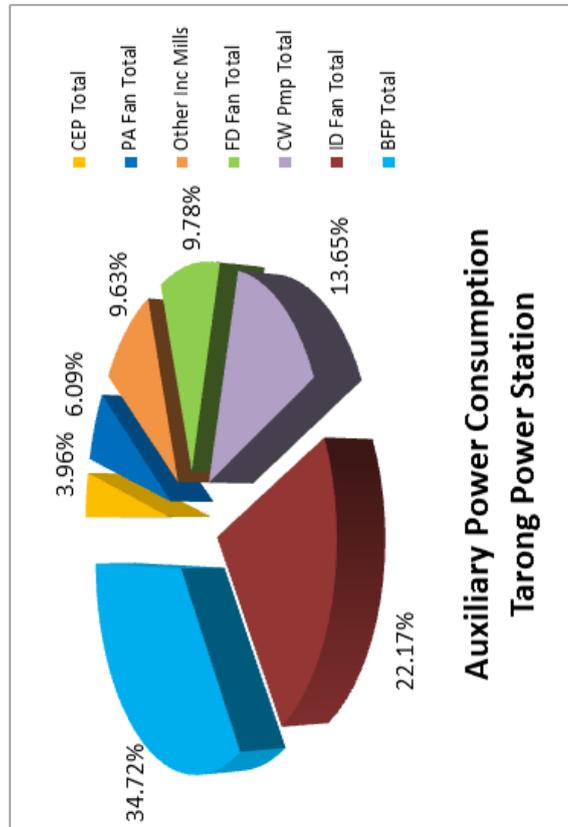


Figure 5.1: A Comparison of the Typical Auxiliary Load Distribution in Coal Fired Power Plant to the Average Tarong Auxiliary Load (EPRI 2011).

Date	6/07/2015	8/07/2015	28/07/2015	6/08/2015	8/10/2015
Ave Gen Load	244.25	255.71	289.50	290.88	325.79
Generated	5982	6137	6948	6981	7819
A Tx (Real)	241.38	244.48	256.18	256.93	285.38
A Gen TX	242.83	245.83	257.59	258.38	286.98
A Unit TX	236.65	239.64	250.93	251.67	278.15
A PA Fan	14.79	15	15.69	15.75	15.58
A FD Fan	22.42	22.57	25.1	25.02	30.1
A ID Fan	54.15	54.36	56.15	55.9	57.08
A CEP	0	0	20.11	20.21	21
A CW Pump	33.33	33.44	34	34	34.04
A BFP	0	0	90.76	91.62	102.81
A 415 V Bd	27.72	28.4	11.33	11.42	18.92
A Precip	0.99	1	1.12	1.13	1.14
C 415 V Bd	8.65	8.73	15.99	15.77	15.47
C BFP	74.49	75.91	89.03	0	0
Bunkering	0.11	0.12	0.14	0.16	0.12
B Tx (Real)	228.67	231.28	262.72	263.53	278.2
B Gen TX	230	232.59	264.16	265.08	279.64
B Unit TX	224.24	226.8	256.82	257.57	270.94
B PA Fan	14.63	14.86	15.59	15.45	15.24
B FD Fan	22.17	22.29	24.49	24.41	26.32
B ID Fan	54.22	54.49	56.04	55.54	57.53
B CEP	18.9	19.09	0	0	0
B CW Pump	34.3	34.41	34.84	34.8	34.72
B BFP	75.66	77.08	0	90.54	101.89
B 415 V Bd	7.17	7.32	19.94	19.39	18.7
B Precip	0.07	0.08	0.07	0.07	0.07

Table 5.3: Unit 4 Auxiliary Energy Usage Figures in MWhrs - All Plant Areas - Output from T3000 Energy Tracking Logic Daily Totals.

5.3 MATLAB Model Output Data

This section presents the outputs from the MATLAB models created during this project.

The methodology section discussed the evolution of the models and proved the accuracy of the overall auxiliary energy figure produced by the models against the plant installed energy meters. Each of the models produced not only an overall auxiliary consumption figure, at different generator load set points, but also the consumption figures for each of the individual drives.

5.3.1 SIMULINK Auxiliary Power Model

Table 5.5 appears at the end of the section and is the output of the Power Model when run through the auxiliary power MW step m script. This gives a baseline result for each drive to use for future reference.

When these figures are combined into plant area totals the same trends in major energy consumption identified in the T3000 energy tracking data becomes apparent in the model output data also. Below in table 5.4 is the total energy consumption by plant area based on the Power Model output data.

Gen Load	150	175	200	225	250	275	300	325	350
CEP Total	16.0	16.7	17.4	18.2	18.8	19.9	20.7	20.7	21.5
PA Total	25.1	28.7	26.1	28.0	29.5	30.2	34.0	33.7	34.1
Other Total	32.7	35.4	34.8	36.0	37.0	40.2	39.5	39.0	39.4
FD Total	36.3	37.8	38.1	40.0	43.8	46.5	51.4	56.3	62.8
CW Total	64.2	65.4	66.3	66.8	67.6	68.8	69.2	69.1	69.6
ID Total	97.3	101.2	103.4	106.4	109.7	110.8	114.3	115.2	117.3
BFP Total	93.7	103.8	127.7	131.3	150.1	171.4	189.2	198.5	217.6
Aux Total	368.1	391.8	421.8	435.2	465.2	496.6	527.5	548.0	578.4

Table 5.4: Auxiliary Energy Usage Figures in MWhrs - Plant Area Totals from SIMULINK Power Model.

When these figures are presented graphically it can be seen that some loads do not increase

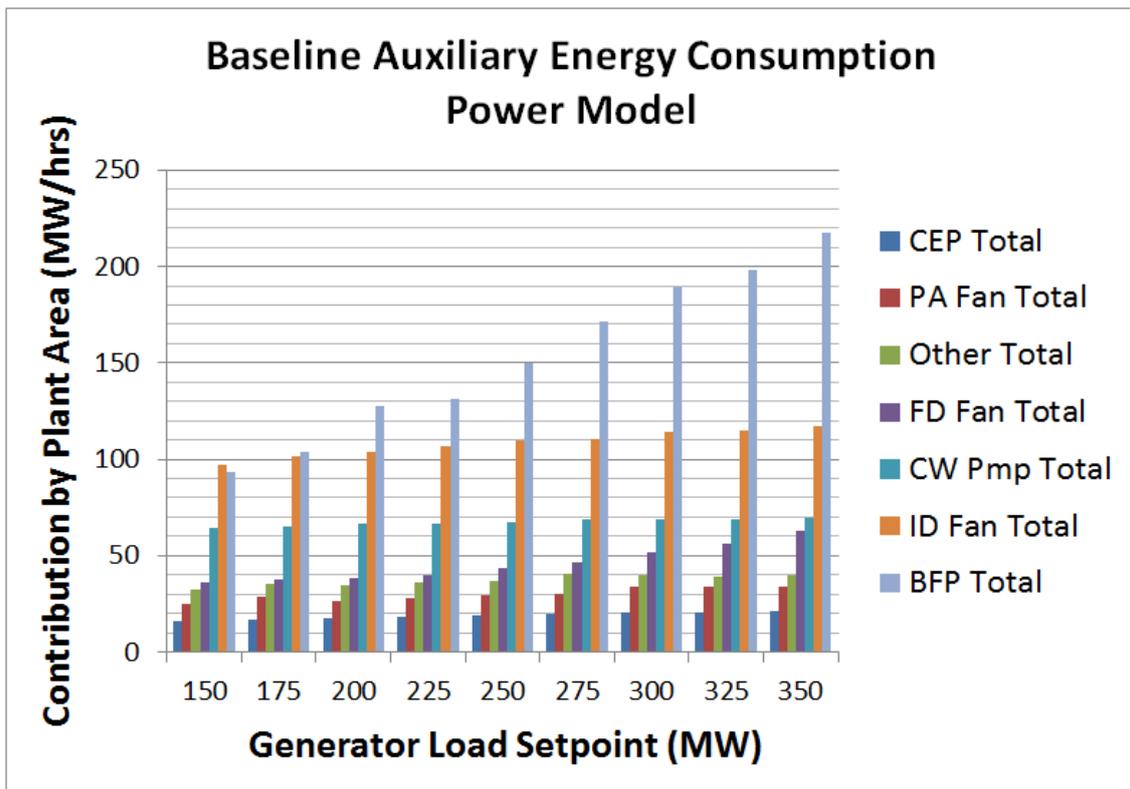


Figure 5.2: Tarong Power Station Baseline Auxiliary Energy Consumption - Power Model Plant Totals.

much of the load range, the CW pumps are good example of a static load. Other loads however increase considerably as the machine loads up, the BFPs are an example of this type of load. The power model plant totals are presented in figure 5.2.

Gen Load	150	175	200	225	250	275	300	325	350
A FD Fan	18.3	19.1	19.0	20.0	22.0	23.2	25.9	28.3	31.5
A ID Fan	48.7	50.8	51.9	53.4	54.8	55.3	57.8	57.1	58.5
A PA Fan	12.7	14.4	13.1	14.1	14.9	15.1	17.0	16.8	17.0
A CEP	16.0	16.7	17.4	18.2	18.8	19.9	20.7	20.7	21.5
A BFP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C BFP	48.2	54.7	63.5	65.4	74.9	85.4	94.6	99.3	107.7
A CW Pmp	32.0	32.5	32.7	33.0	33.3	33.9	34.0	33.9	34.2
A Precip	1.0	1.5	0.8	0.9	0.8	1.1	1.3	1.1	1.0
Bunker	0.0	0.0	0.0	0.0	0.4	0.4	0.1	0.2	0.2
A 415V	15.8	17.2	26.6	27.7	27.6	30.2	28.8	30.4	30.7
C 415V	2.8	2.8	8.1	8.4	8.6	9.0	9.2	15.4	16.1
B FD Fan	18.0	18.7	19.0	20.0	21.9	23.2	25.5	28.0	31.3
B ID Fan	48.6	50.4	51.5	53.0	54.9	55.5	56.5	58.0	58.8
B PA Fan	12.4	14.3	12.9	13.9	14.7	15.1	17.0	16.9	17.1
B CEP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B BFP	45.4	49.2	64.1	65.9	75.1	86.0	94.6	99.2	109.9
B CW Pmp	32.3	32.9	33.6	33.8	34.3	34.9	35.1	35.2	35.4
B Precip	0.9	1.1	1.2	0.8	1.2	1.0	1.1	1.3	1.2
B 415V	15.0	15.7	6.2	6.5	7.1	7.6	8.1	6.2	6.3
Gen Total	3600	4200	4800	5400	6000	6600	7200	7800	8400

Table 5.5: Auxiliary Energy Usage Figures per Drive in MWhrs - Output from SIMULINK Power Model.

5.3.2 SIMULINK Auxiliary Position Model

The output of the Position Model when run through the auxiliary power MW step m script is presented in table 5.7 at the end of this section. This gives a baseline result output from the Position Model. These drive level consumption figures match the outputs from the Power model.

When these figures are combined into plant area totals the same trends in major energy consumption identified in the T3000 energy tracking data becomes apparent in the model output data also. Below in table 5.6 is the total energy consumption by plant area based on the Position Model output data.

Gen Load	150	175	200	225	250	275	300	325	350
CEP Total	16.0	16.7	17.4	18.2	18.8	19.9	20.7	20.7	21.5
PA Total	25.1	28.7	26.1	28.0	29.5	30.2	34.0	33.7	34.1
Oth Total	32.7	35.4	34.8	36.0	37.0	40.2	39.5	39.0	39.4
FD Total	36.3	38.1	38.1	40.0	43.8	46.5	51.4	55.6	62.8
CW Total	64.2	65.4	66.3	66.8	67.6	68.8	69.2	69.1	69.6
ID Total	97.3	101.2	104.8	106.4	109.7	110.8	114.3	115.2	117.3
BFP Total	93.7	103.8	127.7	131.3	150.1	171.4	189.2	198.5	217.6
Aux Total	368.1	392.1	423.2	435.1	465.2	496.6	527.5	547.2	578.4

Table 5.6: Auxiliary Energy Usage Figures in MWhrs - Plant Area Totals from SIMULINK Position Model.

Whilst the results of the position model are very similar they are presented here in an alternate graphically form to examine them from another perspective. With the data presented in this form it can be seen that the total auxiliary load consumed for a 24 hour period, at different generator load set points, increases as the generator output increases. It is however apparent that as the generator load increases the rate at which the auxiliary power loads increases is reduced. An example is that as load increases from 150 MW or 200 MW the auxiliary power requirement increased by approximately 50 MWhrs. But when the load increases from 300 MW to 350 MW the auxiliary load increase is only 44 MWhrs. The position model plant totals are presented in figure 5.3.

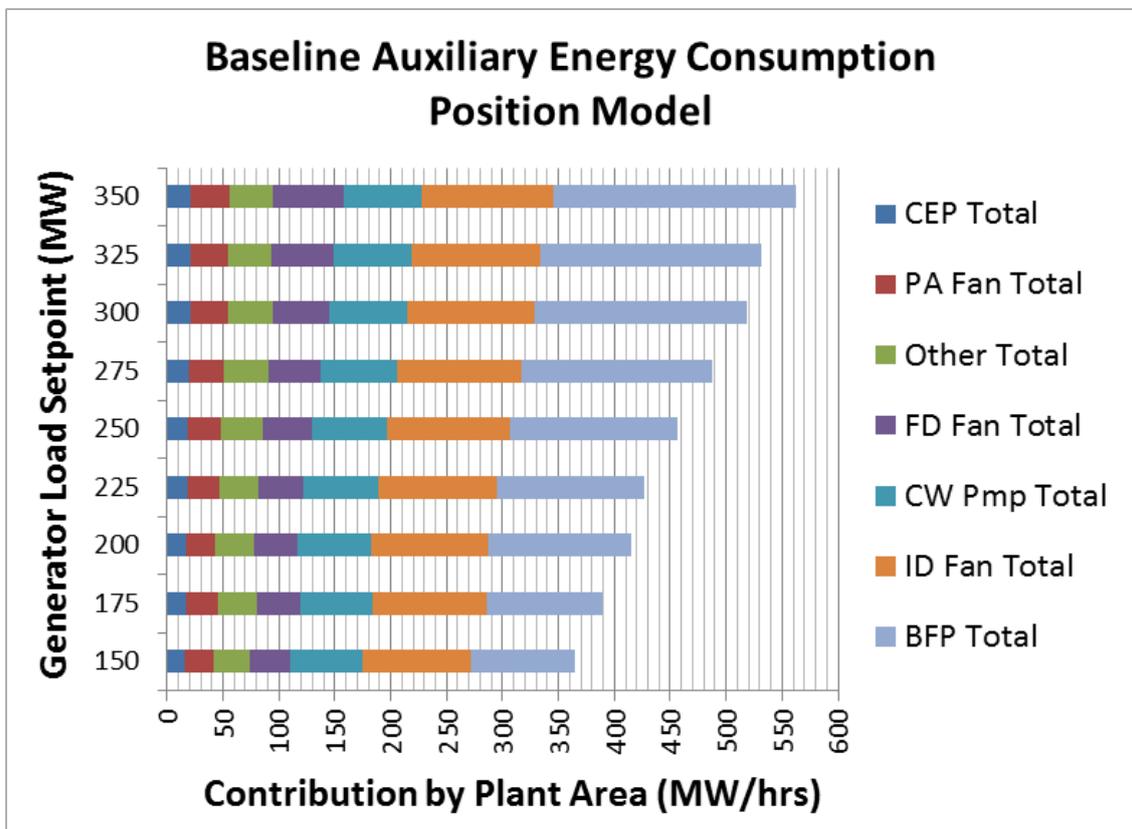


Figure 5.3: Tarong Power Station Baseline Auxiliary Energy Consumption - Position Model Plant Totals.

Gen Load	150	175	200	225	250	275	300	325	350
A FD Fan	18.3	19.0	19.0	20.0	22.0	23.2	25.9	27.6	31.5
A ID Fan	48.7	50.8	52.5	53.4	54.8	55.3	57.8	57.1	58.5
A PA Fan	12.7	14.4	13.1	14.1	14.9	15.1	17.0	16.8	17.0
A CEP	16.0	16.7	17.4	18.2	18.8	19.9	20.7	20.7	21.5
A BFP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C BFP	48.3	54.6	63.5	65.4	74.9	85.4	94.6	99.3	107.7
A Precip	1.0	1.5	0.8	0.9	0.7	1.1	1.3	1.1	1.0
Bunker	0.0	0.0	0.0	0.0	0.4	0.4	0.1	0.2	0.1
A 415V	15.8	17.2	26.6	27.7	27.6	30.2	28.8	30.4	30.7
C 415V	2.8	2.8	8.1	8.4	8.6	9.0	9.2	15.4	16.1
B FD Fan	18.0	19.1	19.0	20.0	21.8	23.2	25.5	28.0	31.3
B ID Fan	48.6	50.4	52.3	53.0	54.9	55.5	56.5	58.0	58.8
B PA Fan	12.4	14.3	12.9	13.9	14.7	15.1	17.0	16.9	17.1
B CEP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B BFP	45.4	49.2	64.1	65.9	75.1	86.0	94.6	99.2	109.9
B CW Pmp	32.3	32.9	33.6	33.8	34.3	34.9	35.1	35.2	35.4
B Precip	0.9	1.1	1.2	0.8	1.2	1.0	1.1	1.3	1.2
B 415V	15.0	15.7	6.2	6.5	7.1	7.6	8.1	6.2	6.3
Gen Total	3600	4200	4800	5400	6000	6600	7200	7800	8400

Table 5.7: Auxiliary Energy Usage Figures per Drive in MWhrs - Output from SIMULINK Position Model.

5.3.3 SIMULINK Auxiliary Process Model

The output from the Process model is presented in table 5.9 at the end of this section. It contains the output of the Process Model when run through the auxiliary power MW step m script. This gives a baseline result output from the Process Model. These drive level consumption figures match the outputs from the Power and Position models.

When these figures are combined into plant area totals the same trends in major energy consumption identified in the T3000 energy tracking data becomes apparent in the model output data also. Below in table 5.8 is the total energy consumption by plant area based on the Process Model output data.

Gen Load	150	175	200	225	250	275	300	325	350
FD Total	36.3	37.8	38.0	40.0	43.8	46.5	51.4	56.3	62.8
ID Total	97.3	101.2	104.8	106.4	109.7	110.8	114.3	115.2	117.3
PA Total	25.1	28.7	26.1	28.0	29.5	30.2	34.0	33.7	34.1
BFP Total	93.1	103.8	121.0	131.3	150.1	171.4	189.2	198.5	217.6
CEP Total	16.0	16.7	17.4	18.2	18.8	19.9	20.7	20.7	21.5
CW Total	64.2	65.4	66.3	66.8	67.6	68.8	69.2	69.1	69.6
Oth Total	32.7	35.4	34.8	36.0	37.0	40.2	39.5	39.0	39.4
A Total	195.6	209.7	233.8	241.2	256.1	273.5	289.5	303.2	318.3
B Total	172.0	182.1	182.7	193.9	209.1	223.1	238.0	244.8	260.1
Aux Total	367.5	391.8	416.5	435.1	465.2	496.6	527.5	548.0	578.4

Table 5.8: Auxiliary Energy Usage Figures in MWhrs - Plant Area Totals from SIMULINK Process Model.

An third alternate presentation of the baseline results of the process model plant totals are presented in figure 5.4. The steep increase of the BFP across the load range is a key point. The other noticeable feature is the steady increase of the ID fan load in contrast the to continually changing slope of the FD fan group.

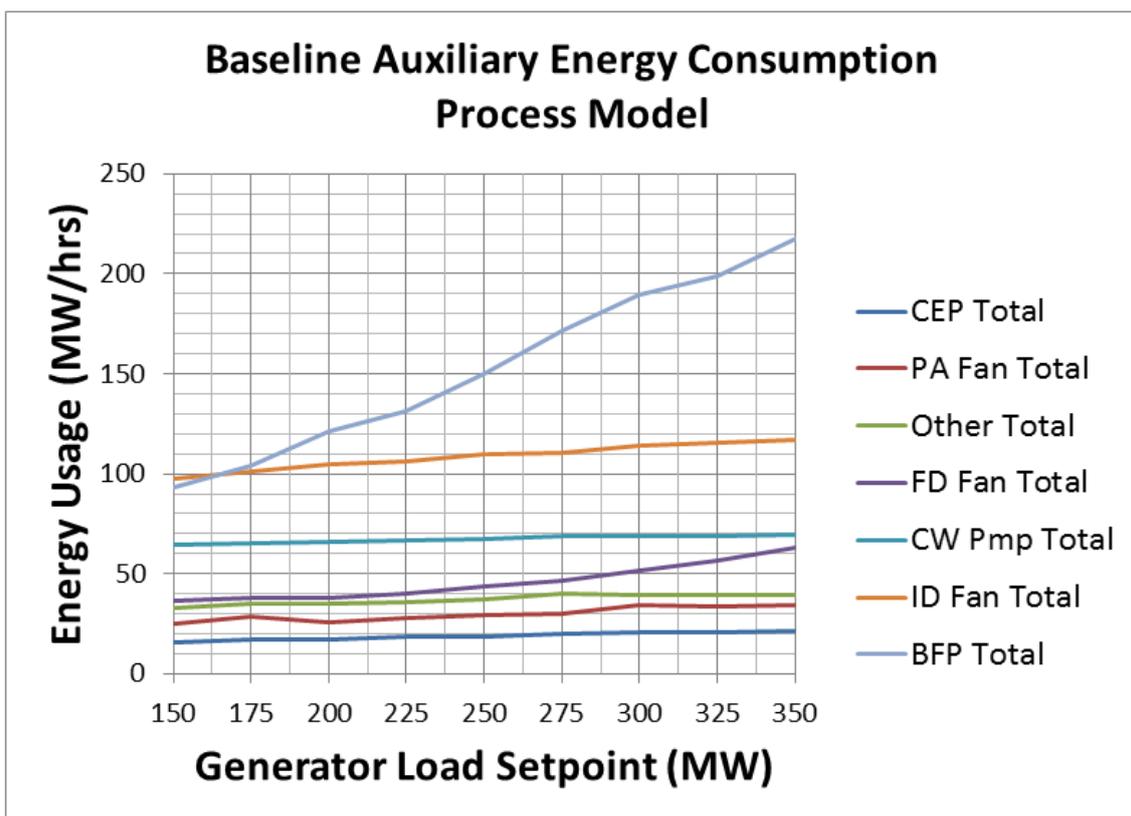


Figure 5.4: Tarong Power Station Baseline Auxiliary Energy Consumption - Process Model Plant Totals.

Gen Load	150	175	200	225	250	275	300	325	350
A FD Fan	18.3	19.1	19.0	20.0	22.0	23.2	25.9	28.3	31.5
A ID Fan	48.7	50.8	52.5	53.4	54.8	55.3	57.8	57.1	58.5
A PA Fan	12.7	14.4	13.1	14.1	14.9	15.1	17.0	16.8	17.0
A CEP	16.0	16.7	17.4	18.2	18.8	19.9	20.7	20.7	21.5
A BFP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C BFP	48.3	54.6	63.5	65.4	74.9	85.4	94.6	99.3	107.7
A CW Pmp	32.0	32.5	32.7	33.0	33.3	33.9	34.0	33.9	34.2
A Precip	1.0	1.5	0.8	0.9	0.7	1.1	1.3	1.1	1.0
Bunker	0.0	0.0	0.0	0.0	0.4	0.4	0.1	0.2	0.1
A 415V	15.8	17.2	26.6	27.7	27.6	30.2	28.8	30.4	30.7
C 415V	2.8	2.8	8.1	8.4	8.6	9.0	9.2	15.4	16.1
B FD Fan	18.0	18.6	19.0	20.0	21.8	23.2	25.5	28.0	31.3
B ID Fan	48.6	50.4	52.3	53.0	54.9	55.5	56.5	58.0	58.8
B PA Fan	12.4	14.3	12.9	13.9	14.7	15.1	17.0	16.9	17.1
B CEP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B BFP	44.9	49.2	57.5	65.9	75.1	86.0	94.6	99.2	109.9
B CW Pmp	32.3	32.9	33.6	33.8	34.3	34.9	35.1	35.2	35.4
B Precip	0.9	1.1	1.2	0.8	1.2	1.0	1.1	1.3	1.2
B 415V	15.0	15.7	6.2	6.5	7.1	7.6	8.1	6.2	6.3
Gen Total	3600	4200	4800	5400	6000	6600	7200	7800	8400

Table 5.9: Auxiliary Energy Usage Figures per Drive in MWhrs - Output from SIMULINK Process Model.

5.4 Overall Auxiliary Energy Usage

This section is to discuss the overall auxiliary energy usage of Tarong Power Station and present the baseline data against which future reduction options can be assessed.

The units auxiliary energy consumption at any single point in time can be represented by a figure that is how many kWhrs auxiliary energy is required to produce 1 MWhr of generator output. There is no single figure that can represent this value as the auxiliary energy consumption efficiency improves as the generator load set point increases. The baseline energy consumption has been calculated on the output of the process based SIMULINK model. This auxiliary energy requirement is at a high of approximately 100 kWhrs per 1 MWhr generated at a generator load set point of 150 MW. The need for auxiliary energy decays away to a low of approximately 70 kWhrs per 1 MWhr generated at a generator load set point of 350 MW. This aligns with the discussion in earlier chapters that the TPS units were design to be continuously running as a 350 MW base load station. This baseline energy consumption pattern can be approximated by the mathematical formula shown below.

$$y = 61 + 150e^{\frac{-x}{118}} \quad (5.1)$$

Where

y - is the average or real auxiliary power required by the unit to produce 1 MWhr of power [kWhr];

x - is the generator load set point [MW].

When this equation is implemented across the generator load range the output plot is shown in figure 5.5 being compared to the process model output across the same load range. The result shows that the mathematical equation proposed can be utilised to approximate the actual plant auxiliary energy needs.

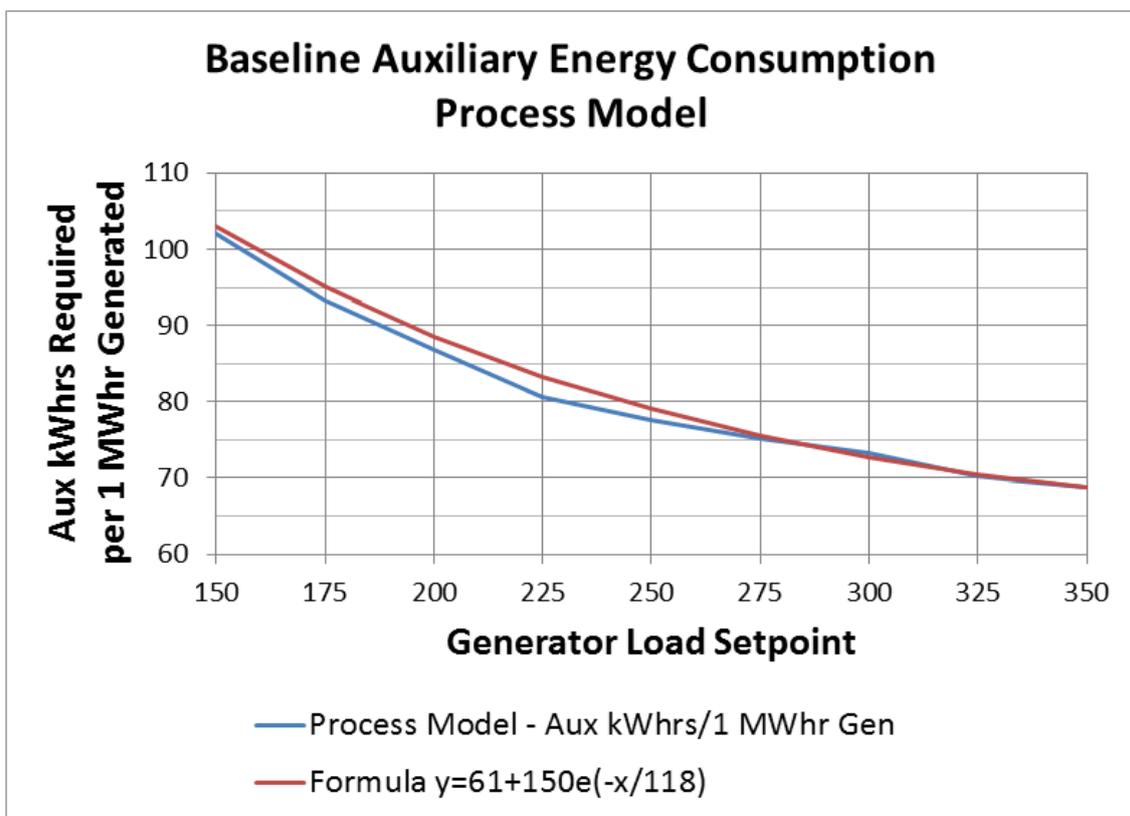


Figure 5.5: Tarong Power Station Baseline Auxiliary Energy Consumption - Process Model versus Formula.

5.5 Other Data

This section discusses other data collected that requires exploration before the reduction proposals are discussed in the next chapter.

Boiler feed pump loading is area that additional data has been collected. Being a major auxiliary power contributor some additional knowledge of the pump system has been collected. It was uncovered during this investigation that the pump curve and the actual loading of the pump against this curve is monitored in realtime within T3000. A snapshot of the A BFP pump curve, with the unit running at 350 MW is include in figure 5.6. This shows that with the unit running at full load that the pumps are running at almost there design limits. At this load that scoop position is approximately 50 % and the load current is approximately 500 A. This current is approaching the maximum limit of 540 A found in the pump design data and T3000 alarms.

Some of load profiles from Unit 4 over the past year were collected to demonstrate the range of loads that occur during the normal running of a unit. Each profile is a 24 hour snapshot of the unit generator load output in MW. These are presented in figure 5.7 and show that a daily unit load profile can vary considerably depending on market conditions, time of year and Stanwell's portfolio status. A unit can run for long periods at a set load or if the market is particularly active it can change load continually throughout the day. The first trend, on the top left, shows the unit running half the time at high load and half the time at medium to low load. The second trend on the top right shows a high load day with the load only coming down from 365 MW during the night and only then to medium load of 220 MW. The bottom left trend shows a day when the market is over supplied during a low state load period, the unit is at 140 MW all day. The last trend on the bottom right shows a fairly depressed market day with the load being primarily 200 MW with periods at 140 MW.

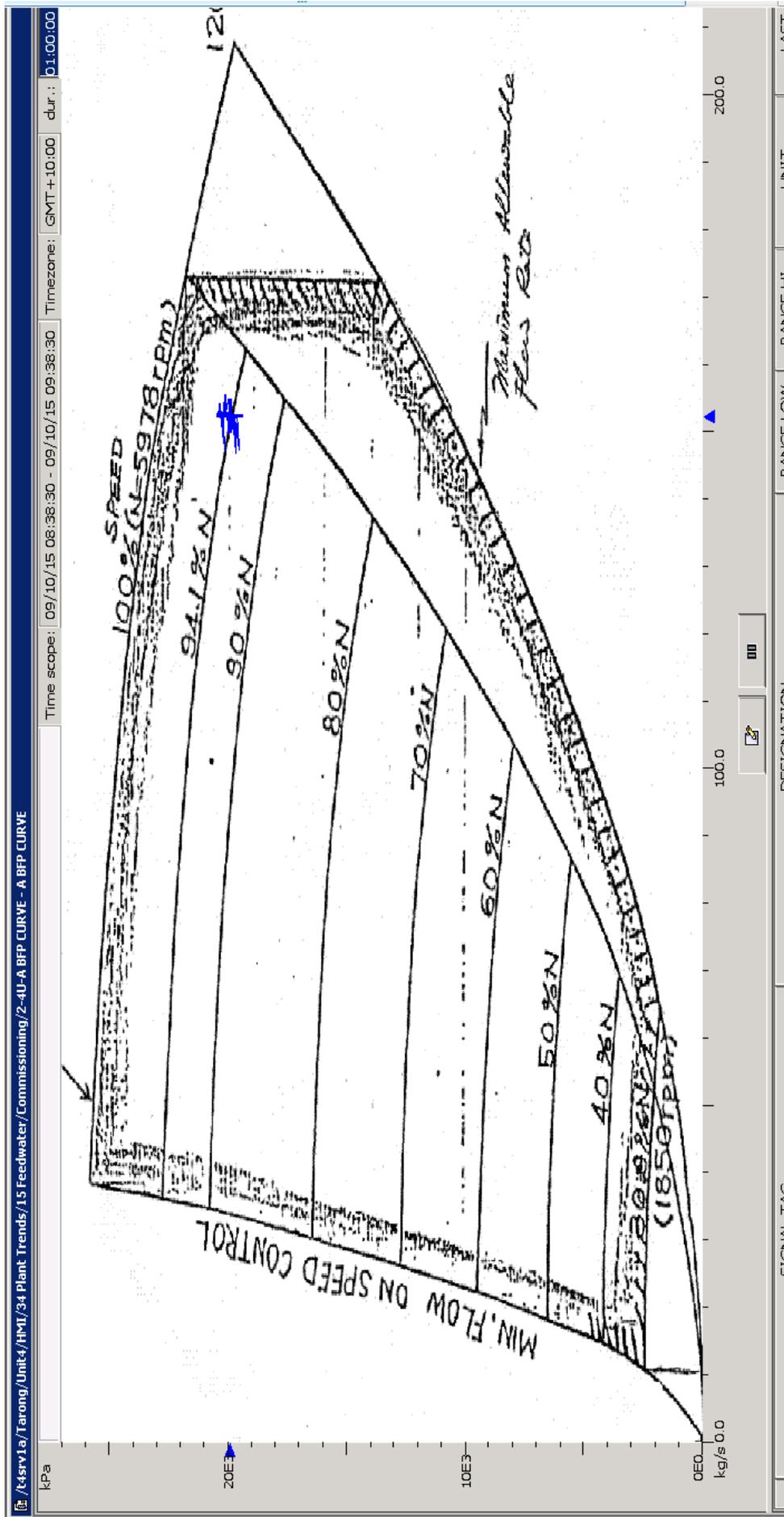


Figure 5.6: A Boiler Feed Pump Curve with the Pump Loading Shown in Realtime - Unit 4A BFP 350MW (Siemens 2015).

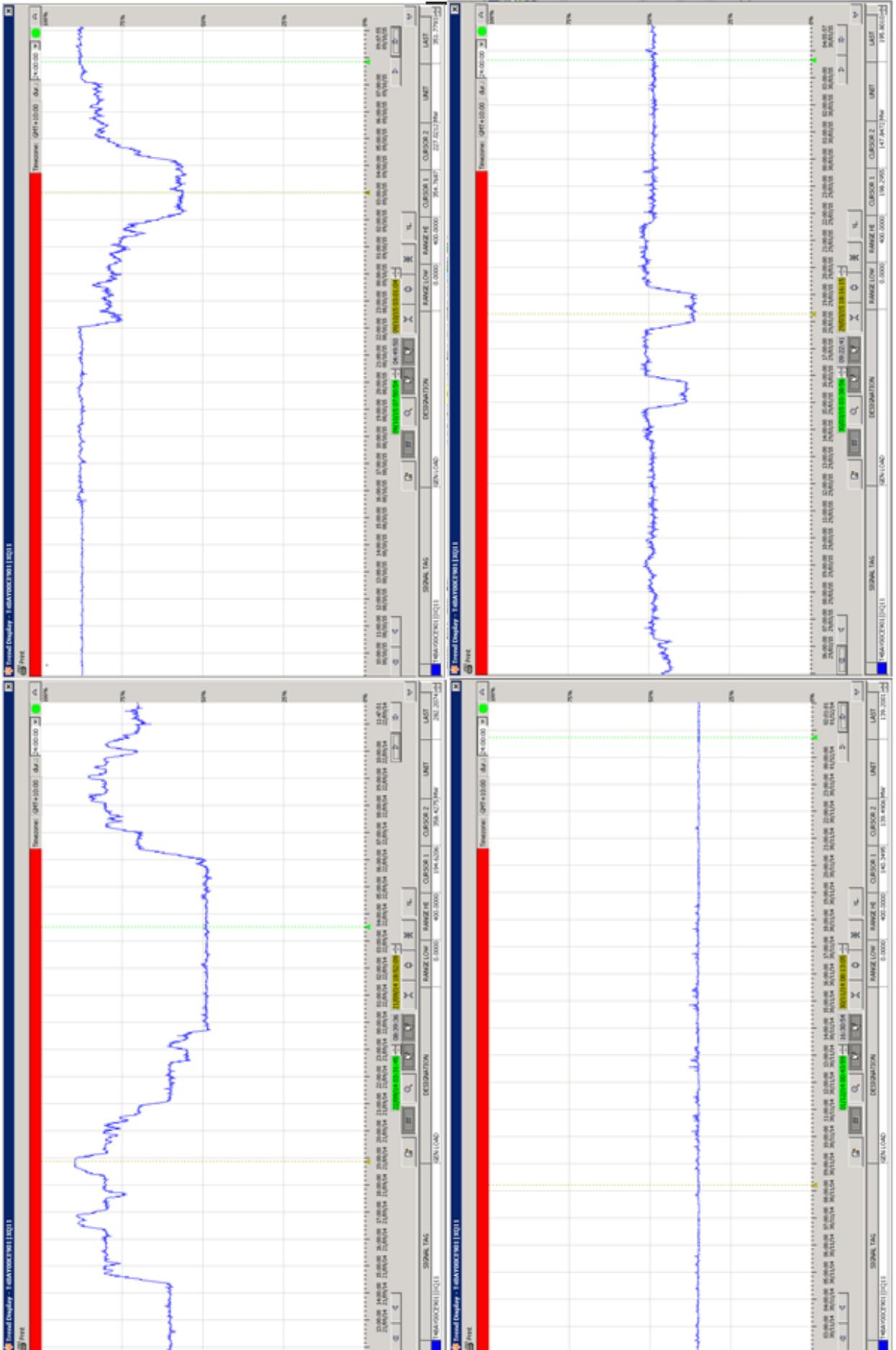


Figure 5.7: Load Profiles of Unit 4 Tarong Power Station. Top Left, 365MW-190MW. Top Right, 365MW-220MW. Bottom Left, 140MW. Bottom Right, 140-200MW (Siemens 2015).

5.6 Data Shortcomings

This section discusses any identified shortcomings in the data collected from all sources.

In the area of the pulverisers or mills the MATLAB models created did not go down to the level of individual mill loading. The total mill consumption calculated from T3000 tracking logic is 5.8 % of the total auxiliary consumption. The mill loading was included in the higher level measurement of the unit 415 V transformers within the MATLAB models. These transformers supply a 415 V distribution board that supplies multiple drives. The mill motors are fed from these boards. Time was not spent on drives below the 6.6 kV level as the data has shown that 80 % of the energy consumption is contributed by the four major 6.6 kV drive groups, BFP's, ID fans, FD fans and CW pumps.

There was no PA flow data available at the output of the PA fans themselves. The vane position controls to the PA bus duct pressure so the flow is not directly required. The individual PA air flows into the mills are measured and these six figures are combined into an overall PA air flow. The data within the process model look up tables that relates to the PA fans air flow used this combined figure divided by two as the required flow data. This has assumed that the total air flow is supplied equally by the 2 fans. For this project the equal distribution of flow is seen to be fit for purpose and allows the sharing of air flows to be explored.

There is no ID fan air flow readings available with the vane position controlling the furnace pressure as a negative. No individual air flows leaving the boiler are available meaning that the position sharing arrangement from the position model has been left in place for the process model.

The model makes no specific allowance for the BFP leak off operation. The leak off valves operate between the BFP outlet and the DA to ensure minimum flow through the BFP is always achieved. As the models range starts at 140MW the leak off valves are normally closed.

The data within the models in relation to the precipitator and bunkering boards is considered to be slightly flawed. These flaws have been allowed to stay as the total auxiliary power consumption of these systems is less than 0.5 % of the total. The models look-up tables could not easily be made to accurately reflect the actual load characteristics of

these process. This is primarily because of the irregular batch process nature of these systems and the shared output of the bunkering routes. The bunkering routes 3 and 4 can both feed Unit 3, Unit 4 and Tarong North boiler bunkers. These routes are only started, on average, once per shift to top-up the boiler bunkers. This is further complicated by the fact that route 4 may top-up Unit 3 and 4 but the auxiliary power consumption is only registered on the Unit 4 switchboard from which it is fed. The precipitator load sits at a low level of continuous consumption with irregular spikes of relatively higher consumption. These spikes have been ignored for the simplicity of the model and the overall negligible impact of them on the auxiliary usage.

5.7 Conclusion

In this chapter the collected data from all sources was presented. The data has shown that the auxiliary energy consumption is a significant financial and environmental cost to Stanwell corporation. The model results demonstrate the breakdown of this consumption by plant area and identify the high level energy consumers. A mathematical relation was established that reflect the baseline energy consumption patterns of the coal fired units at Tarong. The chapter was rounded out with a brief discussion of data shortcomings.

The next chapter will examine potential reduction options and analyse their implications.

Chapter 6

Proposed Options of Energy Reduction

This chapter is to present proposed options for energy reduction on the Tarong Power Station 350 MW coal-fired generation units. A list of options for each plant area will be presented along with an assessment via the MATLAB SIMULINK process model. The options created will look solely at the energy reduction potential. Whilst the options presented will be possible from a process requirement, the initial sections here will not assess the potential long term impacts to the plant. Then a risk comment will broadly discuss potential impacts.

The final section of the chapter on optimum solution will present a possible unit wide low, medium, and high risk approach solution. The low risk will have minimal perceived long term impact whilst the high risk proposal will have an perceived higher impact.

Each section will firstly outline the current operational method of the plant area and its current auxiliary power consumption profile. The sections will end with a proposed operational strategy and the energy impact as assessed by the MATLAB SIMULINK process model result.

6.1 Induced Draft Fans

This section is to look at potential ways in which possible energy reduction in the area of ID Fans could be achieved.

The system consists of two fans that draw air from the boiler through the precipitator passes and discharge the air through the chimney flu. Each fan is driven by a DOL motor with the inlet of fan controlled by a damper vane. Currently the control system runs with both fans in-service across the full load range. The figure 6.1 shows the configuration of the unit Air and Gas systems at full load.

Below in table 6.1 is the current usage summary for the Induced Draft Fan system running at different generator load set points for 24 hours.

Gen Load	150	175	200	225	250	275	300	325	350
ID Sys	97.3	101.2	104.8	106.4	109.7	110.8	114.3	115.2	117.3

Table 6.1: MATLAB Process Model Output - Induced Draft Fan System Energy Usage Figures at 9 Load Points to be used as a Baseline. Generator Load Set Point in MW and Energy Totals in MWhrs.

Below are the possible energy reduction strategies considered. Each option has three sections, the strategy, the auxiliary MW result, and a risk comment.

Reduction Option 1

Strategy

This option is to lift the furnace pressure set point to reduce the differential pressure across the ID fans.

Resultant Usage

This option is seen to viable since the Control System retrofit has given tighter control over the furnace pressure. The influence of this strategy was unable to be tested with the location of the fan running within the fan curve unknown. It is highly likely to have a measurable positive impact on the energy consumption of this plant area warranting future exploration and testing. For the purposes of this testing an assumption of 10

% reduction in ID fan energy consumption has been made. This figure is in line with discussions with mechanical engineering staff regarding the potential influence of lifting the furnace pressure set point. Below in table 6.2 is the resultant usage summary for the Induced Draft Fan group after reduction option 1 is implemented.

Gen Load	150	175	200	225	250	275	300	325	350
ID Sys	87.6	91.1	94.3	95.8	98.8	99.7	102.9	103.65	105.6

Table 6.2: MATLAB Process Model Output - Induced Draft Fan System Energy Usage Figures at 9 Load Points after Reduction Option 1 Implemented. Generator Load Set Point in MW and Energy Totals in MWhrs.

Risk Comment

The primary risk is that during a furnace pressure excursion that the boiler would be more likely to trip rather than ride through as the initial margin to the trip point is already reduced. Additional logic to cope with this possibility and the risk associated with its implementation would need to be considered for this option to become a reality.

Reduction Option 2

Strategy

At lower loads run with only one fan calling the second into service only once the process requires more air than one fan can supply.

Resultant Usage

Below in table 6.3 is the resultant usage summary for the Induced Draft Fan group after reduction option 2 is implemented. This strategy achieves a 45 % reduction to the ID fan group at 150 MW. This strategy is only effective at low loads as the fan supply limit is reached somewhere between 150 and 175 MW. This effective limit is reinforced by anecdotal evidence from the unit operators experiences with only one fan group in-service.

Risk Comment

The primary risk is that the second fan will not start when required and delay the unit load up. This is considered a low risk. The increased starts on the fan, motor and switch

Gen Load	150	175	200	225	250	275	300	325	350
ID Sys	53.6	101.2	104.8	106.4	109.7	110.8	114.3	115.2	117.3

Table 6.3: MATLAB Process Model Output - Induced Draft Fan System Energy Usage Figures at 9 Load Points after Reduction Option 2 Implemented. Generator Load Set Point in MW and Energy Totals in MWhrs.

gear will cause increased maintenance concerned compared to the current running profile.

Reduction Option 3

Strategy

This is an extension of strategy 2 with only 1 fan in-service until 175 MW. Once the second fan is in service the bias on the ID fan loading is setup to ensure that one fan is always optimally loaded with the second varying as required by the process.

Resultant Usage

The most efficient point of the ID fan was unable to be identified from the documentation located. The most efficient point was assumed to be the load at 350 MW. So for the testing of this strategy the B ID fan was locked into the full load position as early as practical, at 275 MW. It was unable to be locked in sooner due to the minimum position set point of A ID fan. Table 6.4 below displays the resultant usage summary for the Induced Draft Fan group under this strategy. This results in a 5 % reduction of energy consumption in this plant area and an overall reduction of 1.1 %.

Gen Load	150	175	200	225	250	275	300	325	350
ID Sys	53.6	101.3	103.8	105.2	108.2	109.5	113.1	116.6	117.3

Table 6.4: MATLAB Process Model Output - Induced Draft Fan System Energy Usage Figures at 9 Load Points after Reduction Option 3 Implemented. Generator Load Set Point in MW and Energy Totals in MWhrs.

Risk Comment

The primary risk is that running with unbalanced air flows will cause uneven wear within the unit airflow paths over long periods of time. The secondary risk is that the second

fan will not start when required and delay the unit load up. This is considered a low risk. The increased number starts on the fan, motor and switch gear will cause increased maintenance concern when compared to the current running profile.

6.2 Forced Draft Fans

This section is to look at potential ways in which possible energy reduction in the area of FD Fans could be achieved.

The system consists of two fans that draw air from the atmosphere and discharge it through the air heater into the boiler. Each fan is driven by a DOL motor with the outlet of fan controlled by a damper vane. Currently the control system runs with both fans in-service across the full load range.

Below in table 6.5 is the current usage summary for the Forced Draft Fan system running at different generator load set points for 24 hours.

Gen Load	150	175	200	225	250	275	300	325	350
FD Sys	36.3	37.8	38.0	40.0	43.9	46.5	51.4	56.3	62.8

Table 6.5: MATLAB Process Model Output - Forced Draft Fan System Energy Usage Figures at 9 Load Points to be used as a Baseline. Generator Load Set Point in MW and Energy Totals in MWhrs.

Below are the possible energy reduction strategies. Each option has three sections, the strategy, the auxiliary MW result, and a risk comment.

Reduction Option 1

Strategy

This option is to run at lower loads with only one fan. The second fan is called into service only once the process requires more air than one fan can supply.

Resultant Usage

The resulting effect of this option on the FD fan groups energy consumption is an 13.5

% reduction at 150 MW. The second fan will still be called into service before the load reaches 175 MW giving an overall 1.3 % reduction in unit auxiliary energy consumption.

Below in table 6.6 is the current usage summary for the Forced Draft Fan system.

Gen Load	150	175	200	225	250	275	300	325	350
FD Sys	31.4	37.8	38.0	40.0	43.9	46.5	51.4	56.3	62.8

Table 6.6: MATLAB Process Model Output - Forced Draft Fan System Energy Usage Figures at 9 Load Points after Reduction Option 1. Generator Load Set Point in MW and Energy Totals in MWhrs.

Risk Comment

The primary risk implementing this option is that the imbalance in airflow will cause inconsistent wear and temperature imbalance within the boiler. There is a low risk that the second fan will not start when called and delay the unit load up. Long term the additional starts on the fans and switch gear holds and increase maintenance risk as compared to the current running arrangements.

Reduction Option 2

Strategy

The second reduction option for this fan group is an extension of the first to initially run with one fan below 175 MW. Once the second fan starts one fan is optimally loaded through the remaining load range with the other fan modulating to deliver the required air flow.

Resultant Usage

This strategy gives a 13.5 % reduction at 150 MW but overall leads to a 1.8 % increase in the overall FD fan group consumption across the full load range. This amounts to an overall increase of 0.18 % in the auxiliary energy usage of the unit.

Below in table 6.7 is the current usage summary for the Forced Draft Fan system.

Risk Comment

Gen Load	150	175	200	225	250	275	300	325	350
FD Sys	31.4	37.9	38.7	41.5	46.4	50.8	52.6	58.4	62.8

Table 6.7: MATLAB Process Model Output - Forced Draft Fan System Energy Usage Figures at 9 Load Points after Reduction Option 2. Generator Load Set Point in MW and Energy Totals in MWhrs.

The primary risk is that the unit load up will be delayed if the second fan does not start when called. The overall impact of this strategy is an increase energy usage.

6.3 Primary Air Fans

This section is to look at potential ways in which possible energy reduction in the area of PA Fans could be achieved.

The system consists of two fans that draw air from the outlet of the FD fan and discharge part of it through the air heater into the mills as hot PA. Some of the discharge bypasses the air heater and is directed into the mills as cold PA. Each fan is driven by a DOL motor with the outlet of fan controlled by a damper vane. Currently the control system runs with both fans in-service across the full load range.

Below in table 6.8 is the current usage summary for the Primary Air Fan system running at different generator load set points for 24 hours.

Gen Load	150	175	200	225	250	275	300	325	350
PA Sys	25.1	28.7	26.1	28.0	29.5	30.2	34.0	33.7	34.1

Table 6.8: MATLAB Process Model Output - Primary Air Fan System Energy Usage Figures at 9 Load Points to be used as a Baseline. Generator Load Set Point in MW and Energy Totals in MWhrs.

Below are the possible energy reduction strategies. Each option has three sections, the strategy, the auxiliary MW result, and a risk comment.

Reduction Option 1

Strategy

The first reduction strategy is to run with one fan in service until the process requires the second fan.

Resultant Usage

The option give a 36 % reduction of the PA fan group power consumption at 150 MW. This leads to a 0.22 % overall reduction in auxiliary energy consumption across the load range. The second fan will be required at 175 MW.

Below in table 6.9 is the resultant usage summary for the Primary Air system

Gen Load	150	175	200	225	250	275	300	325	350
PA Sys	16.0	28.7	26.1	28.0	29.5	30.2	34.0	33.7	34.1

Table 6.9: MATLAB Process Model Output - Primary Air Fan System Energy Usage Figures at 9 Load Points after Implementation of Option 1. Generator Load Set Point in MW and Energy Totals in MWhrs.

Risk Comment

The primary risk is that the second fan will not start was required delaying the unit load up.

Reduction Option 2*Strategy*

This option is an extension of option 1 with one fan being run until the process calls for the second fan. Once the second fan is called one is run at optimum with the other modulating to match the process flow requirements.

Resultant Usage

This strategy gives a 36 % reduction of the energy consumption of the PA fan group at 150 MW. Over the full load range of the unit the resultant usage of the strategy is a 7 % increase of the PA fan group leading to a 0.45 % overall increase in auxiliary energy consumption overall.

Below in table 6.10 is the resultant usage summary for the Primary Air system

Gen Load	150	175	200	225	250	275	300	325	350
PA Sys	16.0	26.0	27.2	27.8	31.7	35.9	38.9	41.2	44.0

Table 6.10: MATLAB Process Model Output - Primary Air Fan System Energy Usage Figures at 9 Load Points after Implementation of Option 2. Generator Load Set Point in MW and Energy Totals in MWhrs.

Risk Comment

The primary risk is that the unit load up will be delayed if the second fan does not start when called. The overall impact of this strategy is an increase energy usage.

6.4 Circulating Water Pumps

This section is to look at potential ways in which possible energy reduction in the area of CW Pumps could be achieved.

This system consists of two pumps which have an hydraulic driven inlet valve and a variable position outlet valve. A common variable position cooling tower bypass valve exists in the system. The system circulates cooling tower bottom pond water through the condenser and back to the top pond of the cooling tower. Currently the control system runs with both pumps turned on DOL with the output valves open at 100 %. The cooling tower bypass valve is used to control the condenser back pressure in the correct vacuum range. The action of this valve allows some water to return directly to the bottom pond and not be cooled by returning to the top pond. This in turn increases the temperature of the bottom pond water that is to be circulated. The figure 6.2 shows the configuration of the unit CW system at full load.

Below in table 6.11 is the current usage summary for the Circulating Water system running at different generator load set points for 24 hours.

Below are the possible energy reduction strategies. Each option has three sections, the strategy, the auxiliary MW result, and a risk comment.

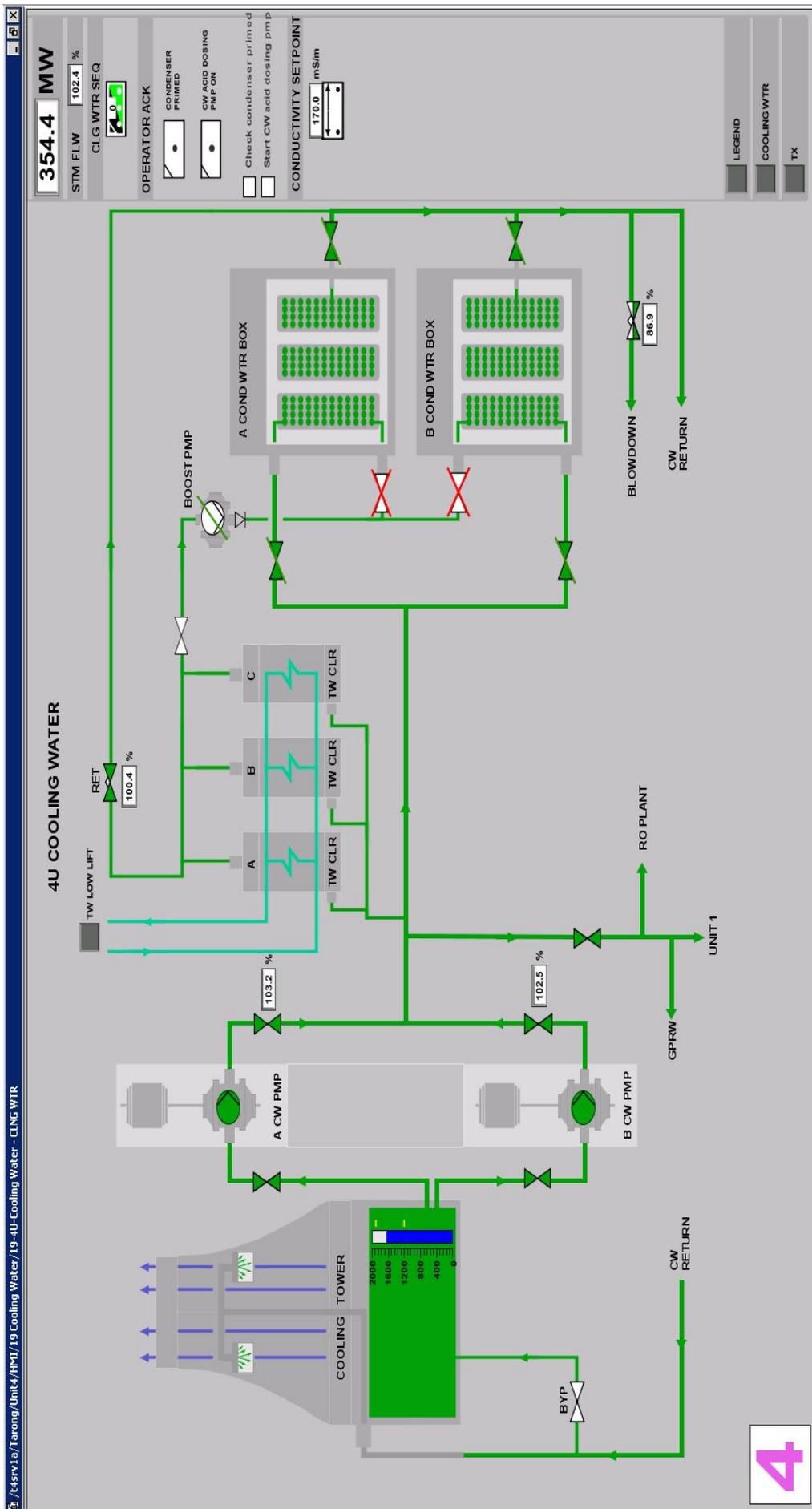


Figure 6.2: Circulating Water System Components - Tarong Power Station (Siemens 2015).

Gen Load	150	175	200	225	250	275	300	325	350
CW Sys	64.2	65.4	66.3	66.8	67.6	68.8	69.2	69.1	69.6

Table 6.11: MATLAB Process Model Output - Circulating Water System Energy Usage Figures at 9 Load Points to be used as a Baseline. Generator Load Set Point in MW and Energy Totals in MWhrs.

Reduction Option 1

Strategy

Delay the start of the second pump until the unit is loaded up to the point of the process requiring the two pumps. As the unit loads up use the condenser vacuum and bypass valve position as an indicator to bring the second pump into service. On load down use the bypass valve position as an indicator to remove the second pump from service.

Resultant Usage

Below in table 6.12 is the resultant usage summary for the Circulating Water system once reduction option 1 is implemented using a conservative value of 200 MW to call the second CW pump service requirement. This results in a reduction of 50 % energy consumption in this plant area below 200 MW. The impact on the overall total auxiliary total is a 1 % reduction.

Gen Load	150	175	200	225	250	275	300	325	350
CW Sys	32.0	32.5	66.3	66.8	67.6	68.8	69.2	69.1	69.6

Table 6.12: MATLAB Process Model Output - Circulating Water System Energy Usage Figures at 9 Load Points after Option 1 Implemented. Generator Load Set Point in MW and Energy Totals in MWhrs

Risk Comment

The primary risk is that the second pump will fail to start when required holding up the unit load up. This risk exists due to the CW hydraulic system requiring some upgrade work. When this work is completed the call to start and stop a second CW pump would be very low risk. Additional starts on the motor and pump set holds some increased risk

compared to the current running arrangements.

Reduction Option 2

Strategy

Use the discharge valves to vary circulating water flow in line with the requirement of condenser vacuum;

Resultant Usage

Below in table 6.13 is the resultant usage summary for the Circulating Water system using a conservative value of 80 % for the reduction of loading below 200 MW. This was difficult to accurately determine due to the lack of data available for these pumps. 80 % was a figure determined based on generic pump load curves.

Gen Load	150	175	200	225	250	275	300	325	350
CW Sys	51.4	52.3	66.3	66.8	67.6	68.8	69.2	69.1	69.6

Table 6.13: MATLAB Process Model Output - Circulating Water System Energy Usage Figures at 9 Load Points after Option 2 Implemented. Generator Load Set Point in MW and Energy Totals in MW/hr

Risk Comment

This option is low risk as both pumps are in-service and the output valve can be manipulated very quickly to give full flow to the condenser. Long term the increase wear is a concern.

6.5 Condensate Extraction Pumps

This section is to look at potential ways in which possible energy reduction in the area of CEPs could be achieved.

The system consists of two pumps that draw water from the condenser hotwell and discharge it through the low pressure heaters into the deaerator. Each pump is driven by a DOL motor with the outlet of pump controlled by a control valve. Currently the control

system runs with one pump in-service across the full load range.

Below in table 6.14 is the current usage summary for the Condensate Extraction system running at different generator load set points for 24 hours.

Gen Load	150	175	200	225	250	275	300	325	350
CE Sys	16.0	16.7	17.4	18.2	18.8	19.9	20.7	20.7	21.5

Table 6.14: MATLAB Process Model Output - Condensate Extraction System Energy Usage Figures at 9 Load Points to be used as a Baseline. Generator Load Set Point in MW and Energy Totals in MWhrs.

There were no energy reduction strategies identified for this plant area.

6.6 Boiler Feed Pumps

This section is to look at potential ways in which possible energy reduction in the area of BFPs could be achieved.

The system consists of three pumps that draw water from the deaerator and discharge it through the high pressure heaters into the boiler drum. Each pump is driven by a DOL motor with the outlet flow of pump controlled by a variable speed oil coupling. Currently the control system runs with two pumps in-service across the full load range. The figure 6.3 shows the configuration of the unit BFP system at full unit load, 350 MW.

Below in table 6.15 is the current usage summary for the Boiler Feed Pump system running at different generator load set points for 24 hours.

Gen Load	150	175	200	225	250	275	300	325	350
BFP Sys	93.1	103.8	121.0	131.3	150.1	171.4	189.2	198.5	217.6

Table 6.15: MATLAB Process Model Output - Boiler Feed Pump System Energy Usage Figures at 9 Load Points to be used as a Baseline. Generator Load Set Point in MW and Energy Totals in MWhrs.

Below are the possible energy reduction strategies. Each option has three sections, the strategy, the auxiliary MW result, and a risk comment.

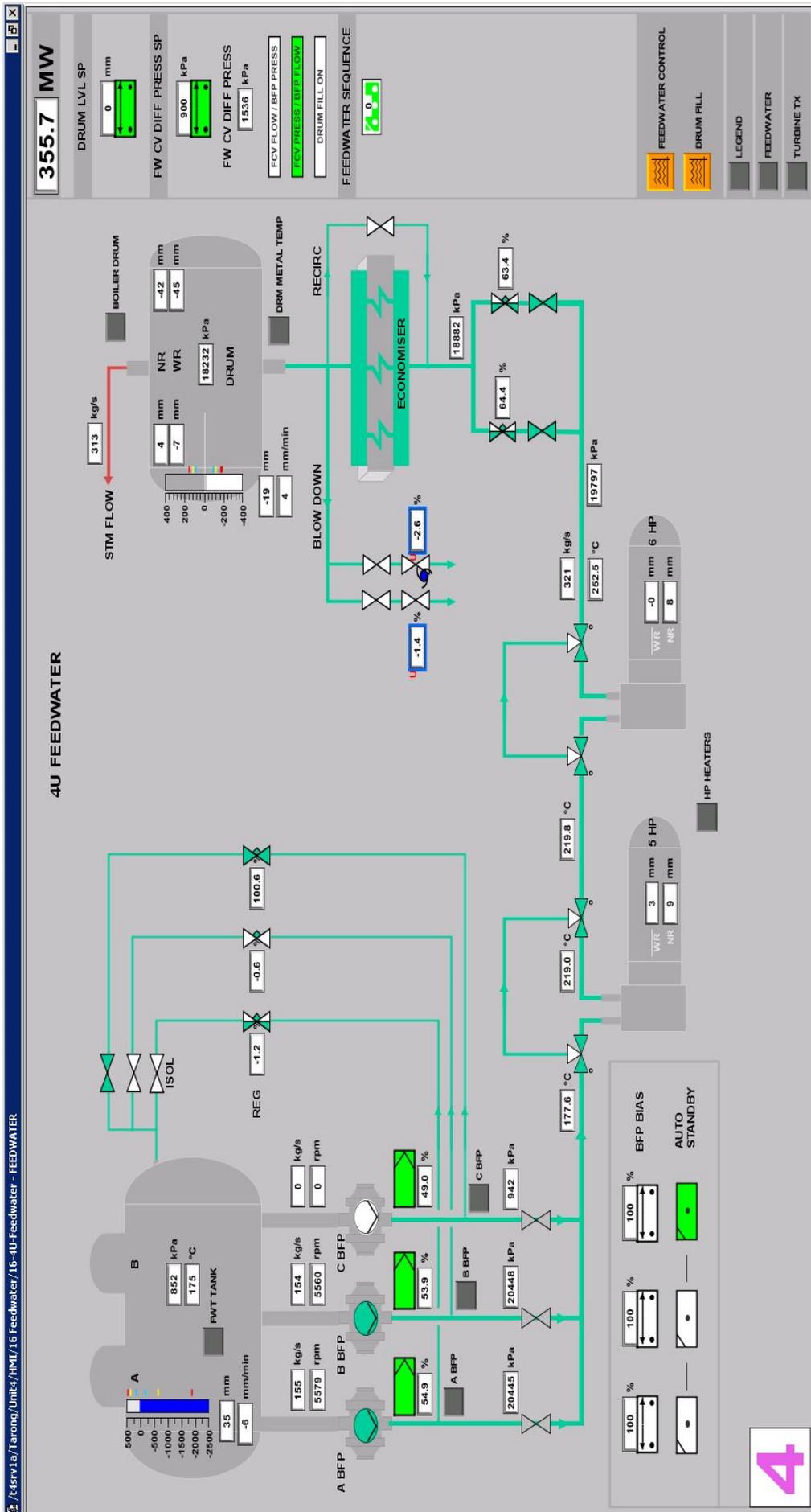


Figure 6.3: Boiler Feed Pump System Components - Tarong Power Station (Siemens 2015).

Reduction Option 1

Strategy

This reduction option is to run at low load below 200 MW with only one BFP in service rather than two running inefficiently.

Resultant Usage

Below in table 6.16 is the resultant usage summary for the Boiler Feed Pump system using only one BFP to supply the full feedwater flow up to 200 MW. This strategy results in a 10 % reduction of energy consumption for this plant area under 200 MW. The closer to 140 MW the more effective this strategy is with the reduction being 12 % at 150 MW generator load set point.

Gen Load	150	175	200	225	250	275	300	325	350
BFP Sys	82.9	92.7	112.3	131.3	150.1	171.4	189.2	198.5	217.6

Table 6.16: MATLAB Process Model Output - Boiler Feed Pump System Energy Usage Figures at 9 Load Points after Option 1 Implemented. Generator Load Set Point in MW and Energy Totals in MWhrs.

Risk Comment

The primary risk is that the second pump will fail to start when required holding up the unit load up. This risk can be considered very low as failure to start issue with a BFP is a rare occurrence. The risk is mitigate further when the third pump is also available. Additional starts on the motor and pump set holds some increased risk compared to the current running arrangements.

Reduction Option 2

Strategy

This option is an extension to BFP reduction option 1. This reduction option is to run at low load below 200 MW with only one BFP in service. Then at 200 MW the second pump is started. At this point the first pump is to be locked in to the optimum efficiency point with the second pump controlling the drum level.

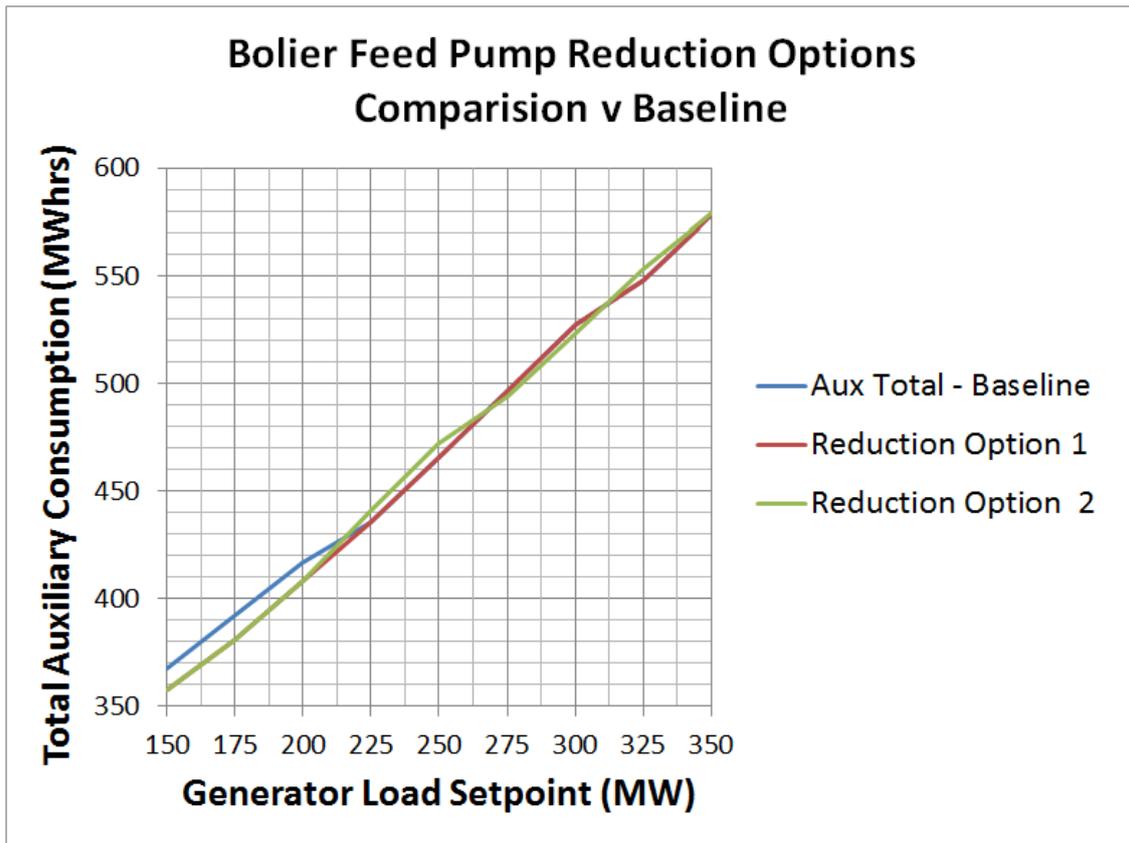


Figure 6.4: Boiler Feed Pump Plant Area - Process Model versus Reduction Options

Resultant Usage

Below in table 6.17 is the resultant usage summary for the Boiler Feed Pump system using only one BFP to supply the full feedwater flow up to 200 MW. Then an efficiency load sharing option from this point upwards. This strategy results in a 0.46 % reduction of energy consumption for this plant area across the full load range. The closer to 140 MW the more effective this strategy is with the reduction being 12 % at 150 MW generator load set point. A trend is included below in figure 6.4 to show the affect across the load range.

Gen Load	150	175	200	225	250	275	300	325	350
BFP Sys	82.9	92.7	112.3	137.0	156.8	168.8	184.7	203.6	218.1

Table 6.17: MATLAB Process Model Output - Boiler Feed Pump System Energy Usage Figures at 9 Load Points after Option 2 Implemented. Generator Load Set Point in MW and Energy Totals in MWhrs.

Risk Comment

The primary risk is that the second pump will fail to start when required holding up the unit load up. This risk can be considered very low as failure to start issue with a BFP is a rare occurrence. The risk is mitigate further when the third pump is also available. Additional starts on the motor and pump set holds some increased risk compared to the current running arrangements. The pumps are designed to run continuously at full efficiency and often do when the unit is fully loaded.

6.7 Reduction Options Summary

This section presents a summary of the reduction options tested on the process SIMULINK model and presented in the sections above.

The impacts of each reduction option tested is presented in the table 6.18 below. This table shows the impact of each proposed reduction options on the energy consumption of the plant area involved. The resulting reduction is expressed as a percentage.

Gen Load MW	150	175	200	225	250	275	300	325	350
Option 1 CW %	-50.2	-50.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 2 CW %	-20.0	-20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 1 BFP %	-11.1	-10.8	-7.2	0.0	0.0	0.0	0.0	0.0	0.0
Option 2 BFP %	-11.1	-10.8	-7.2	+4.3	+4.4	-1.5	-2.4	+2.6	+0.2
Option 1 ID %	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
Option 2 ID %	-45.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 3 ID %	-45.0	+0.2	-1.0	-1.1	-1.4	-1.2	-1.0	+1.2	0.0
Option 1 FD %	-13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 2 FD %	-13.5	+0.2	+1.9	+3.7	+5.8	+9.6	+2.3	+3.7	0.0
Option 1 PA %	-36.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 2 PA %	-36.2	-9.5	+4.3	-0.7	+7.2	+18.9	+14.4	+22.4	+29.0

Table 6.18: Impact of Reduction Options in Each Plant Area at Different Generator Load Set Points in MW - Resulting Impact Presented as a Percentage.

The impacts of each reduction option tested is presented in the table 6.18 below. This table shows the impact of each proposed reduction options on the overall auxiliary energy consumption. The resulting reduction is expressed as a percentage.

Gen Load	150	175	200	225	250	275	300	325	350
Option 1 CW %	-8.8	-8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 2 CW %	-3.5	-3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 1 BFP %	-2.8	-2.9	-2.1	0.0	0.0	0.0	0.0	0.0	0.0
Option 2 BFP %	-2.8	0.0	0.0	+1.3	+1.4	-0.5	-0.9	+0.9	+0.1
Option 1 ID %	-2.7	-2.6	-2.5	-2.5	-2.4	-2.2	-2.2	-2.1	-2.0
Option 2 ID %	-11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 3 ID %	-11.4	+0.1	-0.3	-0.3	-0.3	-0.3	-0.2	+0.3	0.0
Option 1 FD %	-1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 2 FD %	-1.3	+0.1	+0.2	+0.3	+0.6	+0.9	+0.2	+0.4	0.0
Option 1 PA %	-2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Option 2 PA %	-2.5	-0.7	+0.3	-0.1	+0.5	+1.2	+0.9	+1.4	+1.7

Table 6.19: Impact of Reduction Options on the Overall Auxiliary Energy Consumption at Different Generator Load Set Points in MW - Resulting Impact Presented as a Percentage.

6.8 Entire Unit - Optimum Solution

This section is to look at final combination of reduction options that gives the best final resulting energy efficiency. The combinations presented below have taken into account both the actual reduction achievable and the level of risk involved in implementation on the plant.

The table 6.20 below contains a summary of the auxiliary power consumption totals at different generator load set points for 24 hours. The data in this table represents the baseline figure with which the proposed unit solutions can be compared.

Gen Load	150	175	200	225	250	275	300	325	350
Full Unit	368	392	417	435	465	497	528	548	578
kWhr/MW	102.09	93.28	86.77	80.58	77.54	75.24	73.27	70.25	68.86

Table 6.20: MATLAB Process Model Output - Full Unit Auxiliary Energy Usage Baseline Figures at 9 Load Points. Generator Load Set Point in MW and Energy Totals in MWhrs.

6.8.1 Low Risk

Optimal Unit Wide Reduction Option

Strategy

The low risk option to reduce the overall auxiliary power consumption is to implement BFP reduction option 2 and CW reduction option 1 together. These options combine to propose to run with only 1 BFP and 1 CW pump in service below 200 MW. Above 200 MW the circulating water system runs with the two pumps running and a second BFP is called into service. The BFP's are run with one at optimum loading and the second modulating to maintain the required feedwater flow.

Resultant Usage

Below in table 6.21 is the resultant usage summary which presents the resulting full unit 24 hour auxiliary energy consumption after implementation of the low risk strategy. The impact is compared to the current baseline running with the resulting change presented as both a raw MWhr reduction and also as a percentage improvement. The final row of the table presents the total kWhrs required to generate 1 MWhr of electricity at the 9 load set points. This low risk strategy gives an overall reduction in auxiliary energy consumption of 10 % below 200 MW.

Gen Load	150	175	200	225	250	275	300	325	350
Full Unit	325	348	374	441	472	494	523	553	579
MWhr Impact	-42.6	-44.1	-42.3	+5.6	+6.6	-2.6	-4.5	+5.1	+0.5
% Impact	-11.6	-11.2	-10.2	+1.3	+1.4	-0.5	-0.9	+0.9	+0.1
kWhr/1MWhr	90.27	82.79	77.96	81.63	78.64	74.85	72.64	70.91	68.92

Table 6.21: MATLAB Process Model Output - Full Unit Energy Usage Figures at 9 Load Points after Low Risk Options are Implemented. Generator Load Set Point in MW and Energy Totals in MWhrs.

6.8.2 Medium Risk

Optimal Unit Wide Reduction Option

Strategy

The medium risk strategy is an extension of the low risk strategy above. This strategy is to implement the low risk drive running modifications and also to increase the furnace pressure set point closer to the zero to reduce the load on the ID fans, reduction option 1. This set point change will reduce the ID fan load by 10% across the full load range of the unit.

Resultant Usage

Below in table 6.22 is the resultant usage summary which presents the resulting full unit 24 hour auxiliary energy consumption after implementation of the medium risk strategy. The impact is compared to the current baseline running with the resulting change presented as both a raw MWhr reduction and also as a percentage improvement. The final row of the table presents the total kWhrs required to generate 1 MWhr of electricity at the 9 load set points. This medium risk strategy gives an overall reduction in auxiliary energy consumption of 10 - 15 % below 200 MW and a modest reduction of 1 - 3 % across the remaining load range.

Gen Load	150	175	200	225	250	275	300	325	350
Full Unit	315	338	364	430	461	483	512	542	567
MWhr Impact	-52.3	-54.2	-52.8	-5.0	-4.3	-13.7	-16.0	-6.4	-11.2
% Impact	-14.2	-13.8	-12.7	-1.2	-0.9	-2.8	-3.0	-1.2	-1.9
kWhr/1MWhr	87.57	80.38	75.77	79.65	76.81	73.17	71.05	69.43	67.52

Table 6.22: MATLAB Process Model Output - Full Unit Energy Usage Figures at 9 Load Points after Low and Medium Risk Options are Implemented. Generator Load Set Point in MW and Energy Totals in MWhrs.

6.8.3 High Risk**Optimal Unit Wide Reduction Option***Strategy*

The high risk strategy is an extension of the medium risk strategy above. This strategy

is to implement the low risk drive running modifications, increase the furnace pressure set point and also run with only one half of the fan groups in service until the process requires them. This is reduction options ID fan 3, FD fan 1 and PA fan 1. This means that until 175 MW only 1 CW pump, BFP, ID fan, FD fan and PA fan are in service. At 175MW the second ID, FD and PA fans are started. The second CW pump and BFP are brought into service at 200 MW. When the second fan groups starts ID fan loading will be manipulated to share the load to ensure one drive is always optimally loaded. Once the second FD and PA fans are started the loading will be shared as the modeling investigation has found that to be the ideal energy efficiency strategy. To reduce the long term chance of uneven wear rates within the air and gas paths it would be proposed to alternate the fan group that is removed from service at low load. A high level monitoring sequence to ensure long term run hours are matched would also be required.

Resultant Usage

Below in table 6.23 is the resultant usage summary which presents the resulting full unit 24 hour auxiliary energy consumption after implementation of the high risk strategy. The impact is compared to the current baseline running with the resulting change presented as both a raw MWhr reduction and also as a percentage improvement. The final row of the table presents the total kWhrs required to generate 1 MWhr of electricity at the 9 load set points. This high risk strategy gives an overall reduction in auxiliary energy consumption of 15 - 10 % below 200 MW and a reduction of 3 - 5 % across the remaining load range.

Gen Load	150	175	200	225	250	275	300	325	350
Full Unit	259	335	355	421	451	473	501	527	551
MWhr Impact	-108.5	-56.8	-61.9	-14.5	-14.3	-23.8	-26.2	-20.6	-27.3
% Impact	-29.5	-14.5	-14.9	-3.3	-3.1	-4.8	-5.0	-3.8	-4.7
kWhr/1MWhr	71.96	79.76	73.89	77.89	75.15	71.64	69.62	67.61	65.61

Table 6.23: MATLAB Process Model Output - Full Unit Energy Usage Figures at 9 Load Points after Low, Medium and High Risk Options are Implemented. Generator Load Set Point in MW and Energy Totals in MWhrs.

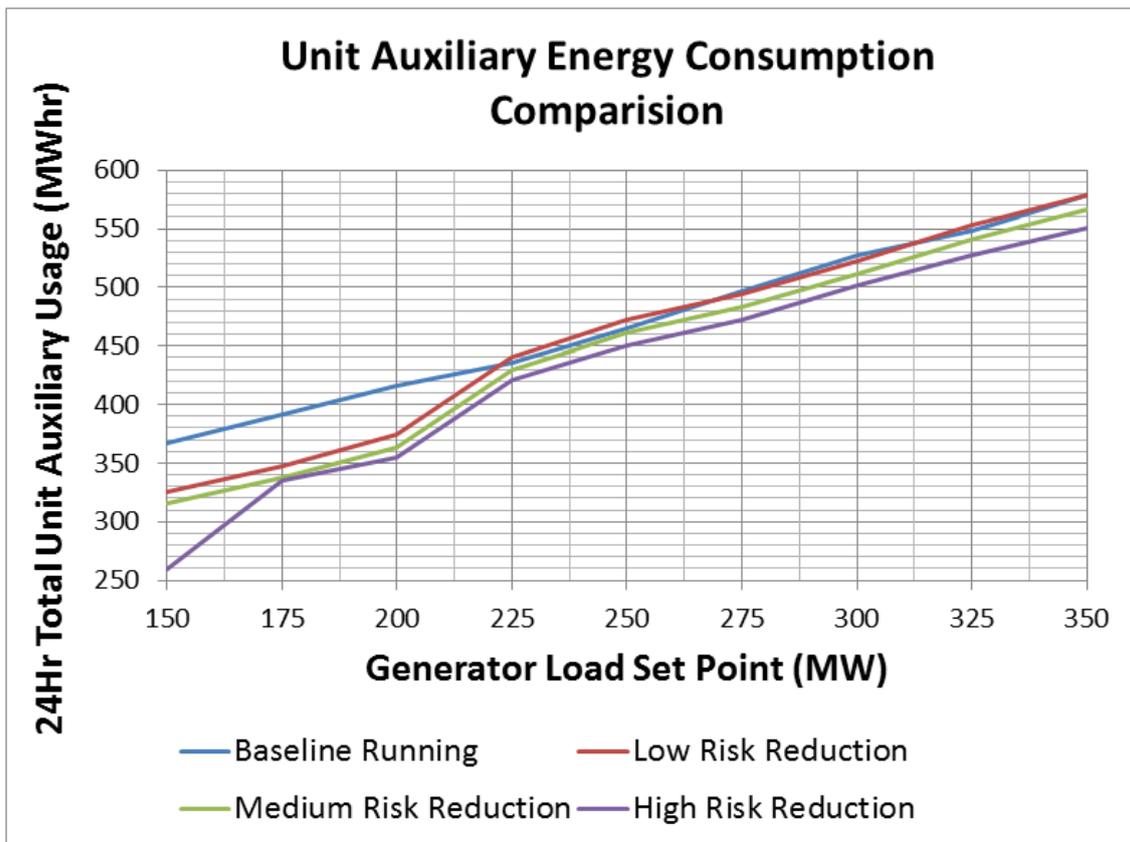


Figure 6.5: Full Unit Auxiliary Energy Consumption Comparison No 1 - Baseline versus Risk Reduction Options.

6.8.4 Reduction Summary

The two trends included in figure 6.5 and 6.6 to show the affect across the load range of the 3 unit wide solutions against the current running baseline.

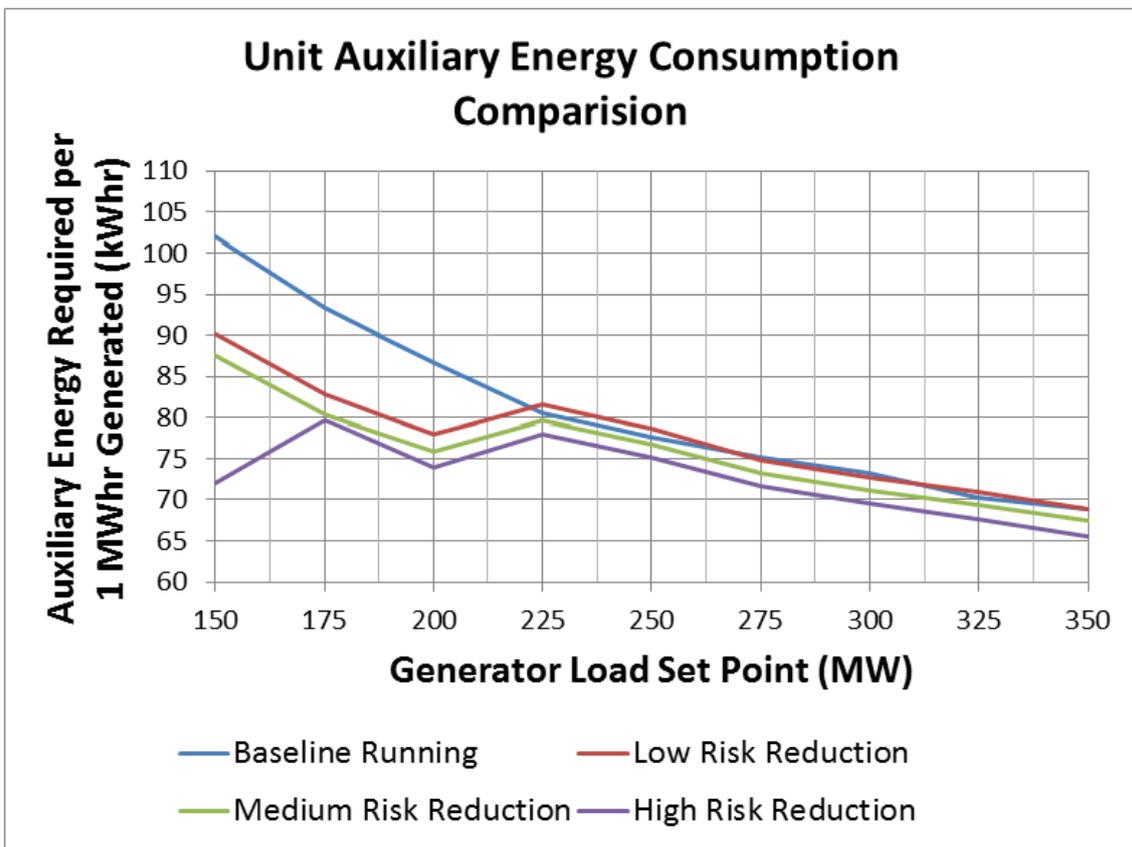


Figure 6.6: Full Unit Auxiliary Energy Consumption Comparison No 2 - Baseline versus Risk Reduction Options.

6.9 Conclusion

In this chapter the potential options for energy reduction through operational methods were explored. Each plant area was explored individually with an overall unit wide ideal solution proposed. Where possible the options proposed were theoretically implemented utilising the created MATLAB models to measure the energy impact of the option. The risk discussions have given grounding for broader discussions that may lead to full implementation on running plant. The next chapter outlines the final conclusions of the project and the potential future work.

Chapter 7

Conclusion and Further Work

This chapter is to present the projects achievements, key findings and to outline any opportunities for future work.

The project has successfully achieved the projects two primary aims of understanding the auxiliary energy consumption at TPS and to identify potential control based energy reduction strategies. The understanding of the auxiliary usage was achieved through the completion of a comprehensive literature review, the successful creation of energy tracking logic within the plant control system, Siemens T3000, and through the creation of multiple MATLAB models. The process of identification of zero capital reduction strategies utilised the knowledge gained during the completion of the primary aims and the knowledge of the author. A memo to Stanwell regarding potential energy reduction strategies and the steps required to implement was created. The creation of T3000 logic achieved the projects secondary aim of leaving in place energy consumption information that could be utilised into the future. The T3000 logic created will allow ongoing realtime monitoring of auxiliary consumption within TPS.

7.1 Project Conclusions

The project successfully created multiple auxiliary energy models in MATLAB. The models were based on data that was extracted from the TPS data historian, PIMS. These models were utilised to understand the auxiliary energy usage at TPS. The understand-

ing and model accuracy was proven against the T3000 energy tracking logic that the project also created. The T3000 logic was in turn confirmed against the permanently installed energy meters. This proved that an accurate model of coal fired power station auxiliary energy consumption is able to be created based on data mining techniques.

The project has concluded that reductions of auxiliary energy consumption at Tarong Power Station is achievable without capital investment. This conclusion is supported by the understanding gained through the comprehensive literature review completed, the creation of T3000 tracking logic, and working MATLAB models. The ability to achieve reduction was confirmed through the use of the created MATLAB SIMULINK process model to successfully load share and prove the auxiliary power reduction. The proposed unit wide reduction options, including results of the SIMULINK trials, is discussed in chapter 6.

A summary and steps to implement the recommended reduction strategies on the actual TPS unit plant are included in Appendix I Memo to Engineering Superintendent - Electrical Maintenance - TPS. This memo also outlines that the reduction options proposed can be applied to all 4 Tarong Power Station units and that there is a potential that the same strategies could be applied to the 4 Stanwell Power Station units for similar gains. This is due to the fact that Stanwell Power Station design and load profiles are very similar to Tarong. This can be extended to say that the project has concluded that any unit with a similar design could benefit from operational improvement based energy efficiency strategies, particularly at low loads. All three possible options are outline below with the Low and Medium risk options being proposed to be implemented within TPS unit plant.

The final proposed low risk unit wide optimal reduction strategy has 2 key components;

1. Circulating Water pump control modification - only one CW pump in-service until the process requirements call for the second pump - approximately 200 MW; and
2. Boiler Feed Pump control modification - only 1 BFP in-service until the process calls for it - approximately 200 MW - a optimum trim solution up to 300 MW will also give some benefit.

This low risk strategy gives an overall reduction in auxiliary energy consumption of 10

% below 200 MW. The overall reduction will vary with load profile, ambient weather conditions and status of the plant in the maintenance cycle. The CW and BFP drive control modifications only give benefit in the low load range. The implementation of these reduction strategies is considered low risk as the primary risk is that the second drive will not start in the time required meaning that the unit load up may be delayed.

The project also found that if a medium risk profile was taken on then additional reduction could be achieved. The additional item below needs to be added to the low risk strategy above;

1. Induced Draft Fan control modification - lifting the furnace pressure set point closer to zero.

The ID fan control modification will be effective across the full load range with an increased risk that the boiler may trip on furnace pressure excursion. This risk is of particular concern when a clinker fall occurs and the pressure ripple it creates forces the pressure high for greater than the 2 second delay time. This is the reason for the medium risk rating of implementing this energy reduction strategy. This medium risk strategy gives an overall reduction in auxiliary energy consumption of 10 - 15 % below 200 MW and a modest reduction of 1 - 3 % across the remaining load range.

The project also found that if a higher risk profile was taken on then additional reduction could be achieved. The additional items below need to be added to the medium risk strategy above;

1. Primary Air fan control modification - only one PA fan in-service until the process requirements call for the second fan - approximately 175 MW;
2. Forced Draft fan control modification - only one FD fan in-service until the process requirements call for the second fan - approximately 175 MW; and
3. Induced Draft fan control modification - only one ID fan in-service until the process requirements call for the second fan - approximately 175 MW. Once the second fan is in service some load manipulation gives additional consumption reduction across the remaining load range.

These 3 higher risk control modifications would also require a duty/standby fan arrangement to be implemented to ensure that wear rates are balanced out. It would be proposed that only half the air and gas group be in-service up until 175 MW. Each time the load cycles into the low load range the opposite side to last is removed from service. This would assist in wear rate balance but a higher level runtime monitoring system would need to sit over the top of this basic duty/standby control proposed to ensure long term balance. This high risk strategy gives an overall reduction in auxiliary energy consumption of 15 - 10 % below 200 MW and a reduction of 3 - 5 % across the remaining load range.

The project has also found another key relating to auxiliary energy consumption at TPS is that over 300 MW the unit is running at peak auxiliary power efficiency and there is little that can be done to reduce the energy consumption rate. Attempts to share drive loading at the higher generator set points have little to no positive effect. As discussed earlier the ID fan load can be reduced across the full load range by lifting the furnace set point.

While this project has made significant contribution to the industry there are items identified during this project that require additional work to complete, these will be outlined in the next section.

7.2 Future Work

This section is to outline potential future work that may use this projects findings as a basis.

The project has identified future work that would further benefit the Tarong Power Station and the broader electricity industry. This future work is broadly grouped into 3 categories, MATLAB, T3000 and Other. These potential areas for future work are outlined below.

MATLAB

The items below are possible enhancements that could be made to the created MATLAB models to assist in continued expansion of the knowledge of auxiliary energy consumption. The models could be expanded or modified to allow other plants to be more easily assessed.

- addition of drive service select inputs similar to the BFP selections;
- creation of live links to the plant data from the MATLAB model to allow manipulation of the load distribution in realtime;
- modify the models to make it more generic, so they can potentially be applied more easily to other plants;
- addition of 415 V drives to the model to allow more detailed investigation of the impacts of drives at that level. Examples of these drives are mill motors, air extraction pumps and flame detection cooling fans;
- creation of not in-service switches for all drives similar to the BFP drives.

T3000

The items below will expand on the current work in T3000 by making the created data more visible and potentially implementing the recommended energy reduction strategies.

- creation of auxiliary energy flow HMI;
- creation of auxiliary energy consumption alarms, realtime and 24 hour moving average;
- creation of auxiliary energy trends;
- BFP transfer logic at low loads;
- CW transfer logic at low loads;
- creation of boiler furnace ride through logic to allow the furnace set point to be lifted;
- BFP trim logic to ensure one pump is always at optimal.

Other

The items below will investigate those items identified during the literature review that were outside of the scope of this project. These items are viewed as having potential industry benefit but were either too wide ranging or requiring capital injection to be considered under this project. All of these items could be investigated from the perspective of auxiliary energy reduction and life cycle of the components.

- review the findings at Tarong for potential implementation at Stanwell Power Station;
- investigate ID fan impeller hard facing to reduce wear rate and overall loading;
- investigate ASD's for the BFP's to reduce plant area energy consumption;
- investigate hard facing of milling components, balls and rings to reduce wear rate and overall loading;
- investigate the potential of reducing size of coal entering the pulveriser to reduce overall loading;
- investigate the energy savings in routinely sweeping the mills to reduce mill loading;
- investigate the impact of air heater overhaul intervals on ID fan loading;
- investigation of ammonia injection into the flu gas to reduce precipitator pressure drop and in turn ID fan loading;
- investigation of installation of power factor correction devices.

Many suggestions above would make ideal stand alone projects or as a combined project to look at reduction of auxiliary energy consumption through capital investment which is the opposite perspective of this projects aims.

7.3 Conclusion

In this chapter the projects achievements, conclusions and opportunities for future work were outlined. The project has concluded that reductions of auxiliary energy consumption at Tarong Power Station is achievable without capital investment. This energy efficiency improvement can be achieved solely through control optimisation using the existing installed infrastructure.

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Appendix A

Project Specification

ENG 4111/2 Research Project

Project Specification

For: **Jason Lang**

Topic: Energy Efficiency Improvement in Coal Fired Power Plant through
Operational Optimisation

Supervisors: Catherine Hills

Sponsorship: Stanwell Corporation Limited

Project Aim: This project aims to model the auxiliary energy usage of a 350MW coal fired unit using MATLAB and T3000 Digital Control System logic. Using this model it aims to propose control methods to reduce the internal electrical energy consumed to produce electricity.

Program:

1. Research into auxiliary energy, energy calculations, energy reduction and control optimisation in coal fired power stations.
2. Collect energy data from existing plant operations and maintenance manuals.
3. Collect historical plant energy usage data for all unit conditions.
4. Create a SIMULINK model, in MATLAB, of the energy profile of a single unit.
5. Create energy tracking logic in the T3000 Digital Control System.

6. Use local energy meter readings on Unit 4 to confirm/tune Digital Control System tracking values.
7. Calibrate the results of the MATLAB model against the real overall measured power for the unit.
8. Use the model to determine optimal solutions for energy reduction through control optimisation.
9. Select the solutions with acceptable risk and good potential and analyse these schemes for practicality and viability.
10. Propose control system modifications and operational guidelines in a report to be delivered to site.

As time, resources and sponsor plant risk assessment permit:

1. Trial optimised energy scheme on the unit simulator and evaluate.
2. Implement optimised energy scheme on a running unit and evaluate.

Appendix B

Conceptual MATLAB Auxiliary Calculation Script

```

%This file is to test the power calculation result for 1 full day
%All voltage and current measurements have been exported from PIMS and
%then imported into MATLAB.
%Once imported the data is split into data arrays and the real power is
%then calculated.
%The results are roughly displayed on the workspace.
%
%Clean up workspace
clear all
close all
%
%Setup blank matrices
row = 1;
%
%Import data from excel spreadsheet
[numdata, txtdata, rawdata] = xlsread('U47thJulyAux.xlsx');
%
%Manipulate column numerical data into individual vectors
GEN_20KV_V = numdata(1:end,1);      %Generator 20kv Bus Volts
MW = numdata(1:end,2);             %MW's Generated
A_UNIT_TX_TOT_MW = numdata(1:end,3); %'A' Unit Transformer MW
A_UNIT_TX_TOT_PF = numdata(1:end,4); %'A' Unit Transformer Power Factor
A_UNIT_TX_AVG_I = numdata(1:end,5); %'A' Unit Transformer Average Current
B_UNIT_TX_TOT_MW = numdata(1:end,6); %'B' Unit Transformer MW
B_UNIT_TX_TOT_PF = numdata(1:end,7); %'B' Unit Transformer Power Factor
B_UNIT_TX_AVG_I = numdata(1:end,8); %'B' Unit Transformer Average Current
A_6_6_BUS_V = numdata(1:end,9);     %'A' 6.6kv Bus Volts
A_6_6_BUS_I = numdata(1:end,10);    %'A' 6.6kv Bus Current
B_6_6_BUS_V = numdata(1:end,11);    %'B' 6.6kv Bus Volts
B_6_6_BUS_I = numdata(1:end,12);    %'B' 6.6kv Bus Current
C_6_6_BUS_V = numdata(1:end,13);    %'C' 6.6kv Bus Volts
BNKR_TX_6_6_I = numdata(1:end,14);  %Bunkering Transformer Current
A_PRECIP_TX_6_6_I = numdata(1:end,15); %'A' Precip Transformer Current
B_PRECIP_TX_6_6_I = numdata(1:end,16); %'B' Precip Transformer Current
A_415V_UNIT_TX_I = numdata(1:end,17); %'A' 415V Unit Transformer Current
B_415V_UNIT_TX_I = numdata(1:end,18); %'B' 415V Unit Transformer Current
C_415V_UNIT_TX_I = numdata(1:end,19); %'C' 415V Unit Transformer Current
A_PA_FAN_LD = numdata(1:end,20);    %'A' Primary Air Fan Motor Load
B_PA_FAN_LD = numdata(1:end,21);    %'B' Primary Air Fan Motor Load
A_FD_FAN_LD = numdata(1:end,22);    %'A' Forced Draft Air Fan Motor Load
B_FD_FAN_LD = numdata(1:end,23);    %'B' Forced Draft Air Fan Motor Load
A_ID_FAN_LD = numdata(1:end,24);    %'A' Induced Draft Air Fan Motor Load
B_ID_FAN_LD = numdata(1:end,25);    %'B' Induced Draft Air Fan Motor Load
A_BFP_LD = numdata(1:end,26);       %'A' Boiler Feed Pump Motor Load
B_BFP_LD = numdata(1:end,27);       %'B' Boiler Feed Pump Motor Load
C_BFP_LD = numdata(1:end,28);       %'C' Boiler Feed Pump Motor Load
A_CEP_LD = numdata(1:end,29);       %'A' Condensate Extraction Pump Motor Load
B_CEP_LD = numdata(1:end,30);       %'B' Condensate Extraction Pump Motor Load
A_CW_LD = numdata(1:end,31);        %'A' Circulating Water Pump Motor Load
B_CW_LD = numdata(1:end,32);        %'B' Circulating Water Pump Motor Load
%
%Calculate fixed variables
sqrt3 = sqrt(3);
LV_V = 415;
%
%E(kwh) = P(W) x t(hr)/1000

```

```

%
%Calculate the daily power for 'A' Unit Transformer
A_PWR = sqrt3.*(GEN_20KV_V*1000).*A_UNIT_TX_AVG_I.*A_UNIT_TX_TOT_PF;
A_PWR_TOTAL = (sum(A_PWR)./1000000)/3600 %Total Calc 'A' Unit Transformer
A_PWR_MET_TOTAL = sum(A_UNIT_TX_TOT_MW) %Total Meas 'A' Unit Transformer
A_PWR_ERROR = ((A_PWR_TOTAL - A_PWR_MET_TOTAL)/A_PWR_MET_TOTAL)*100
%
%Calculate the daily power for 'B' Unit Transformer
B_PWR = sqrt3.*(GEN_20KV_V*1000).*B_UNIT_TX_AVG_I.*B_UNIT_TX_TOT_PF;
B_PWR_TOTAL = (sum(B_PWR)./1000000)/3600 %Total Calc 'B' Unit Transformer
B_PWR_MET_TOTAL = sum(B_UNIT_TX_TOT_MW) %Total Meas 'B' Unit Transformer
B_PWR_ERROR = ((B_PWR_TOTAL - B_PWR_MET_TOTAL)/B_PWR_MET_TOTAL)*100
%
%Calculate the daily power for Bunkering Transformer
BUN_PWR = sqrt3.*LV_V.*BNKR_TX_6_6_I.*A_UNIT_TX_TOT_PF;
BUN_PWR_TOTAL = (sum(BUN_PWR)./1000000)/3600 %Total Calc Bunkering Transf
%
%Calculate the daily power for 'A' Precip Transformer
A_PRE_PWR = sqrt3.*(A_6_6_BUS_V*1000).*A_PRECIP_TX_6_6_I.*A_UNIT_TX_TOT_PF;
A_PRE_PWR_TOTAL = (sum(A_PRE_PWR)./1000000)/3600%Total Calc A Precip Transf
%
%Calculate the daily power for 'B' Precip Transformer
B_PRE_PWR = sqrt3.*(B_6_6_BUS_V*1000).*B_PRECIP_TX_6_6_I.*B_UNIT_TX_TOT_PF;
B_PRE_PWR_TOTAL = (sum(B_PRE_PWR)./1000000)/3600%Total Calc B Precip Transf
%
%Calculate the daily power for 'A' 415V Unit Transformer
A_415V_PWR = sqrt3.*LV_V.*A_415V_UNIT_TX_I.*A_UNIT_TX_TOT_PF;
A_415V_PWR_TOTAL = (sum(A_415V_PWR)./1000000)/3600%Total Calc A 415V Transf
%
%Calculate the daily power for 'B' 415V Unit Transformer
B_415V_PWR = sqrt3.*LV_V.*B_415V_UNIT_TX_I.*B_UNIT_TX_TOT_PF;
B_415V_PWR_TOTAL = (sum(B_415V_PWR)./1000000)/3600%Total Calc B 415V Transf
%
%Calculate the daily power for 'C' 415V Unit Transformer
C_415V_PWR = sqrt3.*LV_V.*C_415V_UNIT_TX_I.*A_UNIT_TX_TOT_PF;
C_415V_PWR_TOTAL = (sum(C_415V_PWR)./1000000)/3600%Total Calc C 415V Transf
%
%Calculate the daily power for 'A' Primary Air Fan
A_PA_PWR = sqrt3.*(A_6_6_BUS_V*1000).*A_PA_FAN_LD.*A_UNIT_TX_TOT_PF;
A_PA_PWR_TOTAL = (sum(A_PA_PWR)./1000000)/3600 %Total Calc A PA Fan Load
%
%Calculate the daily power for 'B' Primary Air Fan
B_PA_PWR = sqrt3.*(B_6_6_BUS_V*1000).*B_PA_FAN_LD.*A_UNIT_TX_TOT_PF;
B_PA_PWR_TOTAL = (sum(B_PA_PWR)./1000000)/3600 %Total Calc B PA Fan Load
%
%Calculate the daily power for 'A' Forced Draft Fan
A_FD_PWR = sqrt3.*(A_6_6_BUS_V*1000).*A_FD_FAN_LD.*A_UNIT_TX_TOT_PF;
A_FD_PWR_TOTAL = (sum(A_FD_PWR)./1000000)/3600 %Total Calc A FD Fan Load
%
%Calculate the daily power for 'B' Forced Draft Fan
B_FD_PWR = sqrt3.*(B_6_6_BUS_V*1000).*B_FD_FAN_LD.*B_UNIT_TX_TOT_PF;
B_FD_PWR_TOTAL = (sum(B_FD_PWR)./1000000)/3600 %Total Calc B FD Fan Load
%
%Calculate the daily power for 'A' Induced Draft Fan
A_ID_PWR = sqrt3.*(A_6_6_BUS_V*1000).*A_ID_FAN_LD.*A_UNIT_TX_TOT_PF;
A_ID_PWR_TOTAL = (sum(A_ID_PWR)./1000000)/3600 %Total Calc A ID Fan Load

```

```

%Calculate the daily power for 'B' Induced Draft Fan
B_ID_PWR = sqrt3.*(B_6_6_BUS_V*1000).*B_ID_FAN_LD.*B_UNIT_TX_TOT_PF;
B_ID_PWR_TOTAL = (sum(B_ID_PWR)./1000000)/3600 %Total Calc B ID Fan Load
%
%Calculate the daily power for 'A' Boiler Feed Pump
A_BFP_PWR = sqrt3.*(A_6_6_BUS_V*1000).*A_BFP_LD.*A_UNIT_TX_TOT_PF;
A_BFP_PWR_TOTAL = (sum(A_BFP_PWR)./1000000)/3600 %Total Calc A BFP Load
%
%Calculate the daily power for 'B' Boiler Feed Pump
B_BFP_PWR = sqrt3.*(B_6_6_BUS_V*1000).*B_BFP_LD.*B_UNIT_TX_TOT_PF;
B_BFP_PWR_TOTAL = (sum(B_BFP_PWR)./1000000)/3600 %Total Calc B BFP Load
%
%Calculate the daily power for 'C' Boiler Feed Pump
C_BFP_PWR = sqrt3.*(A_6_6_BUS_V*1000).*C_BFP_LD.*A_UNIT_TX_TOT_PF;
C_BFP_PWR_TOTAL = (sum(C_BFP_PWR)./1000000)/3600 %Total Calc C BFP Load
%
%Calculate the daily power for 'A' Boiler Feed Pump
A_CEP_PWR = sqrt3.*(A_6_6_BUS_V*1000).*A_CEP_LD.*A_UNIT_TX_TOT_PF;
A_CEP_PWR_TOTAL = (sum(A_CEP_PWR)./1000000)/3600 %Total Calc A CEP Load
%
%Calculate the daily power for 'B' Boiler Feed Pump
B_CEP_PWR = sqrt3.*(B_6_6_BUS_V*1000).*B_CEP_LD.*B_UNIT_TX_TOT_PF;
B_CEP_PWR_TOTAL = (sum(B_CEP_PWR)./1000000)/3600 %Total Calc B CEP Load
%
%Calculate the daily power for 'A' Circulating Water Pump
A_CW_PWR = sqrt3.*(A_6_6_BUS_V*1000).*A_CW_LD.*A_UNIT_TX_TOT_PF;
A_CW_PWR_TOTAL = (sum(A_CW_PWR)./1000000)/3600 %Total Calc A CW Load
%
%Calculate the daily power for 'B' Circulating Water Pump
B_CW_PWR = sqrt3.*(B_6_6_BUS_V*1000).*B_CW_LD.*B_UNIT_TX_TOT_PF;
B_CW_PWR_TOTAL = (sum(B_CW_PWR)./1000000)/3600 %Total Calc B CW Load
%
%Calculate the 'A' bus load totals
A_BUS_LD_TOTAL = BUN_PWR_TOTAL + A_PRE_PWR_TOTAL + A_415V_PWR_TOTAL...
+ C_415V_PWR_TOTAL + A_PA_PWR_TOTAL + A_FD_PWR_TOTAL + A_ID_PWR_TOTAL...
+ A_BFP_PWR_TOTAL + C_BFP_PWR_TOTAL + A_CEP_PWR_TOTAL + A_CW_PWR_TOTAL
A_PWR_ERROR_2 = ((A_PWR_TOTAL - A_BUS_LD_TOTAL)/A_BUS_LD_TOTAL)*100
%
%Calculate the 'B' bus load totals
B_BUS_LD_TOTAL = B_PRE_PWR_TOTAL + B_415V_PWR_TOTAL + B_PA_PWR_TOTAL...
+ B_FD_PWR_TOTAL + B_ID_PWR_TOTAL + B_BFP_PWR_TOTAL + B_CEP_PWR_TOTAL...
+ B_CW_PWR_TOTAL
B_PWR_ERROR_2 = ((B_PWR_TOTAL - B_BUS_LD_TOTAL)/B_BUS_LD_TOTAL)*100
%
MW_GEN = sum(Mw)/3600
AUX_TOTAL = A_PWR_TOTAL + B_PWR_TOTAL

```

A_PWR_TOTAL =

240.3747

A_PWR_MET_TOTAL =

8.6079e+05

A_PWR_ERROR =
-99.9721

B_PWR_TOTAL =
226.3892

B_PWR_MET_TOTAL =
8.1075e+05

B_PWR_ERROR =
-99.9721

BUN_PWR_TOTAL =
0.1228

A_PRE_PWR_TOTAL =
0.8783

B_PRE_PWR_TOTAL =
1.1044

A_415V_PWR_TOTAL =
27.9323

B_415V_PWR_TOTAL =
7.0143

C_415V_PWR_TOTAL =
8.6071

A_PA_PWR_TOTAL =
14.6317

B_PA_PWR_TOTAL =

14.4754

A_FD_PWR_TOTAL =

21.7526

B_FD_PWR_TOTAL =

21.5251

A_ID_PWR_TOTAL =

54.4733

B_ID_PWR_TOTAL =

54.1522

A_BFP_PWR_TOTAL =

0.0645

B_BFP_PWR_TOTAL =

73.5466

C_BFP_PWR_TOTAL =

72.2956

A_CEP_PWR_TOTAL =

0

B_CEP_PWR_TOTAL =

18.7002

A_CW_PWR_TOTAL =

33.2420

B_CW_PWR_TOTAL =

34.1969

A_BUS_LD_TOTAL =
234.0003

A_PWR_ERROR_2 =
2.7241

B_BUS_LD_TOTAL =
224.7152

B_PWR_ERROR_2 =
0.7450

MW_GEN =
5.8192e+03

AUX_TOTAL =
466.7639

Appendix C

Unit Auxiliary Power

Consumption Simulink Model -

Power Model

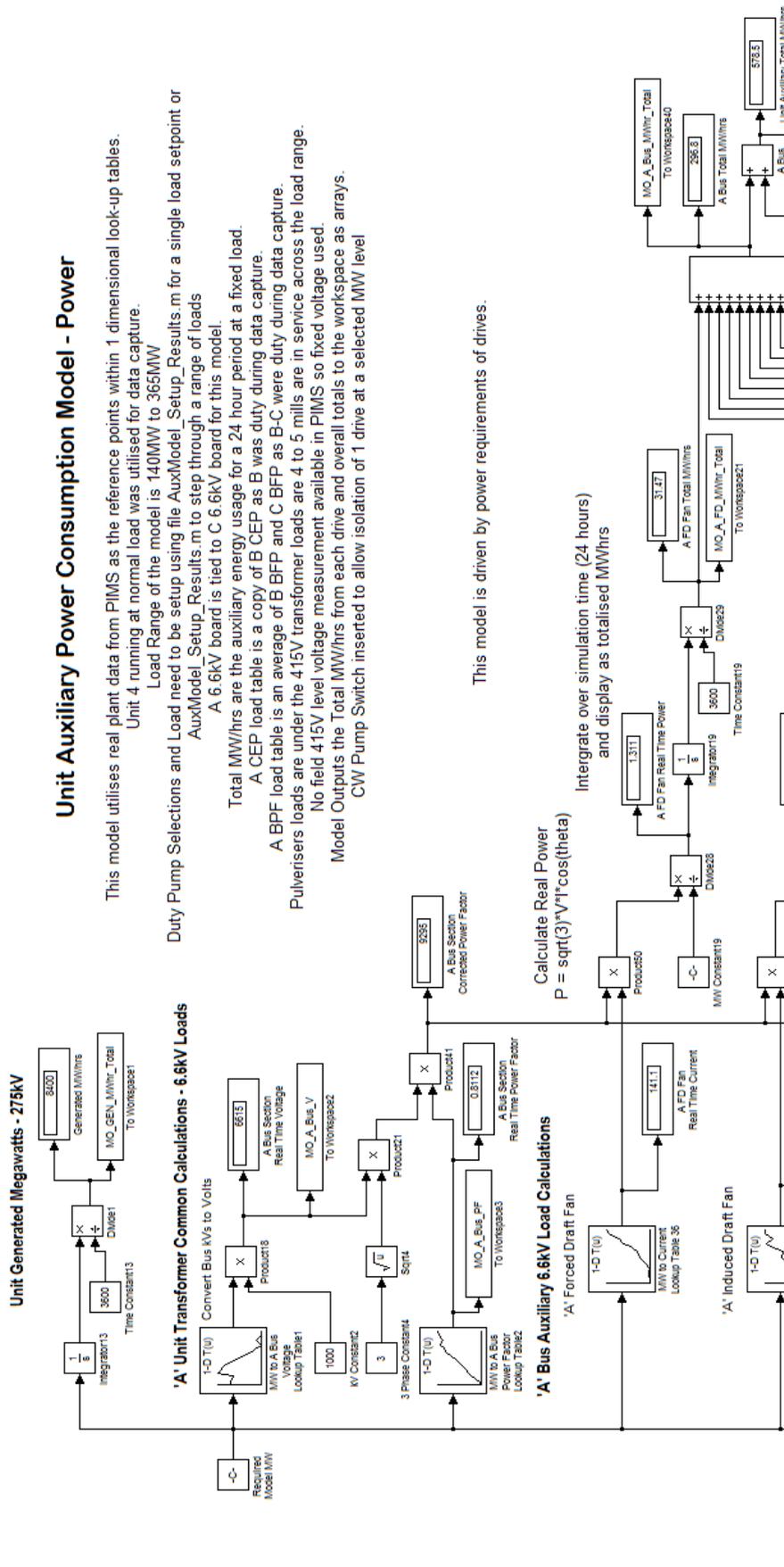


Figure C.1: Unit Auxiliary Power Consumption Simulink Model - Power Model Part 1

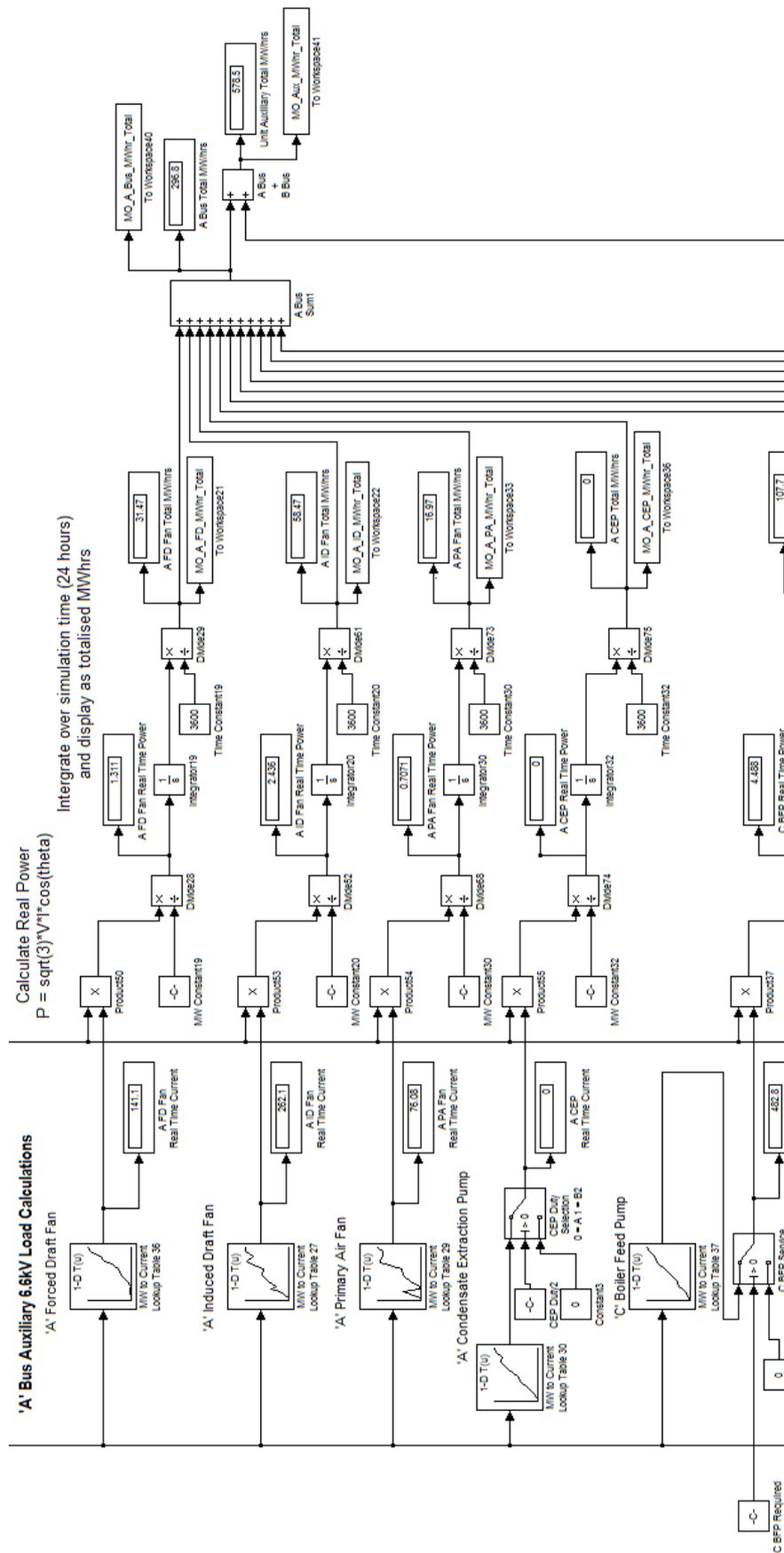


Figure C.2: Unit Auxiliary Power Consumption Simulink Model - Power Model Part 2

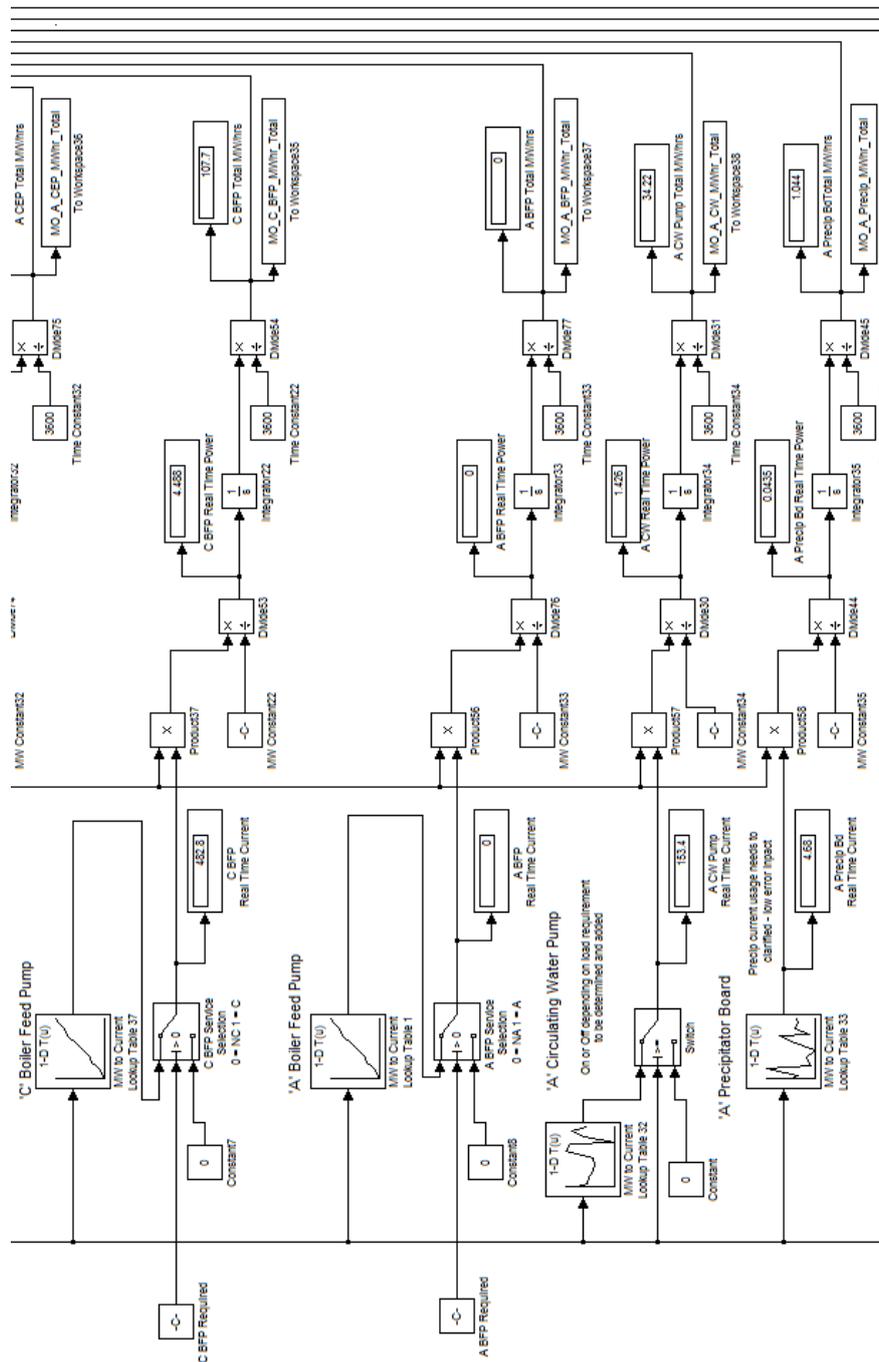


Figure C.3: Unit Auxiliary Power Consumption Simulink Model - Power Model Part 3

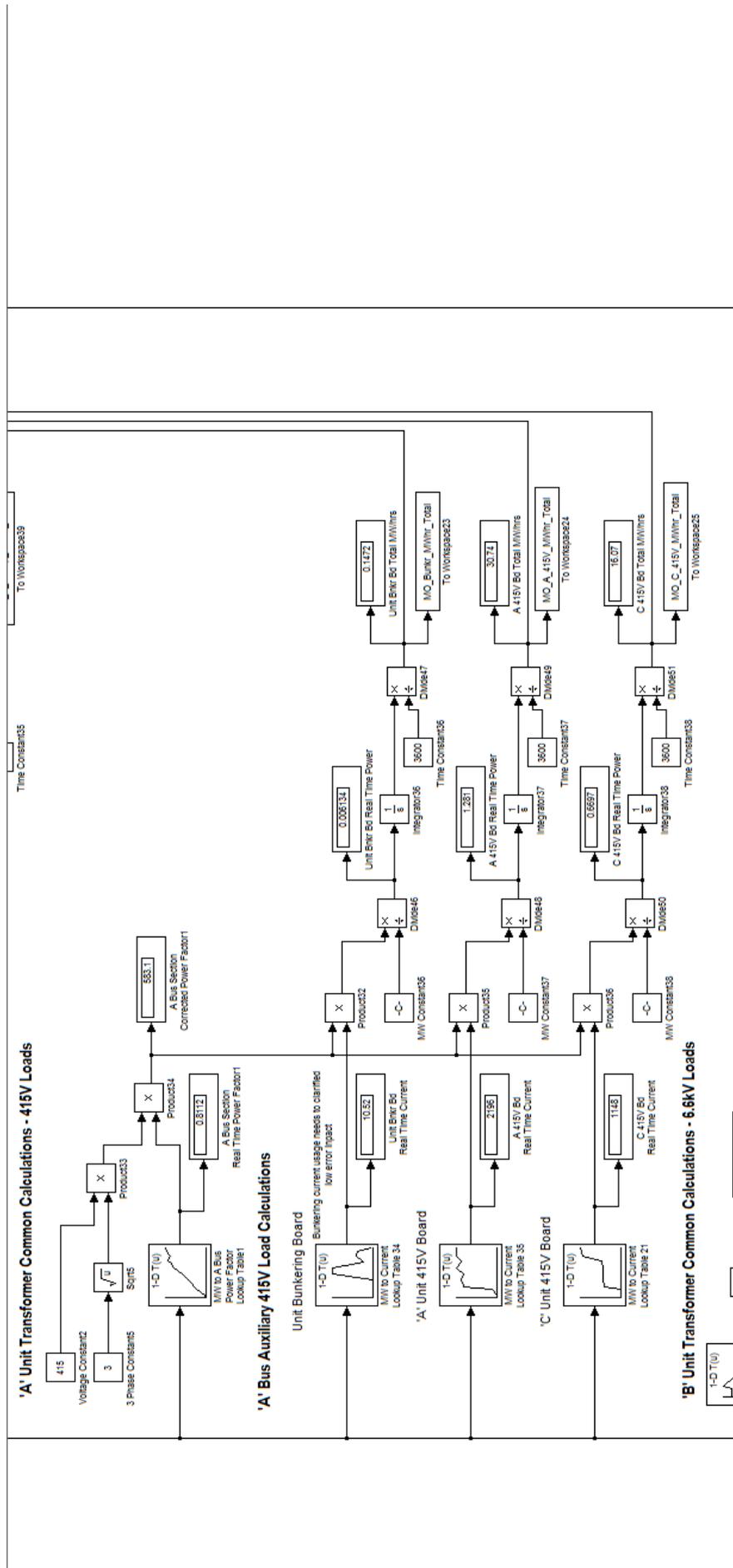


Figure C.4: Unit Auxiliary Power Consumption Simulink Model - Power Model Part 4

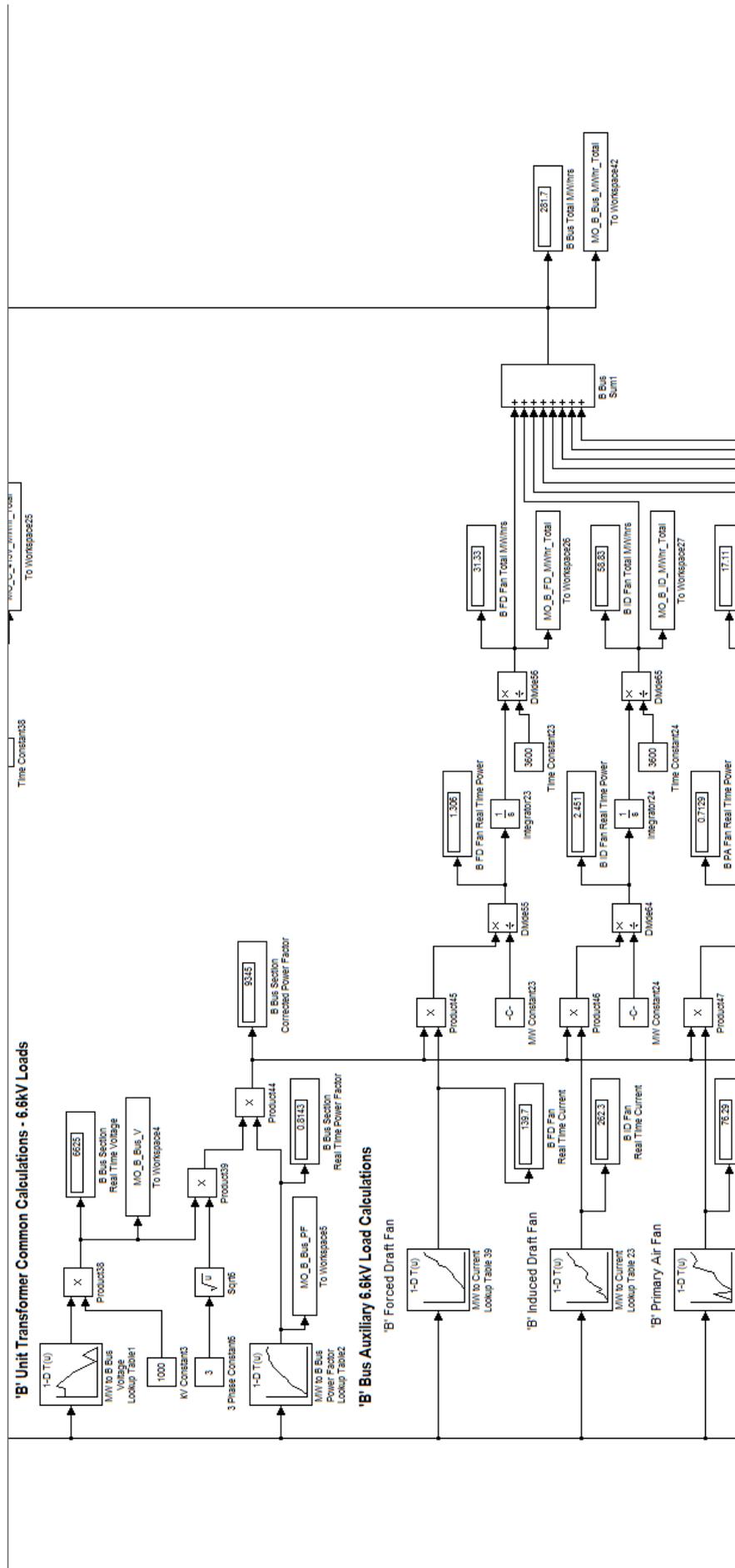


Figure C.5: Unit Auxiliary Power Consumption Simulink Model - Power Model Part 5

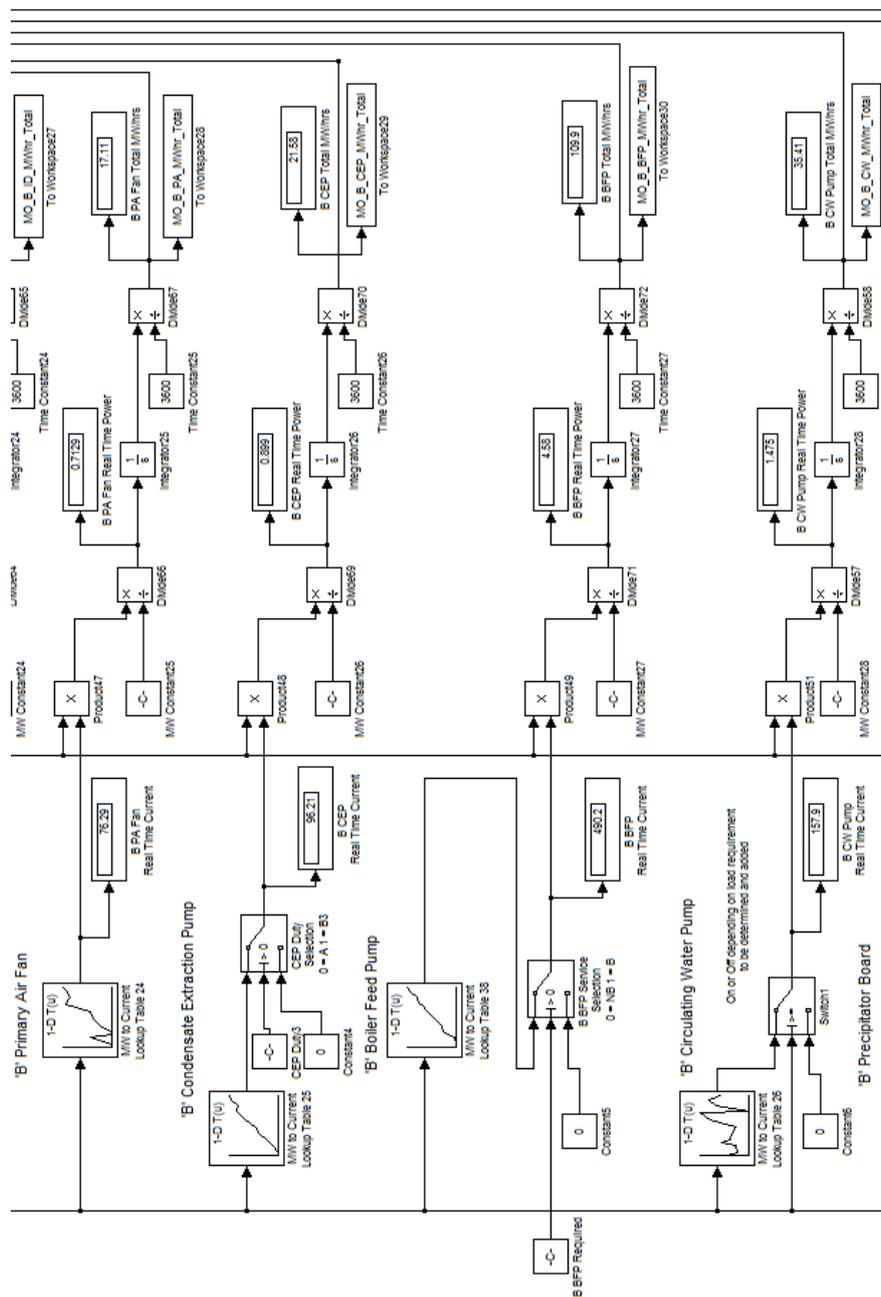


Figure C.6: Unit Auxiliary Power Consumption Simulink Model - Power Model Part 6

Appendix D

Unit Auxiliary Power

Consumption Simulink Model -

Position Model

Unit Auxiliary Power Consumption Model - Position

This model utilises real plant data from PIMS as the reference points within 1 dimensional look-up tables.
 Unit 4 running at normal load was utilised for data capture.

Load Range of the model is 140MW to 365MW

Duty Pump Selections and Load need to be setup using file AuxModel_Setup_Results.m for a single load setpoint or AuxModel_Setup_Results.m to step through a range of loads

A 6.6kV board is tied to C 6.6kV board for this model.

Total MW/hrs are the auxiliary energy usage for a 24 hour period at a fixed load.

A CEP load table is a copy of B CEP as B was duty during data capture.

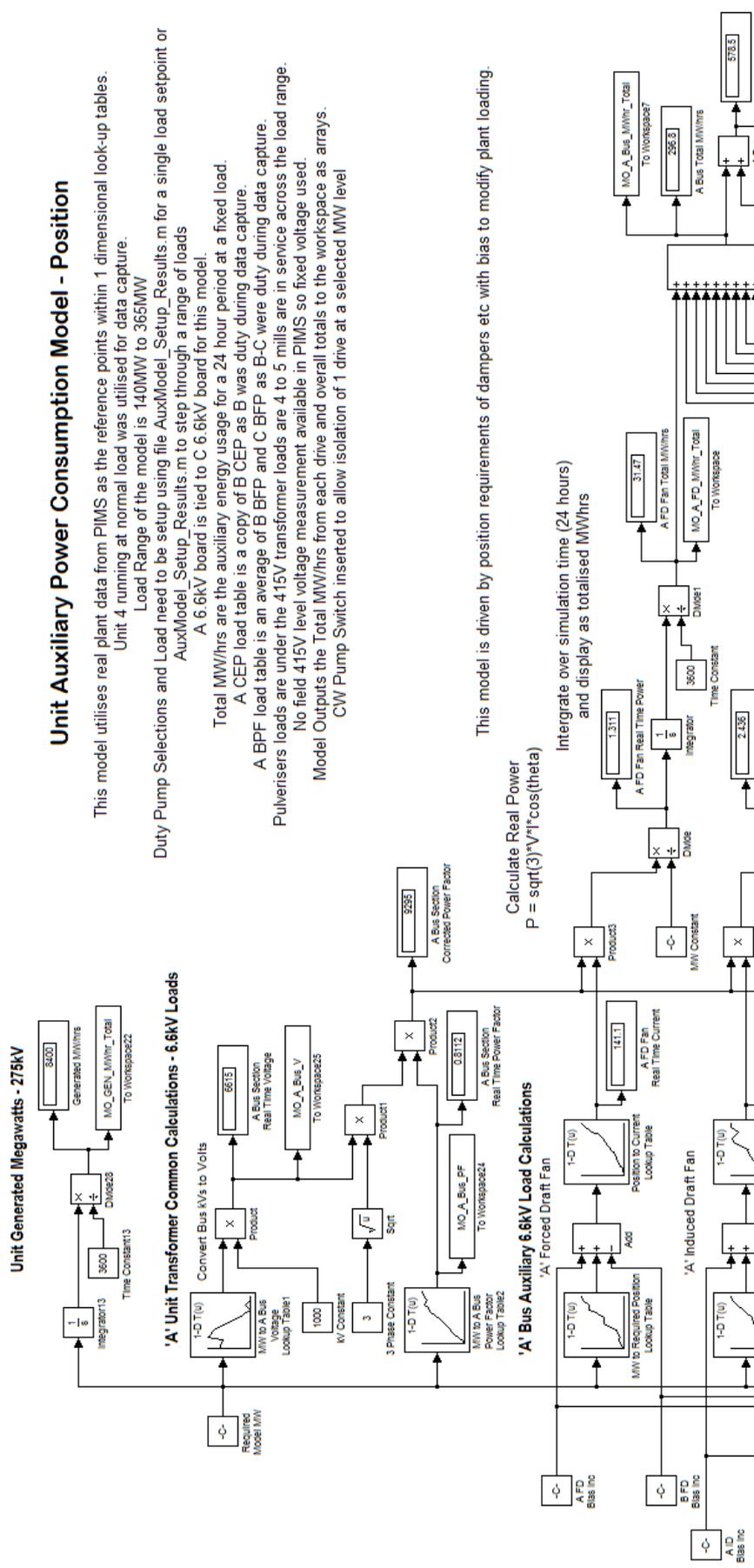
A BPF load table is an average of B BPF and C BPF as B-C were duty during data capture.

Pulverisers loads are under the 415V transformer loads are 4 to 5 mills are in service across the load range.

No field 415V level voltage measurement available in PIMS so fixed voltage used.

Model Outputs the Total MW/hrs from each drive and overall totals to the workspace as arrays.

CW Pump Switch inserted to allow isolation of 1 drive at a selected MW level



This model is driven by position requirements of dampers etc with bias to modify plant loading.

Integrate over simulation time (24 hours) and display as totalised MW/hrs

Figure D.1: Unit Auxiliary Power Consumption Simulink Model - Position Model Part 1

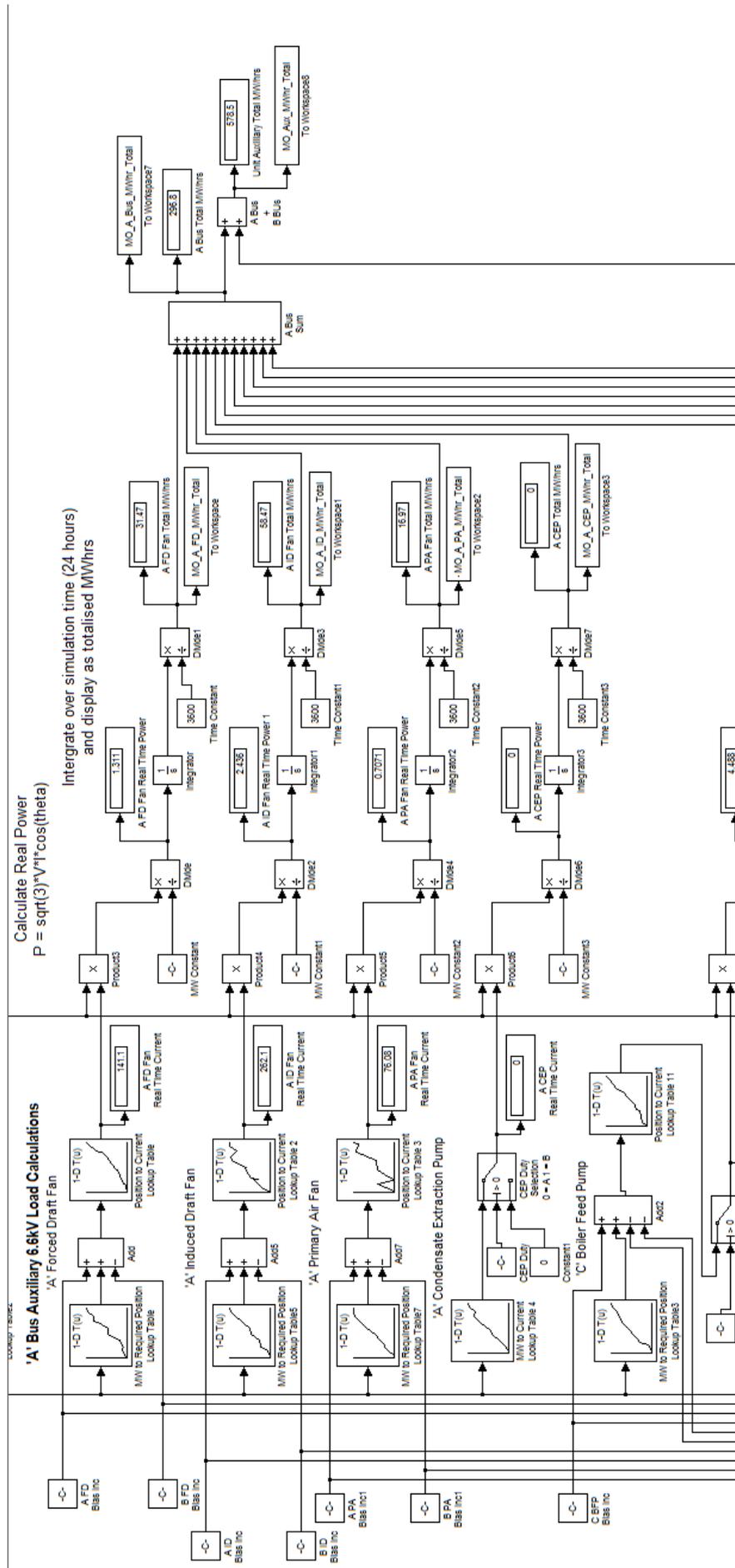


Figure D.2: Unit Auxiliary Fan Power Consumption Simulink Model - Position Model Part 2

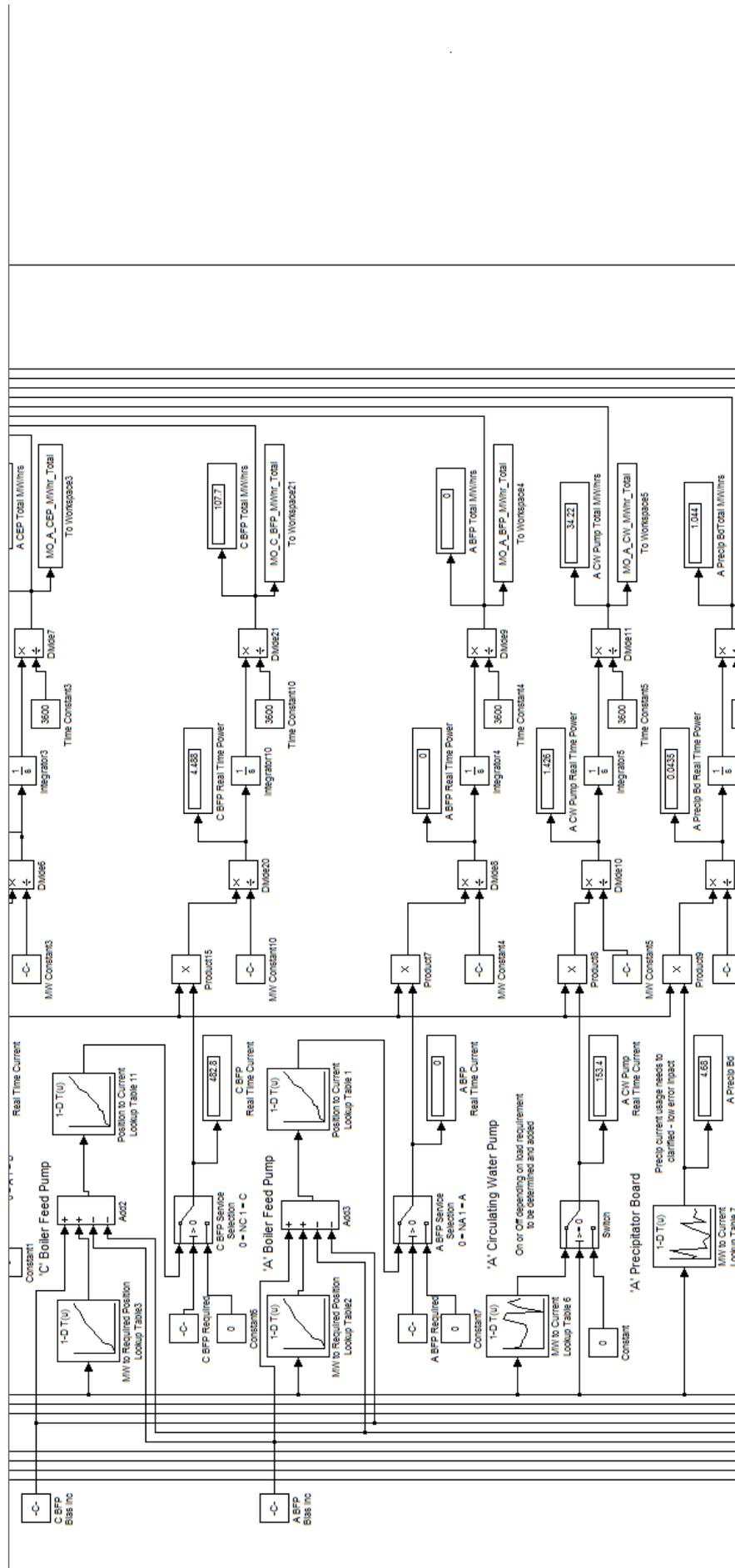


Figure D.3: Unit Auxiliary Power Consumption Simulink Model - Position Model Part 3

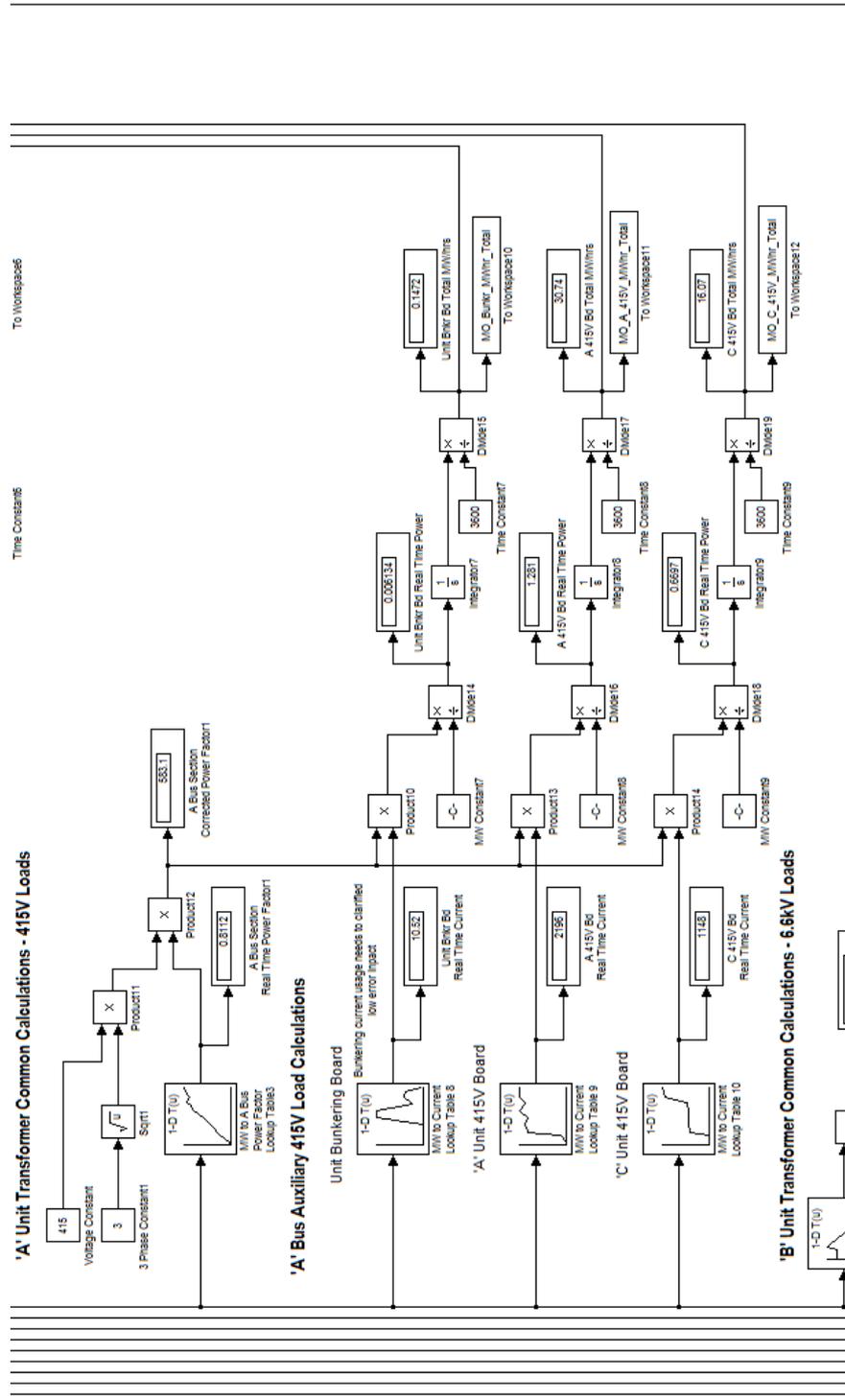


Figure D.4: Unit Auxiliary Power Consumption Simulink Model - Position Model Part 4

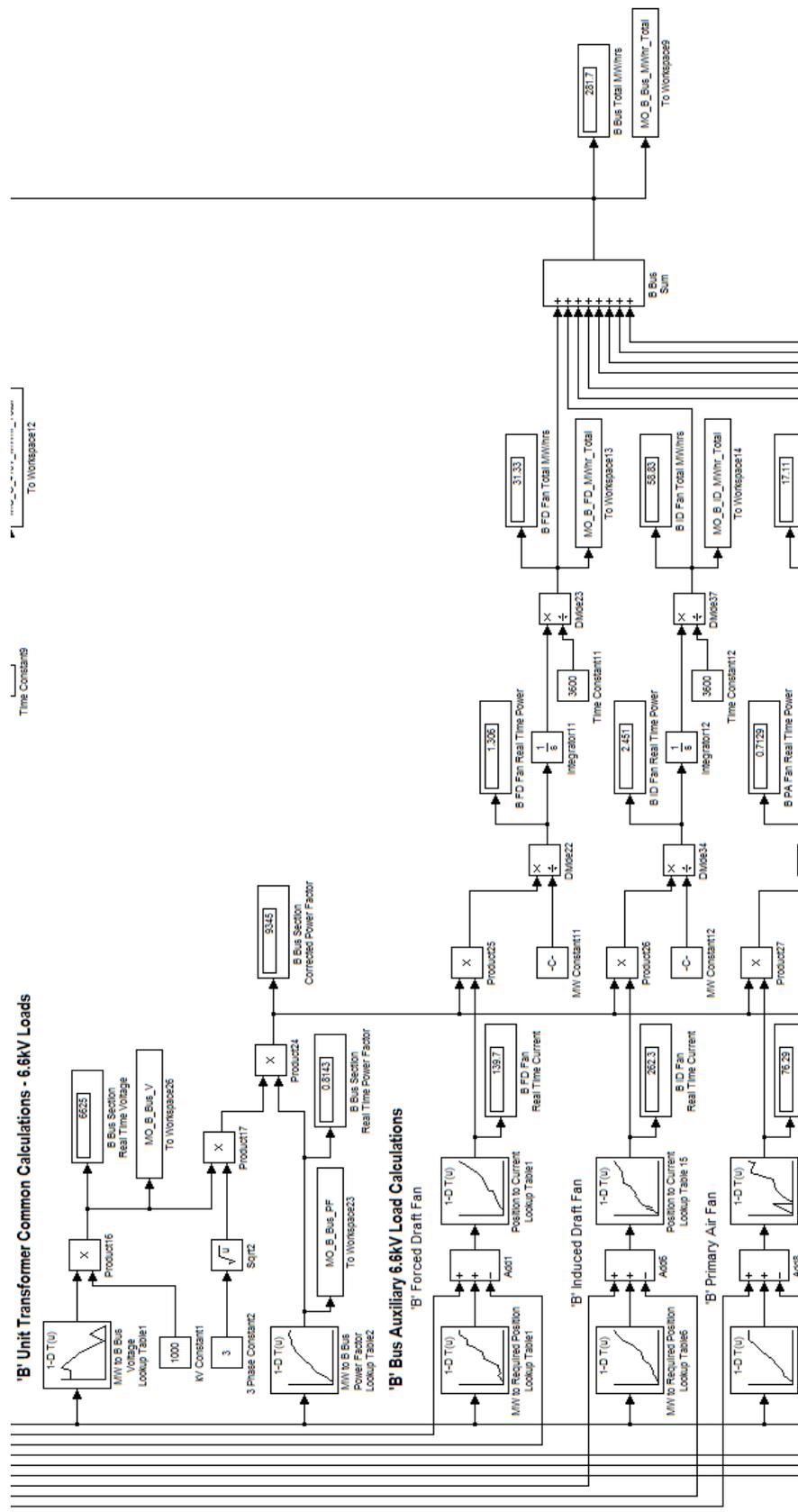


Figure D.5: Unit Auxiliary Power Consumption Simulink Model - Position Model Part 5

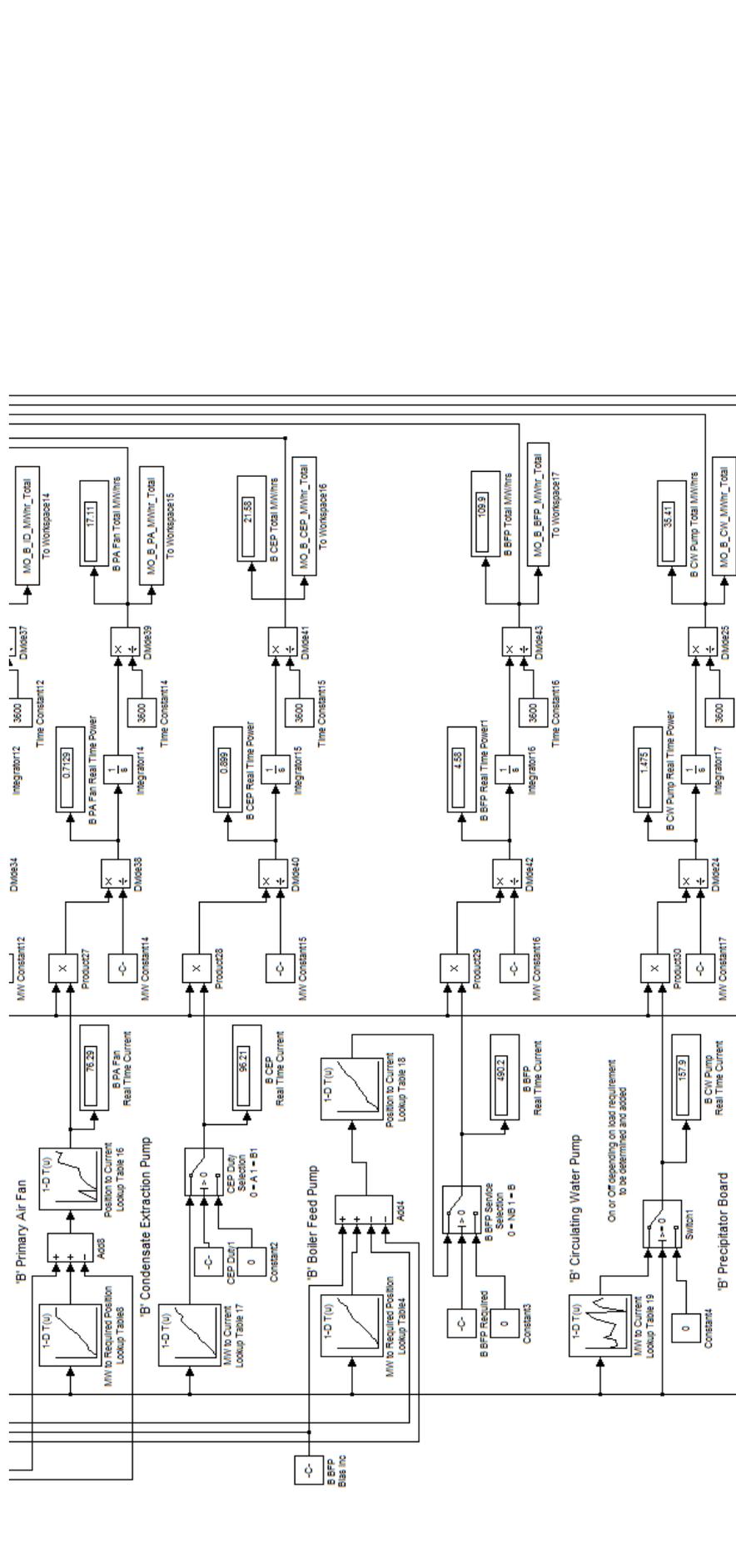


Figure D.6: Unit Auxiliary Power Consumption Simulink Model - Position Model Part 6

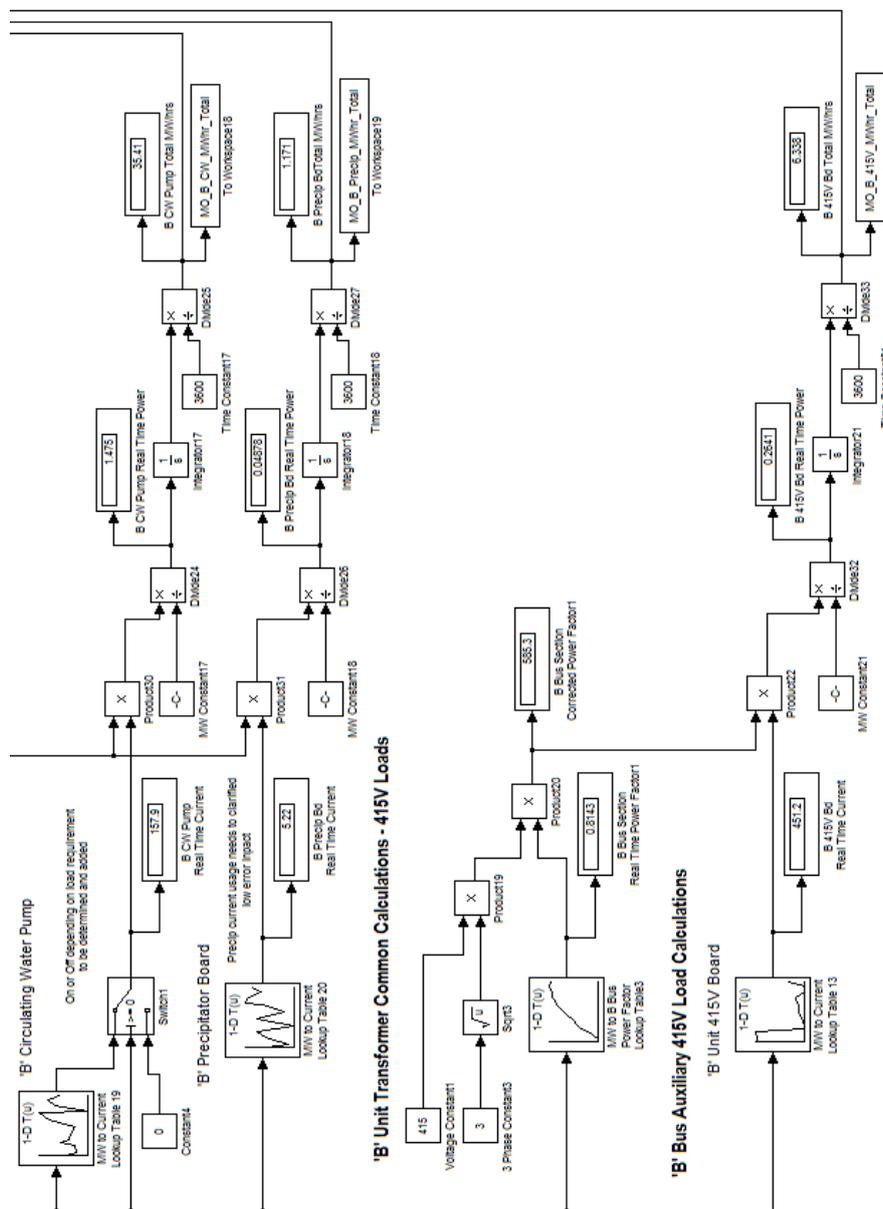


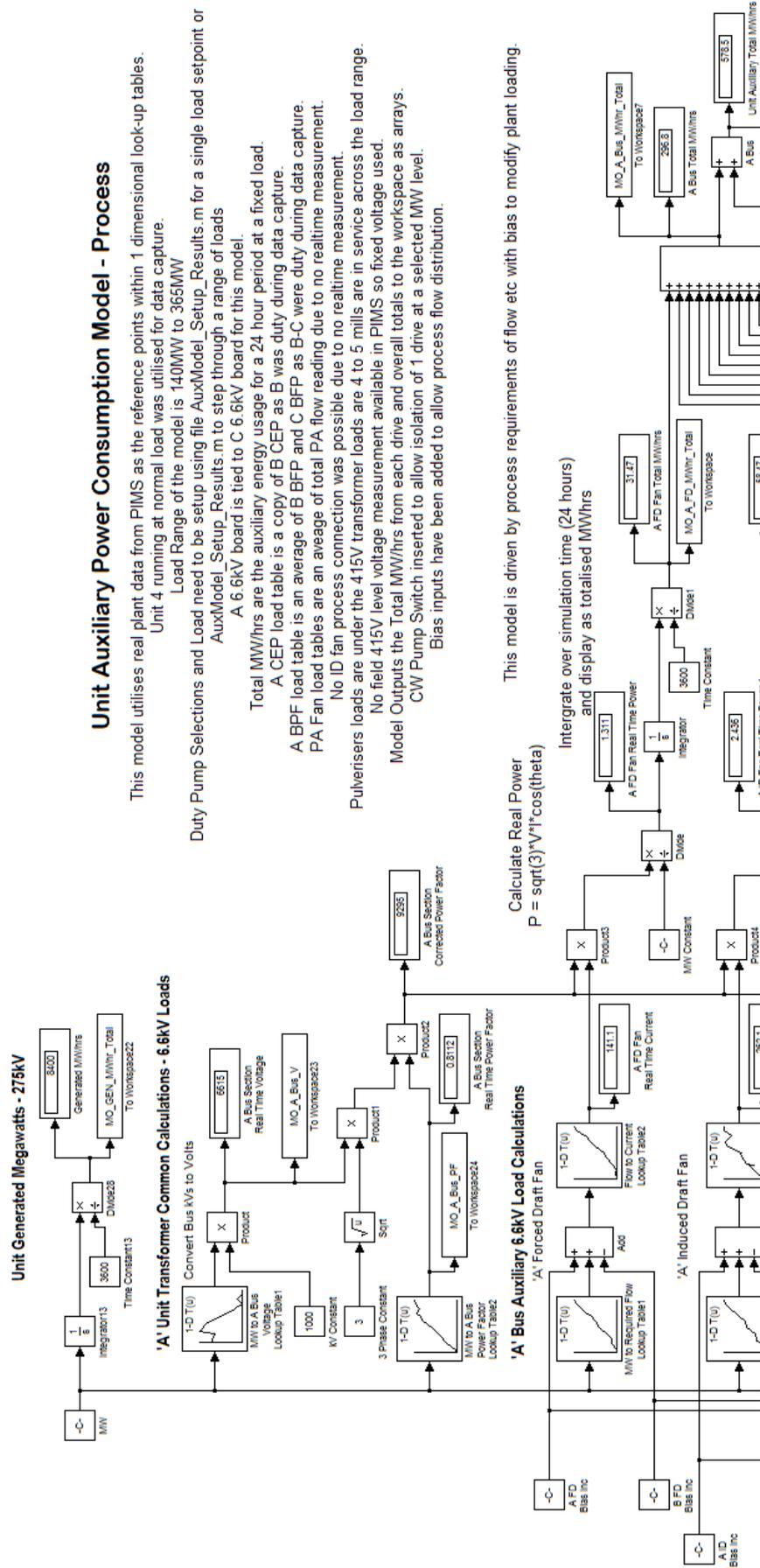
Figure D.7: Unit Auxiliary Power Consumption Simulink Model - Position Model Part 7

Appendix E

Unit Auxiliary Power

Consumption Simulink Model -

Process Model



Unit Auxiliary Power Consumption Model - Process

This model utilises real plant data from PIMS as the reference points within 1 dimensional look-up tables.
 Unit 4 running at normal load was utilised for data capture.
 Load Range of the model is 140MW to 365MW

Duty Pump Selections and Load need to be setup using file AuxModel_Setup_Results.m for a single load setpoint or AuxModel_Setup_Results.m to step through a range of loads
 A 6.6kV board is tied to C.6kV board for this model.
 Total MW/hrs are the auxiliary energy usage for a 24 hour period at a fixed load.
 A CEP load table is a copy of B CEP as B was duty during data capture.
 A BPF load table is an average of B BPF and C BPF as B-C were duty during data capture.
 PA Fan load tables are an average of total PA flow reading due to no realtime measurement.
 No ID fan process connection was possible due to no realtime measurement.
 Pulverisers loads are under the 415V transformer loads are 4 to 5 mills are in service across the load range.
 No field 415V level voltage measurement available in PIMS so fixed voltage used.
 Model Outputs the Total MW/hrs from each drive and overall totals to the workspace as arrays.
 CW Pump Switch inserted to allow isolation of 1 drive at a selected MW level.
 Bias inputs have been added to allow process flow distribution.

This model is driven by process requirements of flow etc with bias to modify plant loading.

Calculate Real Power

$$P = \sqrt{3} V I \cos(\theta)$$
 Integrate over simulation time (24 hours) and display as totalised MW/hrs

Figure E.1: Unit Auxiliary Power Consumption Simulink Model - Process Model Part 1

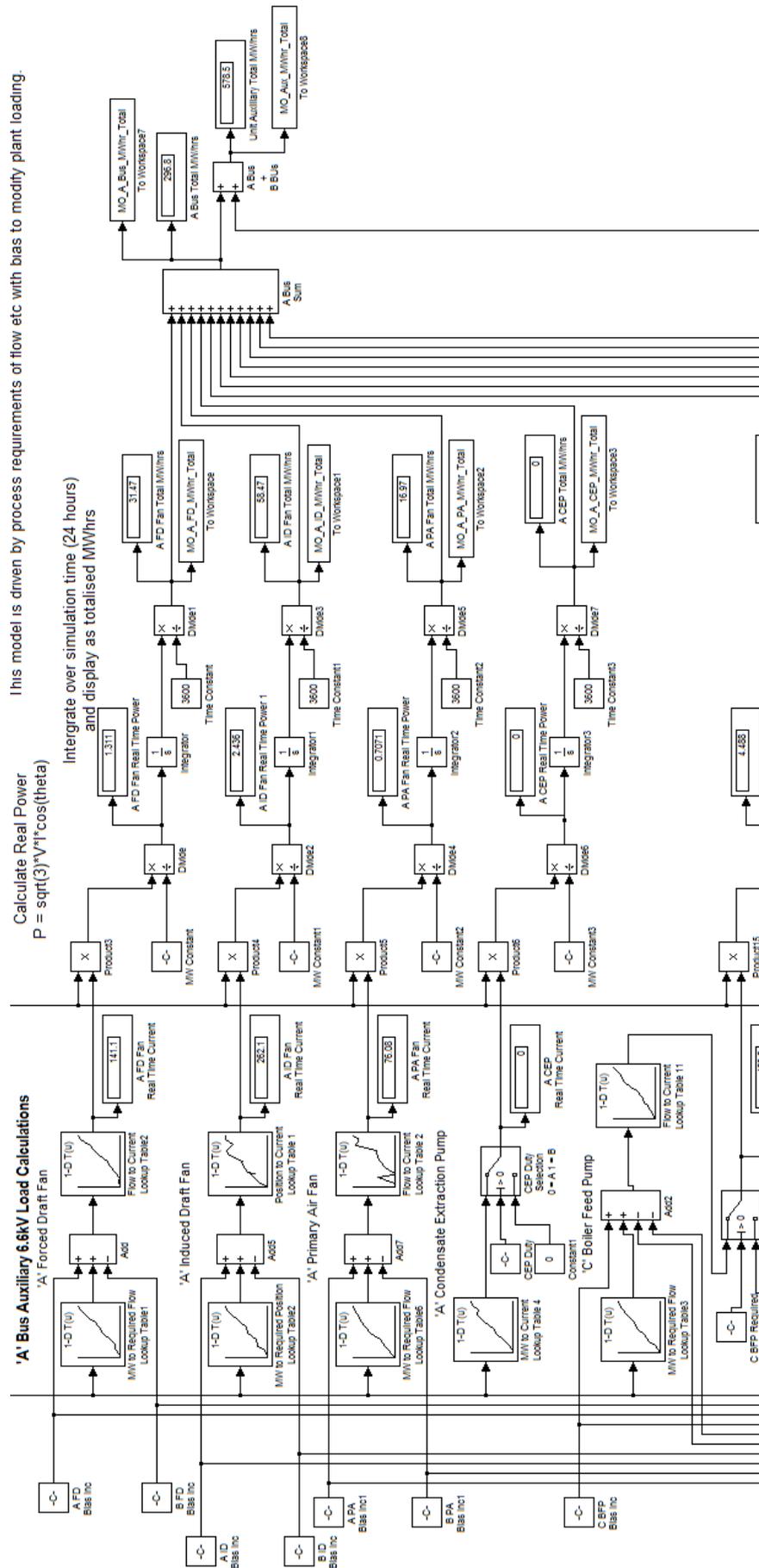


Figure E.2: Unit Auxiliary Power Consumption Simulink Model - Process Model Part 2

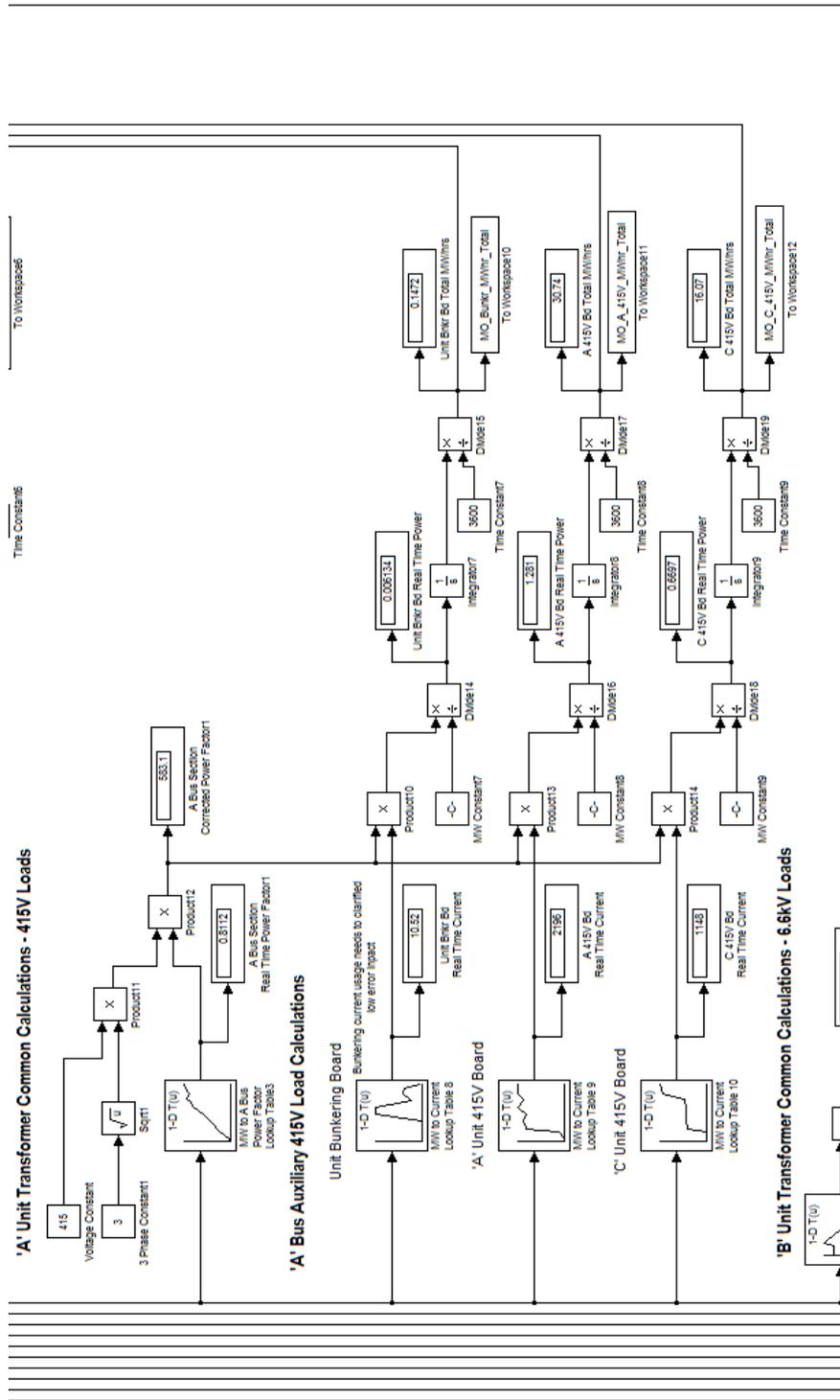


Figure E.4: Unit Auxiliary Power Consumption Simulink Model - Process Model Part 4

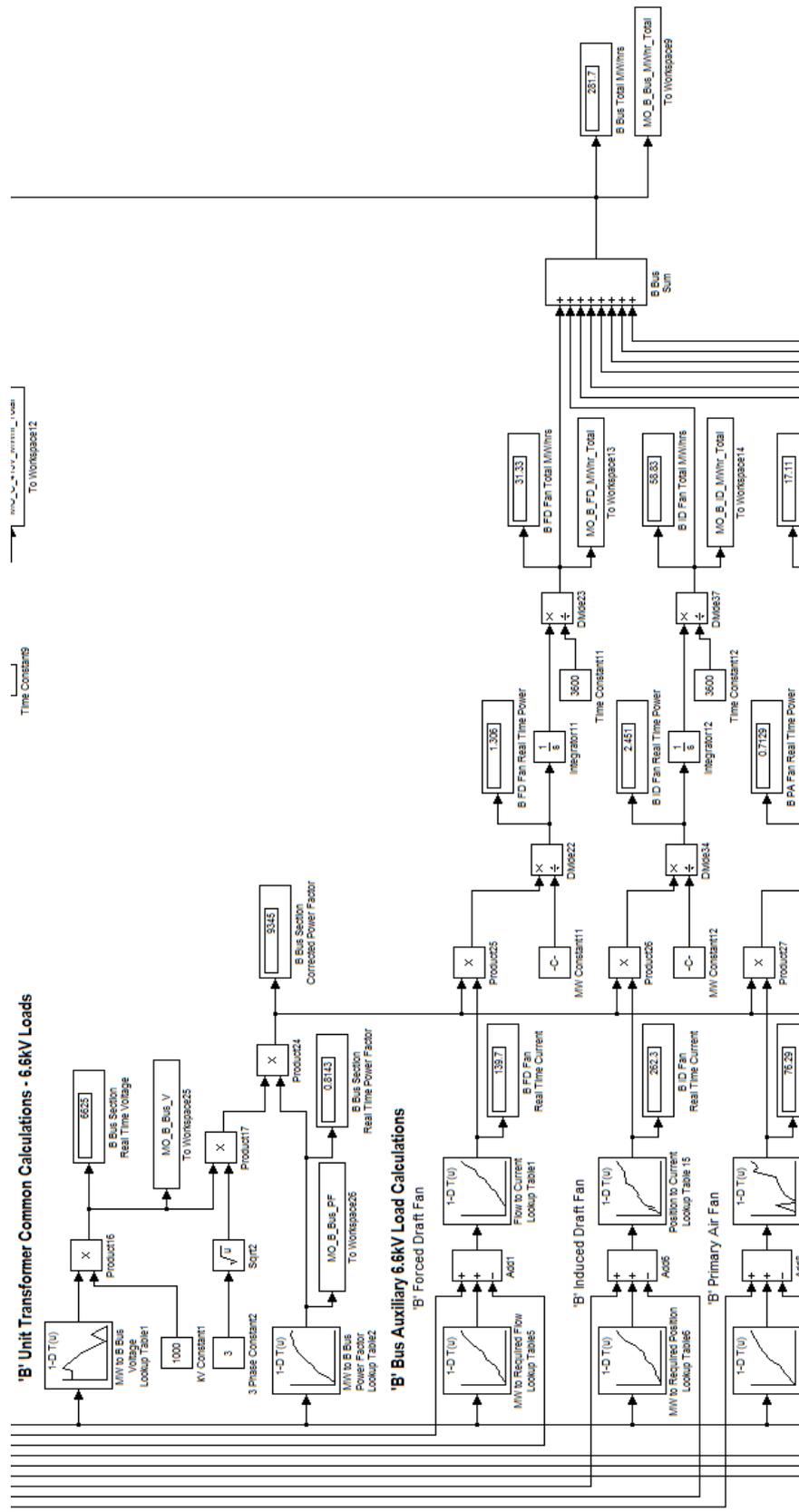


Figure E.5: Unit Auxiliary Power Consumption Simulink Model - Process Model Part 5

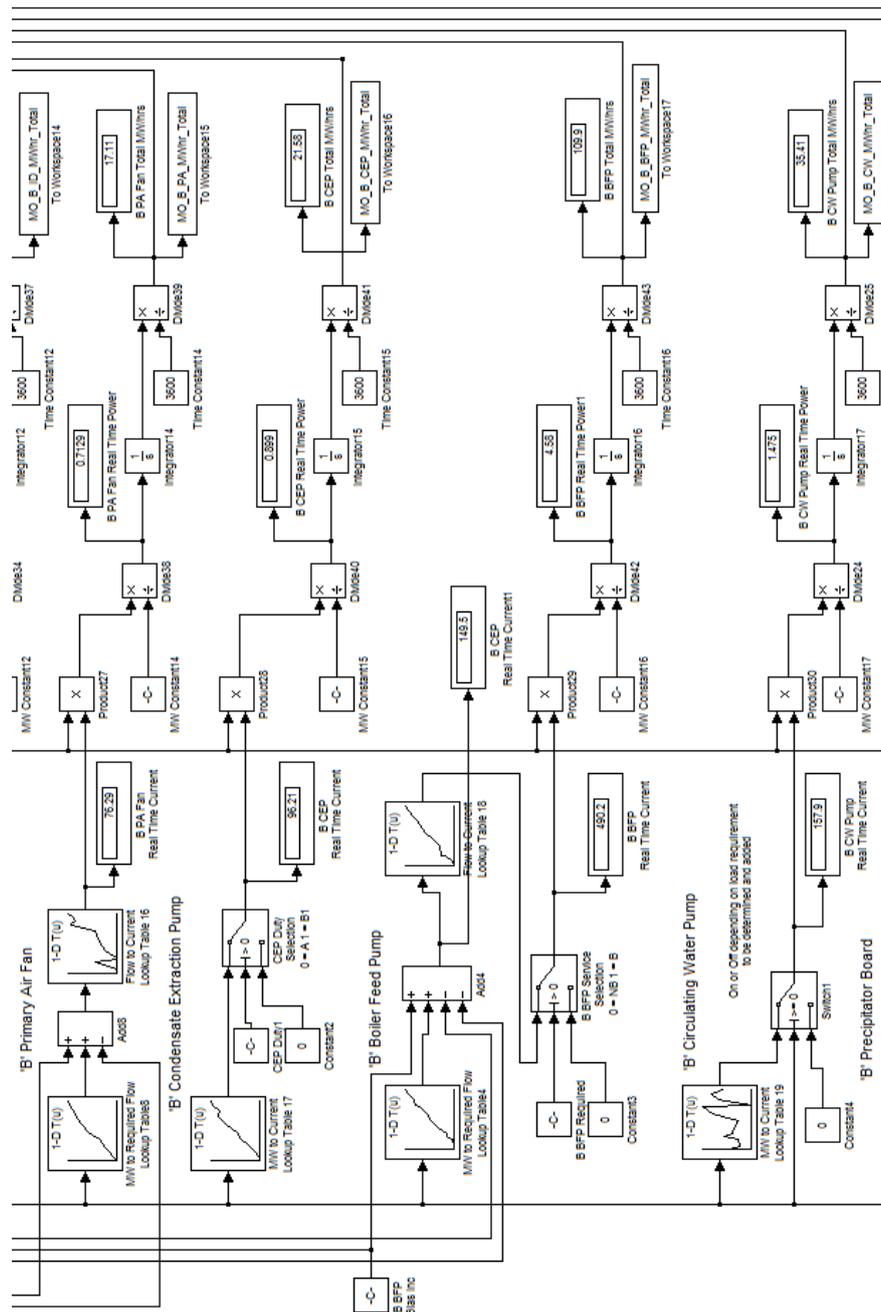


Figure E.6: Unit Auxiliary Power Consumption Simulink Model - Process Model Part 6

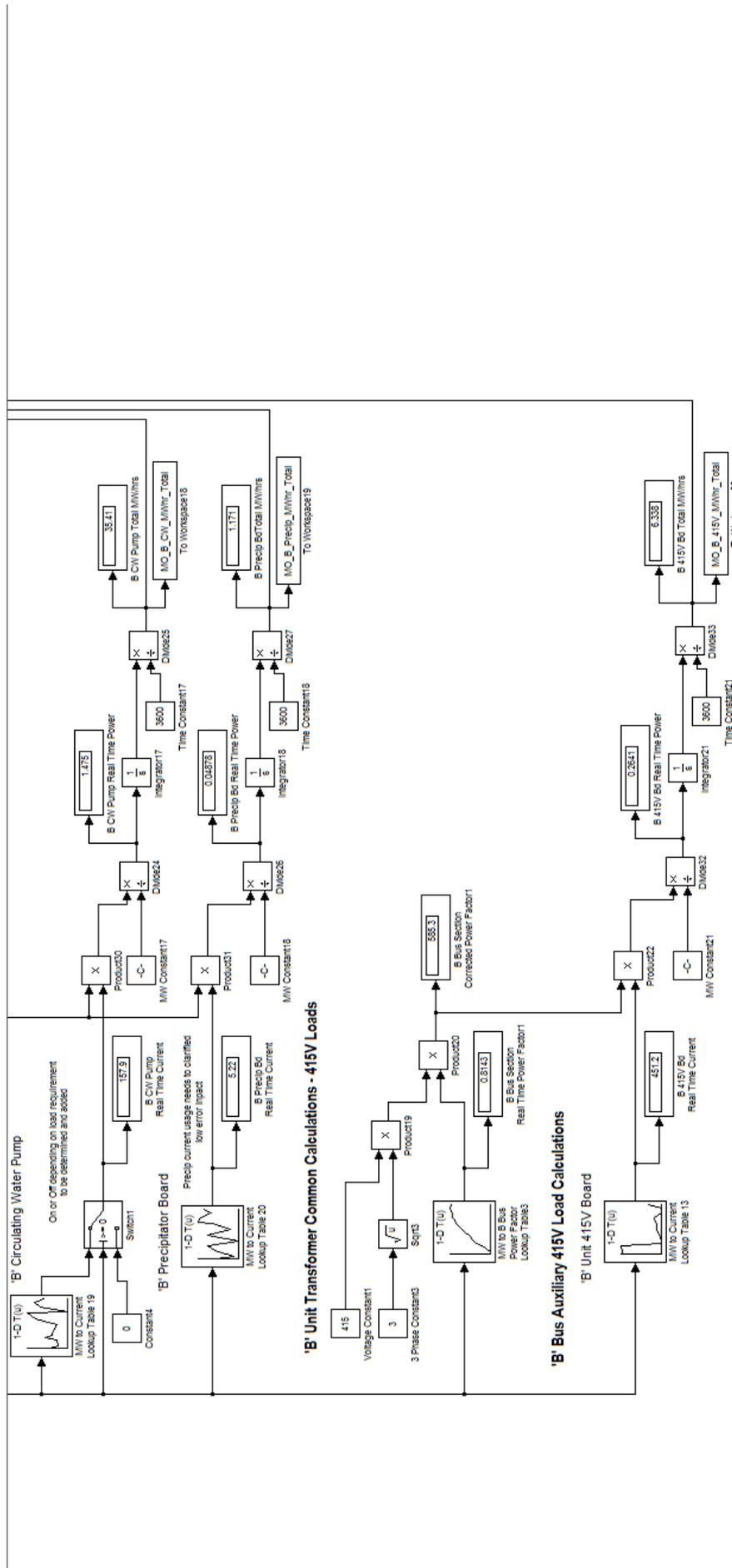


Figure E.7: Unit Auxiliary Power Consumption Simulink Model - Process Model Part 7

Appendix F

Process Information Management System (PIMS) Extracted Data

	\\PIMS\TPS_T4BAA01CE001_XQ01_OUT 20KV BUS VOLTS	\\PIMS\TPS_T4BAY00CE901_XQ11_OUT GEN LD	\\PIMS\TPS_T4BAY20CE001_XQ01_OUT U4 TRFR A TOT MW	\\PIMS\TPS_T4BAY20CE001_XQ07_OUT U4 TRFR A TOT PF	\\PIMS\TPS_T4BAY20CE001_XQ08_OUT U4 TRFR A AVG CURRENT
1					
2					
3	12:00:00 AM	20.35861969	211.5815735	9.260447502	0.775737464
4	11:59:59 PM	20.35860634	211.6588745	9.26177597	0.775735915
5	11:59:58 PM	20.35859489	211.7361603	9.263104439	0.775734365
6	11:59:57 PM	20.35858345	211.813446	9.264431953	0.775732756
7	11:59:56 PM	20.35857201	211.8907318	9.265760422	0.775731206
8	11:59:55 PM	20.35855865	211.9680176	9.26708889	0.775729656
9	11:59:54 PM	20.35854721	212.0291443	9.268416405	0.775728106
10	11:59:53 PM	20.35853577	212.0590515	9.269744873	0.775726557
11	11:59:52 PM	20.35852242	212.0889435	9.271072388	0.775724947
12	11:59:51 PM	20.35851097	212.1188507	9.272400856	0.775723398
13	11:59:50 PM	20.35849953	212.1487579	9.273729324	0.775721848
14	11:59:49 PM	20.35848618	212.1786499	9.275056839	0.775720298
15	11:59:48 PM	20.35847473	212.2085571	9.276385307	0.775718689
16	11:59:47 PM	20.35846329	212.2384491	9.277713776	0.775717139
17	11:59:46 PM	20.35844994	212.2683563	9.27904129	0.77571559
18	11:59:45 PM	20.35843849	212.2982483	9.280369759	0.77571404
19	11:59:44 PM	20.35842705	212.3281555	9.281698227	0.77571249
20	11:59:43 PM	20.3584137	212.3580475	9.283025742	0.775710881
21	11:59:42 PM	20.35840225	212.3879547	9.28435421	0.775709331
22	11:59:41 PM	20.35839081	212.4178619	9.285682678	0.775707781
23	11:59:40 PM	20.35837746	212.4477539	9.287000656	0.775706232
24	11:59:39 PM	20.35836601	212.4776611	9.2871418	0.775704622
25	11:59:38 PM	20.35835457	212.5075531	9.28728199	0.775703073
26	11:59:37 PM	20.35834122	212.5374603	9.287423134	0.775701523
27	11:59:36 PM	20.35832977	212.5673523	9.287563324	0.775700212
28	11:59:35 PM	20.35831833	212.6748657	9.287703514	0.775729895
29	11:59:34 PM	20.35830688	212.7873993	9.287844658	0.775759578
30	11:59:33 PM	20.35829533	212.8999481	9.287984848	0.775789261

Figure F.1: Example of PIMS Data Extracted for the 7th of July 2015 (Siemens 2015)

Appendix G

Located Drawing Data

Below in table G.1 is a sample of the drawings collected during the data collection stage.

Drawing Number	Drawing Title
A2-V-502446-01	Unit AC/DC Power Distribution: Single Line Diagram
A3-V-505763-01	Unit Single Line Diagram Typical for Four Units
A1-V-503115-01	Unit 6.6kV Board Switchgear Detail Diagram Tarong Power Station
A1-V-534312-036	Unit 4 A Boiler Feed Pump Suction Flow T4LAB11CF001 DCS Loop Diagram
A1-V-534312-040	Unit 4 B Boiler Feed Pump Suction Flow T4LAB12CF001 DCS Loop Diagram
A1-V-534312-044	Unit 4 C Boiler Feed Pump Suction Flow T4LAB13CF001 DCS Loop Diagram
A1-V-534311-115	Unit 4 A Forced Draft Fan Air Flow T4HLA01CF001 DCS Loop Diagram

Table G.1: A Sample of Drawings Located during the Data Gathering Stage (Hitachi 2003).

Appendix H

Energy Metering Manual Data

MB Address	Cubicle	Tag	Type	Serial	C/T Ratio	V/T Ratio	Loen	PLC
1	#4A Unit 415 V Tx	TOMET1030	KILO	59504	200/1	60/1	Unit 6.6kV	MET2
2	#4A Precip Tx	TOMET1031	KILO	59527	200/1	60/1	Unit 6.6kV	MET2
3	#4A Unit 6.6 kV Tx	TOMET1032	KILO	59528	2400/1	60/1	Unit 6.6kV	MET2
4	#4 Bunkering Tx	TOMET1033	KILO	59522	200/1	60/1	Unit 6.6kV	MET2
5	#4C Unit 415 V Tx	TOMET1034	KILO	59530	200/1	60/1	Unit 6.6kV	MET2
6	#4 Unit / Stn TIE	TOMET1035	KILO	55149	2400/1	60/1	Unit 6.6kV	MET2
7	#4B Unit 6.6 kV Tx	TOMET1036	KILO	59523	2400/1	60/1	Unit 6.6kV	MET2
8	#4B Unit 415 v Tx	TOMET1037	KILO	59525	200/1	60/1	Unit 6.6kV	MET2
9	#4B Precip Tx	TOMET1038	KILO	58529	300/1	60/1	Unit 6.6kV	MET2
10	Fire Fighting 415 V Transf	TOMET1001	KILO	59511	200/1	60/1	Stn 6.6kV	MET1
11	B Ash Plant 415 V Transf	TOMET1002	KILO	59514	200/1	60/1	Stn 6.6kV	MET1
12	B Admin Area 415 V Tranf	TOMET1003	KILO	59519	200/1	60/1	Stn 6.6kV	MET1
13	B1 Station 415 V Tranf	TOMET1004	KILO	55156	200/1	60/1	Stn 6.6kV	MET1
14	B Coal Recv 415 V Transf	TOMET1005	KILO	59510	200/1	60/1	Stn 6.6kV	MET1
15	D Ash Palnt 415 v Transf	TOMET1006	KILO	55151	200/1	60/1	Stn 6.6kV	MET1
16	B2 Station 415 V Transf	TOMET1007	KILO	59506	200/1	60/1	Stn 6.6kV	MET1
17	B Cooling Tower 415 V Trf	TOMET1008	KILO	59508	200/1	60/1	Stn 6.6kV	MET1
18	B Station Transf	TOMET1009	KILO	59537	2000/1	60/1	Stn 6.6kV	MET1
19	C1 & C2 Station 415 V Transf	TOMET1010	KILO	59512	200/1	60/1	Stn 6.6kV	MET1
20	Gas Turbine Incomer	TOMET1011	KILO	55152	2000/1	60/1	Stn 6.6kV	MET1
21	Tarong North Supply	TOMET1012	KILO	59516	200/1	60/1	Stn 6.6kV	MET1
22	A Station Transf	TOMET1013	KILO	59520	2000/1	60/1	Stn 6.6kV	MET1
23	A Ash Plant 415 V Transf	TOMET1014	KILO	59513	200/1	60/1	Stn 6.6kV	MET1
24	A Admin Area 415 V Trf	TOMET1015	KILO	59521	200/1	60/1	Stn 6.6kV	MET1
25	A1 Station 415 V Transf	TOMET1016	KILO	55155	200/1	60/1	Stn 6.6kV	MET1
26	A Coal Rec 415 V transf	TOMET1017	KILO	59517	200/1	60/1	Stn 6.6kV	MET1
27								
28	C Ash Plant 415 V trf	TOMET1018	KILO	55150	200/1	60/1	Stn 6.6kV	MET1
29	A2 Station 415 v Trf	TOMET1019	KILO	55147	200/1	60/1	Stn 6.6kV	MET1
30	A Cooling Tower 415 V trf	TOMET1020	KILO	59543	200/1	60/1	Stn 6.6kV	MET1
31	CW Makeup 415 V Trf	TOMET1021	KILO	59509	150/1	60/1	Stn 6.6kV	MET1
32	#4A Unit Transf HV	TOMET1039	KILO	59505	1600/1	60/1	X&Y PROT	MET2
33	#4B Unit Transf HV	TOMET1040	KILO	59505	1600/1	60/1	X&Y PROT	MET2
34	#4 Excitation Trf HV	TOMET1058	KILO	59526	200/1	60/1	X&Y PROT	MET2
35	SPARE		KILO	59518	200/1	60/1	Stn 6.6kV	MET1
36	#4 Generator (Excitation Transf)	TOMET1041	KILO	59531	12000/1	60/1	X&Y PROT	MET2
37	#4A PA Fan	TOMET1042	EST-485	58803	150/1	60/1	Unit 6.6kV	MET2
38	#4A FD Fan	TOMET1043	EST-485	58807	400/1	60/1	Unit 6.6kV	MET2
39	#4A ID Fan	TOMET1044	EST-485	58802	500/1	60/1	Unit 6.6kV	MET2
40	#4A Cond Extraction P/P	TOMET1045	EST-485	58804	150/1	60/1	Unit 6.6kV	MET2
41	#4A CW P/P	TOMET1046	EST-485	58798	200/1	60/1	Unit 6.6kV	MET2
42	#4A BFP	TOMET1047	EST-485	58790	600/1	60/1	Unit 6.6kV	MET2
43	#4C BFP	TOMET1048	EST-485	58797	600/1	60/1	Unit 6.6kV	MET2
44	#4B PA Fan	TOMET1049	EST-485	58796	150/1	60/1	Unit 6.6kV	MET2
45	#4B FD Fan	TOMET1050	EST-485	58805	400/1	60/1	Unit 6.6kV	MET2
46	#4B ID Fan	TOMET1051	EST-485	58791	500/1	60/1	Unit 6.6kV	MET2
47	#4B Cond Extraction P/P	TOMET1052	EST-485	58792	150/1	60/1	Unit 6.6kV	MET2
48	#4B CW P/P	TOMET1053	EST-485	58789	200/1	60/1	Unit 6.6kV	MET2
49	#4B BFP	TOMET1054	EST-485	58799	600/1	60/1	Unit 6.6kV	MET2
50	B Ash Water Reclaim	TOMET1022	EST-485	58784	60/1	60/1	Stn 6.6kV	MET1
51	B CW Makeup Pump	TOMET1023	EST-485	58800	75/1	60/1	Stn 6.6kV	MET1
52	R1 Conveyor Drive	TOMET1024	EST-485	58793	75/1	60/1	Stn 6.6kV	MET1
53	A CW Makeup Pump	TOMET1025	EST-485	58787	75/1	60/1	Stn 6.6kV	MET1
54	A Ash Water Makeup Pump	TOMET1026	EST-485	58806	60/1	60/1	Stn 6.6kV	MET1
55	#4A Treated Water Low Lift Pump	TOMET1059	EST-485	58816	800/5	Not Reqd	Unit 415V	MET2
56	#4A Pulveriser	TOMET1060	EST-485	58820	500/5	Not Reqd	Unit 415V	MET2
57	#4A Cond Polisher Booster Pmp	TOMET1061	EST-485	58820	250/5	Not Reqd	Unit 415V	MET2
58	#4C Pulveriser	TOMET1062	EST-485	58822	500/5	Not Reqd	Unit 415V	MET2
59	#4Unit Pulv. A Sealing Air Fan	TOMET1063	EST-485	58825	250/5	Not Reqd	Unit 415V	MET2
60	#4A Condenser Extraction pmp	TOMET1064	EST-485	58827	200/5	60/1	Unit 6.6kV	MET2
61	#4B Treated Water Low Lift Ppm	TOMET1065	EST-485	51396	800/5	Not Reqd	Unit 415V	MET2
62	#4F Pulveriser	TOMET1066	EST-485	51396	500/5	Not Reqd	Unit 415V	MET2
63	#4D Pulveriser	TOMET1067	EST-485	58832	500/5	Not Reqd	Unit 415V	MET2
64	#4B Cond Polisher Booster Pmp	TOMET1068	EST-485	58833	250/5	Not Reqd	Unit 415V	MET2
65	#4Unit Pulv. B Sealing Air Fan	TOMET1069	EST-485	58834	250/5	Not Reqd	Unit 415V	MET2
66	#4B Condenser Air Extraction Pmp	TOMET1070	EST-485	59122	200/5	Not Reqd	Unit 415V	MET2
67	#4E Pulveriser	TOMET1071	EST-485	59124	500/5	Not Reqd	Unit 415V	MET2
68	#4B Pulveriser	TOMET1072	EST-485	59123	500/5	Not Reqd	Unit 415V	MET2
69	#4Dearator Standby Pump	TOMET1073	EST-485	58831	400/5	Not Reqd	Unit 415V	MET2
70	Pozzo Compressor No. 1	TOMET1027	KILO	59565	500/5	Not Reqd	1/2 Ash	MET1
71	Pozzo Compressor No. 2	TOMET1028	KILO	59566	500/5	Not Reqd	1/2 Ash	MET2
72	Pozzo 3/4 Transfer Compressor	TOMET1056	KILO	59567	500/5	Not Reqd	3/4 Ash	MET2
73	Pozzo Compressor No. 3	TOMET1057	KILO	59568	600/5	Not Reqd	3/4 Ash	MET2
74	Pozzo Compressor No. 4	TOMET1058	KILO	59569	600/5	Not Reqd	3/4 Ash	MET2
1	Raw Water Pumps	TOMET1075	KILO	87804	150/5	Not Reqd	CT Area	MET3
2	Pretreatment Plant	TOMET1076	KILO	87803	150/5	Not Reqd	CT Area	MET3
3	Demin 'A' Board	TOMET1077	KILO	87811	600/5	Not Reqd	CT Area	MET3
4	Demin 'B' Board	TOMET1078	KILO	87805	600/5	Not Reqd	CT Area	MET3
5	A' CRA Pump	TOMET1079	KILO	48766	Not Reqd	Not Reqd	CT Area	MET3
6	B' CRA Pump	TOMET1080	KILO	87808	Not Reqd	Not Reqd	CT Area	MET3
7	Hydrogen Plant	TOMET1081	KILO	87804	300/5	Not Reqd	CT Area	MET3

Figure H.1: List of Energy Meters Installed at Tarong Power Station (Godsmark 2001)

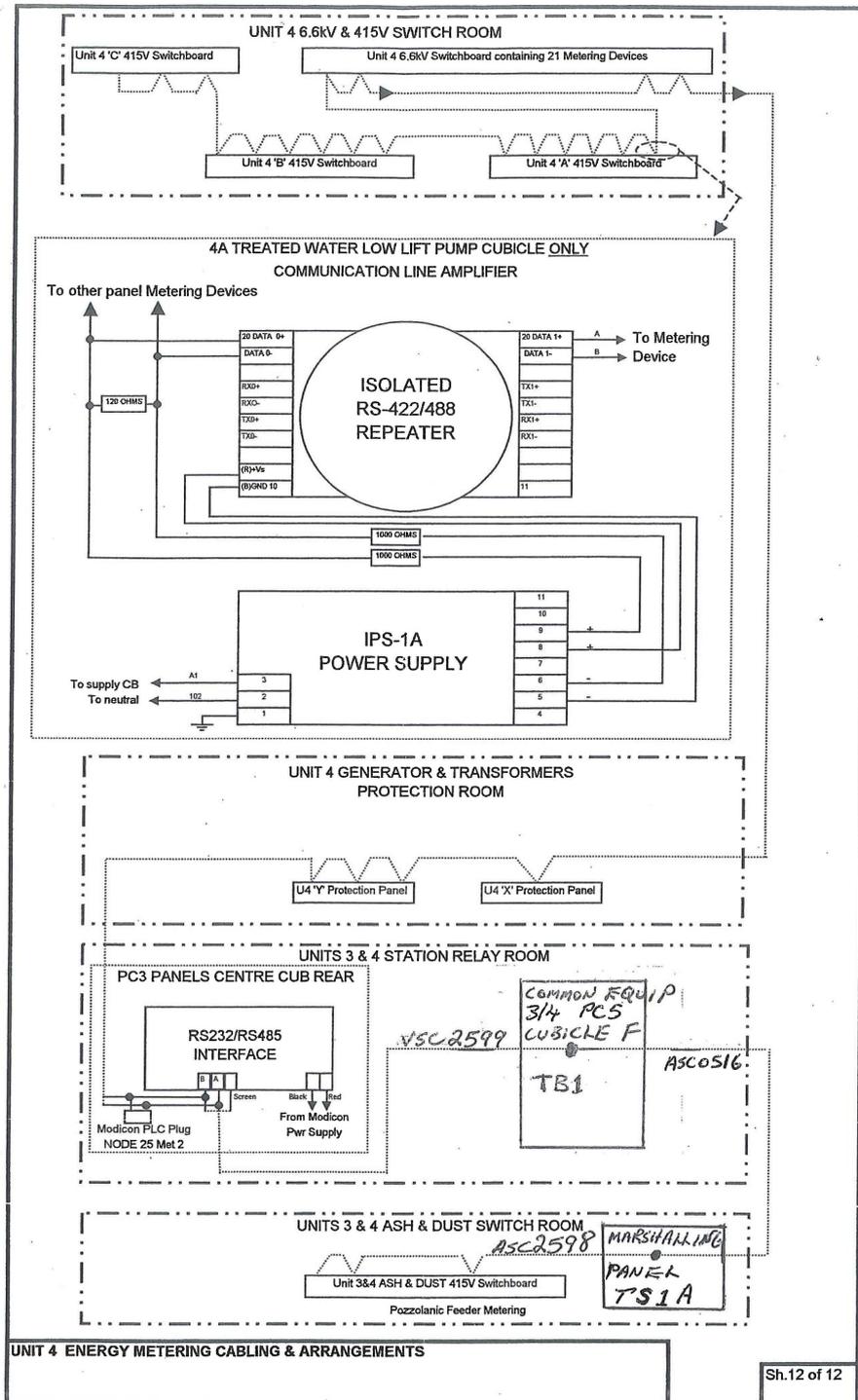


Figure H.2: Drawing of Typical Energy Meter Installation at Tarong Power Station (Godsmark 2001)

ENERGY2	Msg69_Data_7	REAL	404726 4A PA Fan Not Used	NOT USED
ENERGY2	Msg69_Data_9	REAL	404728 4A PA Fan Total VARs	
ENERGY2	Msg70_Data_1	REAL	404730 4A PA Fan A Ph Volts	
ENERGY2	Msg70_Data_3	REAL	404732 4A PA Fan B Ph Volts	
ENERGY2	Msg70_Data_5	REAL	404734 4A PA Fan C Ph Volts	
ENERGY2	Msg70_Data_7	REAL	404736 4A PA Fan A Ph Amps	
ENERGY2	Msg70_Data_9	REAL	404738 4A PA Fan B Ph Amps	
ENERGY2	Msg70_Data_11	REAL	404740 4A PA Fan C Ph Amps	
ENERGY2	Msg71_Data_1	REAL	404742 4A PA Fan A Ph Watts	1094
ENERGY2	Msg71_Data_3	REAL	404744 4A PA Fan B Ph Watts	
ENERGY2	Msg71_Data_5	REAL	404746 4A PA Fan C Ph Watts	
ENERGY2	Msg71_Data_7	REAL	404748 4A PA Fan Frequency	
ENERGY2	Msg72_Data_1	REAL	404750 4A FD Fan 3Ph Volts	
ENERGY2	Msg72_Data_3	REAL	404752 4A FD Fan 3Ph Amps	
ENERGY2	Msg72_Data_5	REAL	404754 4A FD Fan 3Ph Watts	
ENERGY2	Msg72_Data_7	REAL	404756 4A FD Fan 3Ph VARs	
ENERGY2	Msg72_Data_9	REAL	404758 4A FD Fan 3Ph VAs	A 06-6
ENERGY2	Msg72_Data_11	REAL	404760 4A FD Fan 3Ph PF	1094
ENERGY2	Msg73_Data_1	REAL	404762 4A FD Fan Watts MD	
ENERGY2	Msg73_Data_3	REAL	404764 4A FD Fan VA MD	
ENERGY2	Msg73_Data_5	REAL	404766 4A FD Fan Total Watts	
ENERGY2	Msg73_Data_7	REAL	404768 4A FD Fan Not Used	NOT USED
ENERGY2	Msg73_Data_9	REAL	404770 4A FD Fan Total VARs	
ENERGY2	Msg74_Data_1	REAL	404772 4A FD Fan A Ph Volts	
ENERGY2	Msg74_Data_3	REAL	404774 4A FD Fan B Ph Volts	9
ENERGY2	Msg74_Data_5	REAL	404776 4A FD Fan C Ph Volts	
ENERGY2	Msg74_Data_7	REAL	404778 4A FD Fan A Ph Amps	
ENERGY2	Msg74_Data_9	REAL	404780 4A FD Fan B Ph Amps	1095 1094
ENERGY2	Msg74_Data_11	REAL	404782 4A FD Fan C Ph Amps	
ENERGY2	Msg75_Data_1	REAL	404784 4A FD Fan A Ph Watts	
ENERGY2	Msg75_Data_3	REAL	404786 4A FD Fan B Ph Watts	
ENERGY2	Msg75_Data_5	REAL	404788 4A FD Fan C Ph Watts	
ENERGY2	Msg75_Data_7	REAL	404790 4A FD Fan Frequency	
ENERGY2	Msg76_Data_1	REAL	404792 4A ID Fan 3Ph Volts	
ENERGY2	Msg76_Data_3	REAL	404794 4A ID Fan 3Ph Amps	
ENERGY2	Msg76_Data_5	REAL	404796 4A ID Fan 3Ph Watts	
ENERGY2	Msg76_Data_7	REAL	404798 4A ID Fan 3Ph VARs	A 06-6
ENERGY2	Msg76_Data_9	REAL	404800 4A ID Fan 3Ph VAs	1095
ENERGY2	Msg76_Data_11	REAL	404802 4A ID Fan 3Ph PF	
ENERGY2	Msg77_Data_1	REAL	404804 4A ID Fan Watts MD	
ENERGY2	Msg77_Data_3	REAL	404806 4A ID Fan VA MD	
ENERGY2	Msg77_Data_5	REAL	404808 4A ID Fan Total Watts	
ENERGY2	Msg77_Data_7	REAL	404810 4A ID Fan Not Used	NOT USED
ENERGY2	Msg77_Data_9	REAL	404812 4A ID Fan Total VARs	
ENERGY2	Msg78_Data_1	REAL	404814 4A ID Fan A Ph Volts	
ENERGY2	Msg78_Data_3	REAL	404816 4A ID Fan B Ph Volts	
ENERGY2	Msg78_Data_5	REAL	404818 4A ID Fan C Ph Volts	
ENERGY2	Msg78_Data_7	REAL	404820 4A ID Fan A Ph Amps	1096 1095
ENERGY2	Msg78_Data_9	REAL	404822 4A ID Fan B Ph Amps	9
ENERGY2	Msg78_Data_11	REAL	404824 4A ID Fan C Ph Amps	
ENERGY2	Msg79_Data_1	REAL	404826 4A ID Fan A Ph Watts	
ENERGY2	Msg79_Data_3	REAL	404828 4A ID Fan B Ph Watts	
ENERGY2	Msg79_Data_5	REAL	404830 4A ID Fan C Ph Watts	
ENERGY2	Msg79_Data_7	REAL	404832 4A ID Fan Frequency	
ENERGY2	Msg80_Data_1	REAL	404834 4A Cond Extr Pmp 3Ph Volts	
ENERGY2	Msg80_Data_3	REAL	404836 4A Cond Extr Pmp 3Ph Amps	
ENERGY2	Msg80_Data_5	REAL	404838 4A Cond Extr Pmp 3Ph Watts	CEP
ENERGY2	Msg80_Data_7	REAL	404840 4A Cond Extr Pmp 3Ph VARs	A 06-6
ENERGY2	Msg80_Data_9	REAL	404842 4A Cond Extr Pmp 3Ph VAs	9
ENERGY2	Msg80_Data_11	REAL	404844 4A Cond Extr Pmp 3Ph PF	
ENERGY2	Msg81_Data_1	REAL	404846 4A Cond Extr Pmp Watts MD	
ENERGY2	Msg81_Data_3	REAL	404848 4A Cond Extr Pmp VA MD	
ENERGY2	Msg81_Data_5	REAL	404850 4A Cond Extr Pmp Total Watts	
ENERGY2	Msg81_Data_7	REAL	404852 4A Cond Extr Pmp Not Used	NOT USED
ENERGY2	Msg81_Data_9	REAL	404854 4A Cond Extr Pmp Total VARs	
ENERGY2	Msg82_Data_1	REAL	404856 4A Cond Extr Pmp A Ph Volts	1096
ENERGY2	Msg82_Data_3	REAL	404858 4A Cond Extr Pmp B Ph Volts	
ENERGY2	Msg82_Data_5	REAL	404860 4A Cond Extr Pmp C Ph Volts	
ENERGY2	Msg82_Data_7	REAL	404862 4A Cond Extr Pmp A Ph Amps	
ENERGY2	Msg82_Data_9	REAL	404864 4A Cond Extr Pmp B Ph Amps	
ENERGY2	Msg82_Data_11	REAL	404866 4A Cond Extr Pmp C Ph Amps	
ENERGY2	Msg83_Data_1	REAL	404868 4A Cond Extr Pmp A Ph Watts	1096
ENERGY2	Msg83_Data_3	REAL	404870 4A Cond Extr Pmp B Ph Watts	
ENERGY2	Msg83_Data_5	REAL	404872 4A Cond Extr Pmp C Ph Watts	
ENERGY2	Msg83_Data_7	REAL	404874 4A Cond Extr Pmp Frequency	
ENERGY2	Msg84_Data_1	REAL	404876 4A CW Pmp 3Ph Volts	
ENERGY2	Msg84_Data_3	REAL	404878 4A CW Pmp 3Ph Amps	
ENERGY2	Msg84_Data_5	REAL	404880 4A CW Pmp 3Ph Watts	A 06-6
ENERGY2	Msg84_Data_7	REAL	404882 4A CW Pmp 3Ph VARs	1096
ENERGY2	Msg84_Data_9	REAL	404884 4A CW Pmp 3Ph VAs	
ENERGY2	Msg84_Data_11	REAL	404886 4A CW Pmp 3Ph PF	9
ENERGY2	Msg85_Data_1	REAL	404888 4A CW Pmp Watts MD	1097
ENERGY2	Msg85_Data_3	REAL	404890 4A CW Pmp VA MD	
ENERGY2	Msg85_Data_5	REAL	404892 4A CW Pmp Total Watts	
ENERGY2	Msg85_Data_7	REAL	404894 4A CW Pmp Not Used	NOT USED

Figure H.3: Example of Typical Energy Meter PLC Registers and Functions (Godsmark 2001)

Appendix I

Stanwell Corporation Energy Reductions Recommendations Report

MEMORANDUM

TO : David Janes - Engineering Superintendent - Electrical Maintenance - TPS

FROM : Jason Lang

DATE : 25/10/15

FILE : [REDACTED]

Suggested Operational Improvements to Reduce Auxiliary Power Consumption

I have recently completed my final year university project on "Energy Efficiency Improvement in Coal Fired Power Plant through Operational Optimisation" through USQ. The project successfully created multiple auxiliary energy models in MATLAB and T3000 tracking logic within T3000. The models were based on data that was extracted from the TPS data historian, PIMS. These models were utilised to understand the auxiliary energy usage at TPS. The understanding and model accuracy was proven against the T3000 energy tracking logic. The T3000 logic was in turn confirmed against the permanently installed energy meters used in monthly reports.

The T3000 logic has enabled the high level auxiliary energy consumption figures to be broken down to drive level. This logic will remain and can be expanded to give better visibility to the auxiliary energy consumption across all units. Below is the average breakdown of the Tarong Power Station auxiliary usage.

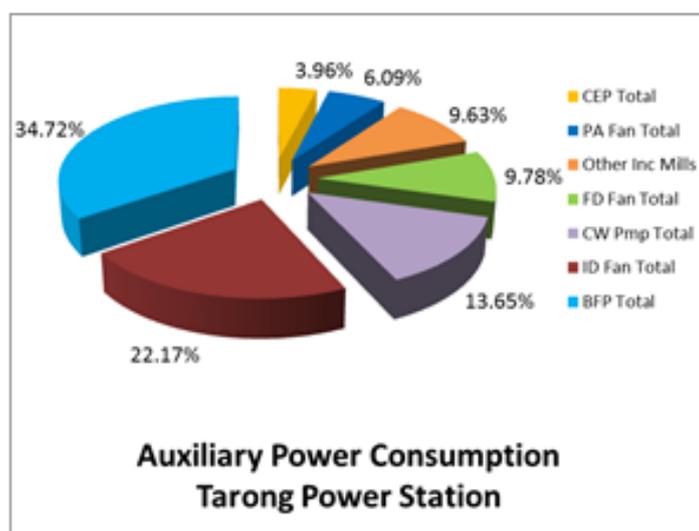


Figure I.1: Part 1 of Energy Reduction Recommendations Memorandum to David Janes

It can be seen that 80% of the auxiliary load comes from the 9 major 6.6kV drives; BFPs, IDs, CWs and FDs. This is where the primary reduction focus of the project started.

The understanding gained from the MATLAB models and T3000 logic has uncovered some key details about the station auxiliary energy consumption patterns. The project has also produced operational based reduction strategies that have the potential to reduce the sites auxiliary energy usage. These strategies have been tested on the MATLAB models to prove their effectiveness. These details and strategies will be presented below.

- 1) Above 300MW the units are running at peak auxiliary energy consumption and that there is little opportunity to reduce the auxiliary energy usage.
- 2) The proposed reduction strategies can be applied to all 4 Tarong 350MW units and the possibility of application to the 4 Stanwell 350MW units should also be explored.
- 3) There is opportunity at low loads to improve the auxiliary energy usage. These will be presented below under low or medium risk profiles below.
 - a) Low Risk – potential 10% reduction below 200MW
 - i) Circulating Water Pumps – Remove one from service below 200MW (Malcolm Westaway/Jason Lang);
 - ii) Boiler Feed Pumps – Remove one from service below 200MW (Jason Lang).
 - b) Medium Risk – potential 5% reduction across the full load range
 - i) Increase the boiler furnace set point closer to zero to reduce the ID fan loading (Les Airs).

Future work required to implement these options on the units plant.

- 1) Test runs within the Simulator plant;
- 2) Expansion of the T3000 tracking logic to create HMI and alarms;
- 3) Improvement of the Circulating Water hydraulic packs to ensure operation of discharge valve when required;
- 4) Creation of boiler pressure excursion ride through logic to reduce the chance of spurious trips during clinker fall;
- 5) Test runs of the proposed reduction strategies in manual mode during plant operation to confirm that actual plant response and energy reduction potential;
- 6) Risk workshops to examine in more detail the proposals and there potential plant impacts;
- 7) Creation and modification of control sequences around these two plant areas.

Further detail is available in the final dissertation document produced for submission.

Jason Lang
Development Engineer
Engineering - Electrical Maintenance - TPS

Figure I.2: Part 2 of Energy Reduction Recommendations Memorandum to David Janes