University of Southern Queensland

Faculty of Engineering and Surveying

Replacement of Steam Turbine Drive with Electric Drive

A dissertation submitted by

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In fulfilment of the requirements of

Courses ENG4111 and 4112 Research Project

Towards the degree of

Bachelor of Engineering (Electrical, Electronic)

Submitted: October, 2009

Abstract

The intent of this project is to investigate the feasibility of replacing steam driven turbines in a sugar mill with electric motors. To do this it was necessary to firstly verify precisely what the task was that the existing drive was doing. In this case the steam turbine was driving a pump that delivered water to two bagasse fuelled boilers in a sugar mill. Also the task involved the investigation and delivery of improving the existing system. By analysing parameters of the current installation such as reliability, efficiency and suitability of the existing installation, a benchmark was created that we could measure any improvements against.

After the plant requirements were determined, the new installation could be designed. Pump and motor sizing was done using flow, head and pressure measurements. Drawings such as Electrical schematics, P &IDs and mechanical layouts were then developed. The electrical and mechanical installation then followed. As part of the upgrade a programmable logic controller and HMI (Human Machine Interface) were programmed to provide better control and supervision of the process.

After installation and commissioning, an assessment was carried out and the level of success of the project was determined. It was shown quantifiably that the capital expenditure was more than justified and that this process could be repeated in many of the remaining steam turbines to achieve similar improvements in efficiency, safety and reliability.

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Barry William Scoines

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Signature

Date

Acknowledgements

I would firstly like to thank my supervisor Dr Ron Sharma who has given me invaluable assistance in the structure and guidance of my project and dissertation.

I would also like to thank my colleagues at work who helped design an install the project and assisted in the commissioning.

I would also like to thank my wife for her moral support and patience during the long hours needed to finish this project and all my studies.

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Chapter 1 Introduction

Chapter 1.1 Outline of the Study

This project essentially looks at the feasibility of replacing the steam driven turbines that drive pumps in a sugar factory with electric motors. Specifically I am analysing a feed water pump that supplies a bagasse fired boiler. Before replacing any equipment it is important to understand the total functionality of the existing installation. Therefore a large part of the analysis is involved in understanding the feed water requirements and the many affected parameters and operating conditions.

Chapter 1.2 Introduction

The sugar industry in Queensland dates back to the middle of the 19th century. The first recorded cane was imported from New Guinea and planted in Ormiston in south east Queensland. It didn't take long for the pioneers to see the potential for sugar cane in north Queensland and despite the extreme remoteness of the region the first plantations were planted in the 1880's.

Steam drives and technology were more prevalent previously than they are now. The by-product from sugar cane is the fibre called bagasse that is a cheap and convenient fuel to produce steam inside a boiler. This is part of the reason why there have been so many steam driven drives in sugar mills. Typical applications include mills, alternators, pumps and fans.

With the advent of electronics and variable speed drives, electric motors have become a more flexible alternative for driving pumps. Indeed in some sugar mills the steam driven turbines that drove the large milling rollers have already been replaced with high voltage variable speed controlled electric motors. This can provide a neater, safer, cheaper, more efficient and reliable alternative.

Chapter 1.3 The Problem

Kalamia Sugar Mill crushes sugar cane in the Burdekin district and produces raw sugar which is consumed locally and sold as an export commodity. The sugar mill can be broadly described as 3 areas that make up the factory.

1. Feeding and crushing section. The juice is extracted from the cane billets
2. Process section. The juice is turned into sugar
3. Boilers. The steam produced from the boilers drives most of the large drives in the factory including mills, pumps, fans and an alternator.

Figure 1.1 outlines the position of the various sections and steam turbines in the factory.

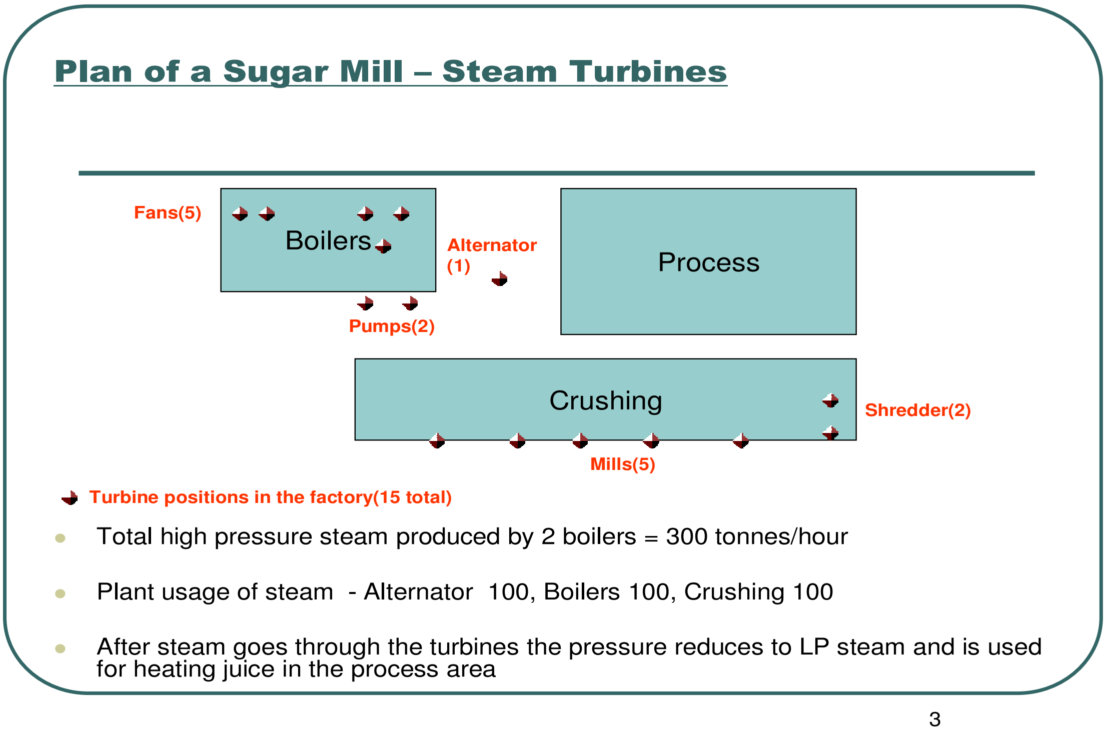

Figure 1.1 Overall plan of Kalamia sugar mill

It is proposed to replace one of the pumps that feed water to the 2 boilers.

Chapter 1.4 Research Objectives

The overall project task is to investigate the feasibility of replacing traditional steam turbine drives with modern electric drives. If the investigation proves positive the replacement will go ahead. To achieve the overall objective some milestones had to be achieved progressively. The objectives of this project can be summarised as follows -

- Identify specific feed water requirements of the two bagasse fired boilers of the factory.
- Evaluate current methods of supplying boilers with feed water.
- Take flow, pressure and temperature measurements of steam driven pumps.
- Analyse cost effectiveness, reliability and suitability of current methods.
- Design an electric replacement including control, supervision, alarm and data capturing systems.
- Analyse the complete system comparing advantages and disadvantages of the two systems.
- Determine if conclusions drawn from this technology can be used in other applications.

Chapter 1.5 Conclusions

The hardware and software design of the new installation is a large part of the project. The programming software used will be in line with what is already installed at the factory i.e. AutoCad, Modicon Concept and Citect.

After installation and commissioning, an assessment is to be carried out to assess the level of success of the project. It is expected to show that the capital expenditure was justified and that this process could be repeated in many of the remaining steam turbines to achieve similar improvements in efficiency, safety and reliability.

Chapter 2 Literature Review

Chapter 2.1 Introduction

This chapter will review literature to establish the reasons for replacing a steam turbine with an electric drive in this particular application. It will also review literature to establish the best system and equipment to use in the replacement project.

Chapter 2.2 Steam turbines versus Electric motors

Drbal,1996:822 gives a good general comparison of boiler feed pump drives. ‘The power required to drive the boiler feed pumps often represents the largest continuous auxiliary load in a power plant. This trade off study addresses the number and arrangement of the boiler feed pumps and the type of drive(electric motors or steam turbines). Electric motor drives are less expensive than steam turbine drives but require power that could be sold on the electric transmission grid. Steam turbine drives use high pressure steam ,and their operations impacts the plants heat rate and power output. Steam turbine drives may offer less operational flexibility than electric motor drives. The availability of the system is dependent on the number of boiler feed pumps, the type of driver and the configuration(series versus parallel arrangement). Replacement energy costs can be assigned to the alternative with a lower system availability.’

The book this is taken from is called Power Plant Engineering. Its content is a summary of the experience gained by many engineers working for the company called Black and Veatch. This company has specialised in power generation over many years. It is a text book and has a style that shows it is only interested in informing the reader. There appears to be no other motive e.g. trying to sell a product.

There are many examples of this conversion being done in various factories across the world in recent years. With the progress in microprocessor technology allowing better control of electric motors it has become easier to justify. The benefits and the advantages of the use of electric motors to replace steam turbines presented by Hansueli Krattiger in his paper are relevant to this project. He describes how his company replaced several steam turbines with electric motor drives in an Argentinian refinery.The largest of which was a 2980 kW, 4100 rpm steam turbine of JC-401T blower of the FCCU “A” catalyst cracking unit.

He describes key factors of the replacement as

• The cost of steam is higher compared to electricity.
• Higher maintenance costs.
• High flow rates of coolant water circulating through
the surface condensers.
• Low efficiency

He then goes on to state that

‘The replacement project feasibility study was based on
following economic considerations:
1. Comparative costs of electric and other types of
drives
2. Efficiency of electric drive systems compared to
other systems
3. Coolant water costs
4. Savings derived from adjusting the flow by speed
Switching
5. Maintenance costs‘

It was the success of his project that helped in the justification for my project.

It must be considered that this paper was written as a description of a commercial installation by the company he worked for i.e. ABB. It is normal that he will tend to emphasize the advantages of such a project.

A paper from the U.S. Department of Energy gives a list of situations where in fact it could make sense to do the opposite i.e. replace electric motors with steam turbines! These situations are listed

‘Suggested Actions
Consider replacing electric motors with steam turbine drives if your facility:
• Contains a high-pressure boiler or a boiler designed to operate at a higher pressure than process requirements.
• Has time-of-use (eg. on/off peak, real-time, etc.) energy purchase and resale contracts with periods when electric power costs are substantially higher than fuel costs.
• Has pumps or other rotating equipment requiring variable speed operation.
• Requires continued equipment operation during electrical power supply interruptions ‘

The paper then lists attributes of steam turbines. These include ruggedness, reliability, low maintenance, ease of control and nonsparking operation(important in explosive atmospheres). It then gives an example of the cost of running a steam turbine compared to an electric motor.

Some of these considerations are not relevant to this installation. We do not require variable speed operation. One of the duty pumps will remain a steam turbine drive so in the event of power failure it will remain on. There is no explosive atmosphere.

These papers appear to contradict each other to a certain extent. Especially in the area of cost savings. Both are saying that the system they are considering is more efficient the other. They have both done calculations on order to prove their point. There are a lot of assumptions made in both sets of calculations including boiler and motor efficiencies and fuel costs for steam generation and electricity.

An important point to note is that at the sugar mill where this steam to electricity conversion has taken place, it is a cogeneration facility. Krattiger states ‘ Steam cogeneration is the simultaneous production of electricity and useful thermal energy. Cogeneration saves money by allowing you to produce your own electricity for a fraction of the cost of utility power. Cogenerated power is cheaper because cogeneration systems can achieve fuel efficiencies of up to 80%, whereas the best utilities can do is about 40%.’ This is very important because it shows that in a plant like ours the electricity costs are very cheap because it is a cogeneration facility. This tips the balance in favour of an electric motor for us. The cost of electricity was the biggest disadvantage put forward by the U.S. Department of Energy paper.

Chapter 2.3 Why use a PLC

Programmable logic controllers (PLCs) are now common place within industry. They have largely superseded hard wired relay logic systems for the control of electrical equipment. The PLC has a microprocessor with a stored program. This program is capable of emulating the interconnection of many relays to perform certain logical tasks. There are many advantages in using plus, some of which are listed below

- More flexible. Changes can be made very easily
- More sophisticated control possible because of the computational abilities
- Troubleshooting aids reduce downtime and make programming easier
- More reliable
- Ability to easily provide information to other computer programs which allow better supervision and control of the process.
- Total installation cost is cheaper and less expensive

Clarence Phipps 1999:139 raises some possible disadvantages stating that ‘The most difficult hurdle we face in troubleshooting a PLC installation is interpreting the designer’s interface addressing’. He goes on to say that switching between drawings, printouts and instruction books can be difficult. Also he points out that learning abbreviated symbols in the program for different functions requires constant reference to instruction manuals. From my personal experience I agree with him to a certain extent. However as long as the drawings are done accurately and are consistent this is not a problem. PLC programs need to be coded logically and have good cross referencing. So I believe his issues are benign if the installation is to a high standard and adequate training of the programmers, drafters and maintenance staff is ensured.

The advantages of PLCs are so overwhelming now that it is a compelling argument to use them over relay logic and there is no argument that this is the best option for this type of application.

Chapter 2.4 What is the Best PLC for this Application

Standardisation is important when considering new hardware in a factory. In this case Modicon PLCs are used extensively throughout the sugar mill and within other CSR sugar mills. An advantage of standardisation is that personnel only have to become familiar with one brand of equipment. New installations will integrate more seamlessly with existing plant. Less spares are required. These are financially important arguments for standardisation and there would have to be some compelling reasons to change brands.

There are many brands of PLC on the marketplace. All the companies are trying to sell their own product. In order to judge which one was best suited to our application it was necessary to identify the important criteria to be used as a benchmark then set about researching each brand and type.

A PLC system is comprised of several components. Generally there is a back plane that the components plug into. The modules are typically

- Power supply
- Central processing unit (CPU) where the program resides
- Input modules (digital and analogue) Interface to the real world
- Output modules (digital and analogue) Interface to the real world
- Communication modules. For communication between separate backplanes, other PLC, networks etc.

After much searching I could not find much in the way of comparison of plcs in books or other printed media. However on the internet I found a comparison chart called PLC_Comparison_chart_2007_v5.xls done by JesperMP. In his comparison he looked at highest selling brands i.e. Siemens, Allen Bradley, Mitsubishi, Omron, Modicon and many others. The criteria that he covered that I believe were important in our application were as follows

- Support for IEC programming languages
- Redundancy solutions
- Integrated machine safety solutions
- HMI solutions
- Primary Bus families

Of all these criteria the five brands I mentioned above rated similarly. However Siemens only used ST(structured text) and SFC(Sequential flow chart) languages which requires specialized programming skills. Omron was weak when it comes to integrating it with auxiliary devices and programs.

Other criteria that I believe are important that can be found from data sheets include.

- Clock speed of CPU
- User logic memory size
- Local I/O capacity

- Distributed I/O capacity

The Quantum Automation catalogue gives these parameters for Modicon Quantum PLCs. This is the brand of PLC that is currently used in the factory. There are four levels of CPU in the Quantum range which vary in performance and price. The 140 CPU 534 14 has a clock speed of 133MHz, memory size of 2.5Mb, local I/O capacity of 64 words and distributed I/O capacity of 500 words per network with 63 drops per network. All these parameters would be more than sufficient for this project.

Other Criteria that I believe are important include

- Integration into existing factory equipment
- Cost
- Parts availability
- Service support
- Ease of use

SCADA(supervisory, control and data acquisition) is a program run on computers and displayed on monitors giving operators a visual display of what is happening in the factory. It allows them to monitor and control the processes. Currently the factory uses a program called Citect. This is platform that integrates seamlessly with the current Modicon PLCs. New software drivers would need to be purchased to use a different PLC with Citect.

Cost and availability are similar for all brands.

Chapter 3 Relevant Theory

Chapter 3.1 Steam Turbines

Invented by Charles Parsons in 1884, the steam turbine provides a useful means of converting pressurized steam into rotating mechanical energy. It's most common usage is generating electricity by attaching the rotor of an alternator to its output shaft. However our current use for it is to pump feed water to a boiler to create the very steam that drives it. By improving the thermodynamic efficiency through the use of multiple stages in the expansion of the steam, the steam turbine made its predecessor the reciprocating steam engine obsolete.

In a turbine there is a fixed stator and a spinning rotor. There are 2 types of turbine - Impulse turbines and Reaction turbines. Both these turbines do the work of turning the rotor by directing the steam via the stationary nozzles which while dropping the steam pressure, increase its speed. This pushes against the moving rotor blades and turns them. The rotor of the reaction turbine are arranged to form nozzles as well which makes use of the reaction force as the steam accelerates through the rotor nozzles. Typically, higher pressure sections are impulse type and lower pressure stages are reaction type.

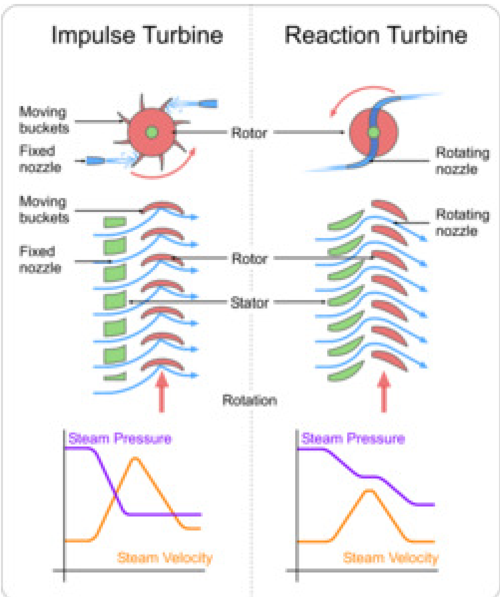

Figure 3.1 Schematic diagram outlining the difference between an impulse and a reaction turbine

- http://en.wikipedia.org/wiki/Steam_turbine

Chapter 3.1.1 Steam Turbine Efficiency

Isentropic efficiency η by definition is given by

$$\eta = (hHP - hLP) / (hHP - hLPisen)$$

where

- hHP is the specific enthalpy of the steam at the turbine inlet
- hLP is the specific enthalpy of the steam at the turbine exhaust
- hLPisen is the specific enthalpy of the steam at turbine exhaust pressure but after isentropic expansion from the HP conditions

We define the ratio

$$m = \eta FL/(1 - \eta FL)$$

where ηFL is the turbine isentropic efficiency at full load

The isentropic efficiency η at load P can be estimated by

$$\eta = m \cdot P / (PR + m \cdot P)$$

where PR is the rated turbine power.

The specific enthalpy at the turbine exhaust conditions is then

$$hLP = hHP - \eta \cdot (hHP - hLPisen)$$

The steam consumption at operating load P is given by

$$ms = P / (hHP - hLP)$$

- taken from http://www.sugartech.co.za/turbinecalcs

Chapter 3.2   3 Phase Induction Motors

An Induction motor has basically two parts – Stator and Rotor

The Stator is made up of a number of stampings with slots to carry three phase windings. It is wound for a definite number of poles. The windings are geometrically spaced 120 degrees apart. Two types of rotors are used in Induction motors

A squirrel-cage rotor consists of thick conducting bars embedded in parallel slots. These bars are short-circuited at both ends by means of short-circuiting rings. Induction motors can be compared with a transformer because of the fact that just like a transformer it is a singly energized device which involves changing flux linkages with respect to a primary (stator) winding and secondary (rotor) winding.

A squirrel cage phase induction motor can be compared to other electric motors such as DC motors, wound rotor induction motors, synchronous motors and single phase motors. Its features are compared below

Advantages

- Rugged and reliable
- High efficiency
- Low cost
- No brushes required

Disadvantages

- Starting torque low
- When load increases speed reduces
- Fixed speed unless extra equipment introduced
- Low power factor at high loads

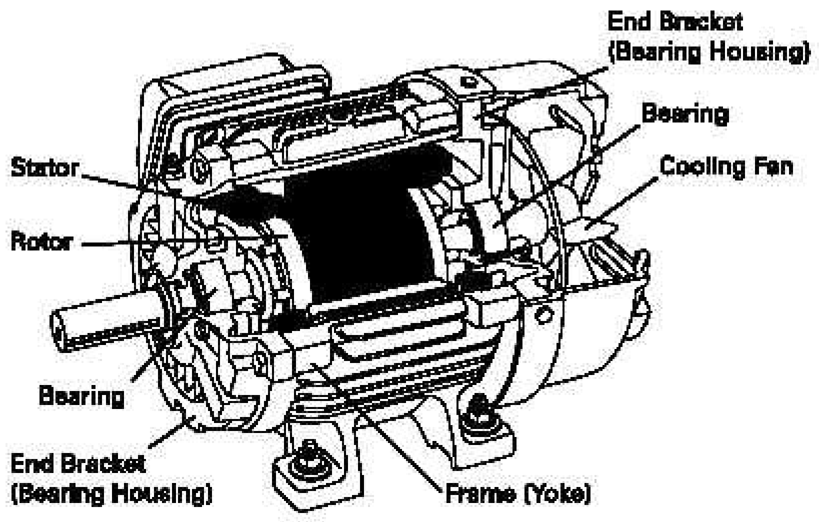

Figure 3.2 Cutaway view of motor

- http://www.engineeringtoolbox.com

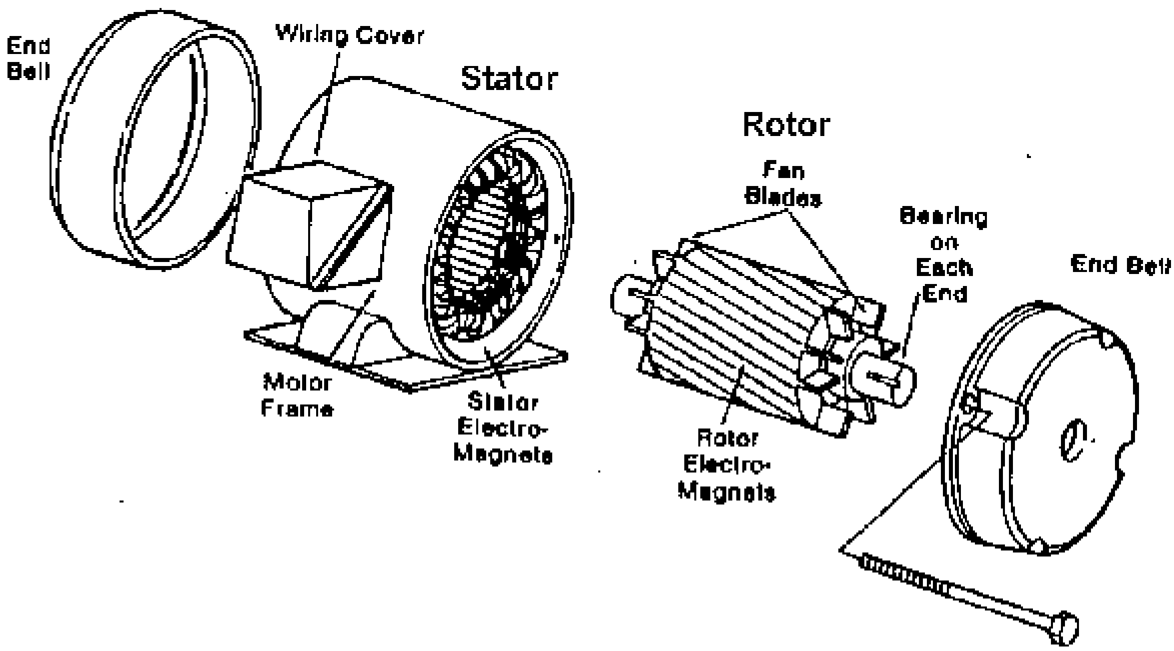

Figure 3.3 Exploded view of motor

- http://www.engineeringtoolbox.com

The exact equivalent circuit model of an Induction motor is-

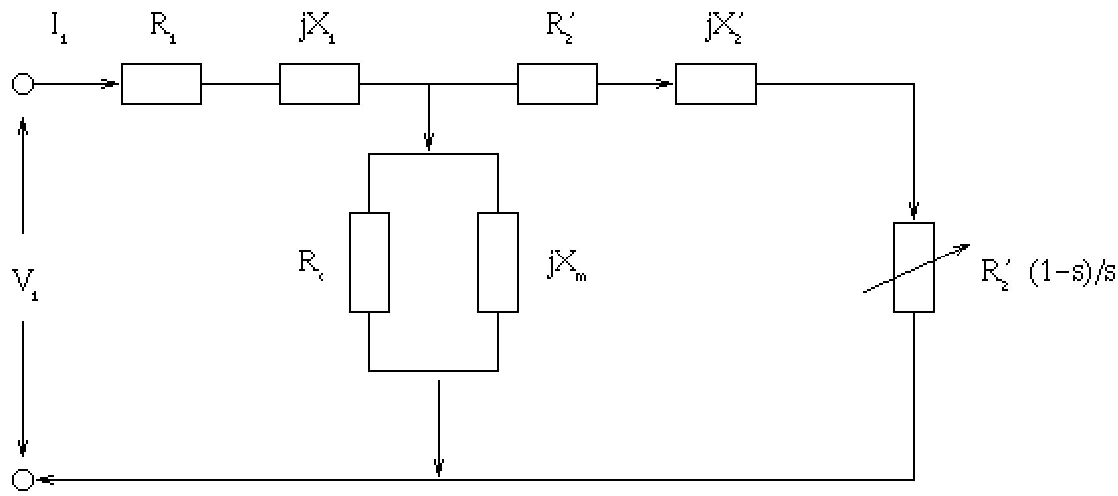

Figure 3.4 Equivalent Circuit of an Induction motor

R1 is the stator resistance per phase

X1 is the stator reactance per phase

R2' is the equivalent rotor resistance referred to stator per phase

X2' is the equivalent rotor reactance referred to stator per phase

Rc is the resistance representing core losses

Xm is the magnetizing reactance per phase

V1 is the per phase supply voltage to the stator

s is the slip of the motor

Chapter 3.2.1 Induction Motor Efficiency

A motor's efficiency is a measurement of useful work produced by the motor versus the energy that it consumes (heat and friction). A 90% efficient motor with a total watt draw of 400kW produces 360 kW of useful energy (300 x .9 = .360). The 40 kW lost (400 - 360 = 40) becomes heat.

Electrical motor efficiency is the ratio between the shaft output power and the electrical input power

Motor efficiency = Pout / Pin

Power In = Power Out + Losses

Power flow in an Induction motor

The power flow diagram could be described as a loss diagram. It gives a visual description of all the loss between input electrical power through to mechanical delivered at the output shaft. It is very useful in determining motor efficiency.

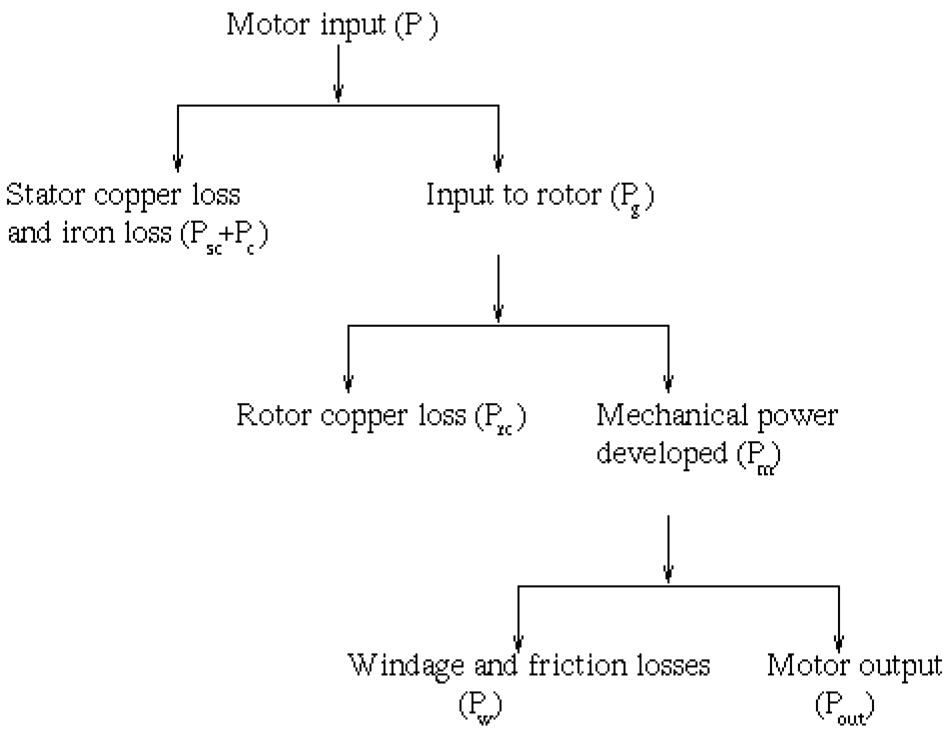

Figure 3.5 power flow diagram of motor

At each level of the above figure the left hand arrow points to the loss at that stage. Because the losses are the key factor in calculating efficiency they demand detailed analysis

Losses = Stator Losses+ Rotor losses+ windage and friction
Losses = Stator iron loss+ Stator copper loss+ Rotor copper loss+ windage and friction

Stator Losses

Input power is dissipated as copper losses in the stator windings and as stator iron losses which are also known as hysteresis and eddy currents in the stator core.

Primary and Secondary Resistance Losses

The electrical power lost in the primary rotor and secondary stator winding resistance are also called copper losses. The copper loss varies with the load in proportion to the current squared - and can be expressed as

Pcl = I^2 X R

Pcl = stator winding copper loss (W)
R = resistance (Ω)
I = current (Amp)

Iron Losses
These losses are the result of magnetic energy dissipated when the motors magnetic field is applied to the stator core.

Stray Losses
Stray losses are the losses that remain after primary copper and secondary losses, iron losses and mechanical losses. The largest contribution to the stray losses is harmonic energies generated when the motor operates under load. These energies are dissipated as currents in the copper windings, harmonic flux components in the iron parts, leakage in the laminate core.

Mechanical Losses
Mechanical losses include friction in the motor bearings and the fan for air cooling.

As stated previously, 3 phase induction motors have a very high efficiency. They convert electrical energy to mechanical energy at high levels of efficiency because the losses are relatively low in comparison to other energy converters such as steam turbines. The table below table below describes minimum efficiency standards for motor manufacturers in the USA. It can be seen that the bigger the motor the higher the efficiency

Electrical motors constructed according to NEMA Design B must meet the efficiencies below:

Power (hp)	Minimum Nominal Efficiency1)
1 - 4	78.8
5 - 9	84.0
10 - 19	85.5
20 - 49	88.5
50 - 99	90.2
100 - 124	91.7
> 125	92.4

Table 1 NEMA motor efficiency table

Project System efficiency calculations

To calculate the change in overall system efficiency eventuating from the upgrade it is necessary to define the system elements. Before the upgrade high pressure steam was fed directly to the turbine from the boilers. Now we are feeding this extra steam that is not used by the feedwater pump to the much larger alternator. The economy of size is where the gain in efficiency.

The Alternator is rated at 10 mega watts whereas the feed water pump is only 450 kW. The quoted efficiency of the alternator in converting steam energy to first kinetic energy and then electrical energy is 52%

The feed water pump only has one conversion of energy from steam to kinetic. However the quoted efficiency is only 47%

The overall efficiency of the new installation must now include the conversion from electrical energy to kinetic energy. The motor efficiency is quoted as 93% at 100% full load current. Full load current is 513 amps. Using the current transformer reading over various operating conditions it was found the motor averages 508 amps which is close to full load current. Anyway efficiency only drops marginally for a drop in current.

This means the overall efficiency is

Efficiency = .52 X .93 = 48.6%

Although this is only 1.6% gain and might not seem like a lot, over the course of 1 year the savings are considerable.

The pump uses approximately 6 tonnes of steam per hours.

Total steam used in a 22 week crush = 3686 hours X 6 tonnes/hr = 22116 tonnes

Steam saved = 22116 X .16 = 3538.56 tonnes

The extra steam is then used in the Alternator to export electricity. The alternator uses about 100 tonnes of steam per hour to generate about 8 MWhrs of power. Therefore the 3538 extra tonnes of steam equates to

35.38 MWhrs of power per crushing season. The rates for export power sold vary depending on what time of day it is exported. I will take an average of 10 cents per kWHr. This means:

Total saving per crush period = 35.38 X $100 = $3538

Chapter 3.2.2 Torque and Slip Characteristics

For obtaining the expression for torque we can uses what is called Thevinins equivalent circuit

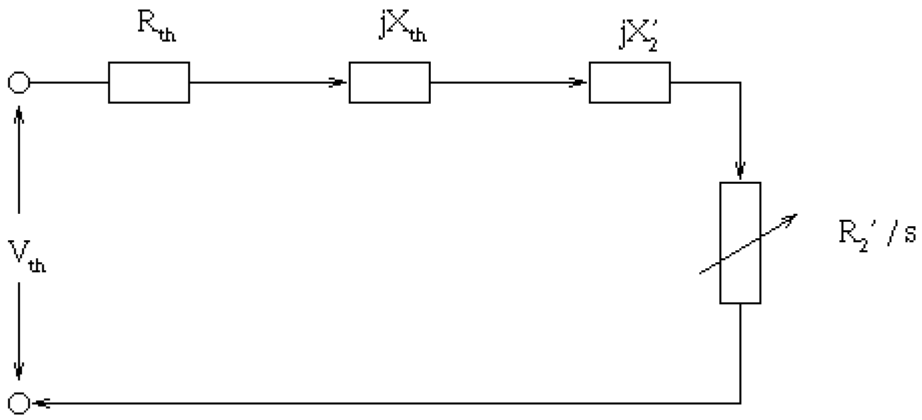

Figure 3.6 Thevenin's equivalent of the circuit of a motor

Zth = Rth+jXth is the Thevenin's equivalent impedance.

where

Rth = Stator resistance

jXth = stator reactance

jX'2 = rotor reactance referred to the stator

R2'/s = rotor resistance referred to the stator

Now Zth is the parallel combination of the shunt branch and Z1 i.e., the stator impedance. So to calculate rotor current I2-

I2' = Vth / [(Rth + R2'/s) + j (Xth + X2')]

The torque developed T is given-

T = Pm / wm

Where

Pm = mechanical power developed

Wm = motor speed

Substituting into formula

$$T = \frac{3 \times Vth^2 \times R2}{(2 \times Pi \times Ns) \times [(Rth + R2''/s + j(Xth + X2')] \times s}$$

To obtain the starting torque we put s=1 in the above equation.

$$Tstart = \frac{3 \times Vth^2 \times R2}{(2 \times Pi \times Ns) \times [(Rth + R2''/s + j(Xth + X2')]}$$

To obtain the maximum torque produced, the condition is dT/ds=0.

Applying this condition we get smaxT that is the slip at maximum torque Tmax.

$smaxT = Rs' / \sqrt{Rth^2 + (X2' + Xth)^2}$

We then put in this value of torque in the expression for torque to get the value of maximum torque.

$$Tmax = \frac{3 \times Vth^2 \times \sqrt{Rth^2 + (Xth + X2')^2}}{(2 \times Pi \times Ns) \times [(Rth + \sqrt{Rth^2 + (X2' + Xth)^2}) + j(Xth + X2')]}$$

Now to simplify the equation we can neglect Rth so the equation for max torque is

$$\frac{3 \times Vth^2}{(2 \times Pi \times Ns) \times 2 \times (X2' + Xth)}$$

From this we can derive relationships between starting, maximum and running torque

$$\frac{Tstart}{Tmax} = \frac{2 \times smaxT}{(1 + smaxT^2}$$

And

$$\frac{Td}{Tmax} = \frac{2 \times s \times smaxT}{(s^2 + smaxT^2}$$

So the torque equation obtained above can be expressed as-

$$T = \frac{Q1}{(Q2 + Q3 \times s + Q4 / s}$$

Where $Q1 = \frac{3 \times Vth^2 \times R2'}{2 \times Pi \times Ns}$

$Q2 = 2 \times Rth \times R2'$

$Q3 = Rth^2 + (Xth + X2")^2$

$Q4 = R2'$

Initially when the motor starts, the slip is high. So Q2/s=0. Hence the torque produced is proportional to the speed Nm. However when the motor attains stable speed, slip is negligible. Hence Q3.s =0 and the torque is inversely proportional to the speed Nm . From these relationships, the general shape of speed -torque characteristics of Induction motor can be obtained.

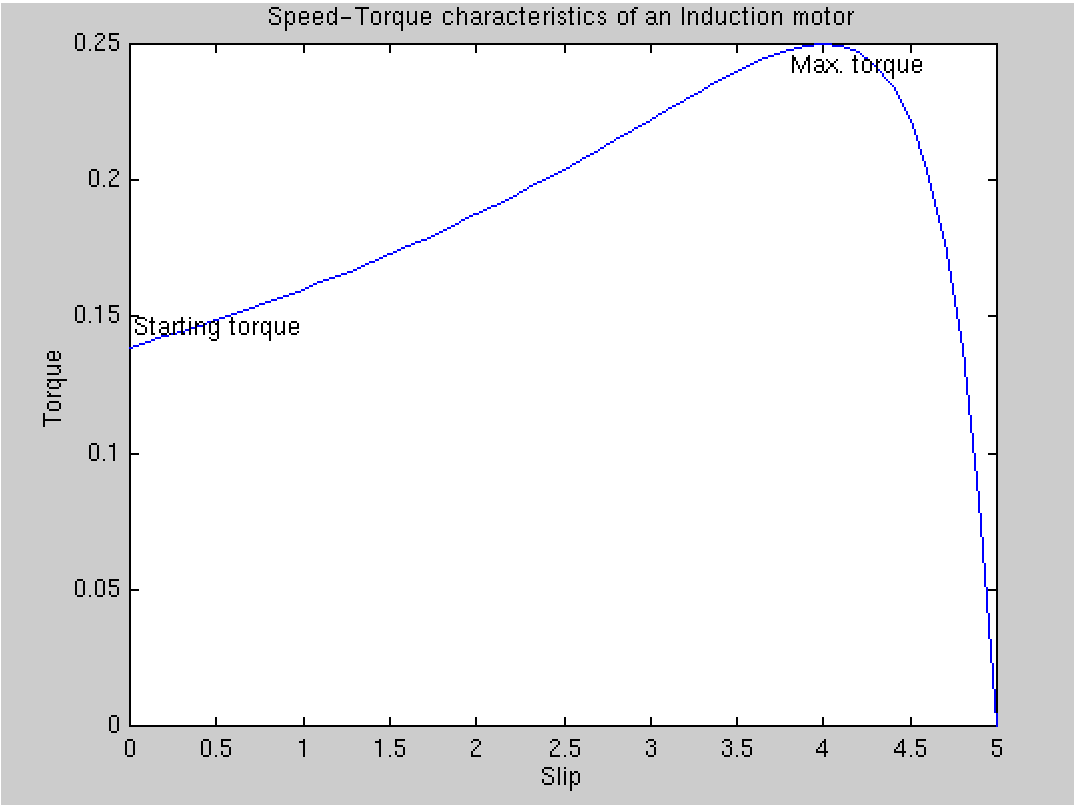

Figure 3.7 Torque slip curve of a motor

Factors affecting the speed-torque characteristics of an Induction motor :

- Applied voltage : We know that T is proportional to V2. Thus not only the stationary torque but also the torque under running conditions changes with change in supply voltage.

- Supply frequency : The major effect of change in supply frequency is on motor speed. The starting torque is reduced with increase in frequency.

- Rotor resistance : The maximum torque produced does not depend on R2'. However, with increase in R2', the starting torque increases. The slip at which Tmax is reached increases too which means that Tmax is obtained at lower motor speeds.

Chapter 4 Methodology

Chapter 4.1 Approach

The broad approach I took to obtain the necessary data was firstly to research the given specifications of the 'as built' installation. Initially I consulted the original boiler manuals where I obtained flow rates and pressures required at maximum boiler steam output.

The larger boiler is quoted as able to supply 180 tonnes per hour of steam at maximum output. The smaller boiler is quoted as able to supply 120 tonnes per hour of steam at maximum output

The second part of my approach was to obtain real data from the plant when it was in operation. I deemed this necessary to allow for any changes to the original installation that would make the original specifications inaccurate. Measurements were taken using a portable magnetic flow meter strapped to pipe work at appropriate positions in the feed water system. The measurements were taken at various levels of total steam output from low loads up to MCR.

To take the pressure measurements a Rosemount gauge pressure transmitter was used. It was calibrated with a Wallace and Tiernan calibration instrument to provide and output of 4 to 20 mA corresponding to an input pressure of 0 to 3000 kPa.

The results of the data gathering are covered in chapter 6 – Results and Discussion.

Chapter 4.2 Legislation and Standards

When designing, installing and testing the installation it was important to use several standards and codes of practice that are statutory legislation applying to electrical installations in Queensland. These documents form a frame work which must be followed when making decisions on the project design and installation. These include the following

- Wiring Rules AS/NZS 3000:2007
- Selection of Cables AS/NZS 3008.1.1:1998
- Electrical Safety Act 2002
- Safe Working on Electrical Installations AS/NZS 4836:2001
- Code of Practice – Electrical Work
- Electrical Installations – Testing and Inspection guidelines – AS/NZS 3017 : 2001

As well as this there are 'in house' CSR procedures that have been developed to comply with workplace health and safety requirements.

- SHE-038-CG Electrical Isolation
- SHE-062-CG Electrical Safety
- SHE-099-CG Testing of Electrical Equipment

These documents base most of the procedure on a risk assessment to ensure safety is prioritised by addressing hazards and implementing appropriate control measures. See Appendix C for a copy of the risk matrix and risk assessment used for the project

Chapter 4.3 Resource Planning

When planning a large project of this type it is imperative to ensure the resources will be available to complete it. A general overview of resources required follow.

Equipment and Facilities

- Obviously a new motor is required. A WEG Mining 300 kW 2 pole 415V 3 phase electric motor has been quoted.

- Pump - Although it would be possible fit the motor to the existing pump it makes sense to install a more modern pump which is smaller in physical size but more efficient than the old one

- Machinery floor space. Approximately 9 square metres of floor space will be used. The position of the new installation will fill the old area and modifications to pipe work will require more space.

Workshops

- The nearby electrical workshop will be used to fabricate such items as switch board panels, cable ladder and mounting brackets

- A boilermaker's workshop will be used to fabricate steel work items such as base plates, brackets and pipe work

Computers and software

- A laptop computer will be used to program the code in the plc.

- Software that will be used is :

    1. Modicon plc software Concept version 2.61
    2. Citect scada software version 6.2

Power Components

- Form 3 switchboard
- Switchgear – isolator, contactor, thermal overload, isolator
- Cable – 50 metres 185mm2 XLPE single core
  - control cable Dekeron 0.75mm2 screened single pr, 2 pr, 4pr, 8pr, 16pr

Control Components

- Modicon plc 534
- Analogue input card
- Analogue output card
- Digital input card
- Digital output card

Consumables

- Cable ties
- Scotch 33 tape
- Cable lugs and bootlace lugs

Chapter 5 Design

Chapter 5.1 Motor Controls

The electric motor is fed by cables from a switch room approximately 10 metres from it. The electrical cubicle that the controls are in is part of a 415 volt motor control centre that supplies most of the motors that are associated with one of the boilers. There are approximately 30 other cubicles that make up this motor control centre.

The motor control centre is supplied through a 1MVA transformer which has a full load current rating on the secondary side of 1390 amps. The load of all the other motors when in full production was a maximum of 800 amps. The new motor we added has a full load current of 513 amps. If we start the motor DOL (direct on line) it will draw approximately 6 times FLA for a short time. This will overload the transformer and possibly cause a trip. For this reason reduced current starting has been incorporated in the design in the form of auto transformer starting. This method used a tapping point on a transformer to supply a reduced voltage on start up. Using an electronic timer full voltage is switched onto the motor by bypassing the transformer.

The photo below shows the inside of the cubicle. Top centre is the main switch/circuit breaker. The middle section shows the line, star and run contactors in that order. The auto transformer is shown resting at the bottom.
Above the run contactor is the electronic overload. The 24volt controls is shown on the top left hand corner.

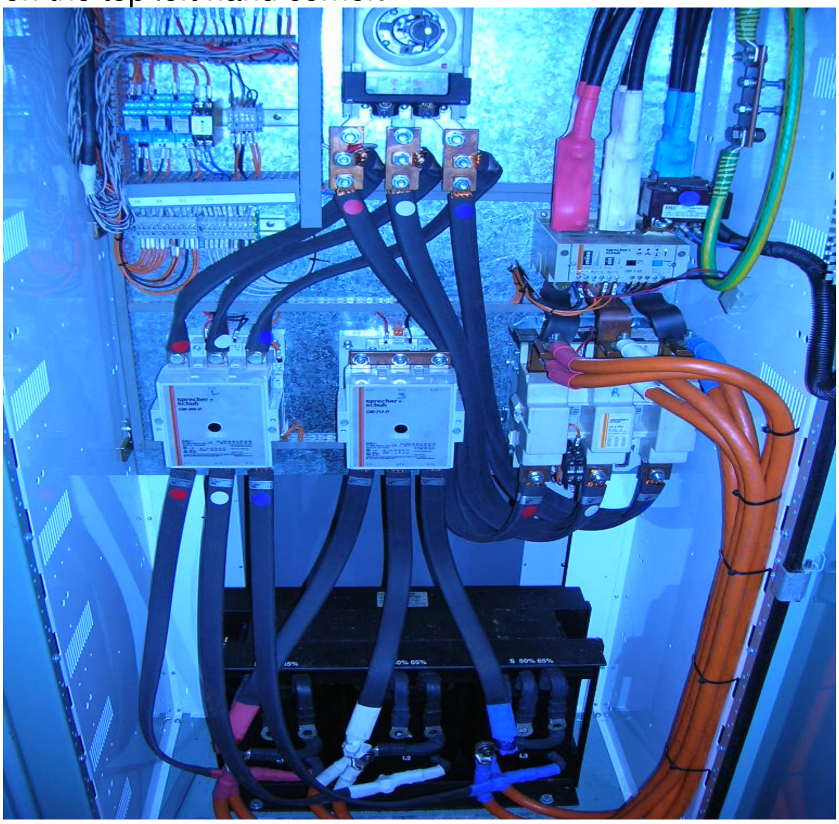

Figure 5.1Inside electrical cubicle

Schematic Drawing Number K543203000_01

The electrical schematic drawing is used to explain the operation of the circuit controls in the following section. This drawing is shown below. The detail of the drawing is too small to read on this overall drawing. Therefore I have broken it up into 4 sections. These drawings follow the overall drawing and need to be referred to in the following section that explains the operation of the circuit.

Figure 5.3 is the top left hand section of the drawing. It mainly shows the 415 volt power circuit – the power contacts of the run, star and line contactors, and the auto transformer.

Figure 5.4 is the bottom left hand section of the drawing. It mainly shows the 415 volt power circuit – the electronic overload CT, the local isolator and the motor
It also shows the PLC interface relays and contacts corresponding to its inputs and outputs.

Figure 5.5 is the top right hand section of the drawing. It shows the coils of the power contactors and the top half of the 24 volt control circuit

Figure 5.6 is the bottom right hand section of the drawing. It shows the bottom half of the 24 volt control circuit
Following the drawings is a step by step explanation of how it works.

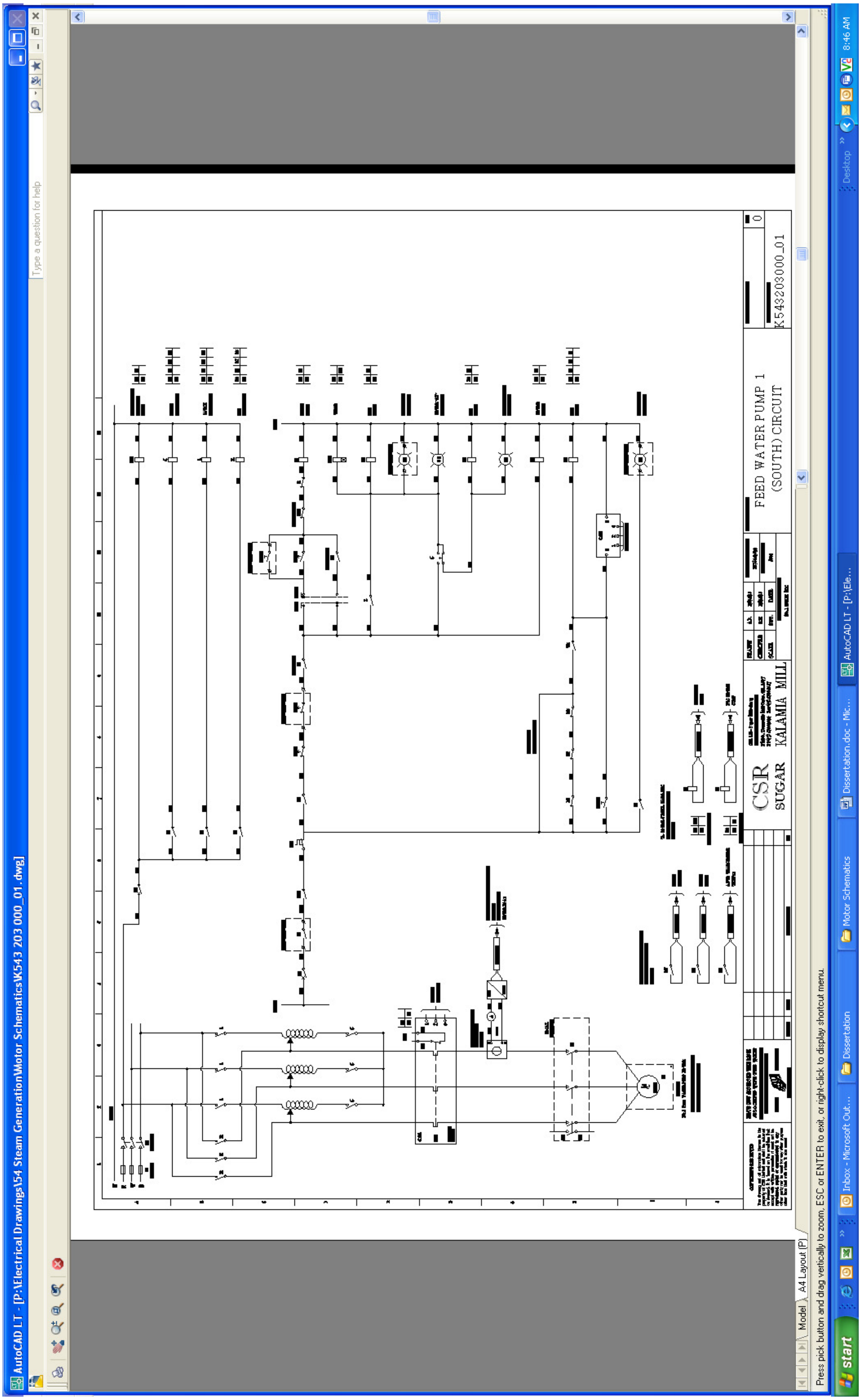

Figure 5.2 Schematic Drawing Number K543203000_01

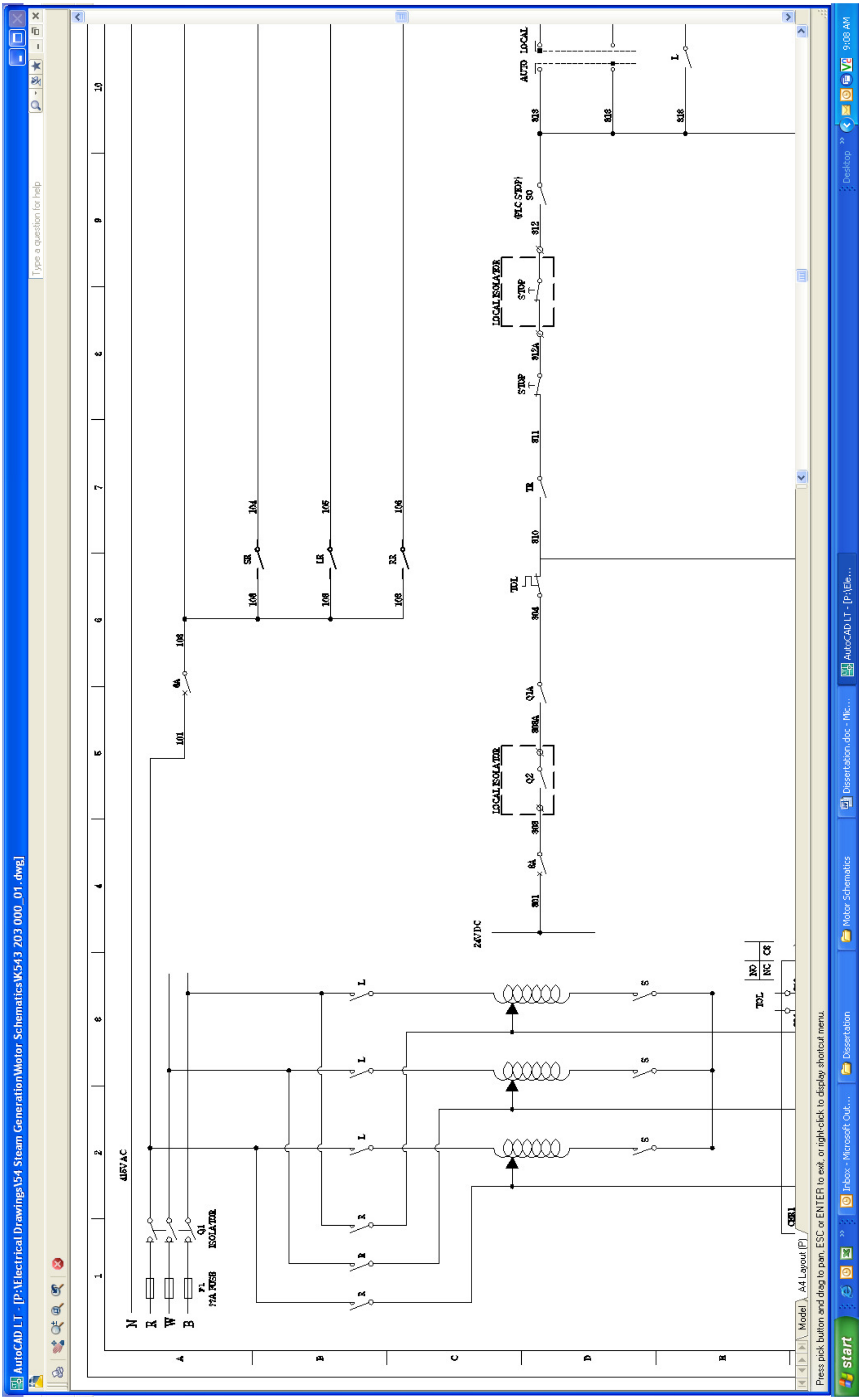

Figure 5.3 Schematic Drawing Number K543203000_01 top left

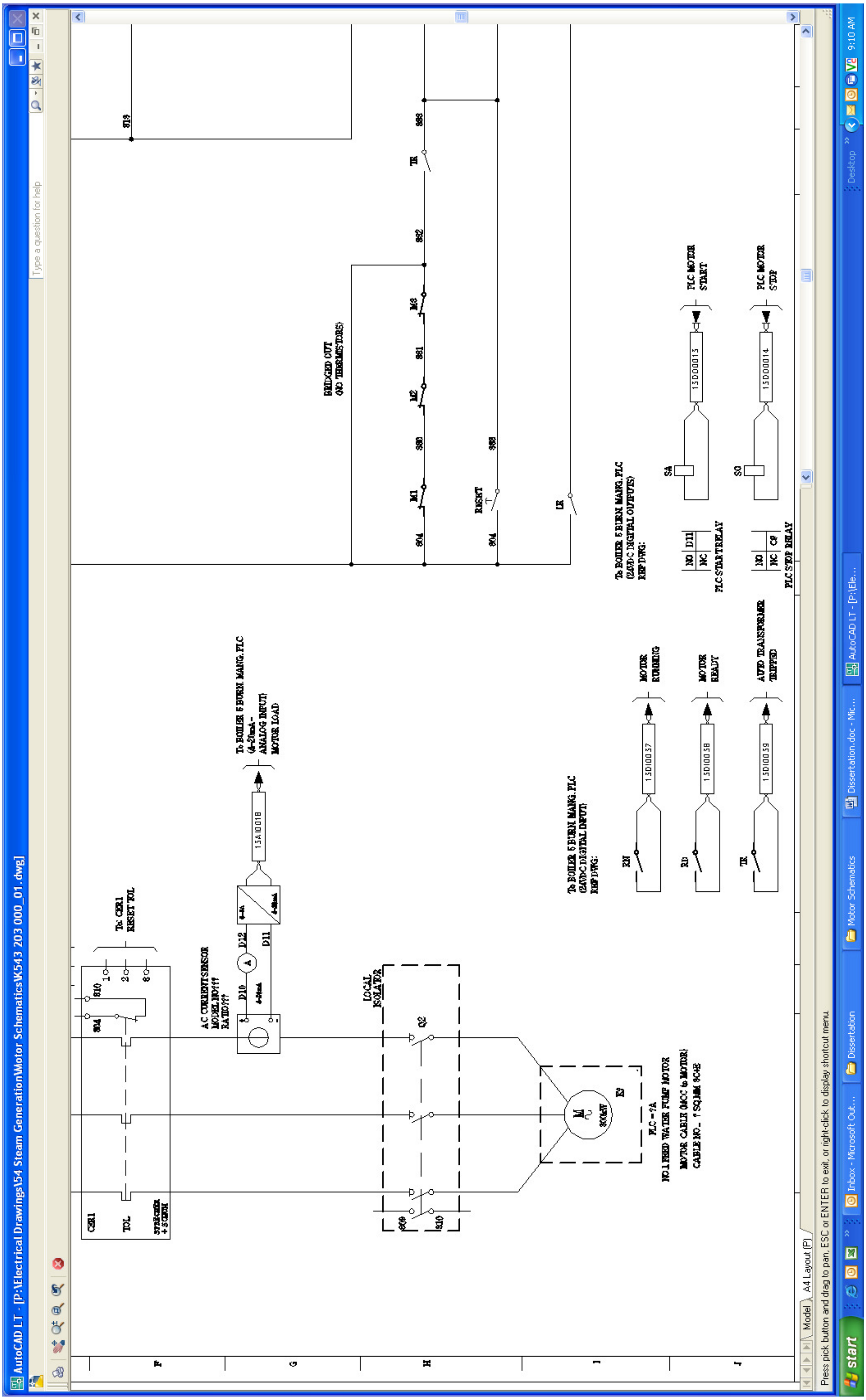

Figure 5.4 Schematic Drawing Number K543203000_01 bottom left

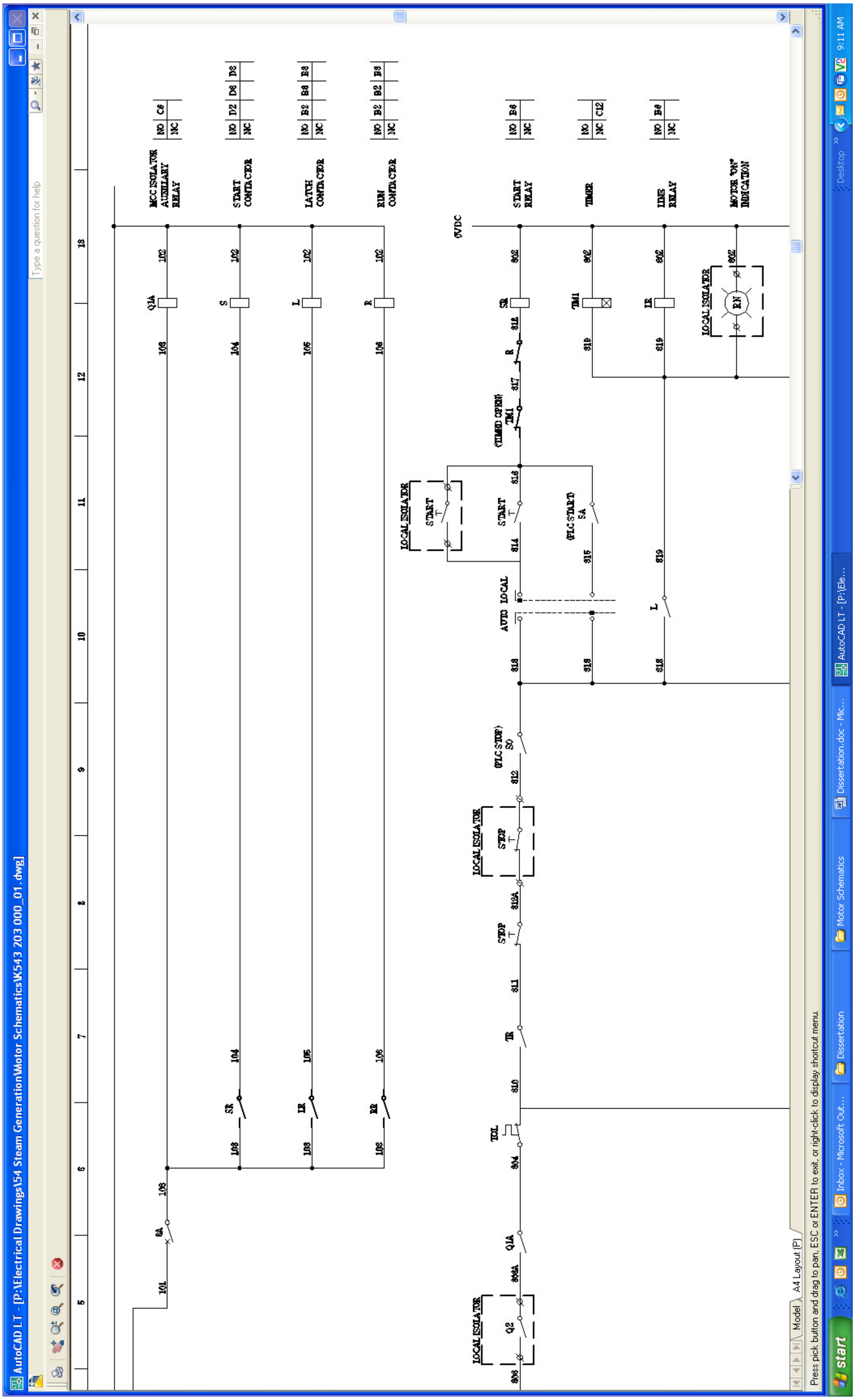

Figure 5.5 Schematic Drawing Number K543203000_01 top right

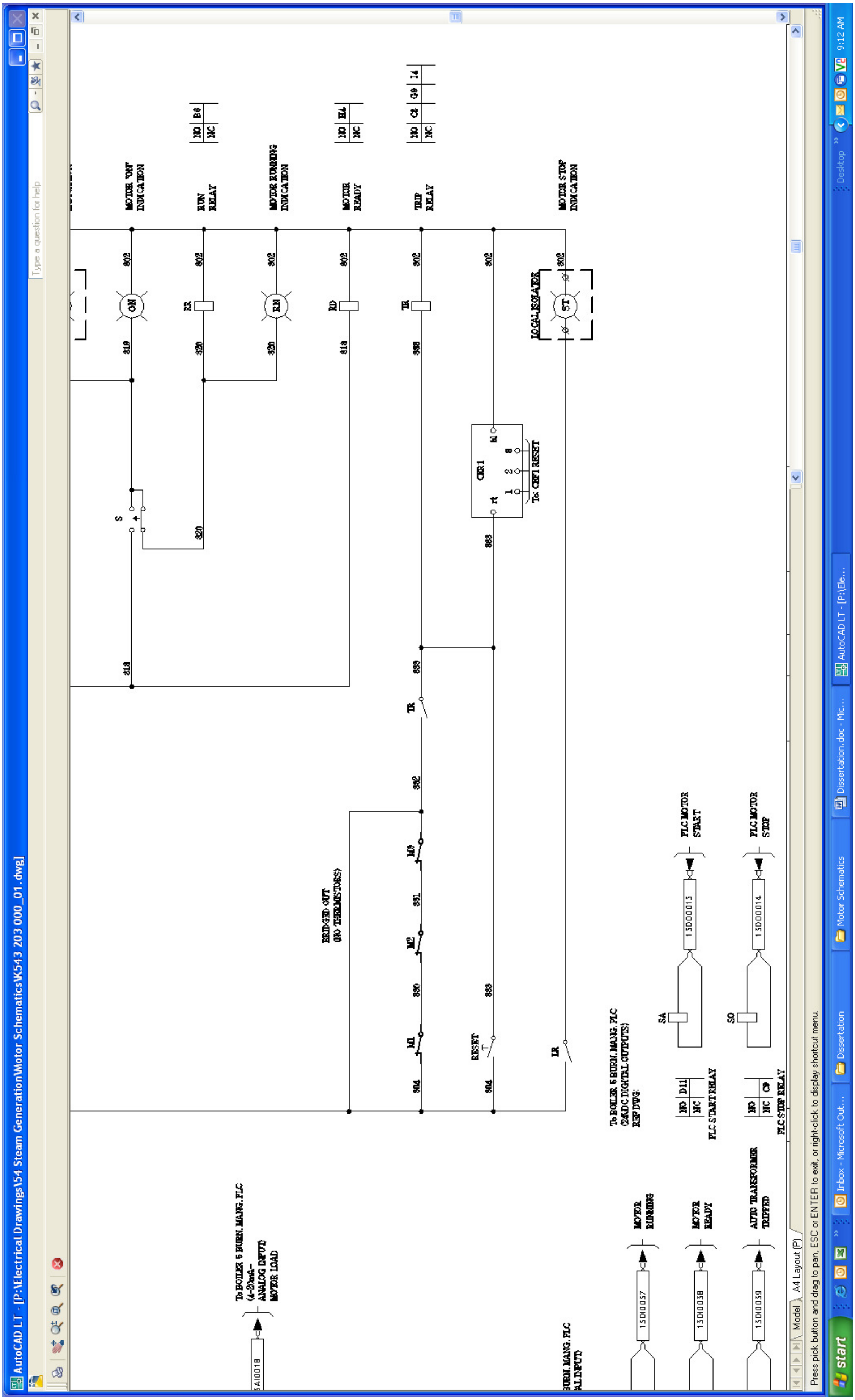

Figure 5.6 Schematic Drawing Number K543203000_01 bottom right

Schematic Explanation – Drawing Number K543203000_01

The motor schematic is divided into 415/240 volt power section and a 24 volt control section. To aid in the explanation of the circuit I will use the reference borders. Numbers 1 to 13 give a horizontal reference while letters A to J down the left hand side give the vertical reference. This helps greatly in locating referenced objects.

Power: The left hand side of the drawing shows the 415 volt supply fed through fuses and an isolator. The handle for the switch is on the front panel of the motor control centre cubicle. After this the power goes through the auto transformer used for reduced current starting.

- S stands for start contactor
- L stands for line contactor
- R stands for run contactor

The current then flows through

- the electronic overload current transformer mounted in the MCC
- the blue phase flows through a CT to give current feedback
- a local isolator
- to the motor terminals

Across the top of the drawing is the 240 volt part of the control circuit. This is necessary because we use 240 volt coils in our power contactors. The start, run and line contactors coils are interfaced with the 24 volt controls through control contacts SR, LR and RR.

Control: The PLC interface relays and panel contacts corresponding to PLC outputs and inputs respectively are shown at the bottom of the drawing. These inputs and outputs are the means by which the controlling PLC sees what's going on and does the corresponding actuations

Outputs

- PLC motor start – relay SA – 13DO00013 (digital output 13)
- PLC motor stop – relay SO – 13DO00014 (digital output 14)

Inputs

- Motor running input - RN – 13DI00037 (digital input 37)
- Motor ready input - RN – 13DI00038 (digital input 38)
- Autotransformer tripped input - TR – 13DI00039 (digital input 39)

Modes of operation: There are 3 modes of operation

1. Local Manual
2. Citect Manual
3. Citect Auto

In local manual mode the auto / local switch on the drawing (located in the MCC) is switched to local. The starting of the pump can only be done from one of the 2 field start buttons

In Citect manual mode the auto / local switch on the drawing (located in the MCC) is switched to Auto. The starting of the pump can only be done from the Citect HMI control page faceplate which must be in manual mode

In Citect manual auto the auto / local switch on the drawing (located in the MCC) is switched to Auto. The starting of the pump can only be done from the Citect HMI control page faceplate which must be in auto mode.

Explanation of start up:

Once the Start button has been pushed (or the SA relay energised via Citect), relay SR is energised and held in by contact SA (NB not possible according to drawing in Local Manual).

1. Relay SR will immediately energise.

   - This will turn on coil S – the start contactor

   - The S contact at F10 will change state energising TM1 and LR.

   - Therefore contactor L will also close. We now have power going through to the motor through a part of the autotransformer. The current is reduced. The star point of the transformer is made with the contacts of contactor S.

2. When TM1 times out after 20 seconds the following happens

   - TM1 contact at D12 opens which de energises SR, S contactor and S contact at F11 returns to original state. This energises RR and in turn R which is the run contactor. In effect the Start contactor contacts open and the Run contactor contact close almost immediately. The impedance introduced during start up via the auto transformer has now been removed.

Protection and other Miscellaneous:

Over current protection

The electronic overload relay made by Sprecher and Schuh is a type CER1. It is shown on the drawing in 2 places – F2 and H11. The indication at F2 shows the 3 phases going through the current transformers of the relay. This is an electronic relay i.e. it doesn't have bi metal strips actuating the trip circuit but rather electronic sensing.

Wire numbers 304 and 310 are connected to the normally closed contact of the relay. They are also shown at position C6 where they open the control circuit in the event of a thermal overload.

The same relay needs 24volts supplied to it to operate. This is shown at H11.

Auto transformer winding temperature protection

The auto transformer has thermistors embedded in its windings. When the temperature rises above a set value the thermistors pass enough current to energise the protection relays M1, M2, M3. The contacts off these relays are shown at H7 and H8. The trip relay TR needs to be energised otherwise the control circuit is open at D7.

Once the thermistors have tripped the circuit the motor cannot be restarted until the reset button at H7 has been pressed. TR is then held in by its own latching contact and resupplies power to the CER1 relay.

Displayed on the next page are 3 photos which give better detail of figure 5.1

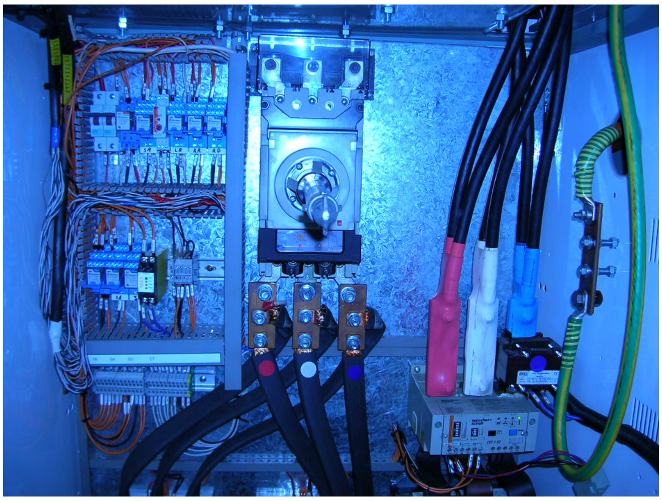

Figure 5.7 24 volt circuit, main isolator, electronic overload

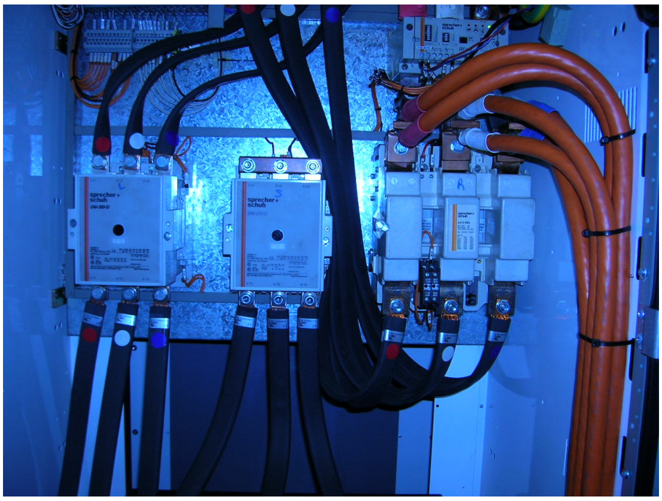

Figure 5.8 24 power contactors line, star and run

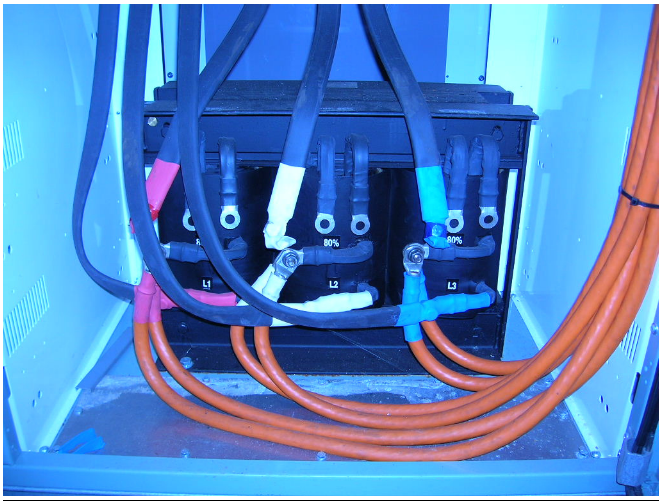

Figure 5.9 auto transformer

Chapter 5.2 PLC

The choice of PLC was based on many factors. Firstly and most importantly it is important to standardise our equipment. Therefore as long as the predominant brand of PLC in the factory could do a good job and fulfil the requirements of the project it would be difficult to justify buying a different type of PLC.

Many factors must be considered when deciding on the right PLC. Typical specifications that should be considered

- CPU clock speed
- User memory size
- Scan time
- I/O capacity

The specifications for hardware selected can be found in Appendix B

Other issues that must be considered include less technical but equally important

- Ease of programming
- Cost of equipment
- Replacement part accessibility
- Communication ports
- Software compatibility

There are several types of PLC systems within the Modicon family of PLC. These different types have been developed to suit different applications. A brief description follows

- Quantum – This is a larger system used to control a big integrated plant. Memory size is larger, CPU speed faster and it lends itself to remote drops connected via communication cables. Can easily be connected to various communication protocols such as Ethernet, Modbus and Modbus +

- Momentum – This is a smaller, more compact PLC. It is very versatile and can be connected remotely to remote drops. It tends to be for smaller, more spread out plant.

- Compact – This is also a smaller PLC but is now becoming outdated and it is now being superseded by the Momentum

We decided to use the Quantum system as this system is already used extensively in the factory and lends itself well to the application. It is envisioned to rewire the whole motor control centre to PLC in the near future. The Quantum system is best for expanding into the future.
We are using a PLC to interface the plant controls with that of the motor. The hard wired motor controls that were explained in the previous chapter are self contained to a certain point. However to allow the operator to interact with the

plant via the computer screens and to provide automatic monitoring, alarming and control, the PLC is used. The PLC communicates with the real world via analogue and digital inputs and outputs. As shown on the previous schematic drawings they are as follows.

Digital inputs

• Motor running	digital input 13DI0037
• Motor ready	digital input 13DI0038
• Auto transformer tripped	digital input 13DI0039

Digital outputs

• PLC motor start	digital output 13D00013
• PLC motor stop	digital output 13D00014

Analogue Input

• Motor Load	analogue input 13AI0018

Apart from the inputs and outputs that are shown on the schematic there are others that are also associated with the project. These include

- Digital inputs from the 4 feed water valves that must be open before the pump can run. There is an isolation and control valve on both sides of the pump. i.e. suction and discharge

- Digital inputs from the other 2 feed water pumps to indicate if they are running

- Analogue inputs from a differential pressure transmitter across an inlet filter to show when it needs to be cleaned and a gauge pressure transmitter on the suction side of the pump.

PLC Hardware

The hardware comes as separate modules that clip onto a backplane.
Some of this equipment was already installed for earlier work but to understand the system it is necessary to describe all of the existing and new equipment. The modules described below are arranged from right to left on the backplane

- Power supply – CPS224 00. This is the 24 volt power supply to the backplane. It is supplied by 240 volts and is rated at 8 amps.

- Central processing unit – CPU53414B. This is where the program resides. It has battery backup which holds the program in RAM if power is lost. There are 3 communication ports on the front – 2 are Modbus and the other is Modbus+. They are female DB9 sockets.

- Ethernet interface – NOE77701. This is a dedicated communication module that is configured to relay data between the CPU and the factory network. It has an IP address. The information transferred it used by the SCADA program CITECT on the operator monitors to allow personnel to interact with that plant.

- Remote drop – CRP93100. This is the master head for a communication link between backplanes or drops. Another backplane(drop) is located remotely which has input and output cards which send information through this link to the CPU

- Analogue Input card – ACI04000. This is where the wiring from field analogue devices interfaces with the PLC. Nominally they are supplied from a separate 24 volt supply and input 4 to 20mA to the module corresponding to such things as pressure, flow and level.

- Analogue Output card – ACO13000. This is where the wiring to field analogue devices interfaces with the PLC. Nominally they are supplied from a separate 24 volt supply and output 4 to 20mA to field devices such things as actuator positioners and digital displays.

- Digital input card – DDI35300. This is where the wiring from field digital devices interfaces with the PLC. Nominally they are supplied from a separate 24 volt supply and are either on or off. The relays in the motor control cubicle tell the PLC if the motor is running, ready and tripped via this card.

- Digital output card – DDO35300. This is where the wiring to field digital devices interfaces with the PLC. Nominally they are supplied from a separate 24 volt supply and are either on or off. The interface relays in the motor control cubicle that start and stop the motor are driven via this card.

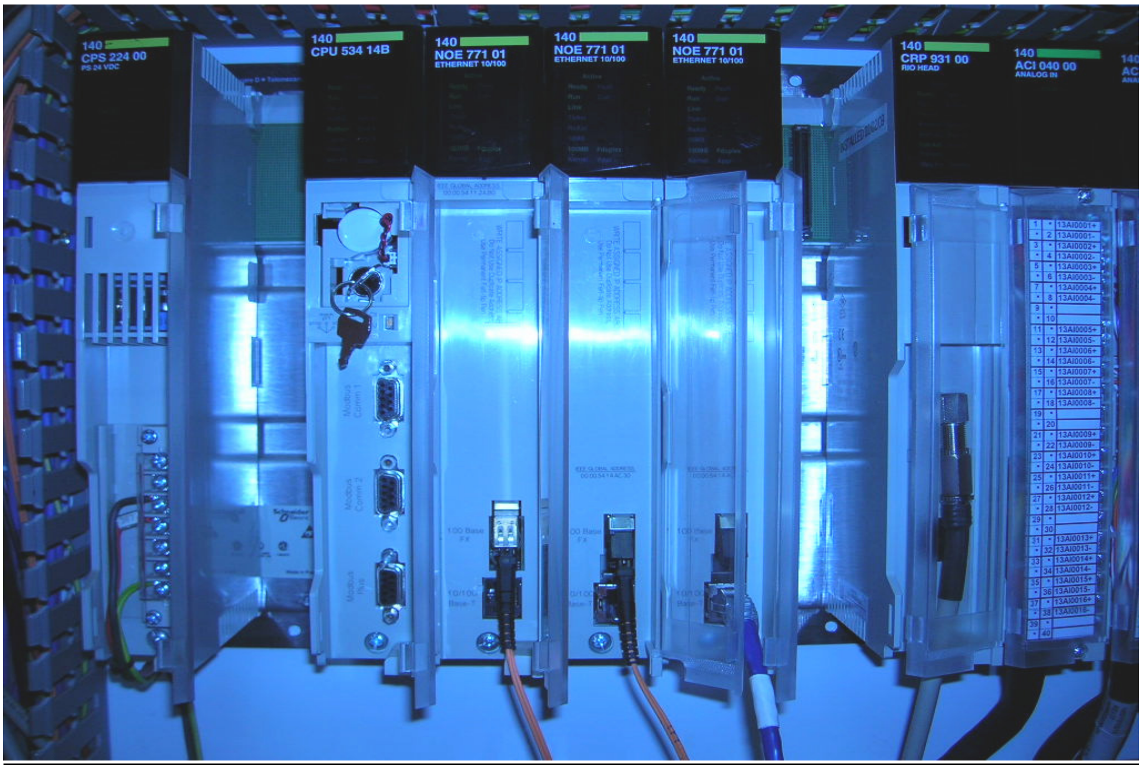

Figure 5.10 Close up of PLC rack

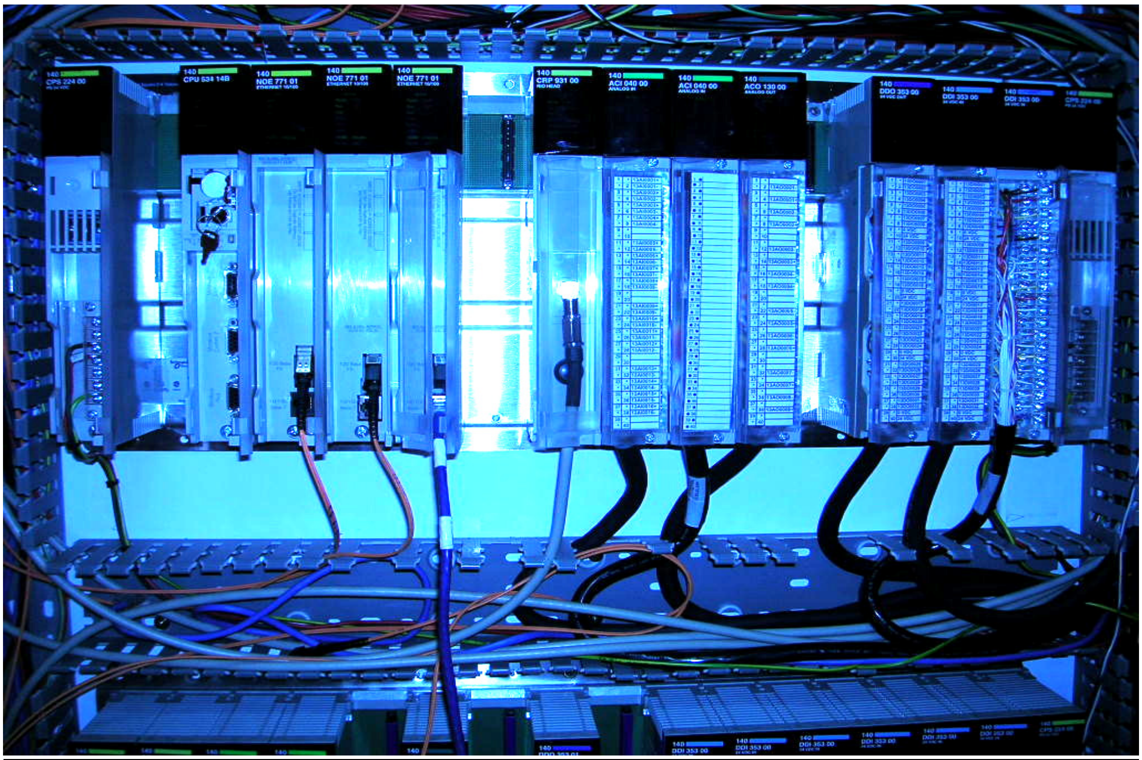

Figure 5.11 Whole PLC rack

Software

We are using Modicon software to program the PLC. The name of the software is Concept. In comes in 4 different forms

- Function block diagram
- Structured text
- Ladder
- Sequential flow chart

Each of these forms has been developed to conform to an IEC standard. They have each been developed to suit different types of applications. For a process that has a lot of complicated, inter related steps Sequential flow chart is a better option. For a continuos process which requires a variety of functions Function block diagram is the most suitable. This is what we have used.

There is a library of function blocks that perform many functions. For our particular application only a handful are required. The simplest types are AND, OR, NAND, NOR type blocks that most people understand

PLC Logic Explanation

I start my explanation with the reference to the screen dumps below of the Concept program. The first image shows the overall page of the function block diagram.

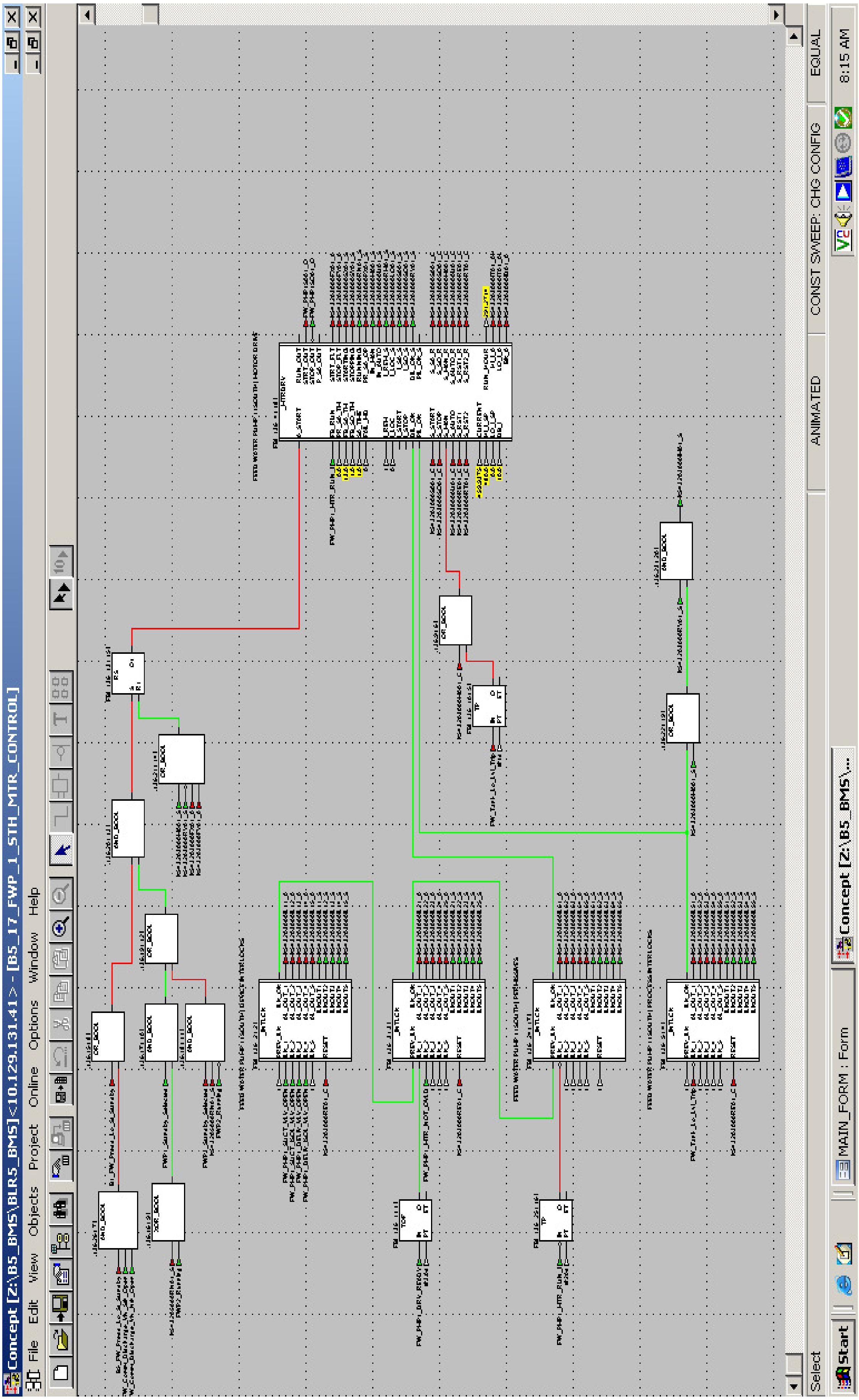

Figure 5.12 Complete FBD page

Overall FBD page
I have split this up into 3 pages to allow for easier explanation.

1. Figure 5.13 – Basically the right hand side of the page contains the motor drive block. First is the explanation of the motor drive block. Refer to image C2.
2. Figure 5.14 – The top left of the page contains several AND and OR blocks which is the auto start logic
3. Figure 5.15 – The bottom left of the page which is the interlock logic

Figure 5.13

Refer to the figure below.
The _MTRDRV block is the main control block used to control the motor. It is a derived block i.e. not provided with the programming software but rather developed by the end user company – in this case CSR. Although the internal workings of the block are not presented here the tables following give an understanding of how the signals are processed.
The left side of the block show the inputs to it and the right side shows the outputs from it.
The input and output tables 3 and 4 following the figure explain how the block works.

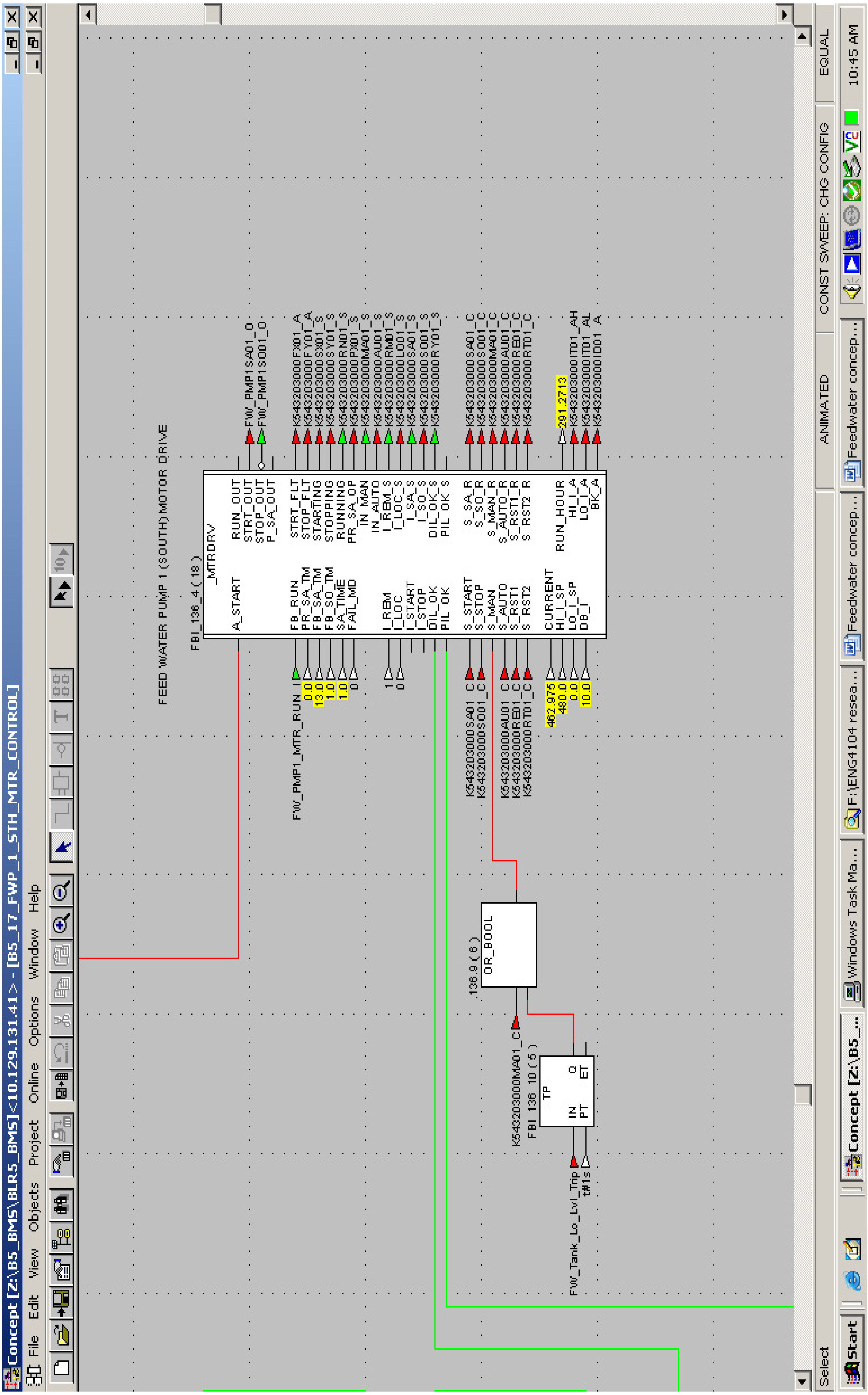

Figure 5.13 Motor drive block – right hand side of complete FBD page

<table>
<tr><td>A_START</td><td colspan="2">This is the start input when the block is in auto mode. The output STRT_OUT will turn on when this is on. This bit is controlled by logic on the same FBD page and will be explained after</td></tr>
<tr><td>FB_RUN</td><td colspan="2">Real world input I037, 0.1.1.15 from schematic drawing to say motor is actually running</td></tr>
<tr><td>PR_SA_TM</td><td>Prestart time</td><td rowspan="5">All variables that are able to be accessed and change from the citect page. The block compares these values to actuals and raises an alarm on citect if values are outside specified limits</td></tr>
<tr><td>FB_SA_TM</td><td>Starting wait time</td></tr>
<tr><td>FB_SO_TM</td><td>Stopping wait time</td></tr>
<tr><td>SA_TIME</td><td>Starting time</td></tr>
<tr><td>FAIL_MD</td><td></td></tr>
<tr><td>I_REM</td><td colspan="2">Remote – set to ‘1’. This means remote inputs are used to control the block in manual mode.</td></tr>
<tr><td>I_LOC</td><td colspan="2">Local – set to ‘0’</td></tr>
<tr><td>I_START</td><td colspan="2">Local start – Not used</td></tr>
<tr><td>I_STOP</td><td colspan="2">Local stop – Not used</td></tr>
<tr><td>DIL_OK</td><td colspan="2">Device interlocks. Those interlocks that are directly associated with the pump. Input must be on to start the motor. Logic feeding this will be explained below</td></tr>
<tr><td>PIL_OK</td><td colspan="2">Process interlocks. As above but associated interlocks to other parts of the plant</td></tr>
<tr><td>S_START</td><td>Start</td><td rowspan="6">Citect inputs from faceplate
Remote manual and auto control</td></tr>
<tr><td>S_STOP</td><td>Stop</td></tr>
<tr><td>S_MAN</td><td>Manual</td></tr>
<tr><td>S_AUTO</td><td>Auto</td></tr>
<tr><td>S_RST1</td><td>Reset</td></tr>
<tr><td>S_RST2</td><td>Reset</td></tr>
<tr><td>Current</td><td colspan="2">Real world analogue input indicating motor current 3018, 0.1.1.10</td></tr>
<tr><td>HI_I_SP</td><td colspan="2">This is a value that is used to generate alarms.It can be adjusted via the plc progam or directly from Citect</td></tr>
<tr><td>LO_I_SP</td><td colspan="2">This is a value that is used to generate alarms.It can be adjusted via the plc progam or directly from Citect</td></tr>
<tr><td>DB_I</td><td colspan="2">This is a value that is used to generate alarms.It can be adjusted via the plc progam or directly from Citect</td></tr>
</table>

Table 2 MTR_DRV Block inputs

<table>
<tr><td>START_OUT</td><td colspan="2">Real world output 0013 drop 1, rack1, slot13. Used in wiring schematic to turn on motor</td></tr>
<tr><td>STOP_OUT</td><td colspan="2">Real world output 0014 drop 1, rack1, slot13. Used in wiring schematic to turn off motor</td></tr>
<tr><td>START_FLT</td><td colspan="2">Used in Citect to generate an alarm</td></tr>
<tr><td>STOP_FLT</td><td colspan="2">Used in Citect to generate an alarm</td></tr>
<tr><td>STARTING</td><td colspan="2">Used in Citect to generate an alarm</td></tr>
<tr><td>STOPPING</td><td colspan="2">Used in Citect to display</td></tr>
<tr><td>RUNNING</td><td colspan="2">Used in Citect to display if motor is running</td></tr>
<tr><td>PR_SA_OP</td><td colspan="2">Not used</td></tr>
<tr><td>IN_MAN</td><td colspan="2">Used in Citect to display if motor is in manual</td></tr>
<tr><td>IN_AUTO</td><td colspan="2">Used in Citect to display if motor is in auto</td></tr>
<tr><td>I_REM_S</td><td colspan="2">Used in Citect to display if motor is in remote</td></tr>
<tr><td>I_LOC_S</td><td colspan="2">Used in Citect to display if motor is in local</td></tr>
<tr><td>I_SA_S</td><td colspan="2">Used in Citect to display if motor has started</td></tr>
<tr><td>I_SO_S</td><td>Start</td><td rowspan="6">Data sent back to Citect to display Remote manual and auto control</td></tr>
<tr><td>S_STOP</td><td>Stop</td></tr>
<tr><td>S_MAN</td><td>Manual</td></tr>
<tr><td>S_AUTO</td><td>Auto</td></tr>
<tr><td>S_RST1</td><td>Reset</td></tr>
<tr><td>S_RST2</td><td>Reset</td></tr>
<tr><td>Current</td><td colspan="2">Real world analogue input indicating motor current 3018, 0.1.1.10</td></tr>
<tr><td>HI_I_SP</td><td colspan="2">This value is sent to Citect</td></tr>
<tr><td>LO_I_SP</td><td colspan="2">This value is sent to Citect</td></tr>
<tr><td>DB_I</td><td colspan="2">This value is sent to Citect</td></tr>
</table>

Table 3 MTR_DRV Block outputs

Figure 5.14
Refer to Figure 5.14

The A_START input is the start input when the block is in auto mode. The logic that controls this block is on the left hand top side if the FBD page

Explanation

By starting output Q1 stays on even after the S input has gone off. After S is 0, the R1 input must go to 1 for the output to go off. The output is the input to the A_START of the MTR_DRV block which is the auto on command.
from the right hand side, we have a RS(reset-set block) which is the same as a flip flop. Therefore the
It is important to note when deciphering in the logic that there are 3 feed water pumps in the system of which this is the control for feed water pump 1. They supply a common manifold that feeds the 2 boilers in the factory.

Descriptively the RS flip flop needs the following to get a high on the output

- Either of the boilers is low on pressure
- And either
    1. this feed water pump (feed water pump 1) is selected on standby
    2. or pump 3 is on standby and pump 2 is not running

To stop the pump in auto mode you need a high signal on the R input to the flip flop while there is a low on the S input. This corresponds to all of the above conditions not being met and any of the inputs to the OR block feeding the flip flop R input being met.

There are 4 'interlock' block placed vertically on the page. The first one is displayed on this figure. The next 3 are displayed on figure 5.15.The first 3 are essentially wired in series and feed the DIL interlock input of the MTR_DRV block. This means all the inputs to these three interlock blocks need to be on to allow the motor to start no matter what mode it is in. Those interlocks are listed below

First block
- pump inlet control valve open
- pump inlet isolation valve open
- pump outlet control valve open
- pump outlet isolation valve open

There are proximity switches on these valves that indicate they are open

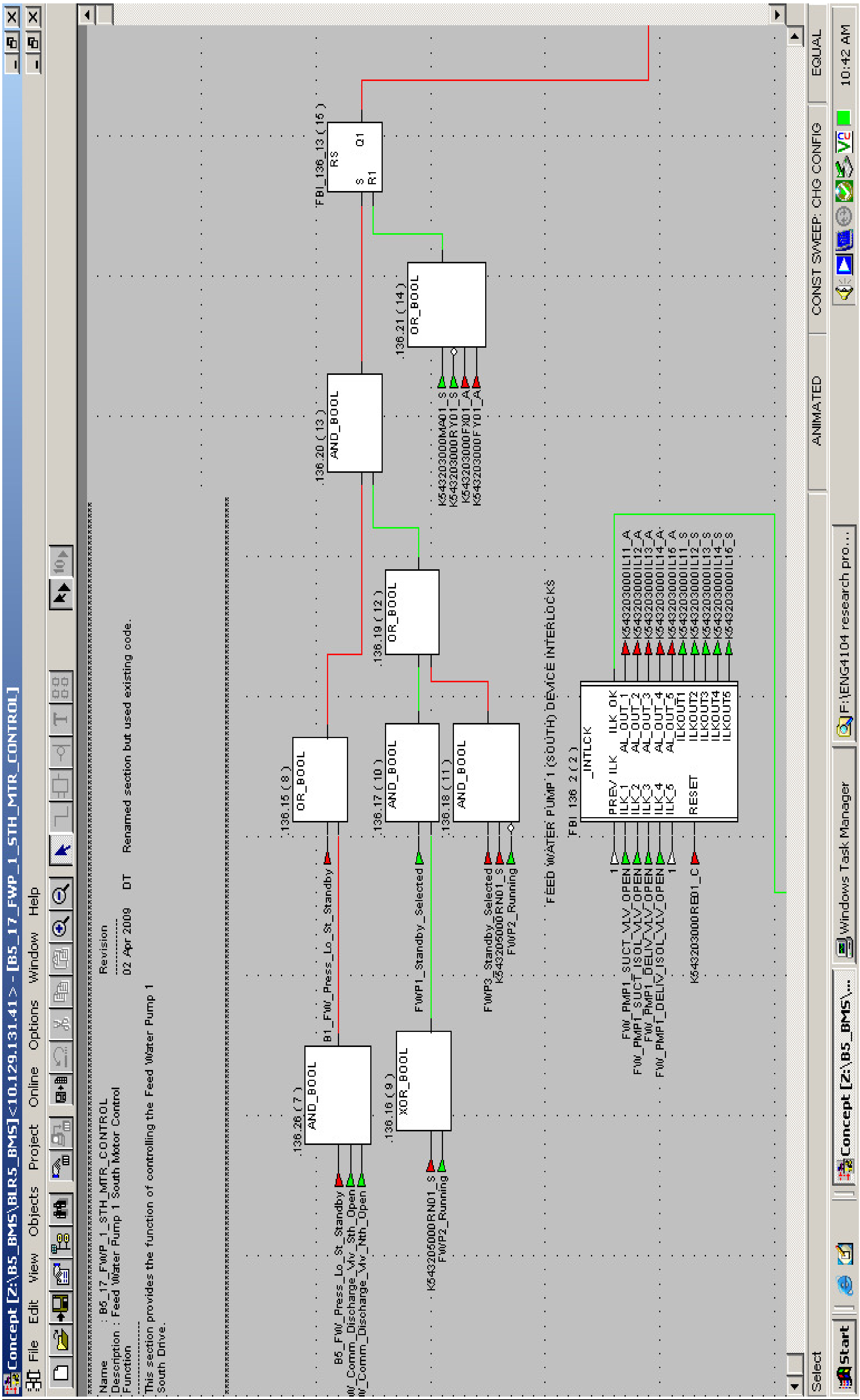

Figure 5.14 left hand top corner of the FBD page

Figure 5.15
Refer to image figure 5.15 below

Explanation

First block

- There is a 3 second time delay shown which prevents the motor being reset for that time after an overload event
- The motor overload is shown here as an interlock

Second block

- A pulse timer feeds the input of this block. Essentially it prevents the motor being restarted within 20 seconds of it being turned off to prevent damage. It uses the input shown on the schematic which comes off the RUN contactor.

Third block

- The feed water tank level needs to be above the level low trip value. This interlock is there to prevent cavitation of the pumps

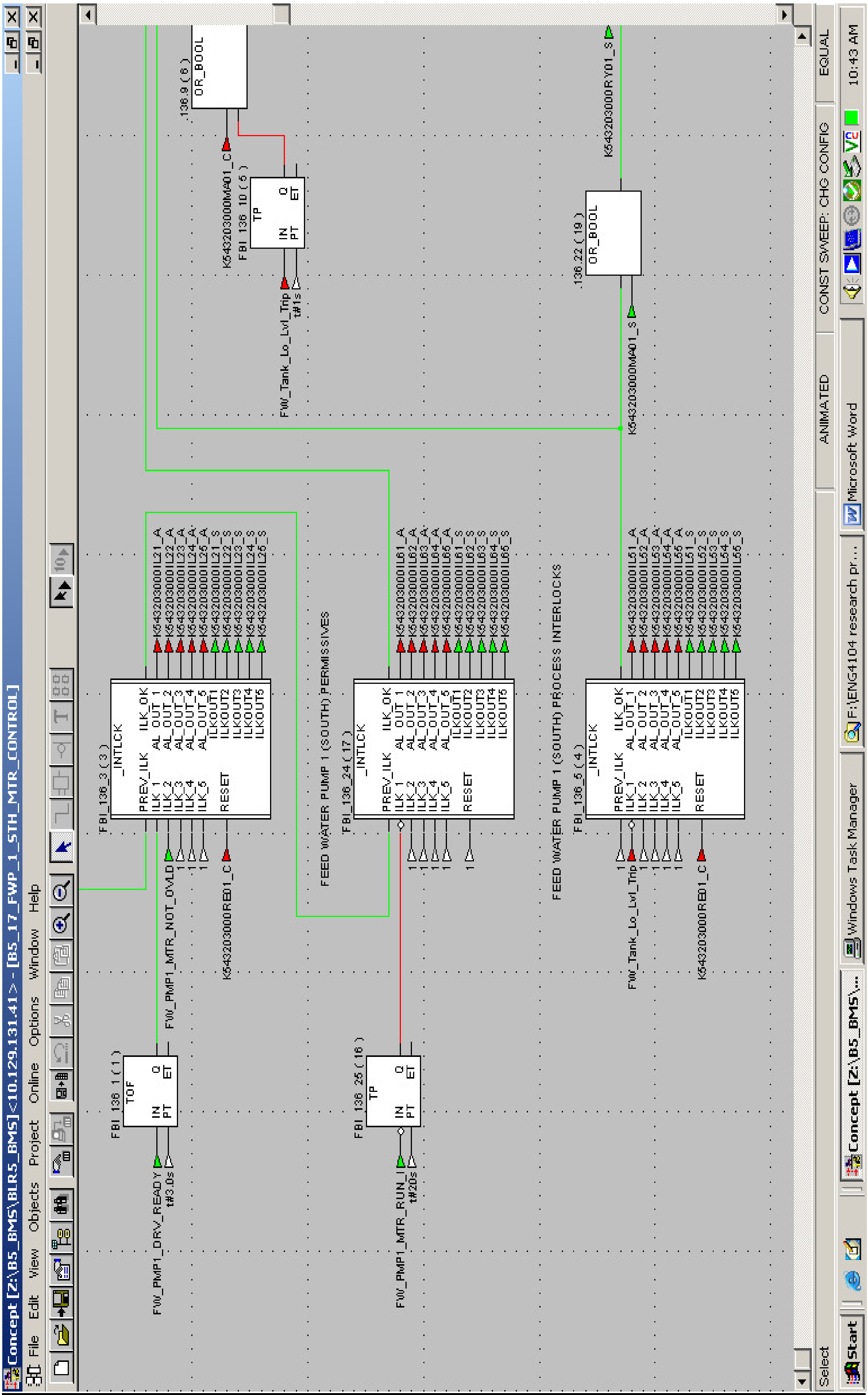

Figure 5.15 left hand bottom corner of the FBD page

Chapter 5.3 SCADA

SCADA is an acronym for Supervisory Control and Data Acquisition. It is a means of HMI (human / machine interface). To interface between the operator and machinery a SCADA program is used to create an image of the plant. These images are assembled as pages that can be switched between on a computer monitor.

The particular software product used in this project is called Citect.
We used a program called Citect which gets its information from the PLC, discrete components and operator input.
This program allows the operator to

1. See what's going on
2. Intervene manually when necessary
3. Diagnose faults
4. Read alarms when conditions are out of acceptable range

There are several packages within the Citect program. They are Builder, Editor and Runtime. In Citect builder the pages are created. The aim is to imitate the plant on the screen. A library of objects is used to give a visual picture of the plant. Citect Editor is used to configure Citect to communicate with other devices such as PLCs. Citect Runtime is the mode that the software runs in when being used by the operators. The information is current and the real world devices can be interfaced.

The following images are screen dumps of some of the pages developed for this project.
Figure 5.16
The feed water pump associated with this project is called No.1 FW Pump (South) shown near the middle of the page. Features of interest include

- The pump symbol is green indicating that it is running. It turns red when it is stopped
- The suction and delivery valves are also shown in green because they are open
- 3 analogue input displays next to the pump give real time values of strainer differential pressure, suction pressure and motor load
- The 3 feed water pumps supplying a common manifold which feeds both the boiler drums are clearly shown with connecting pipe work

Figure 5.17

When the image of the feed water pump is double clicked the window shown in this figure pops up. This is typical of a digital device window. This is a very useful fault finding tool for the operators. The parameters list under the headings of Permissives, Device interlocks and Process interlocks have a circle next to them. If the pump won't start for any of the reasons described by the parameters, the circle will be coloured blue. This lets the operator know straight away what's preventing the motor from running.

The information in this window is linked heavily with the PLC program. Lots of the information in the Concept FBD is shown on the page. As well as the parameters this includes information on the MTR_DRV block such as Run Hours, Current Hi alarm and Current Lo alarm. The setting of the alarm points can be changed directly from Citect when you are logged in under an appropriate name. This saves having to go into the PLC program to do it.
Also of note on the left hand side of the window is the auto/manual control. This is selected on the window with the 'A' or the 'hand' symbol on the left hand bottom corner.

Figure 5.18

This window is typical of an analogue loop window. It has popped up by double clicking on the B1 Feed water Pressure control box on figure#. This window interacts with a Proportional-Integral control loop programmed within the PLC. Note the PV and SP boxes on the left hand side. This corresponds to process variable and set point of the analogue control loop. The output of the loop is shown as a value of 19.5 in the green box which is a percentage output based on the difference between to PV and SP.
Note the trend on the right hand side trends what the valve has been doing over time with respect to PV, SP and output.

Figure 5.19

This is an active alarm page. Note that on the 3 previous pages on the bottom menu bar the most recent current alarm is displayed. To the left of the alarm are 3 'clock' symbols representing active, summary and disabled alarms. This figure shows an example of active alarms. The different colours represent varying degrees of alarm - active, urgent and critical. They are also audible and need to be reset or disabled to turn off the audible alarm. This ensures the operator is aware of the alarm condition.

Figure 5.20

This is a photo of the control desk where the operator sits. There are three monitors to allow the viewing of 3 different pages at once

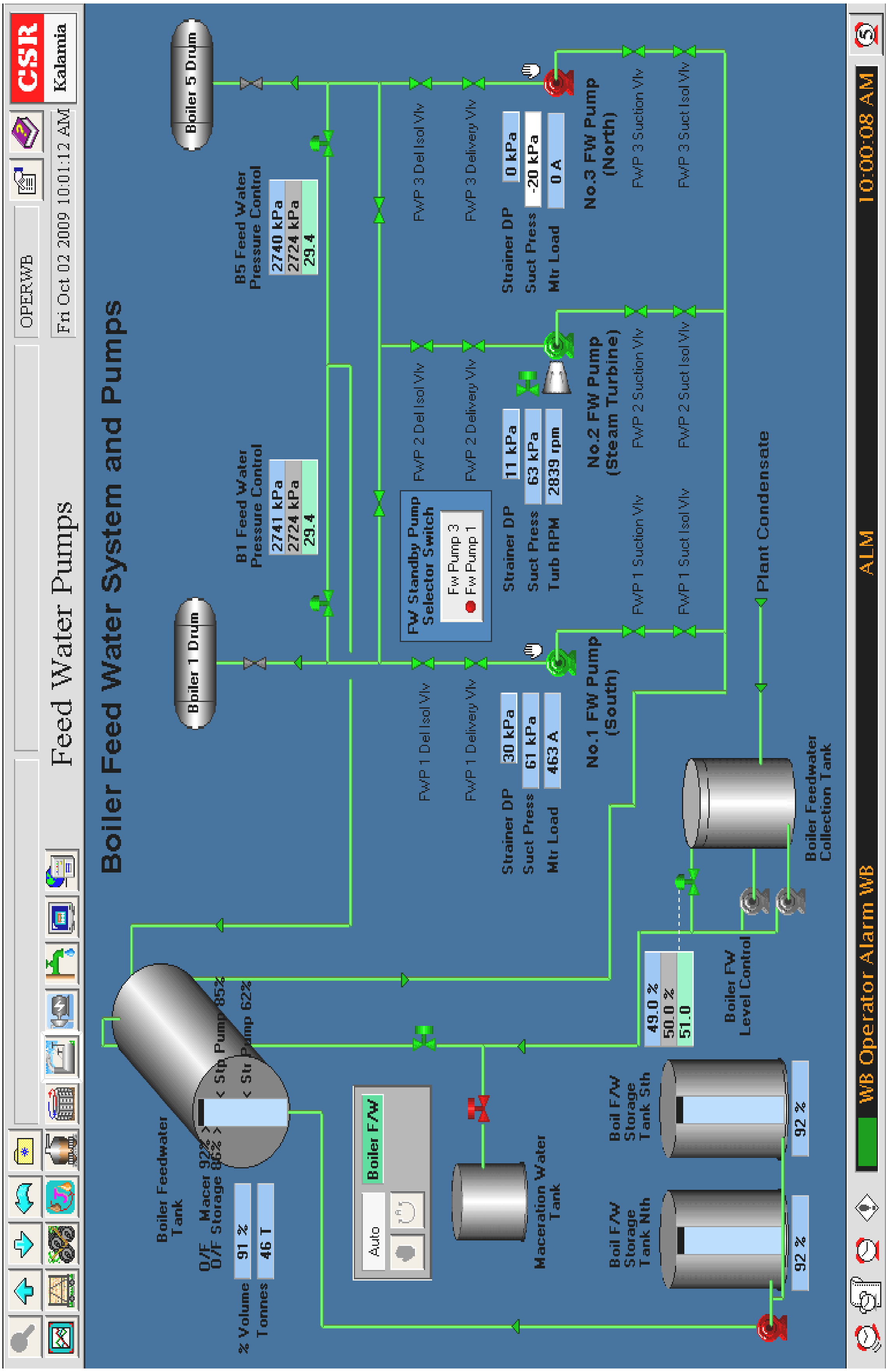

Figure 5.16 Page displaying boiler feed water system and pumps

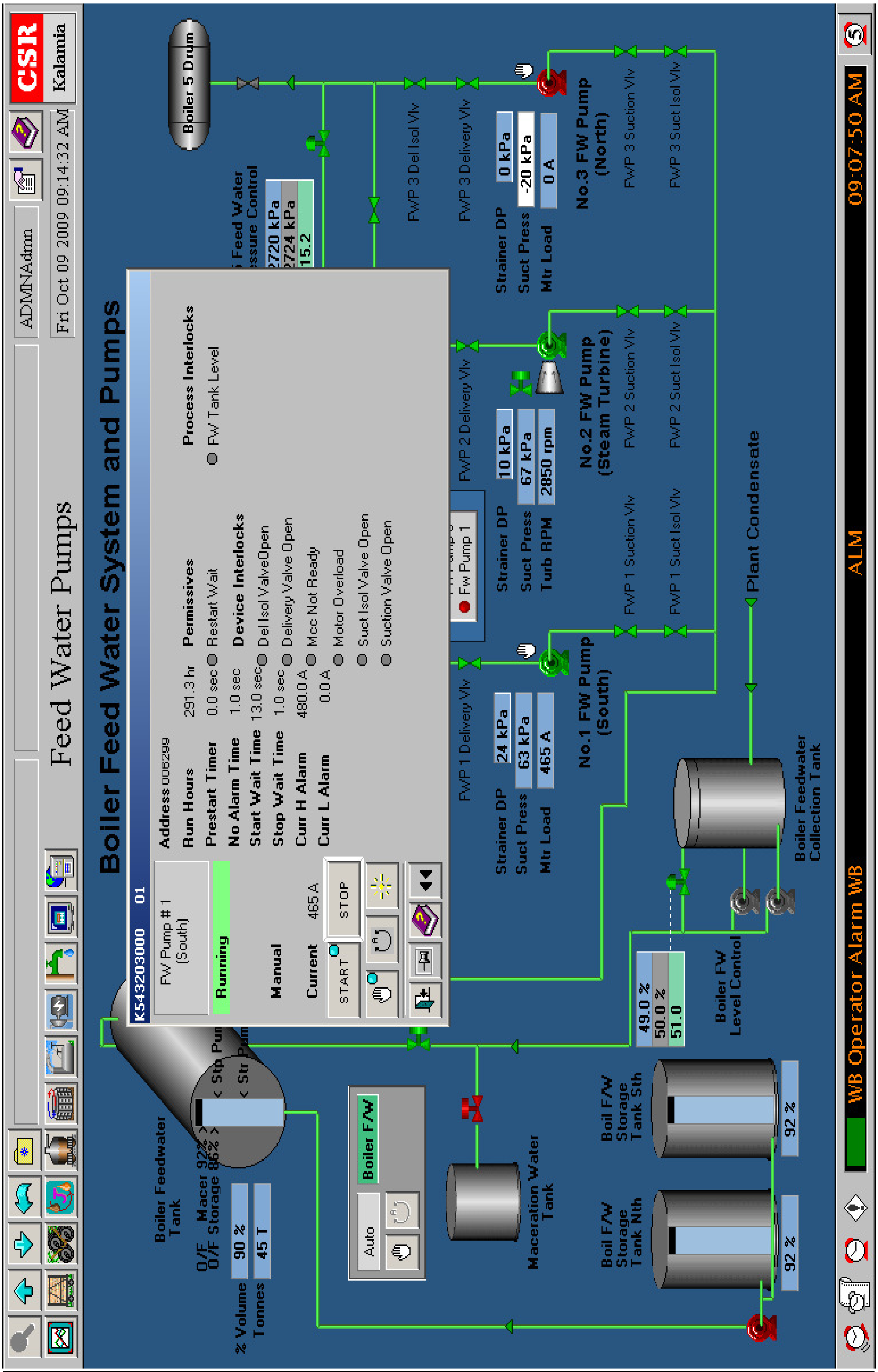

Figure 5.17 Digital device window

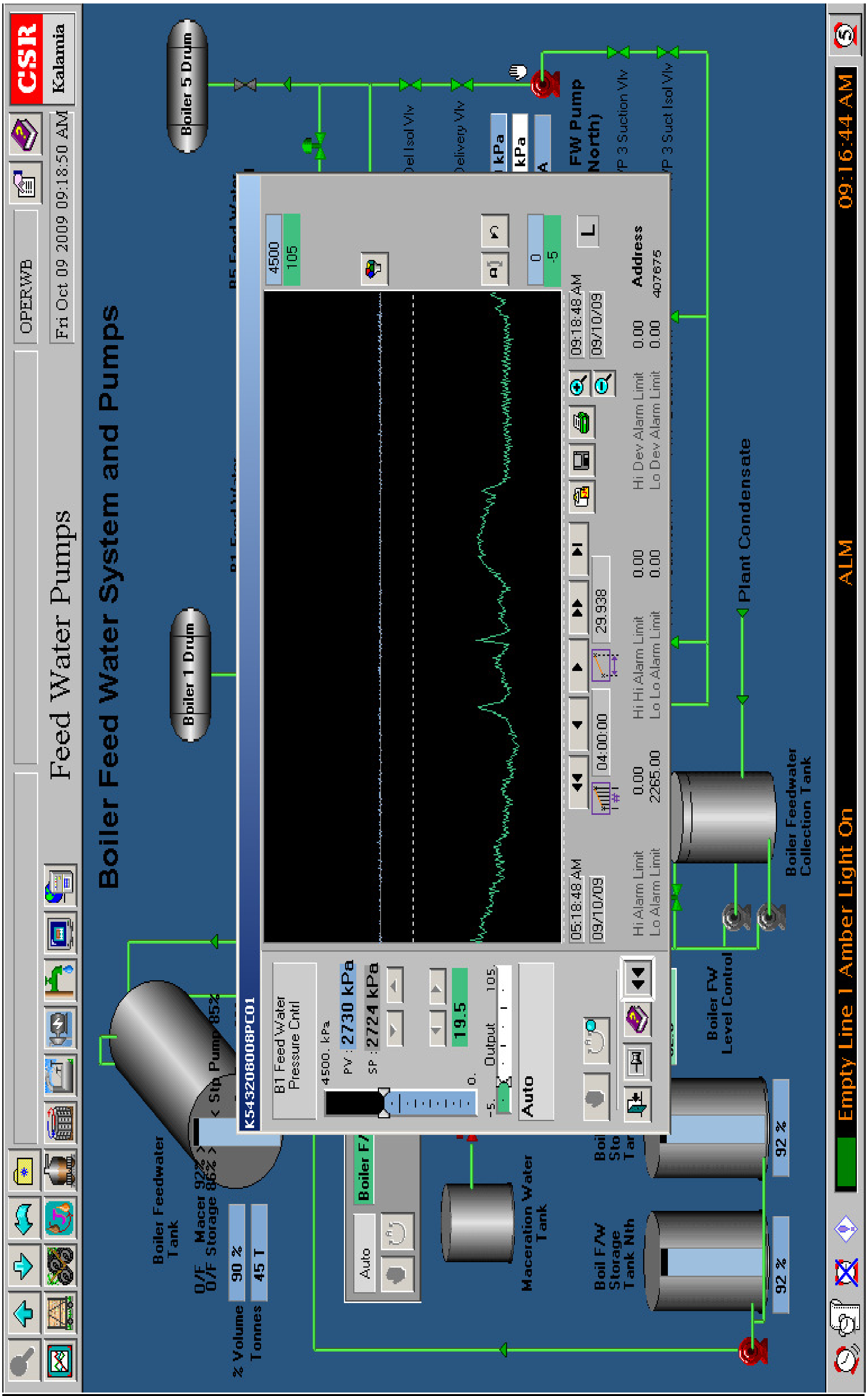

Figure 5.18 Page displaying trend of analogue device

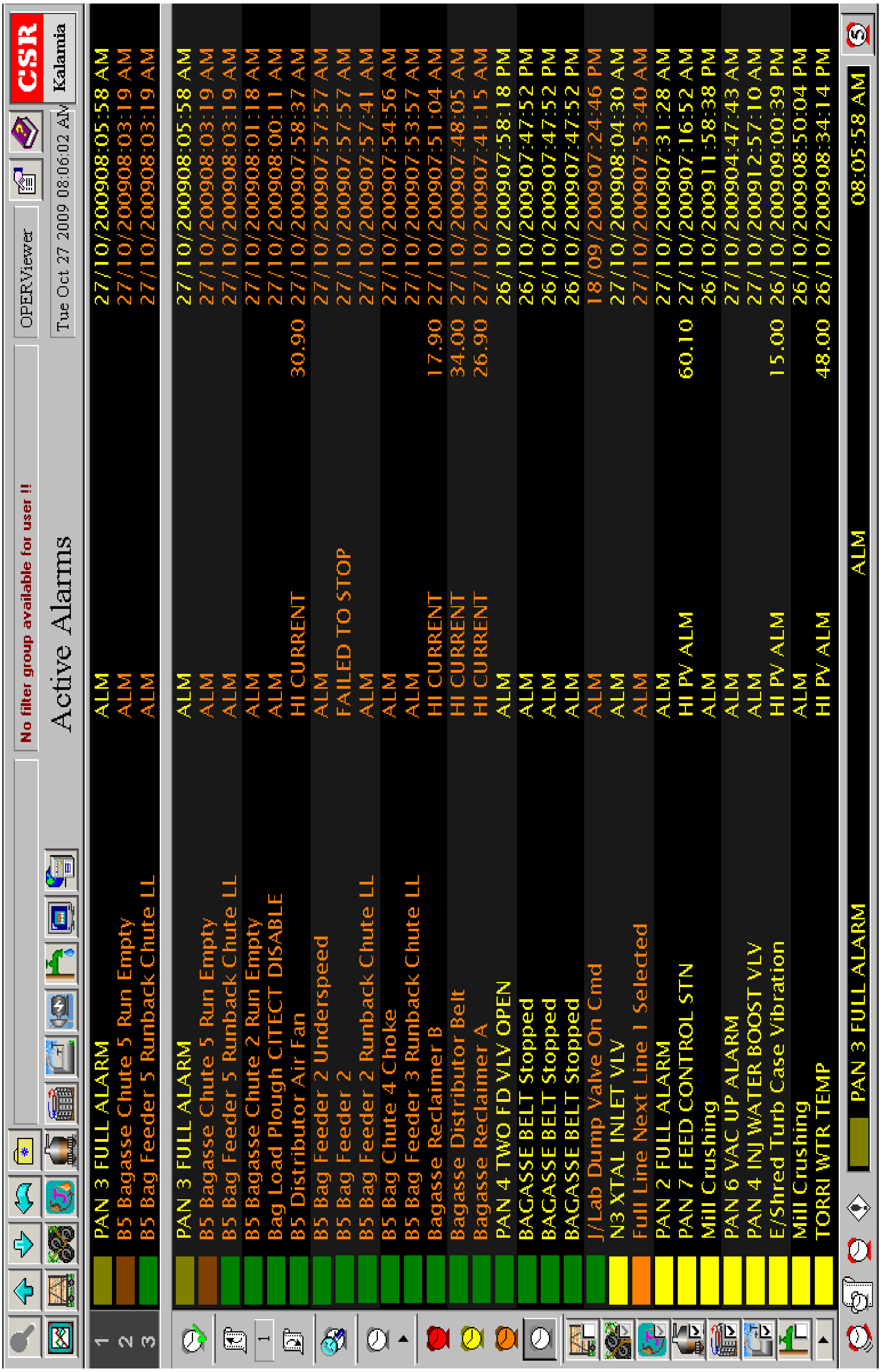

Figure 5.19 Alarm page

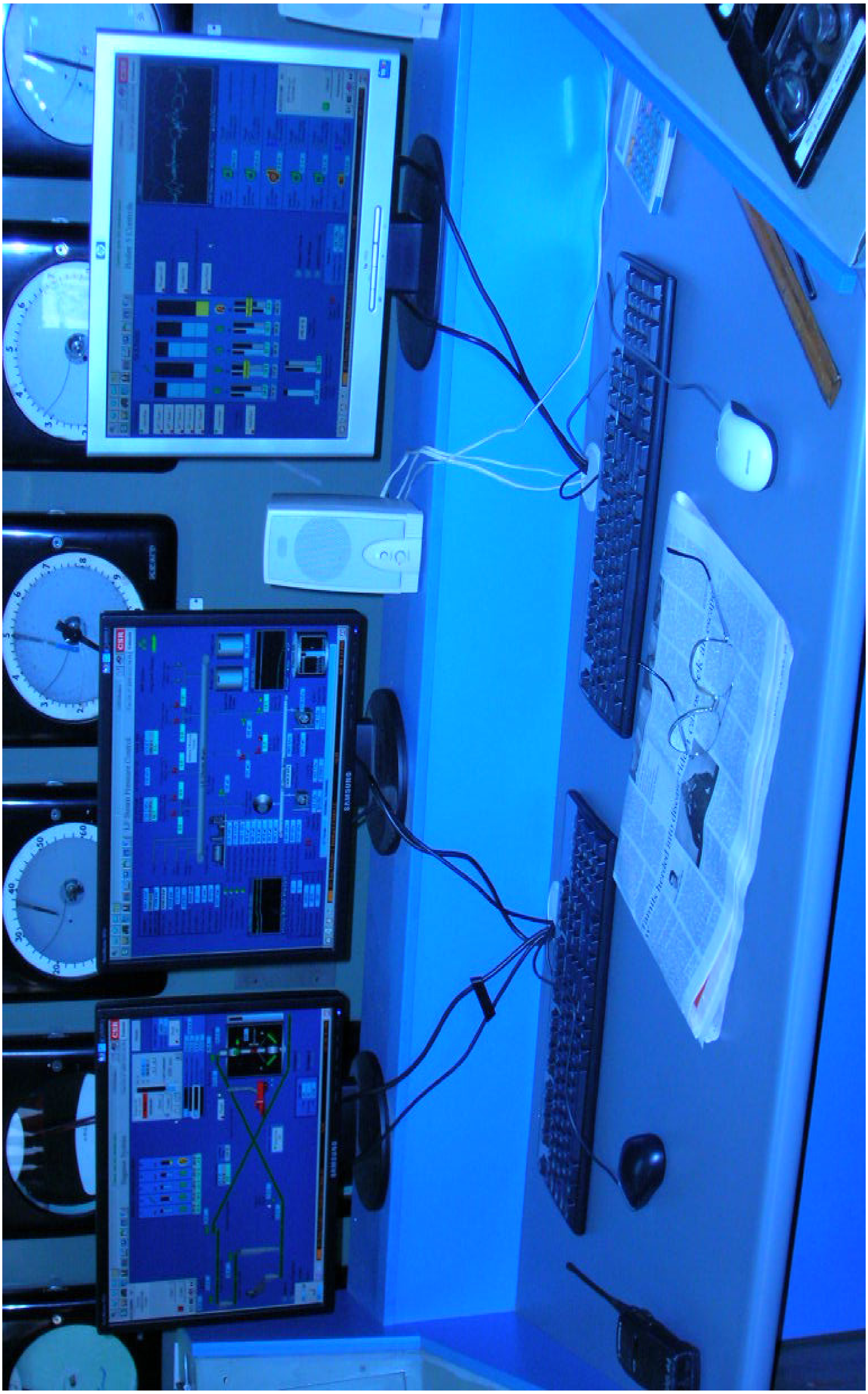

Figure 5.20 Operators control desk

Chapter 6 Results and Discussion

Chapter 6.1 Feedwater Flow

Using the methods outlined in Chapter 4 I obtained the data in the following table for flow and pressure at various rates of crushing. This data was measured in December at the end of that year's crushing period.

Crushing Rate Tonnes per hour	Corresponding water/steam flow requirement in tonnes/hour	Corresponding water/steam flow requirement in litres/second	Measured feed water pressure kPA
450	272	78.685	2725
460	274	79.264	2728
470	278	80.421	2724
480	280	81	2728
490	289	83.60	2730
500	295	85.339	2730
510	298	86.207	2732

Table 4 Flow rates and pressures 2008

So the Flow rate required for maximum crushing rate is was measured at 86.207 litres per second. Allowance must be made to accommodate the possibility of increased future capacity of the boilers. By modifying the factory there has been a gradual increase in crushing rate over the years. It is possible that modifications will also be made on the boilers in order to provide a necessary future requirement for steam with a corresponding feed water flow requirement. For this reason I have decided to stipulate that the capacity is there to provide 100 litres of water per second.

As mentioned previously 2 pumps will be running at one time to provide this output. The 2 existing pumps that are remaining are both rated at 238 m^3/hour which is 66 litres /second. This means the 2 existing pumps are capable of supplying the required flow. The pump that is being replaced has a rated maximum flow of 48 litres per second but for the sake of standardisation the new pump will be the same as the remaining ones.

The project was completed and put into service in June. Measurements were taken again to compare flow rates and pressures with the following results

Crushing Rate Tonnes per hour	Corresponding water/steam flow requirement in tonnes/hour	Corresponding water/steam flow requirement in litres/second	Measured feed water pressure kPA
450	275	79.553	2727
460	277	80.138	2729
470	280	81	2731
480	283	81.867	2730
490	291	84.182	2732
500	296	85.628	2734
510	300	86.785	2734

Table 5 Flow rates and pressures 2009

As expected there was very little difference between the results. The new pump has a larger capacity but this should not affect the flow to the boiler or the pressure of the water. This is normal when you think of the control philosophy behind boiler level control and feed water pressure control.

The boiler level control loop controls the level of the water in the boiler drum. This is critical because too high a level will cause water entrainment into the steam lines and cause damage to turbines. Too low a level will allow boiler tubes to overheat and damage the tubes. The controller is a 3 element type which means the difference between steam and feedwater flow are compared b to compensate for swell and shrink in the drum. The difference is added to the error between drum level set point and the actual drum level reading. The output or controlled element is the feed water flow control valve. Even though the new pump has a higher capacity, the flow will in theory be the same because the drum level control has not changed. What has happened is the flow control valve now operates at a more closed position.

The pressure is controlled by bypass valves that return water back to the feed water storage tank. Because the pump now pushes more water the bypass valves will now operate in a more open position to keep the pressure the same. This reveals a disadvantage of installing a larger pump that allows for future expansion. More water is being bypassed back to the tank so effectively reduces overall efficiency. This however is minor when compared to the efficiency gains obtained by the rest of the project.

Chapter 6.2 Reliability

To compare the reliability before and after the project it was necessary to collate breakdown results before and after the project. The table below is a snapshot of the breakdowns recorded for the whole sugar mill for the crushing season of 2008. I have highlighted in red the breakdowns that occurred in plant associated with the project.

Start Time	Finish Time	Description of fault and section of Plant
14/12/2008 1:56	14/12/2008 2:14	NO.5 MILL UNDERSPEED SWITCH
12/12/2008 13:53	12/12/2008 14:06	LOW STEAM
12/12/2008 10:32	12/12/2008 13:12	LOW STEAM
9/12/2008 16:21	9/12/2008 16:33	NO.4 MILL TURBINE STOPPED
9/12/2008 15:07	9/12/2008 16:20	NO.4 MILL TURBINE STOPPED
9/12/2008 2:16	9/12/2008 2:41	NO.4 MILL TURBINE TRIP
9/12/2008 1:49	9/12/2008 1:55	NO.4 MILL TURBINE STOPPED
28/11/2008 7:28	28/11/2008 7:32	NO. 4 MILL TURBINE STOPPED
25/11/2008 11:27	25/11/2008 11:38	NO. 4 MILL TURBINE STOPPED
22/11/2008 17:45	22/11/2008 19:30	LOW STEAM - NO.5 BOILER LEVEL CONTROLLER
20/11/2008 9:19	20/11/2008 9:31	LOW STEAM - NO. 5 BOILER LEVEL CONTROLLER
14/11/2008 15:46	14/11/2008 15:56	CITEC COMPUTER PROBLEMS
14/11/2008 15:37	14/11/2008 15:42	**PROBLEMS WITH NO. 5 BOILER DRUM LEVEL CONTROLLER**
14/11/2008 12:27	14/11/2008 12:29	OVERIDE WEST SHREDDER TURBINE THRUST BEARING ALARM
10/11/2008 18:13	10/11/2008 18:21	TIP DIDNT FIND HOME POSITION
10/11/2008 17:25	10/11/2008 18:10	NO.5 MILL UNDERSPEED SENSOR
10/11/2008 15:47	10/11/2008 17:25	FULL BIN STOP SWITCH NOT WORKING
10/11/2008 14:18	10/11/2008 14:26	FULL BIN STOP SWITCH NOT WORKING
10/11/2008 10:06	10/11/2008 10:10	FULL BIN STOP SWITCH NOT WORKING
9/11/2008 20:30	10/11/2008 2:03	NO.5 BOILER FEEDWATER CONTROLLER PROBLEM
31/10/2008 13:42	31/10/2008 13:47	NO.5 BOILER FEEDWATER CONTROLLER PROBLEM
31/10/2008 9:46	31/10/2008 9:51	NO.5 BOILER FEEDWATER CONTROLLER PROBLEM
27/10/2008 12:21	27/10/2008 12:29	NO.5 BOILER FEEDWATER CONTROLLER PROBLEM
27/10/2008 10:51	27/10/2008 10:52	NO.5 BOILER FEEDWATER CONTROLLER PROBLEM
27/10/2008 9:36	27/10/2008 10:01	NO.5 BOILER FEEDWATER CONTROLLER PROBLEM
24/10/2008	24/10/2008	GOLIATH ARMS STUCK IN BIN

2:20	3:44	
16/10/2008 7:03	16/10/2008 9:41	NO.1 BOILER FEED WATER CONTROLLER
15/10/2008 0:02	15/10/2008 5:30	BAGASSE BELT STOPPED/NO.1 BOILER FEED WATER CONTROLLER
14/10/2008 19:29	14/10/2008 19:58	NO.1 BOILER FEEDWATER CONTROLLER PROBLEM
13/10/2008 11:35	13/10/2008 11:43	NO.1 & NO.5 BOILER - PROBLEMS WITH FEED WATER CONTROLLER
10/10/2008 9:48	10/10/2008 9:58	NO.1 BOILER FEEDWATER CONTROLLER FAILURE
8/10/2008 8:37	8/10/2008 8:48	NO.1 BOILER FEEDWATER CONTROLLER FAILURE
8/10/2008 8:01	8/10/2008 8:16	NO.5 BOILER TRIP/ FEED WATER CONTROLLER
7/10/2008 0:37	7/10/2008 0:55	BOILER PROBLEMS HIGH WATER
6/10/2008 21:39	6/10/2008 22:13	BOILER PROBLEMS HIGH WATER
4/10/2008 15:42	4/10/2008 16:23	PROBLEMS WITH BOILER FEEDWATER CONTROL
3/10/2008 22:03	3/10/2008 22:09	PROBLEMS WITH BOILER FEEDWATER CONTROL AND BLACKOUT
30/09/2008 11:33	30/09/2008 12:33	PROBLEMS WITH BOILER FEEDWATER CONTROL AND BLACKOUT
24/09/2008 13:31	24/09/2008 14:52	PROBLEMS WITH BOILER FEEDWATER CONTROL
24/09/2008 12:55	24/09/2008 12:58	PROBLEMS WITH BOILER FEEDWATER CONTROL
24/09/2008 12:46	24/09/2008 12:48	PROBLEMS WITH BOILER FEEDWATER CONTROL
21/09/2008 20:42	21/09/2008 20:58	EXTRACTER NOT IN HOME POSITION
21/09/2008 4:20	21/09/2008 4:22	PROBLEMS WITH BOILER FEEDWATER CONTROL
21/09/2008 2:35	21/09/2008 2:38	PROBLEMS WITH BOILER FEEDWATER CONTROL
17/09/2008 2:14	17/09/2008 2:21	BOILER FEED WATER CONTROL PROBLEMS
16/09/2008 12:06	16/09/2008 12:18	NO.5 BOILER FEEDWATER PROBLEMS
16/09/2008 11:28	16/09/2008 11:32	BOILER FEEDWATER PROBLEMS
16/09/2008 11:09	16/09/2008 11:15	BOILER FEEDWATER PROBLEMS
16/09/2008 10:50	16/09/2008 10:57	NO.5 MILL TURBINE TRIPPED-TURBINE HUNTING
15/09/2008 22:22	15/09/2008 22:23	NO.4 MILL TURBINE TRIPPED - TURBINE HUNTING
15/09/2008 21:41	15/09/2008 21:44	NO.4 TURBINE TRIP
15/09/2008 15:47	15/09/2008 15:55	NO.4 TURBINE TRIP - HIGH REVS
15/09/2008 9:20	15/09/2008 9:31	FIT GAUGE TO NO 4 TURBINE GOVERNOR
15/09/2008 0:24	15/09/2008 0:28	FIT NEW I/P TRANSDUCER NO 4 TURBINE
14/09/2008 19:12	14/09/2008 19:17	NO 3 MILL P/F U/S SWITCH
14/09/2008 11:02	14/09/2008 11:11	BOILER FEEDWATER CONTROL PROBLEMS
13/09/2008	13/09/2008	BOILER FEEDWATER CONTROL PROBLEMS

4:56	4:58	
11/09/2008 21:36	11/09/2008 21:43	BOILER FEEDWATER CONTROL PROBLEMS
10/09/2008 18:57	10/09/2008 19:07	NO.4 MILL TURBINE TRANSDUCER FAILURE
10/09/2008 14:00	10/09/2008 14:07	**BOILER FEEDWATER CONTROL PROBLEMS**
4/09/2008 2:11	4/09/2008 2:27	BOILER FEEDWATER CONTROL PROBLEMS
2/09/2008 2:02	2/09/2008 2:07	BOILER FEEDWATER CONTROL PROBLEMS
2/09/2008 0:51	2/09/2008 0:56	BOILER FEEDWATER CONTROL PROBLEMS
1/09/2008 19:23	1/09/2008 19:30	BOILER FEEDWATER CONTROL PROBLEMS
30/08/2008 18:35	30/08/2008 19:32	PROBLEMS WITH EVAPORATOR PLC
29/08/2008 12:20	29/08/2008 13:12	BOILER FEEDWATER CONTROL PROBLEMS
28/08/2008 9:13	28/08/2008 10:18	SHREDDER LUBE OIL FAILURE
28/08/2008 8:15	28/08/2008 8:25	SHREDDER TRIP EAST SHREDDER CASING VIBRATION
28/08/2008 7:49	28/08/2008 7:54	AIR COMPRESSOR TRIP - SUGAR DRIER STOPPED
25/08/2008 2:58	25/08/2008 4:09	TURBO ALTERNATOR FAULT
24/08/2008 15:03	24/08/2008 15:04	WEST COMPRESSOR UNLOAD SOLENOID FAILED (LOW AIR PRESSURE)
20/08/2008 22:09	20/08/2008 22:43	EAST SHREDDER BEARING OIL FLOW
20/08/2008 20:32	20/08/2008 21:31	EAST SHREDDER BEARING OIL FLOW
20/08/2008 14:03	20/08/2008 19:33	EAST SHREDDER TURBINE TRIPPED - CASE VIBRATION
20/08/2008 13:03	20/08/2008 14:03	EAST SHREDDER TURBINE TRIPPED - CASE VIBRATION
20/08/2008 6:05	20/08/2008 7:02	EAST SHREDDER BEARIN OIL FLOW
16/08/2008 8:11	16/08/2008 8:17	EAST SHREDDER TURBINE CASE VIBRATION
16/08/2008 7:04	16/08/2008 8:10	EAST SHREDDER TURBINE CASE VIBRATION
16/08/2008 5:51	16/08/2008 6:05	SHREDDER TRIP- MACHINE CONDITION (EAST CASING VIBRATION)
14/08/2008 2:15	14/08/2008 2:17	REPOSITION NORTH EYE ON TIP - LOOSE WIRE
11/08/2008 13:26	11/08/2008 13:29	EAST SHREDDER TURBINE TRIP - CASE VIBRATION
9/08/2008 10:57	9/08/2008 11:01	REPLACE AIR LINE ONN THE SPOTTER
9/08/2008 8:26	9/08/2008 8:33	SHREDDER TRIP ON HIGH CASING VIBRATION
8/08/2008 20:51	8/08/2008 21:05	EAST SHREDDER TURBINE TRIP - HIGH CASING VIBRATION
8/08/2008 9:28	8/08/2008 9:32	A SIDE RECLAIMER WENT OUT ON UNDERSPEED
8/08/2008 7:43	8/08/2008 7:47	EAST SHREDDER TURBINE TRIP - HIGH CASING VIBRATION
8/08/2008 3:18	8/08/2008 3:30	EAST SHREDDER TURBINE TRIP - HIGH CASING VIBRATION

Table 6 Breakdown Data 2008

To compare the reliability after the project was completed, the following table shows the list of breakdowns from the 2009 crushing season. Again the breakdown data for the area affected by the project is coloured red.

StartTime	EndTime	Description
27/10/2009 13:30	**27/10/2009 13:33**	**NO.3 MILL UNDERSPEED SWITCH**
24/10/2009 4:22	24/10/2009 4:25	NO.2 INTERCARRIER STOPPED
20/10/2009 15:23	20/10/2009 15:26	SPOTTER INVERTER OVERLOAD
17/10/2009 0:08	17/10/2009 3:30	REPLACE DRIVE MOTOR ON NO.2 INTER-MEDIATE CARRIER DRIVE
10/10/2009 8:26	10/10/2009 8:30	NO 3 MILL P/F HYDRAULICS TRIP
9/10/2009 0:25	9/10/2009 0:27	ADJUSTMENT TO NO.3 TRACK SWITCH
6/10/2009 18:06	6/10/2009 18:13	ERGON ENERGY BUMP - FD FANS SHUTDOWN ON BOILERS
5/10/2009 11:54	5/10/2009 13:57	ELECTRICAL FAULT - UPS FAILURE
27/09/2009 11:45	27/09/2009 12:34	LIFTING DECK WENT INTO DEFAULT
27/09/2009 9:45	27/09/2009 11:04	ALTERNATOR TRIPPED
19/09/2009 8:12	19/09/2009 8:15	EMPTY BIN PUSHER FAILED TO REACH NORTH LIMIT
12/09/2009 17:57	12/09/2009 18:07	COMPUTER PROBLEMS AT WEIGHBRIDGE
4/09/2009 7:49	4/09/2009 7:51	NO.3 MILL TILT SWITCH
4/09/2009 7:43	4/09/2009 7:44	LINE 1 NOT REACHING TRACK SWITCH
3/09/2009 0:05	3/09/2009 1:40	B SIDE RECLAIMER UNDERSPEED SWITCH REPLACED
2/09/2009 22:04	2/09/2009 22:30	B SIDE RECLAIMER UNDERSPEED (BAGASSE BELT STOP)
2/09/2009 20:45	2/09/2009 21:10	B SIDE RECLAIMER UNDERSPEED (BAGASSE BELT STOP)
2/09/2009 16:21	2/09/2009 18:46	N0.5 BOILER TRIP (DISTRIBUTOR AIR FAN FAILED)
30/08/2009 3:28	30/08/2009 3:52	MAGNET MOTOR FAILED
30/08/2009 2:36	30/08/2009 2:50	MAGNET MOTOR FAILED
26/08/2009 21:28	26/08/2009 21:30	SPOTTER INVERTER FAULT
24/08/2009 6:46	24/08/2009 6:51	NO.5 JUICE PUMP DELIVERY PIPE BROKEN
19/08/2009 7:49	19/08/2009 7:50	PREPARED CANE ELEVATOR CENTER CHOKE SWITCH
19/08/2009 2:07	19/08/2009 2:10	PREPARED CANE ELEVATOR CENTRE CHOKE SWITCH
18/08/2009 12:09	18/08/2009 12:30	ADJUST TRACK SWITCHES ON LIFTING DECK
16/08/2009 22:11	16/08/2009 22:32	ALTERNATOR NOT RESPONDING TO SET POINT

15/08/2009 7:53	15/08/2009 7:56	NO 3 MILL P/F U/S SWITCH
15/08/2009 3:14	15/08/2009 3:26	MOTOR TRIPPED OUT ON OVERLOAD - HIGH LEVELS OF BAGASSE
15/08/2009 1:48	15/08/2009 2:16	MOTOR TRIPPED OUT ON OVERLOAD - HIGH LEVELS OF BAGASSE
14/08/2009 3:09	14/08/2009 3:10	FULL YARD LINE 1 SLOW TO COME IN FAILED TO REACH TRACK SWITCH
13/08/2009 13:00	13/08/2009 13:02	NO.3 INTERCARRIER UNDER SPEED
10/08/2009 23:45	11/08/2009 0:58	UNCOUPLING DECK NOT WORKING (RELAY BURNED OUT)
10/08/2009 23:10	10/08/2009 23:27	UNCOUPLING DECK NOT WORKING (RELAY BURNED OUT)
10/08/2009 21:11	10/08/2009 21:15	UNCOUPLING DECK NOT WORKING
4/08/2009 22:01	4/08/2009 22:08	REVERSE ROTARY JUICE SCREEN
4/08/2009 20:16	4/08/2009 20:18	LINE 2 SLOW COMING IN
1/08/2009 15:50	1/08/2009 16:18	REPLACE NO.3 MILL CHOKE SWITCH NO.2
1/08/2009 5:42	1/08/2009 5:44	PREPARED CANE ELEVATOR CHOKE SW CENTER
31/07/2009 14:11	31/07/2009 14:19	NO.2 INTERCARRIER CHOKE SWITCH
30/07/2009 21:02	30/07/2009 21:12	NO.3 INTER-CARRIER OIL COOLER MOTOR BURNT OUT
29/07/2009 11:32	29/07/2009 11:37	NO.3 MILL CHOKE SWITCH STUCK ON
11/07/2009 0:51	11/07/2009 2:05	TIPPLER DRIVES - SIGNAL FOR TIP DRIVES STICKING ON
10/07/2009 7:14	10/07/2009 22:29	REPLACE THRUST BEARING ON WEST SHREDDER TURBINE
10/07/2009 6:10	10/07/2009 7:14	SHREDDER TRIP ON MACHINE CONDITION
9/07/2009 4:35	9/07/2009 5:12	CHOCKED CHUTE PRESSURE FEEDER STALL NO.3
9/07/2009 4:30	9/07/2009 4:33	ZERO SPEED NO.3 PRESSURE FEEDER FAILED
9/07/2009 0:40	9/07/2009 0:48	ZERO SPEED SWITCH NO.3 PRESSURE FEEDER ADJUSTED
3/07/2009 18:25	**3/07/2009 18:29**	**BROKEN WIRE IN GOLIATH ARM SENSOR**
3/07/2009 18:06	3/07/2009 18:13	BROKEN WIRE IN GOLIATH ARM SENSOR
3/07/2009 18:02	3/07/2009 18:03	BROKEN WIRE IN GOLIATH ARM SENSOR
3/07/2009 7:19	3/07/2009 7:55	BURNT OUT SOLENOID ON NO.5 PLOUGH ON NO.1 BOILER
30/06/2009 22:25	30/06/2009 22:48	ROTARY JUICE SCREEN FEED J BOX UNDER WATER
30/06/2009 20:32	30/06/2009 20:34	ROTARY JUICE SCREEN UNDER SPEED
29/06/2009 17:51	29/06/2009 17:57	PREPARED CANE ELEVATOR CHOKE SWITCH
29/06/2009 8:38	29/06/2009 8:56	ROTARY JUICE SCREEN UNDER SPEED SWITCH
28/06/2009 14:09	28/06/2009 14:16	NO.4 INTERCARRIER STOP DUE TO NO.5 MILL UNDERSPEED SENSOR
28/06/2009 13:41	28/06/2009 13:45	NO.4 INTERCARRIER STOP DUE TO NO.5 MILL UNDERSPEED SENSOR
28/06/2009	28/06/2009	NO.4 INTERCARRIER STOP DUE TO NO.5 MILL

13:34	13:35	UNDERSPEED SENSOR
28/06/2009 13:19	28/06/2009 13:24	NO.4 INTERCARRIER STOP DUE TO NO.5 MILL UNDERSPEED SENSOR
28/06/2009 11:45	28/06/2009 12:18	NO.4 INTERCARRIER STOP DUE TO NO.5 MILL UNDERSPEED SENSOR
28/06/2009 11:31	28/06/2009 11:42	NO.4 INTERCARRIER STOP DUE TO NO.5 MILL UNDERSPEED SENSOR
28/06/2009 11:00	28/06/2009 11:17	NO.4 INTERCARRIER STOP DUE TO NO.5 MILL UNDERSPEED SENSOR
28/06/2009 9:06	28/06/2009 9:08	NO.4 INTERCARRIER STOP DUE TO NO.5 MILL UNDERSPEED SENSOR
27/06/2009 16:18	27/06/2009 16:37	NO.5 MILL TURBINE STALLED
27/06/2009 15:21	27/06/2009 15:27	GOLIATH IN WRONG POSITION
22/06/2009 12:21	22/06/2009 13:46	BAGASSE BELT STOPPED - REPLACE ZERO SWITCH 'A'RECLAIMER
22/06/2009 4:08	22/06/2009 4:17	ZERO SPEED SWITCH ON 'A' SIDE RECLAIMER FAILED
22/06/2009 3:44	22/06/2009 4:06	ZERO SPEED SWITCH ON 'A' SIDE RECLAIMER FAILED
20/06/2009 5:03	20/06/2009 5:06	SPOTTER OVERLOAD
20/06/2009 3:51	20/06/2009 4:04	BIN PUSHER OVERLAOD
17/06/2009 10:01	17/06/2009 10:11	NO.3 PRESSURE FEEDER STALL - LOST RUN INDICATION
16/06/2009 16:24	16/06/2009 16:30	OVER CURRENT ON EMPTY BIN PUSHER
15/06/2009 12:06	15/06/2009 15:10	CHANGED NO.3 INTER-CARRIER DRIVE MOTOR
14/06/2009 18:38	14/06/2009 18:49	BAGASSE RECLAIMER B UNDERSPEED
13/06/2009 21:37	13/06/2009 21:39	NO 1 MILL APRON TILT SWITCH
13/06/2009 21:23	13/06/2009 21:36	BAGASSE RECLAIMER B UNDERSPEED
13/06/2009 12:15	13/06/2009 12:51	MAIN CIRCUIT BREAKER ON CLARIFICATION BOARD TRIPPED
12/06/2009 3:14	12/06/2009 4:09	BAGASSE BELT STOP
11/06/2009 10:20	11/06/2009 10:28	BOILER TRIP LOW WATER

Table 7 Breakdown Data 2009

Comparing the two sets of tables we see that in 2008 there were 40 stoppages for a total of 1332 minutes lost time. In 2009 that changed to only one stop accounting for 8 minutes of lost time. Although these results are impressive it must be realised that the raw data might not be 100% accurate. The description of the stoppage is quite general and does not necessarily point directly to the improvement areas of the project. The information input by the operators is at times subjective. However it is an indication that reliability has improved markedly. It will be important to continue recording breakdown statistics for at least another 5 years to gain a better understanding of long term performance. The cost of the mill stopping is estimated at $3000 per hour. This works out to a saving based on these reliability figures of over $66 000 for the year.

Chapter 7 Conclusion

7.1 Advantages and disadvantages

The project was generally a success. The aims and objectives were completed satisfactorily and the capital expenditure has been justified. One problem in the installation has been occasional cavitation in the pump. Several possible reasons include incorrect pipe size to the suction side, feed water tank too small and makeup pump timing incorrect. Some modifications have been made and have been successful.

The installation has now been operational for over 5 months and has brought the following advantages

- Improved reliability. Without a doubt the new system does not suffer from spurious trips that were common when old over speed protection caused the pump to stop unnecessarily. With the visual computer display that is now provided the operators can keep a closer eye on conditions that require attention that they could not have known about before. Conditions such as high motor current, filter blockage, high feed water pressure are now all easily seen on the screen and are flagged immediately through the automatic alarm page. This allows the operator to take action early to correct any alarm condition.

- Improved efficiency. By feeding the steam that used to turn the relatively small feed water pump turbine into the much larger turbine of the 10MW alternator turbine, the steam is transferred into kinetic energy much more efficiently. The corresponding generation of electricity and change into the mechanical energy through the electric motor is more efficient overall

- Creation of working area. The new installation removes the need for large valves and bulky pipe lagging. This has freed up a large area which makes working around the area more comfortable and easier

- Long term costs of maintenance will be reduced. Electric motors are much more common than steam turbines, are less expensive to repair and replacement motors can be justifiably stored on site. If there is a failure the down time will therefore be reduced. Maintenance staff generally have a higher knowledge base of electric motors so training costs are reduced

- Safety is improved. High pressure steam at 1750kPa is a dangerous hazard that can kill. Although the same can be said of electricity it is easier to maintain an electrical installation over many years in a safe condition. Steam pipes have many joins at flanges and valves where the gaskets are prone to deterioration over time which allow steam leaks to develop. Electric cables if joined and installed correctly are less prone to deterioration over time.

7.2 Further work and possibilities

It is important to continue to monitor the operation of the installation to ensure the benefits are real to see if any unforeseen problems arise. Flow and pressure measurements continue to be monitored under varying load conditions to ensure feed water requirements are met. Further refining of the cavitation problem will be considered. The feed water tank may be increased in size as well as the suction pipe size.

This technology could be used in most of the other fans and pumps in the factory and indeed in the sugar industry as well. In other sugar mills turbines have been replaced with high voltage electric motors on the milling train. This has required large capital outlay as these drives need to be speed controlled with expensive variable speed drives. However it has been proved to be justifiable.

Chapter 8 References

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Chapter 9 Appendix A

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **BARRY SCOINES**

TOPIC: ELECTRIC DRIVE CONVERSION IN A SUGAR MILL

SUPERVISOR: Dr. Ron Sharma

ENROLMENT: ENG 4111- S1, D, 2009
ENG 4112- S2, D, 2009

PROJECT AIM: To investigate the feasibility of replacing traditional steam turbine drives with modern electric drives controlled by PLC and SCADA interface.

PROGRAM: Issue A, 12th march 2009-03-12

1. Research design of bagasse fired boilers and their feed water requirements.

2. Evaluate current methods of supplying boilers with feed water. Take flow, pressure and temperature measurements of steam driven pumps.

3. Analyse cost effectiveness, reliability and suitability of current methods.

4. Design an electric replacement including control, supervision, alarm and data capturing systems.

5. Analyse the complete system comparing advantages and disadvantages of the two systems. Draw conclusions about where this technology can be used elsewhere.

6. Submit an academic dissertation on the research.

If time permits:
7. Design improvements to the system after installation and commissioning.

AGREED:

___________________(Student) _____________________(Supervisor)

___/___/___ 19 /03 / 2009

Examiner/Co-examiner: ________________________

Chapter 10 Appendix B

Quantum CPUs

Presentation
Quantum CPUs, which are compatible with Concept and ProWORX software, are single-slot PLCs with built-in executive memory, application memory and communication ports. With all memory components on-board, you do not need extra chips or cartridges for configuration.
Flash-based executive memory
Quantum CPUs use flash memory technology to support the CPU's executive memory and instruction set. Flash is a state-of-the-art, non-volatile memory technology that enables field upgrades by downloading files over the Modbus or Modbus Plus port as new features and maintenance updates become available.
Memory backup and protection
The CPUs store the application program in battery-backed RAM. This battery is located on the front of the module and can be replaced while the CPU is running.
To protect the application program from inadvertent changes during operation, the processors feature a memory-protect slide switch. An LED goes on when this switch is activated.
Math coprocessor
For math-intensive applications, a math coprocessor is available on select CPU models. The coprocessor significantly improves execution times for the 984 Process Control Function Library (PCFL) and Equation Editor, as well as math operations in the IEC languages. Improved floating point execution times mean more power for processing process algorithms and math calculations.
Write protection
PLC write protection minimizes the possibility of a programmer inadvertently writing from a source PLC to a memory area in a destination PLC . Whatever data is not enabled is prevented from writing, both locally and over the network. This data protection option provides security against data transfer errors.
Communication ports
All CPUs support Modbus and Modbus Plus networking strategies. Simple rotary switches on the back of the modules are used to define the network address of the Modbus Plus port(s). Each device on a Modbus Plus network must have a unique address in the range 1...64. Modbus port settings include: baud rate, parity, number of data bits, number of stop bits, protocol and Slave address. By default, these settings are 9600 bps, even parity, 8 data bits, 1 stop bit, RTU mode and address 1.
A switch on the front of the CPUs can be used to configure the Modbus port as a modem communication interface (2400 bps, even parity, 7 data bits, 1 stop bit, ASCII mode and address 1).
The **140 CPU 434 12A and 140 CPU 534 14B** processors have 2 serial Modbus ports:
Modbus port 1, with full modem interfacing ability
Modbus port 2, with RTS/CTS flow control (does not support modem connection)
b
b
version: 8.0 48202-EN.indd

Description

Description
The **140 CPU ppp** processor front panel comprises:
1 Model number and colour code
2 LED array
3 Removable, hinged door and customizable identification label
4 Battery slot
5 Two slide switches
6 One Modbus port A
7 One Modbus port B
8 One Modbus Plus port

Note:
The **140 CPU 113 0**p processors have one Modbus and one Modbus Plus communication port.

Slide switches

Each of the two slide switches has three-position functionality:
The left slide switch activates the memory write-protection. In the upper position, write protection is enabled; in the middle position, write protection is disabled.
The right slide switch determines the startup communication parameters for the Modbus port. The middle position, RTU, is the factory-set default. The upper position, ASCII, is for modem communications *(1)*. If you need to set special startup parameters for the Modbus port – for example, if your Modbus address is not 1 – you can set application-specific parameters in memory and set the slide switch in the bottom position.

Language choices

Advanced IEC 61131-3 languages

Quantum's 5 IEC 61131-3 languages are:
Sequential Functional Chart: provides overall structure and coordination for process or machine control applications.
Function Block Diagram: particularly well suited to process control applications.
Ladder Language: excellent for combinational and interlocking logic.
Structured Text: higher level language which is a terrific solution for complex algorithms and data manipulation.
Instruction List: low level language for optimizing the size of the program code generated.
984 Ladder Logic
A high performance, low level language whose application source code resides in the controller.
A full set of over 80 instructions is included with every Quantum CPU. The 984 instruction set ensures compatibility and easy integration paths for installed Modicon applications, including:
Immediate I/O access and interrupt servicing

Concept/ProWORX standard CPUs

48202-EN.indd version: 8.0

Characteristics

Characteristics

Module type 140 CPU 113 02 140 CPU 113 03 140 CPU 434 12A 140 CPU 534 14B
Functional safety certification –
Approvals UL 508, CSA 22,2-142, C UL, FM Class 1 Div. 2, e
Processors 80186 80486
Math coprocessor No Yes
Clock speed MHz 20 66 100
User memory Max. IEC program 109 Kb 368 Kb 896 Kb 2.5 Mb
Max. LL 984 program 8 Kwords 16 Kwords 64 Kwords
Capacity Bits **bps** 8192 I/8192 Q 64 K combined
Registers **words** 9999 max. 57 K max.
Extended memory **words** – 96 K
Logic solve time (984 LL instructions) **ms/K** 0.3…1.4 0.1…0.5
Watchdog timer ms 250 (software-adjustable)
Real-time clock accuracy s/day ± 8 at 0…60℃
Local I/O Maximum I/O words 64 I/64 Q
Remote I/O (RIO) I/O words/drop 64 I/64 Q
Number of drops 31
Number of networks 2
Distributed I/O (DIO) I/O words/drop 30 I/32 Q
I/O words/network 500 I/500 Q
Drops/network 63
Number of networks 3
Communication ports Modbus (RS 232) 1 2
Modbus Plus 1
Maximum number of NOM, NOE, CRP or MMS
modules
2 6
Key switch No Yes
Memory backup Product reference 990 XCP 980 00
Battery type Lithium
Voltage **V** 3 c
Capacity **mAh** 1200
Typical current **µA** 5 7 45 85
Maximum current **µA** 110 210 70 135
Storage life **yr** 10
Bus current required mA 780 790 1250

Modicon Quantum automation platform

Concept/ProWORX standard CPUs

version: 8.0 48202-EN.indd

References

Migration of Quantum CPUs
As both the **140 CPU 434 12A** and **140 CPU 534 14B** Quantum CPUs are compatible with Concept or ProWORX software, they can be upgraded to be compatible with the Unity Pro software without any hardware modification.. This process of migrating from Concept to Unity Pro is achieved by updating the CPU operating system.
This update is performed with the aid of the OS-Loader tool included with Unity Pro (see page 43120/25).
The upgraded processor **140 CPU 434 12A** is then equivalent to the corresponding Unity processor **140 CPU 434 12U.**
Note: *Migration of the* **140 CPU 534 14B** *processor requires the version of Unity Pro u 3.0.*
CPUs
Memory (total) **Coprocessors Safety Reference Weight**
kg
256 Kbytes No – **140 CPU 113 02** 0.300
512 Kbytes No – **140 CPU 113 03** 0.300
2 Mbytes Integrated – **140 CPU 434 12A** 0.850
4 Mbytes Integrated – **140 CPU 534 14B** 0.850
Accessories
Description Length

Safety Reference
(1)
Weight
kg
Programming cable for
Modbus interface
3.7 m – **990 NAA 263 20** 0.300
15 m – **990 NAA 263 50** 1.820
Backup battery – – **990 XCP 980 00** –
Quantum automation series
hardware reference guide
– – **840 USE 100 0p** –
(1) Add one of the following digits at the end of the reference: **0***: English,* **1***: French,* **2***: German,* **3***: Spanish.*

Modicon Quantum automation platform

Concept/ProWORX standard CPUs

48202-EN.indd version: 8.0

Power supply modules

Presentation

Quantum power supply modules serve two purposes - they provide power to the system rack and protect the system from noise and voltage swings. All power supply modules feature overcurrent and overvoltage protection. They operate in most electrically noisy environments without the need for external isolation transformers.
In the event of an unforeseen loss of power, the power supply modules ensure that the system has adequate time for a safe and orderly shutdown. A power supply module converts the input voltage to regulated + 5 V DC for the requirements of the CPU, the I/O modules and those of all the communication modules installed in the rack. The power between the sensors/preactuators and the I/O points on the Quantum system is not provided by these power supply modules.
Three types of power supply module are available for use in local or remote (RIO) architectures:
Low power standalone power supply modules
High power summable power supply modules
High power redundant power supply modules
For distributed I/O (DIO) architectures, low power standalone power supplies are available. These are dedicated to distributed architectures and integrated in distributed I/O drop adaptors. Distributed power supplies are described in the pages on the distributed I/O architecture.

Functions

Standalone power supply modules

A standalone power supply module provides a 3 A current to the Quantum rack. When the system only requires low power, a standalone power supply module is an economical choice. These standalone power supply modules are available for 115/230 V a, 24 V c and 125 V c supply voltages.

Summable power supply modules

A summable power supply module provides a 8 A or 11 A current to the Quantum rack. These summable power supply modules can operate in either standalone or summable mode. When two summable power supply modules are installed in the same rack, they automatically operate in summable mode, providing a current of 16 A or 20 A (depending on the model). In summable mode, both power supply modules must be the same type and must be installed in the left and right end slots of the rack for maximum life. If one of the two power supply modules fails, power is lost to the rack.
If only one summable power supply module is installed in a rack, it operates in standalone mode, supplying a current of 8 A or 11 A to this rack.

Summable power supply modules are available for 115/230 V a, 24 V c and 48/60 V c supply voltages.

Redundant power supply modules

A redundant power supply module provides a current of 8 A or 11 A (depending on the model) to the Quantum rack. For high-availability applications, two redundant power supply modules will provide a redundant current of 8 A or 11 A.

If one of the two power supply modules fails, the one that remains operational maintains the supply of the required power. Each redundant power supply module has a status bit that can be monitored by the application program or by a supervision system, in order to react quickly if the power supply fails.

If an additional power supply module is necessary in a configuration with redundant power supply modules, a third redundant power supply module can be added to the rack, increasing the available capacity to 16 A or 20 A. If one of the three power supply modules fails, those which remain operational revert to standard redundant mode, supplying a redundant current of 8 A or 11 A to the rack.

A redundant power supply module can be used as a standalone power supply module.

Redundant power supply modules are available for 115/230 V a, 24 V c, 48/60 V c and 125 V c supply voltages.

Characteristics

Characteristics

Type of module 140 CPS 111 00 *(1)* **140 CPS 114 10** *(2)* **140 CPS 114 20** *(2)* **140 CPS 124 20** *(3)*

Functional safety certification – Non-interfering

Approvals UL 508, CSA 22.2-142, cUL, FM Class 1 Div. 2, e

Input
characteristics

Input voltage **V a** 100…276 93…138 or 170…276

Input frequency **Hz** 47…63

Input current at 230 V a **A** 0.2 0.6 0.75 0.6

at 115 V a **A** 0.4 1.1 1.3 1.1

Inrush current at 230 V a **A** 20 19

at 115 V a **A** 10 38

Rating **VA** 50 130

External fusing **A** 1.5 slow-blow 2.0 slow-blow

Input power interruption 1/2 cycle at full load and minimum line voltage/frequency, and at least 1 s between interrupts

Harmonic distortion **%** Less than 10% of fundamental rms value

Output to bus Voltage **V c** 5.1

Current **A** 3 max., 0.3 min. 8 at 60℃ Summable: 20 at 60℃

Standalone: 11 at 60℃

11 at 60℃

Protection Overcurrent, overvoltage

Internal power dissipation W 2.0 + (3 x Iout), where

Iout is in A

6.0 + (1.5 x Iout), where

Iout is in A

6.0 + (1.5 x Iout), where

Iout is in A

Type of module 140 CPS 211 00 *(1)* **140 CPS 214 00** *(2)* **140 CPS 224 00** *(3)*

Functional safety certification –

Approvals UL 508, CSA 22.2-142, cUL, FM Class 1 Div. 2, e

Input
characteristics

Input voltage **V c** 20…30

Input current **A** 1.6 3.8 max.

Inrush current **A** 30 25 at 24 V c, 14 at 20 V c

Input ripple **V c** – 94…189 Hz

Input power interruption **ms** 1.0 at 20 V c

External fusing (recommended) **A** 20.0 at 25 V c 100 ms max. with external capacitor

2.5 slow-blow 5.0 slow-blow

Output to bus Voltage **V c** 5.1

Current **A** 3 max., 0.3 min. 8.0
Protection Overcurrent, overvoltage
Overvoltage withstand V c – 2.3 x maximum rated input
voltage for 1.3 ms
Internal power dissipation W 2.0 + (3 x Iout), where Iout is in A 6.0 + (1.8 x Iout), where Iout is in A
Alarm relay No Yes
Type of module 140 CPS 414 00 *(2)* **140 CPS 424 00** *(3)* **140 CPS 511 00** *(1)* **140 CPS 524 00** *(3)*
Functional safety certification –
Approvals UL 508, CSA 22.2-142, cUL, FM Class 1 Div. 2, e
Input
characteristics
Input voltage **V c** 48…60 100…150
Input current **A** 3.8 max. 0.4 0.5 at 125 V c
Inrush current **A** 14.0 at 40 V c 10 28 at 125 V c
Input power interruption **ms** 13.0 at 48 V c 1.0 max.
External fusing (recommended) **A** 2.0 medium time lag 3/4 slow-blow 2 slow-blow
Output to bus Voltage **V c** 5.1
Current **A** 8.0 3 max., 0.3 min. 8.0
Protection Overcurrent, overvoltage
Internal power dissipation W 15.6 at 8 A 17.2 at 8 A 2.0 + (3 x Iout), where
Iout is in A
6.0 + (1.5 x Iout),
where Iout is in A
Alarm relay Yes No
Use: (1) standalone, (2) summable, (3) redundant.
version: 8.0 48203_EN.indd

Chapter 11 Appendix C

Likelihood: How much chance is there of it happening.	**Consequence:** What is the most likely result if it occurs?				
	Minor 1	**Important** 2	**Serious** 3	**Major** 4	**Catastrophic** 5
A. Almost Certain	**S 15**	**S 10**	**H 6**	**H 3**	**H 1**
B. Likely	**M 19**	**S 14**	**S9**	**H 5**	**H 2**
C. Possible	**L 22**	**M 18**	**S 13**	**H 8**	**H 4**
D. Unlikely	**L 24**	**L 21**	**M 17**	**S 12**	**H 7**
E. Rare	**L 25**	**L23**	**M 20**	**S 16**	**S 11**

Table 8 Risk Matrix

Risk Priority	
High	High risk; detailed research and management planning required at senior levels
Significant	Significant risk; senior management attention needed
Moderate	Moderate risk; management responsibility must be specified
Low	Low risk; manage by routine procedures

Table 9 Risk Priority

	Consequence		
	Safety	Financial Loss	Environmental
1. Minor	First Aid Treatment	Low financial loss, <$1000	Transient situations under control (e.g. waste material awaiting disposal)
2. Important	Medical treatment with return to work	Medium financial loss, between $1,000 and $10,000	Unlicensed and unplanned on-site release immediately contained
3. Serious	Medical treatment required with lost time	High financial loss, between $10,000 and $100,000	Any on-site release contained with outside assistance. Unlicensed off-site release with no detrimental effects
4. Major	Fatality, extensive injuries or chronic disease	Major financial loss, between $100,000 and $1M	Unlicensed off-site release with detrimental effects but no residual impact
5. Catastrophic	Multiple fatalities, extensive injuries or chronic diseases	Huge financial loss, >$1M	Unlicensed toxic release off site with detrimental effects and residual impact. Serious breach of License conditions

Table 10 Consequence

Likelihood	
A. Almost Certain	This event is expected to occur in most circumstances (e.g. 10 times per year)
B. Likely	The event will probably occur in most circumstances (e.g. Once per year)
C. Possible	The event should occur at some time (e.g. One in 10 years)
D. Unlikely	The event could occur at some time (e.g. One in 100 years)
E. Rare	The event may only occur in exceptional circumstances (e.g. One in 1,000 years)

Table 11 Likelihood

Activities, Hazard Identification and Risk assessment Analysis

Now by identifying the job steps (Activities) and hazards associated with each, I will assign a risk score based on the above risk matrix. I develop control measures to reduce the risk and then re-assign a new (hopefully reduced) risk score

Activity	Hazard	Risk Score	Control Measures	Risk Score
Measurements to be taken during several operating conditions of feed water and boiler system using instruments. These include measures of flow, pressure and temperature	Heat from steam and water pipes	M18	Wear correct PPE and stay clear of hot pipe work where possible	L21
	Steam leaks	S13	Cover any steam leaks with approved material. Correct PPE- gloves, safety glasses	M20

Removal of redundant equipment	Manual handling	M18	Use lifting tools where necessary. Use correct lifting procedures	L23
	Working at heights - falls, gravity	S13	Erect certified scaffolding	M20
Installation of power equipment - electric motor, cable ladder, switchboard, switchgear, isolator, cable	Manual handling	M18	Use lifting tools where necessary. Use correct lifting procedures. Use glove, safety glasses, hard hat	L23
	Working at heights - falls, gravity	S13	Erect certified scaffolding	M20
	Electricity	S13	Isolate, test for de-energised state and padlock. Use rescue kit and standby person Control Measures	M20
Installation of control equipment - plc components, control wiring	Electricity	S13	Isolate, test for de-energised state and pad lock. Use rescue kit and standby person	M20
	Physical, cuts, scrapes etc	L22	Use glove and adequate lighting	L25
Commissioning of new plant	Moving machinery	S13	Be aware of testing procedure. Be aware equipment can start at any time	M20

	Electricity during testing and fault finding	S13	Use rescue kit and standby person. Wear class 00 insulating gloves. Use Cat III tester.	M20

Table 12 Activities, Hazard Identification and Risk assessment Analysis