ENG450 Engineering Internship
BEC ENGINEERING PTY LTD.

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19/11/2010
1 Declaration

I declare that all the work submitted for assessment within this dossier is my own work; except where sources are acknowledged and does not involve plagiarism. This internship report has not been submitted in part or in whole to fulfil the requirements of any other subject or course.
2 Abstract

Once gold ore is mined, using underground or open-cut methods, it is sent to the closest mill where it is crushed into a finely grounded paste. This report discusses two methods employed to start up a large synchronous machine used for milling operations in the mining industry. To understand this, basic principles are extracted from the electrical and mechanical engineering fields.

The report also explores the common techniques used for communication between engineers involving piping and instrumentation diagrams (P&IDs). The importance of P&IDs and their purpose in the engineering field is also explained. The majority of the Australian and International standards designed specifically for P&IDs are not covered as part of this dossier. This is based heavily on the operations that are being undertaken are in South Africa, where P&ID standards are minimal.
3 Acknowledgements

The technical content contained in this dossier was obtained during work experience with BEC Energy and Control Systems Engineering Pty Ltd and without the support and guidance of the following people mentioned below, it would not have been possible to have such an opportunity. My deepest thanks to these individuals:

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4 Introduction

It is taken for granted the electric utility service that is ever-present in developed countries. Electric utilities are present and wired to nearly every residential home or business, and supply standard voltage and frequency levels that permit ranges of applications to be ‘plugged in’ and utilised. Not only will the electric power delivered cause the device to operate, it will do so reliably.

Society have become so reliant on electrical power for heating, cooling, cooking, lights, refrigeration systems, communication, and more in everyday life. Similarly the mining industry relies on electrical power for essentially all their unit operations that run uninterrupted apart from maintenance and during shutdown.

It is estimated in Australia that more than 1.7 million three phase electric motors run in commercial and industrial facilities. This accounts for a staggering 28% of the country’s electricity use. “Most organisations would use at least one motor, if not thousands. The energy consumed by Australian industry is set to be close to $3 billion per year and produce 37 million tonnes of carbon dioxide through burning fossil fuels.” (1)

On mine sites where there are a lot of motors driving operations, there is a real potential to improve the reliability and efficiency of motors. Having the correct selection criteria and good management of motor driven equipment is essential for the initial and running costs associated with motors. For a typical organisation the cost of running a motor can be up to 100 times more than the initial purchase price, and around 60% of the organisation’s total energy costs.

The mining industry is consistently striving to achieve more energy efficient methods for consuming electrical power. Reducing power consumption and greenhouse gas emissions is a significant challenge to ensure Australia’s social, economic and environmental well being.
To put a figure on it, for each percentage point improvement in motor system efficiency, translates to savings of about 400 000 MWh and associated 400 000 tonnes of greenhouse gas emissions. This is equivalent of taking 9 000 cars of the road. (1)

The project to be undertaken involves developing a specific PLC code which ensures Power Factor Correction on a synchronous motor as to keep down operation costs due to penalties imposed by the utility for running with a low power factor. Reducing the amount of power required to operate many of these machines throughout an industrial facility will reduce operating costs and improves overall plant motor efficiency.
5 Background

The internship project to be undertaken with BEC Engineering Pty Ltd, involves efficiently “soft-starting” a 4103kW, 6600V synchronous machine to drive a Ball Mill. This project has been designed, installed and commissioned in Golden Pride, Tanzania, Africa. Upon success, the second phase of the project is to transfer this new elite start-up method into the Mt Rawdon Gold Mine site situated in Queensland, Australia.

The physical setups around the Ball Mill are similar in both projects. Both sites posses an alternating current (AC) three phase wound rotor induction motors (WRIM). Referred to as a “Pony Motor”, it is utilised to initiate driving the synchronous motor up to synchronous speed. Clutch 1 from Figure 5-1 depicts the mechanical pneumatic clutch that engages the ‘up to speed’ asynchronous motors rotor to the synchronous motors shaft to start driving the machine. As Clutch 2 closes when the synchronous motor is synchronised, it absorbs the load of the to the ball mill. A simple version of this is shown in Figure 5-1.

![Figure 5-1 Project Overview Block Diagram](image_url)

5.1 “Start Up” Box
The major difference between the two projects is the control methods that drive the systems motor speed. This is shown by the “Start Up” box in Figure 5-1.
In Golden Pride, a Variable Voltage Variable Frequency (VVVF) device is utilised to ramp up the speed of the Pony Motor in order to synchronise the synchronous motor. Installing the same VVVF into the Mt Rawdon mine site is the task at hand. At present the ‘start up’ method used in the Mt Rawdon site is a Grid Resistance Starter (GRS). Properties of the GRS are evaluated in Section 7 of the report after discussing the background of the two mine sites.
6 Mine Sites

The delegated task involved developing an understanding of specific subsections of gold processing operations within two different mine sites. In order to understand the specific nature of the given project it is necessary to acquire background information on the Mt Rawdon Mine, Queensland Australia and Golden Pride Mine, Tanzania Africa. Specifically selected mineral processing unit operations employed will be evaluated throughout Section 9.

6.1 Golden Pride Mine
The Golden Pride mine is located in Tanzania, East Africa, 750km north-west of the port of Dar es Salaam and 200km south of Lake Victoria. A brief history about the mine; “The earliest organized prospecting and mining in Tanzania began with gold discoveries in the Lake Victoria region in 1894. Diamond mining was minor prior to 1940 but was majorly boosted with discovery of the Mwadui Mine in during 1940s.” (2)

Besides gold and diamonds mining, which have been the major sources of mineral production. “Other commodities have been relatively modest, namely for copper, lead, phosphate, coal, kaolin and gemstones.”(3)

The critical unit operation interest is the “start-up” method surrounding the Ball Mills synchronous motor.

6.2 Mt Rawdon Mine
The Mt Rawdon operation is an open pit gold and silver mine and its process plant is located in South East Queensland. A brief history about the mine; “Lihir Gold Limited (LGL) acquired the Mt Rawdon project in June 2008 with a merger with Equigold NL. Equigold purchased the project in 1999 and began construction the following year. The first gold production was complete in February 2001, since then has produced over 700,000 ounces of gold. The approximate mine life is another seven to ten years.” (4) Just recently as from September 2010 Newcrest Mining Limited took ownership of the Mt Rawdon Operation following the merger of Newcrest and LGL.
Note that the mining unit operations of the ore, for example, the drilling, blasting and shipping stages of the raw material from the mine to the processing plant will be considered and referred to as the *upstream process* for this report and as such the unit operations involved within upstream process is not covered.

The unit operation that will be discussed is Ball Milling. The project is based around starting up the synchronous motor in order to run milling operations. The specific properties characterising Ball Milling are covered in Section 9.1.2.2.
7 Grid Resistance Starter

In Mt Rawdon, a GRS is employed as the apparatus to accelerate rotation of the Pony Motors rotor. A GRS works based on resistors in series and parallel that are initially all connected to the armature. From Ohms law, when the resistors are all connected, there is a large starting resistance to the system and thus only allowing a low current to pass into the motor. The principles of GRS operation is best explained when referring to the schematic diagram shown in Figure 7-1:

![Figure 7-1 Mt Rawdon GRS Schematic](image)

The three sections highlighted in red, blue, and green reveal important details on how a GRS works.

The red highlighted section contains a multiline representation of the three phase pony motor. Contactors C2, C3, C4 and C5 represent banks of resistors and are connected to the armature.
through contactors. The resulting high resistance only allows for low current to pass into the motor. The physical display of a GRS can be seen in Figure 7-2.

![Figure 7-2 GRS Used in Mt Rawdon](image)

The drawing is incorrect in that the contactors in the **red** highlighted section C2-C5 are all initially open. This implies that as the timers time out, the contacts connecting the resistors to the motor close, adding resistance to the systems. Figure 7-1 suggests that starting resistance is low initially with all contactors open allowing current into the motor to be at its maximum. This is the opposite to how the GRS system operates.

The **blue** highlighted section depicts once the Run Relay contact is closed, timers are initiated to open contacts which reduces resistance to the pony motor system, allowing more current to pass hence increasing to motors output torque gradually. The amount of time between opening contacts and loosing resistance to the system is achieved through PLC programming. In this case the timers are set to open contactor C2 after 35s, C3 after 49.2s, C4 after 54.5s and, C5 after 56.78s. These times were commissioned on site and are only illustrative as the timing system in Golden Pride have needed to be commissioned by experienced personal. Misinterpretation of the schematic could have resulted in not recognising that the drawing is actually incorrect, and understanding how the timer system works.
The green highlighted section depicts how the Run Relay is initiated. The box with %Q0002 represents a digital output being sent from the PLC through the MCC terminal, activating the Run Relay.

There is a belt connecting pony motor rotor that transfers the mechanical rotational energy generated to the synchronous motor. As this belt wears overtime, increased starting torque is required from the pony motor to start up the synchronous machine. The properties of a GRS offer no torque altering characteristics to the motor, they simply ramp up the current entering the machine by dropping out resistors. The need for a torque alerting device is now apparent.

Figure 7-3 is further depicts how the GRS works once the Run Relay is enabled.
7.1 **Objective**

Overall, this project focuses on the current start-up method involving a GRS to be replaced with a VVVF device. This is partially due to this inefficiency surrounding synchronisation in that inadequate torque is produced by the Pony Motor by using the GRS according to Mt Rawdon expert personnel. To account for this torque

Background research into the following topics was essential in understanding the system as whole:

1. Gold mining unit operations;
2. AC power theory;
3. AC motor theory;
4. Analysing P&IDs, drive schematics, termination drawings;
5. Programmable Logic Control (PLC) Golden Pride ball milling code;
6. PLC Mt Rawdon ball milling code;
7. PLC development environments;
8 Progress of work on Milling Project

Due to the takeover of the Mt Rawdon gold mine site and processing plant by Newcrest Pty Ltd, in September 2010, BECs involvement with plant upgrades ceased effective immediately. The takeover disrupted many tasks that were planned out in form of a Gantt Chart. Many of these important tasks essential to operation were left incomplete and unresolved due to this unforeseen circumstance.

In particular the PLC coding side of the project which was the major task essentially, as the project was more software orientated than hardware. Even though no code upgrades were made, significant progress was made involving the design and creation of Signal Block Flow Diagrams and ladder logic I/O lists for each site.

Before looking into these it must be noted the unit operations that were studied in order to gain greater appreciate of the system.
Unit Operations

Unit operations are the processing steps that occur within distinct equipment in a process. Unit operations are individual operations that when connected create an overall process. “A process may have several unit operations to obtain a desired product.”(5)

There are many unit operations for a large process such as gold and silver refining, so breaking down the process into single step operations makes them easier to comprehend. It is important to note “the conservation laws apply not only to the process as a whole but to each individual unit operation.”(5)

The unit operations within a process form the fundamental principles of chemical engineering. These chemical engineering unit operations consist of five classes: (6)

1. *Fluid flow processes*: - fluid transportation, filtration;
2. *Heat transfer processes*: - evaporation, condensation;
3. *Mass transfer processes*: - distillation, extraction, absorption, drying;
4. *Thermodynamic processes*: - refrigeration;

The purpose of the next section is to give the general idea of how some of these unit operations are associated with refining gold and silver. There is no information on how to design these unit operations, as that is another topic and is not applicable.

9.1 *Mineral Processing Unit Operations*  
As mentioned unit operations may be commonly divided into five general headings for classification. It is now important to concentrate on some of the unit operations surrounding the mineral processing of gold. The unit operations discussed are common and relative to each mine site. Although the unit operations are specific to the two processing plants, their theory can be applied across multiple fields and disciplines.
Specifically, when discussing mineral processing unit operations it generally involves four types of unit operations:

1. *Comminution*: – particle size reduction;
2. *Sizing*: – separation of particle sizes by classification or screening;
3. *Concentration*: - extorting the physical and surface chemical properties;
4. *Separating*: - Different to *Sizing* as this section delves into solid/liquid separation.

### 9.1.1 Comminution Unit Operations

Comminution is particle size reduction of materials. Common in mining and mineral processing to unlock minerals from gangue. Gangue is the economically worthless material surrounding, or even mixed in, with a wanted material in an ore deposit.(7)

The first phase of comminution of materials begins in the mining stages involved with drilling and blasting, followed by excavators to generate materials easy enough to be transportable by haul trucks or a conveying system.(7)

The next step of comminution of mined minerals is *crushing*. Crushers utilise one or more methods to achieve particle size reduction, such as impact, abrasion, compression and attrition.

The type of crusher to be used is dependent on several factors:

1. Material type and properties;
2. Quantity of size reduction required;
3. Particle distribution;
4. Particle shape;
5. Maintenance;
6. Throughput;
7. Energy requirements;
8. Overall processing cost per ton.(7)
Measurements or background knowledge of these elements essentially needs to be accurate in order to select the correct crusher for a required task.

The idea of crushers is to reduce the physical size, or change the form of the material. Crushers are normally categorised as primary, secondary and/or tertiary crushing devices, and as material is passed from primary to secondary to tertiary crushers the size of the particles progressively decreases.

Three relative and common types of primary and secondary crushers include jaw crushers, cone crushers, and gyratory crushers. Commonly a tertiary crusher is utilised and employed to generate small-finite particle sizes of the material. A common grinding unit operations is the High Pressure Grinding Rollers (HPGRs). (8)

Below in Figure 9-1 is an example of a stage in gold refining depicting multiple unit operations surrounding size reduction of materials. Once the ore from the upstream process transported to the processing plant, in the case of Mill Number One from Figure 9-1, a jaw crusher is used as the primary method of crushing before being sent on a conveyor to deposit into stockpiles. Similar to the case in Mill Number Two however the primary method of size reduction is by a gyratory crusher before transportation to the stockpile.

Note that in these situations presented cone crushers are utilised as a secondary crusher methods. However it is not uncommon to have cone crushers as the method of primary and secondary crushing.

But why crush ore? The objective of milling gold ores is to extract the highest quality gold for the highest financial return. In order to do this, “the ore must be finely ground to redeem the gold particles.” (8)
9.1.1.1 Jaw Crushers

A jaw crusher consists of a set of mechanical vertical jaws, one being fixed whilst the other moves back and forth relative to it by a cam or pitman mechanism. As seen in Table 9-1 below the distance between these jaw plates are farther apart at the top and gradually get smaller towards the bottom. This ensures the material is progressively undergoing size reduction until the ore is small enough to escape the bottom opening. (9)

Below in Table 9-1 is a step by step procedure that a jaw crusher undertakes during operation.

| Start: Ore is transferred into the jaw crusher, which then begins size reducing the ore. |
| Finish: Ore is transferred elsewhere as smaller particles for further operations. |
9.1.1.2 Gyratory Crushers

A gyratory crusher is a compression type primary crushing device. As shown in Figure 9-2 and Figure 9-3. “…These crushers consist of a long spindle with attached steel conical grinding elements. The spindle is suspended at the top by a "spider" and the bottom end is seated in an eccentric sleeve. The eccentric sleeve rotates and causes the spindle to move in a conical path within the fixed outer crushing chamber.” (10)

As the gap closes the grinding element and the fixed surface generates the crushing action required to decrease material particle size.

![Figure 9-2 Basic operational principle of a gyratory crusher (11)](image1)

![Figure 9-3 Underground gyratory crusher (6)](image2)

Table 9-2 Gyratory Crushing Operation (11)

<table>
<thead>
<tr>
<th>Start, Ore is transferred in at the top of the crusher, which can be above or underground as in Figure 9-3</th>
<th>As the ore passes through narrower spaces, size reduction occurs. Cone moves from side to side in order to crush the ore up against the side walls of the crusher.</th>
<th>Finish, Ore is then crushed after this size reduction procedure.</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Image 3" /></td>
<td><img src="image4" alt="Image 4" /></td>
<td><img src="image5" alt="Image 5" /></td>
</tr>
</tbody>
</table>

An example of how these machines work is shown in Table 9-2 above. Note that the rotational motion of the crusher is that about the $x$-axis and $z$-axis only and no vertical translation occurs.
This crusher is generally the only choice for mines with large throughput rates of approximately greater than 900 tons per hour. With the ability of managing input feed rates, gyratory’s offer that flexibility in that they can be fed by dump truck shown in Figure 9-4, they have a large unrestricted opening and will operate well under choke conditions. (10)

Another type of primary or secondary crusher is the cone crusher.

**9.1.1.3 Cone Crushers**

A cone crusher uses compression type crushing and these crushers have the capability of being either a primary, secondary or tertiary methods of size reduction. This will be dependent on the crusher selection criteria discussed in Section 9.1.1. “Cone crushers are a variation of gyratory crushers and operate on the same basic principle of an eccentric motion of an inner crushing cone against an outer chamber.”

Geometrically the difference between a cone and gyratory crusher is cone crushers entail a “shorter spindle and a larger crushing diameter surface gyrating inside an inverted truncated cone. It also travels at a higher speed with greater travelling distance. The crushing cone is supported at the bottom which allows the outer chamber to lift and pass hard tramp material without damaging the crusher.” (13)
9.1.2 Grinding Mill and Machines

A grinding mill is a unit operation that involves breaking a solid material into smaller pieces (commonly used in the tertiary stage of crushing). “The grinding of solid matters occurs under exposure of mechanical forces that trench the structure by overcoming of the interior bonding forces. After the grinding the state of the solid is changed: the grain size, the grain size disposition and the grain shape.” (14)

The importance of grinding a material to an process engineer is that it increases the surface area of a solid, and it manufactures a solid with a desired grain size. It is also worthy of noting that grinding processes generally require large consumptions of energy. Careful consideration should be taken when deciding whether or not one of these devices would be efficient for the processing plant’s production rate.
9.1.2.1 SAG Mill
SAG is an acronym for Semi-Autogenous Grinding, and applies to mills that utilize steel balls in addition to large rocks for grinding. SAG mills are characterized by their large diameter and short length. Size reduction is achieved by the rotating cylinder filled with large steel balls which rotated up the cylinder then dropping smashing the ore on impact. A SAG Mill can be used as a primary or secondary crushing unit. It operates similar to a Ball Mill however it also has plates lined on the inside of the mill that lift the material on rotation and drop it causing it to break. Some SAG Mills require 28MW of power for operation.

9.1.2.2 Ball Mill
Ball mill is an efficient tool for grinding materials into fine powder. There are two ways of grinding: the dry process and the wet process. It can be divided into tabular type and flowing type according to different forms of discharging material.

Below in Figure 9-6 is an actual image of the Ball Mill out of service.
9.1.3 Ball Mill Operating principle:
The ball mill is a key item of regrinding. This ball mill is horizontal type and tubular running device. The material enters spirally and evenly along the input material hollow axis by the input material device on each mine. In this ball mill stone or metal balls are installed on the scaleboard, when the barrel body rotates and then produces centrifugal the steel ball is carried a specific height and fall grinding the material on striking. (15)

9.1.4 Concentration Unit Operations
There are several methods utilised in order to increase the concentration of a desired mineral. Methods available differ, in principle however the method chosen will depend on the relative physical and surface chemical properties of both mineral and gangue. Gangue is the undesirable, commercially worthless, waste material that surrounds or is in close proximity with the desired mineral. (16) These will not be explored further in this dossier, understanding electromagnetic induction and the principles behind motor operation was essential for the project.
10 History of the motor

There are many individuals who deserve credit for the development of efficient AC motors today. In particular Michael Faraday:

10.1 Faraday’s principle:
Michael Faraday (22/09/1791 – 25/08/1867), was an English chemist and physicist. His best known work is that with electricity and magnetism. Faraday built a device to produce what he called electromagnetic rotation.

In other words, “a continuous circular motion from the circular magnetic force around a wire and a wire extending into a pool of mercury with a magnet placed inside that would rotate around the magnet if supplied with current from a chemical battery.” In other words he showed that it was possible to produce continuous motion from the interaction of electricity and magnetism. (17). Apart from being the first independent contribution to electromagnetism, it was the first time that continuous motion had been produced from chemical energy. This is the principle behind the electric motor.

![Figure 10-1 Faraday's Electromagnetism Experiment](image-url)
11 Categorising of electric motors

Electric motors have been classified under one of three categories:

1. Alternating Current Type
2. Direct Current Type
3. Universal Type (D.C motor operating on AC power)

Rated output also is used to categories motors, as an example, a 500 Watt motor is often referred to as a *fractional horsepower motor* (FHP).

All rotating electric motors require synchronism between a moving magnetic field and a moving current sheet for average torque production. There is a difference between an asynchronous motor and synchronous motors. This is further discussed in Table 14-1.

The two motors of use in the project, as mentioned:

1. 132kW Three phase AC Asynchronous *Wound Rotor Induction Motor* (WRIM)
2. 4.3MW Three phase AC Synchronous Motor.

Before exploring the functionality and principle of operation for these two motors, the key components to a typical AC motor needs addressing.

**11.1 Key components of a typical AC motor**

Two three phase AC motors are used in this project, both compiled for separate individual tasks. It helps knowing the key components of this common device. Typical AC motors, see Figure 11-1, have hardware consisting of several parts:

1. Outside *stationary stator* with coils supplied with AC current producing a rotating magnetic field;
2. Inside *rotor* that is attached to the *output shaft* that is supplied a torque by the rotating field;
3. *Casing enclosure*, for protection of the stator windings;
4. *Name plate*, specifications reference;
5. *Stator Core*, a thin stacked lamination that are wound with insulation wire;
6. **Stator Windings**, generally copper windings around the stator that induce a magnetic field when a current is supplied to the windings;

7. **Rotor Bar**, this is typical for a *squirrel cage motor*, a type of induction motor, however this motor is not used in this project and as such which will not be discussed.

8. **Cooling fan**, reduces the temperature of the motor. (18)

![Typical components of an AC motor, inside and outside views.](image)

Proceeding with knowledge of the components of a typical AC motor is the essential **Selection Criteria** phase.

### 11.2 Selection Criteria

When considering designing or selecting a motor for an operation, the following criteria must be taken into account:

1. Operating Current;
2. Operating Voltage;
3. Operating Slip;
4. Operating Torque;
5. Power Factor, see Section 13.2.
6. Frequency.
11.2.1 Operating Voltage and Current
Along with motor selection criteria, operating voltage and current principles can apply to understanding the analogue signals of the system.

This section serves to explain the characteristics of a single phase system, three phase real, reactive and apparent power; and power factor which will provide an introduction into power factor correction, covered in Section 13.2. These topics also lead into AC motor power theory, a key motivation for the project. Comprehending these topics assisted in appreciating the complexity of the Ball Mill start up operation.

It is necessary to distinguish the method of power that is supplied to the operation, in both cases is three phase power, still it is important to understand basics of single phase power first.
11.2.1.1 Single Phase System

When determining the power delivered by a source to a load, there are three situations to consider. The current, voltage, and power versus time curves for where there is a purely resistive load, a purely inductive load, and a pure capacitive load. Table 11-1 depicts all three situations:

<table>
<thead>
<tr>
<th>Voltage/Current Curve</th>
<th>Power Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Resistive Load</td>
<td><img src="image" alt="Power Curve" /></td>
</tr>
<tr>
<td>Pure Inductive Load</td>
<td><img src="image" alt="Power Curve" /></td>
</tr>
<tr>
<td>Pure Capacitive Load</td>
<td><img src="image" alt="Power Curve" /></td>
</tr>
</tbody>
</table>
The motors used in the system powered all from a three phase system. The above information is the stepping stone from single phase AC power analysis to three phase AC power analysis.

### 11.2.1.2 Three Phase AC System

A good method for describing three phase voltage in comparison to single phase voltage is to consider a bicycle.

A single phase voltage of 120 volts is the equivalent of one person riding a bicycle. This means that only one stroke is produced that will peak and produce power from the one person riding. It is possible to have single phase voltage of 240 volts, instead though, this is equivalent of two people riding a bicycle. This is more efficient than a single phase 120 volt motor. (19)

A three phase voltage can be compared to three riders on a bicycle. Here three power producing strokes are provided by:

1. First rider leaving peak stroke and second rider enters peak stroke;
2. Second rider leaves peak stroke and third rider enters peak stroke, and;
3. Third rider leaves peak stroke and procedure repeats itself with the first rider entering peak stroke, etc.

In terms of three phase motors, the example shows how more power is produced due to the three different phases peaking which provide a smooth, continuous power to drive the rotor. See Figure 11-2 for the bicycle representation of three phase power. Below that, in Figure 11-3 is the graphical representation of what was discussed.

![Figure 11-2 Bicycle equivalent single, and three phase power produced. (19)](image-url)
Surprisingly the most common form of polyphase systems is the three phase power system used in industrial applications and power transmission. They are extremely useful for transmitting power to electric motors.

There is an advantage of a three phase power transmission using three wires, in comparison to a single phase power transmission over two wires. The power transmitted in the single phase is the product of the voltage and current in each wire, however determining three phase power the voltage is multiplied by the current then by the square route of three. Thus the three phase system transmits 73% more power and only uses 50% more wire. (19)
11.2.2 Power Factor
The PLC analogue inputs monitor vital measurements taken from the systems measuring devices in order to control the single analogue output of the system accordingly. Power factor, motor power, reactive power, bus volts, motor volts are the analogue input signals that are monitored. The resulting analogue output is a D.C excitation that ensures the system is operating within a desired power factor range. Without an electrical engineering background developing knowledge of “power within ac circuits” was essential to comprehend how Power Factor Correction works.

It is a very complex topic involving detailed electrical and mathematical knowledge, basically though power factor represents the out-of-phase displacement between the voltage and current. The polarity of the reactance to the system is dependant if the systems behaviour is inductive or capacitive.
12 Three phase AC asynchronous induction motor

Asynchronous AC Induction machines are the most widely used of all electric motors. They are generally rugged and simple to build and offer satisfactory asynchronous performance. Having such widespread applications, along with continuing research and development for improving efficiency, a general knowledge of induction machines is vital. Document limitations do not permit thorough explication of all aspects of induction motor analysis, but serves as a good background of the topic.

Asynchronous AC induction motors have stator windings that are electrically connected to an AC power source. Via transformer action, current is induced into the rotor circuit and the resulting magnetic field interacts with the stator’s field which causes the rotation of the rotor.

If the rotor was rotating at the same frequency as the rotating magnetic field in the stator, there would be no relative motion between them. Thus, no flux lines would cut across the rotor bars hence no magnetic field would be induced. For there to be induction the rotor must rotate slower than the stator field, thus rotating at less than synchronous speed.
The strength of the interacting magnetic fields in the stator and rotor is proportional to the produced torque of an induction motor. This torque varies from zero to the rated slip speed. The term *locked rotor torque* or *starting torque* is the minimum torque developed from when the rotor is at rest or 0 rpm. The current required to produce this starting torque is sometimes seven times than that of the actual full load current.

![Figure 12-1 Three Phase Induction Motor](image)

The Pony Motor used on both sites is a Wound Rotor Induction Motor (WRIM). This type of motor has a rotor that is comprised of a set of coils that are electrically terminated in the slip rings. This type of motor is used when *variable speed* is required. Compared to a squirrel cage rotor, WRIMs are expensive and require more maintenance of the slip rings and brushes.

Actual RPM for an induction motor will be less than this calculated synchronous speed by an amount known as *slip*, that increases with the torque produced. With no load, the speed will be very close to synchronous. (20)

The slip of the AC motor is calculated by: (21)

\[
S = \frac{(N_s - N_r)}{N_s}
\]

Where:

- \(N_r\) = Rotational speed, in revolutions per minute.
- \(S\) = Normalised Slip, 0 to 1.
As an example, a typical four-pole motor running on 60 Hz might have a nameplate rating of 1725 RPM at full load, while its calculated speed is 1800 RPM. (21)

The speed in this type of motor has traditionally been altered by having additional sets of coils or poles in the motor that can be switched on and off to change the speed of magnetic field rotation. However, developments in power electronics mean that the frequency of the power supply can also now be varied to provide a smoother control of the motor speed. (21)

However induction motors are great for starting up a system with no or little load. When there is load more power is required from the motor for stable operation.
13 Synchronous Motor

The origin of the name comes from: “syn” meaning equal and “chronos” meaning time.

Synchronous machines can behave as both a generator, transferring mechanical to electrical energy; or as a motor, transferring electrical energy into mechanical energy. As the rotor moves, there is a change in energy stored, as shown in Figure 13-1. This energy can either be extracted from the magnetic field to become mechanical energy, this is motor operation. Or the energy can be stored in the magnetic field and over time flow into the electric circuit powering the stator, this is a generator. Induction motors can be accelerated to steady state operations by simply applying AC power to the fixed stator windings within the motor.

A synchronous motor starts as an induction motor, however when the rotor speed is near the stator speed (synchronous speed), the rotor becomes locked in step with the stator due to application of field excitation. (22)

Synchronous motors in general consist of the following parts, also see Figure 13-1:

1. Stator: Outer shell of the motor carrying the armature winding. The armature creates a rotating magnetic field inside the stator;
2. Rotor: Rotating portion of the motor;
3. Slip rings in the rotor, supply the D.C power to the field windings.

![Figure 13-1 Typical Synchronous Machine (22)](image)

What distinguishes synchronous motors is the rotor spinning with coils passing magnets at the same rate as the AC current and resulting rotating magnetic field driving it. In other words there is zero slip under normal operating conditions. These motors operate with the line frequency.
13.1 Frequency

The output frequency of a synchronous motor voltage depends upon the speed of rotation of the rotor and the number of poles. A synchronous motor runs at synchronous speed with 0% slippage. (23)

The higher the frequency, the faster the rotational rotor speed. Alternatively the lower the frequency, results in lower rotor speed. If the number of poles on the rotor increases, the higher the frequency is for a given speed.

Mathematically, the speed of a synchronous motor or generator is governed by the number of poles and the speed of rotation, expressed in Equation 13-1.

Equation 13-1 Mathematical representation of motor speed (23)

\[ v = \frac{120f}{p} \]

Where:

\( v \) = Speed of rotation (r.p.m)
\( f \) = AC supply frequency (line frequency, Hz)
\( p \) = Number of magnetic poles

The synchronous motor to be used in Mt Rawdon is a 6 pole, 50Hz polyphase AC supply, meaning theoretically the speed of rotation should be expected to be:

Equation 13-2 Determining synchronous speed for Mt Rawdon machine

\[ v = \frac{120 \times 50\text{Hz}}{6\text{Poles}} = \frac{6000}{6} = 1000 \text{ r.p.m} \]

Synchronous motors are not always, but often categorised into two major types:

1. Non-Excited
2. Direct-Current Excited
“Non-excited motors are manufactured in reluctance and hysteresis designs, these motors employ a self-starting circuit and require no external excitation supply.” (24) These systems are commonly employed to operations involved where a constant rotor speed is accurately required.

An example of a direct-current excitation synchronous motor is that in Figure 13-1. The direct D.C source provides the rotor with the necessary current to keep the motor in phase. Damages to a synchronous motor when it goes out of phase can be seen in Section 22.2 of the Appendix.

In situations that require high-horse powered operations, synchronous motors provide two important functions:

1. Highly efficient in converting AC energy into work, and;
2. Operate at leading or unity power factor, thus has capability for power factor correction.

Control and optimisation of the motor through use power factor control or VAr operation will help in reducing the VAr penalties imposed by the utility and improve voltage stability within the plant.
13.2 Power Factor Control

One use for this type of motor is its use in a power factor correction scheme. Synchronous motors with power factor correction control are often referred to as synchronous condensers. This exploits a feature of the machine where it consumes power at a leading power factor when its rotor is over excited. It thus appears to the supply to be a capacitor, and could thus be used to correct the lagging power factor that is usually presented to the electric supply by inductive loads. The excitation is adjusted until a near unity power factor is obtained (often automatically). Machines used for this purpose are easily identified as they have no shaft extensions. Synchronous motors are valued in any case because their power factor is much better than that of induction motors, making them preferred for very high power applications.

To ensure the motor does not ‘Slip’ it is supplied with a Field Current Boost Command which elevates the field current to a preset level providing increased armature current with Leading PF due to increased MVAr Export. It must be noted that the magnitude of this boost is dependent on the HV System Performance with Leading PF acceptability. The boost time for this is only two seconds during which the Mill Load Clutch is engaged. After the Mill Load is applied and the boost is removed, PID control in the PLC initiates the calculations for load correction. This is covered PID control loop is discussed in more detail in Section 15.
14 Comparing Asynchronous to Synchronous

Below in Table 14-1 which compares the two types of motor to not only show their differences and similarities, but the advantages and disadvantages of selecting which motor.

Table 14-1 Comparing Synchronous to Asynchronous (20)

<table>
<thead>
<tr>
<th>Motor Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Asynchronous (AC three phase) | • Ability to connect directly to the AC source.  
|                        | • Low maintenance  
|                        | • Durable (Rugged)  
|                        | • Purchase price is less than that of a synchronous motor.                       | • Wants to turn at constant speed.  
|                        | • As an example, a 4-pole motor cannot turn faster than 1500rpm.  
|                        | • Draws large starting current.                                                 |
| Synchronous            | • Speed is independent of the load, provided an adequate field current is applied.  
|                        | • Accurate control in speed and position using open loop controls, like in the case of a stepper motor.  
|                        | • They will hold their position when a D.C current is applied to both the stator and the rotor windings.  
|                        | • Their power factor can be adjusted to unity by using a proper field current relative to the load. Also, a "capacitive" power factor, (current phase leads voltage phase), can be obtained by increasing this current slightly, which can help achieve a better power factor correction for the whole installation.  
|                        | • Their construction allows for increased electrical efficiency when a low speed is required, such in the case of this project with the Ball Mill.  
|                        | • They run either at the synchronous speed or they do not run at all, which can be considered an advantage or disadvantage pending the application. | • Initial Cost of the machine is large in comparison to an induction motor.  |
15 PLC PID Control Method

The calculations are made from a PF Feedback signal that determines the error between the setpoint PF value to establish the correct field excitation to maintain unity PF for the specific load application.

The Exciter PID control method is shown in Figure 15-1 below:

![Figure 15-1 PID Control Exciter Control Loop](image-url)
The PID is always ENAB (Enabled Except – A condition inside the PLC code) when the Boost Control is applied. The setpoint reference input to the PID controller comes from fixed preset data which provides for a PF reference of 1.0.

The process variable (the feedback signal obtained from the SR469 Multilin) provides data which the PID controller calculates the error and required CV (Control Variable) output. The CV requires scaling to suit the analogue output value of 4-20mA to be representative of an additional field current 81A above the minimum preset of 119A D.C provided by the field regulator module. This is regulated by the PLC.

It should be noted that the PID controls the active component of the MVAr Export to provide the correct motor excitation.

**Manual Mode**
The PID remains active but the output is logically disabled and the input from the control panels potentiometer is enabled. This is then forwarded to the analogue output as a 4-20mA signal. The values are scaled that 0-100% represents an additional 81A D.C to the already minimally excited condition of 119A D.C.

**Automatic Mode**
The PID remains active and the output from the PID is enabled and transferred to the analogue output as a 4-20mA signal representing the additional 81A D.C required for the maximum capable field current of 200A D.C.

**Off Mode**
The PID is active with the output to the analogue output being disabled allowing for test capabilities for checking the PID operation and enabling the facility to inject a suitable simulated 4-20mA signal as the power factor feedback.
A diagrammatic representation for stepping the boost function in the automatic PID control mode is depicted in Figure 15-2.
16 Signal Line Block Diagrams

Signal Block Diagrams were created with the intention of displaying the “main" signals being transferred between instruments within the system. Essentially the task involved locating the signals involved with the operation the Pony Motor VSD in the GP Project. Mapping these signals allowed for a clear depiction of the method of which the signals though-out the system are being transferred, and summarising this into a single page single line diagram, proved invaluable when explaining the advanced principles of operation.

There recently was a flood in the office building causing multiple millions of dollars in damages. Unfortunately as a result, BEC’s archive room containing hardcopies of all the previously completed archived projects suffered severe water damage. Many of the associated files with this project revision were extensively damaged, delicate care was undertaken when separating files within the folders.

An important set of skills were developed from observing, analysing and understanding different types of technical drawings such as P&IDs, single line, termination diagrams and drive schematics. The number of technical drawings for both process plants is in the thousands, however only a select handful of these were useful.

Having previous experience with these diagrams in understanding the layout of the actual drawing and purpose proved an extra challenge when specifically learning BECs standards/design of drawings which was daunting to begin with.

One really important note is to make sure that all the drawings required are readily available (if possible) as significant time was spent throughout this task attempting to obtain all the technical drawings. The location of these ranged from the archive room, an archive server, intranet, and a CD-ROM backup archive. The challenged emerged of knowing where to look for the required drawings for the project. This was resolved through extensive searching though all archives. In other words there was no quick and easy solution when obtaining the necessary documentation.
It is important to note here that there is a section within the company that is in charge of these documents. The work group internal to BEC is known as Documentation Control.

Working solo is challenging in the engineering field, one difficulty was not having anyone to bounce ideas off. If a signal was not understood, the page would get marked in red ink then a meeting would take place to discuss the issue with the Lead Engineer.

The created Signal Block Diagrams did not exist prior to commencement of the project, and both are shown in Figure 16-1 and Figure 16-2.
Figure 16-1 Signal Block Flow Diagram Mt Rawdon
Figure 16-2 Signal Block Flow Diagram Golden Pride
17 Ladder Logic I/O List

With motivation for the project being vastly software orientated, it was necessary to create a reference point for all the logic I/O in the PLC code for both mine sites. To do this effectively a Microsoft Excel spreadsheet was utilised to store necessary information. Rather than scroll through Ladder Logic code on a PC or flicking through code on paper it was possible to create an electronic compacted check list. This would ease the load incredibly for future work on the task. It is possible now to find where all the VSD code is and determine if its involved in operations, interlocks, or/and monitoring. This code is the necessary code to be transferred in the VersaMax environment in the Mt Rawdon system.

In order to compare the similarities and differences between the system operating at Golden Pride and Mt Rawdon, lists of all the PLCs inputs and outputs are tabulated in the attached Microsoft Excel files named “LLogicIOListMtRawdon.xlsx” and “LLogicIOListGoldenPride.xlsx”. These are also available in Section 23 and 24 of the appendix.

Table 17-1 contains the headings created in both spreadsheets and a description of what was contained under these headings:

<table>
<thead>
<tr>
<th>Headings</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Is it a Analogue Input (AI), Analogue Output (AO), Digital Input (DI), Digital Output (DO)?</td>
</tr>
<tr>
<td>Field Tag</td>
<td>Field Tag Name for specific device</td>
</tr>
<tr>
<td>I/O Function</td>
<td>State (example, &quot;Ready to Start&quot;)</td>
</tr>
<tr>
<td>Data Type</td>
<td>Boolean, Integer... etc</td>
</tr>
<tr>
<td>PLC Address</td>
<td>Specific PLC address</td>
</tr>
<tr>
<td>PLC Address Confirmation</td>
<td>Where in Ladder Logic is a signal</td>
</tr>
<tr>
<td>PLC Tag Name</td>
<td>Tag name useful to operator</td>
</tr>
<tr>
<td>PLC Rack/Slot</td>
<td>What Rack/Slot on PLC is signal wired</td>
</tr>
<tr>
<td>Indication</td>
<td>What type of indication (colour)</td>
</tr>
<tr>
<td>Signal Range</td>
<td>4-20mA</td>
</tr>
<tr>
<td>Engineering Range</td>
<td>4mA=4000 and 20mA=20000 in the PLC</td>
</tr>
<tr>
<td>High/Low Limit</td>
<td>Limits preset from knowledge of the system</td>
</tr>
<tr>
<td>Setpoint</td>
<td>Signal Setpoint for Power Factor Control</td>
</tr>
<tr>
<td>Stored Values</td>
<td>Stored values from knowledge of the system</td>
</tr>
<tr>
<td>Drawing Reference</td>
<td>Which specific drawing did signal come from</td>
</tr>
</tbody>
</table>
18 Programmable Logic Controller (PLC)

Both sites use different Programmable Logic Controllers (PLC) to conduct operations. A PLC is essentially a control device that consists of a programmable microprocessor, and is programmed using a specialised computer language. Typically, the program is written in a development environment on a computer, and then is downloaded onto the PLC directly through cable connection. This program is installed in the PLC’s non-volatile memory.

There are many commercially recognised suppliers and vendors of PLCs in the market today. The Golden Pride project uses an Alan Bradley SLC 5/05 PLC with the development program environment utilised in RSLogix500. The Mt Rawdon project rely on a GE Fanuc Series 90/30 PLC, the development program environment used to complete this coding is VersaMax.

There are a number of Operator Control/Indication Centres located throughout the plant. These control centres enable the operator to control and monitor packaged equipment, as well as the overall plant. Figure 16-1 and Figure 16-2 also offer the advantage of pointing out the different control centres that monitor and force operation.

The Plant Control Room contains two computers connected to the PLC network operating the plant SCADA software. The computers are redundant such that the plant process information is viewed and logged with only one computer in operation. In addition to the SCADA software, one computer is also loaded with the PLC software and can be used for programming and fault finding on the PLC network.

The functionality of the plant SCADA system is to:

1. Control of control loops;
2. Indication, trending and logging of plant instrumentation signals;
3. Alarm annunciation for plant alarms;
4. Plant status display, and;
5. Remote control of drives specified with remote control facilities.

Modes of operation were mentioned in Section 15 before with the specific actions occurring in each state. Again:

**18.1.1.1 Manual**

Manual Mode will enable the operator to directly control the manipulated variable. The operator will set the controller output to a value between 0 % and 100 %.

**18.1.1.2 Automatic**

Automatic Mode provides unattended process monitoring and regulation. The operator enters the targeted set value of the process variable and the controller will automatically regulate the manipulated variable in order to achieve the desired process value.

**18.2 Understanding Code**

The goal was to replace the existing LRS system with VVVF instrumentation for a more efficient synchronous motor start up procedure. In order to achieve this, it was necessary to understand the PLC control philosophy throughout both sites, but first the site with VVVF code, Golden Pride. Going through the Signal Block Flow Diagrams and the Ladder Logic I/O Lists are good starts to understanding the code in both systems from scratch. It would be difficult for future to be done on the PLC coding without this background knowledge of the system being presented initially.

Section 22.1.1 of the Appendix has four table that were created when going though code on paper that was supposed to be the same as the code inside the developing environment. This was not the case as the

Another difficulty encountered was the electronic copy of the code for Mt Rawdon’s operation had no symbols or tag names. All that was on the ladder logic code was the specific I/O address for each state or action. Caution was taken during this session ensuring that the code was updated
with symbols. This assisted in understanding how the ladder logic blocks operated and the functionality of each rung of code in VersaMax.
19 Schematic Diagram Analysis

Part of the intern role was based on analysing P&IDs and modify them by updating an existing Instrument List for a client. A Microsoft Excel spreadsheet stores all the instrument details that get transferred into the clients database. It serves more than just a purpose of quick reference. A Tenova P&ID that was analysed is show below. Take note of the two highlighted sections.

![Figure 19-1 Example of a Tenova P&ID](image-url)
Firstly the **red box** in Figure 19-1 is analysed, zoomed up in Figure 19-2:

![Figure 19-2 Zoomed in section of example Tenova P&ID](image)

From this section of the drawing there is a Pressure Indicator Switch (PIS), Pressure Alarm Low (PAL), Position Switch High (ZSH), Position Switch Low (ZSL), Position Indicator High (ZIH), Position Indicator Low (ZIL) and three Solenoid Valves (SV). The acronyms for each of these devices is input into the database along with the associating number. The two SVs that have decimals in their numbers, these are known as *modifiers* and are input into another column in the spreadsheet. Numbers without modifiers have their modifier cell left blank. The 231-DV-573 is a Dump Valve and this information is located in the **green box** located towards the bottom of the drawing, zoomed in Figure 19-3.

![Figure 19-3 Unit Operation Connection for I/O](image)
To keep consistency and track of instruments that have been input, a hard copy of the P&ID would be highlighted as depicted in Figure 19-4.

Figure 19-4 Zoomed in section of example Tenova P&ID, highlighted as representative of the hardcopy after insertion.

In the end that part of the drawing is complete and time to move on to the next section that has I/O.

Figure 19-5 Final Product after one section of the drawing has been analysed
This job required a thorough investigation and proper steps taken to ensure that the list was correct. If there were mistakes, for example, an instrument is tagged incorrectly, the drawing would be marked with the corrections or a question mark in red and sent to the lead engineer for review.

This occurred with an Abesque P&ID where the Underspeed Switch (CZS) on the Conveyor No.3 (200-CV-311) where the tag was numbered 4632 when the numbering design criteria for that specific P&ID ranged between 4730-4760. This is depicted in the blue box in Figure 19-6 and Figure 19-7.

Figure 19-6 Abesque P&ID example with markups

The two tags HV-4736 and HV-4737 marked in red were numbers given that were in compliance with the design criteria. This meant that there could not be two of the same tag names with same numbers. Also the numbers given have to be within a given set for that P&ID (for this drawing 4730-4760). These numbers were apart from that arbitrary.
Notice in these drawings the machines names and descriptions highlighted in the red boxes are next to the appropriate unit operation. Unlike the Tenova P&ID diagrams where these details of these were located on the top or bottom of the drawing.
19.1 Excel Functions used for operations and debugging

Internal of the Instrumentation list were two important functions being used to ensure the continuity throughout. VLOOKUP and an IF(COUNTIF) functions. The V in VLOOKUP stands for vertical. Use VLOOKUP instead of HLOOKUP when your comparison values are located in a column to the left of the data that you want to find.

19.2 VLOOKUP Syntax

Searches for a value in the first column of a table array and returns a value in the same row from another column in the table array.

VLOOKUP(lookup_value,table_array,col_index_num,range_lookup)

This was used in order to input, for example a Solenoid Value. The user would input the acronym SV into a column and in another column would appear be the full name of the device. So if HV was input, Hand Value would appear in the appropriate column. (27)

19.3 IF(COUNTIF) Syntax

The IF statement wrapped around the COUNTIF statement is an added extra to the function. The COUNTIF function serves as a check for same tag name with the same tag number. Instruments are not allowed to be repeated so this is a quick testing method to see how many doubles or triples there are in the list. One problem with this when the list is so large and there are many rows as well, is that the COUNTIF function only displays a number of how many times that cell is repeated. The IF statement basically states that: IF the cell is greater than 1 (then there is a double) then Display “XXXX” and paint the background of that cell Cyan. This way it was possible to zoom out and see the whole spreadsheet and just scroll down until the coloured cell full of ‘XXXXs’ appears.

The COUNTIF function has the following syntax:

COUNTIF(range,criteria)

Where:

Range: Is the range of cells from which you want to count cells.
**Criteria:** Is the criteria in the form of a number, expression, cell reference, or text that defines which cells will be counted. For example, criteria can be expressed as 32, "32", ">32", "apples", or B4.(28)
Summary

Whilst not being able to code Mt Rawdon’s Ball Mill start up system, invaluable experience was gathered and progress made. Having the availability of all the logic I/O in one spreadsheet assisted when emulating the system in that there was a quick reference point readily available. Along with the signal block flow diagrams that successfully outlined all the operating and monitoring states for the PLCs in the different Control Centres.

Knowledge gained about AC power and AC motor theory gave great insight to the costs and unit operations commonly used in mine sites. Ball Milling is a common unit operation to mine sites and starting these up can sometimes involve contacting the utility to receive permission due to the large amounts of required power. With this in mind and the penalties imposed on poor plant power factor, ensuring this operation was successfully simulated was necessary. This would have involved coding the VSD code in VersaMax and running the Emulation tool inside the developer environment.

The major computer programmes which time was allocated to were MS Office, RSLogix500, RSLinx, RSEmulator and VersaMax.

Going through many P&ID’s and consistently doing the same thing over and over can be tedious. It must be noted that this role as tedious as it may seem is extremely important and accuracy of these drawings is vital. The role as the intern of going through these drawings and then meeting with the lead engineer for drawing updates or corrections developed my skills technically and professionally.
21 Bibliography


BEC Engineering Pty Ltd

Christopher Colson
29. **Ford, Dr Peter.** *University of Bath's Department of Physics.* 2007.
### 22 Appendix

#### 22.1.1 Golden Pride Summary of Code between Hardcopy and Softcopy

<table>
<thead>
<tr>
<th>FUNCTION SUMMARY</th>
<th>TECHNICAL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Panel Power Supply Monitor</td>
<td>Flag: - O/K When HIGH</td>
<td>When Field Supply Contactor AUX Closed; and power not exceeding Converter Fuse.</td>
</tr>
<tr>
<td><strong>2</strong> Reset Alarms</td>
<td>Flags: - Auto/Man Alarm Reset - Check Relay Reset</td>
<td>When Reset PushButton on front panel is pressed; or Alarm Auto Reset Timer is run ever execution. 2 second TON. So timer allows 2 seconds to reset alarms automatically.</td>
</tr>
<tr>
<td><strong>3</strong> Minimum Preset Field Current Detection</td>
<td>Sets a 3 Second TOF Timer Once Threshold is detected off &gt;5A D.C.  If not reached the following conditions are met: -Alarm trip interlock healthy when on; -Regulator off or fault trip; -Latches a Fault and perhaps illuminates an interlock lamp.</td>
<td>Field Converter is energised by closure of Field Supply Contactor AUX. Min current&gt;5A D.C and within a 3 second period Measured by the AC Input CT Rectifier Assembly, Signal is processed through U2T1 Sensor (what sensor is this one??)</td>
</tr>
<tr>
<td><strong>4</strong> Field Regulator Monitor</td>
<td>Flag: Field Regulator O/K When HIGH</td>
<td>Field Supply Contactor AUX Closed is Healthy or Over current input normally closed when O/K and/or Field undercurrent or Fault detected when field is energised; Field undercurrent detect buffer enabled. Alarm Reset And Field Supply Contactor AUX Closed</td>
</tr>
<tr>
<td>ANALOGUE CODE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FUNCTION SUMMARY** | **TECHNICAL** | **DESCRIPTION** |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Data Scaled</td>
<td>4mA = 4000</td>
<td>Data is scaled such that the input of ‘x’ mA = Data Value</td>
</tr>
<tr>
<td></td>
<td>12mA=12000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20mA=20000</td>
<td></td>
</tr>
<tr>
<td><strong>2</strong> Copy <em>AI</em> Configuration Data</td>
<td>N7:60 → 0:5.0</td>
<td>COP used; <em>AI</em> Module Configuration Data resides in words N7:60 → N7:67. Need confirm but is converting integers into 4-20mA Signal?</td>
</tr>
</tbody>
</table>
### LD4 CONTROL SET UP

<table>
<thead>
<tr>
<th>PID CODING SUMMARY</th>
<th>TECHNICAL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 PID Control Block Setup</td>
<td>Process Variable → Power Factor CV → Output → Field Current</td>
<td>Setup of a Closed Loop PID Controller.</td>
</tr>
<tr>
<td>2 Setup PID SP's</td>
<td>PF with SP_{t=0} → PF= 1.0 Unity=8000 Data PF with SP_{t=30} → PF=0.85 Lead=10000 Data</td>
<td>On Synchronisation, PF SP is set to 1.0 Unity=8000 Data; Clutch Engages; For 30mins PF adjusted to 0.85 Lead=10000 Assists power station by allowing SAG mills to get online, presenting an inductive load</td>
</tr>
</tbody>
</table>
before injecting *reactive power* into the power system. Can cause Gensets to trip on reverse *reactive power*.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
| **3** | PF FB Data Configured for PID loop | PF FB Data 4000 – 20000  
Reconfigured  
For PID use data = 0 - 16000 | CPT block used to manipulate the input PF data from 4000-20000 into 0-16000 to be able to be used in PID loop. |
| **4** | PID Output Scaled | PID output  
0-12000 scaled to 0-6000 for **AO** use. | This PID output is scaled to suit the analogue output module data format with FF. |
| **5** | Auto Control | Scales the data required for Field Current Control using ADD Block.  
Two integers added together and output is written to the **AO** register. | Enables PID output and combines with SP FF data for analogue output. |
| **6** | Scaling PF SP to use as FF Control for PID Operation | CPT Block.  
Dest: N7:18=Scaled SP FF Register.  
Expression: N7:32-6000=Non Scaled SP. | SP is scaled and fed forward for auto field current control.  
Scales the Non Scaled SP and Sends it as a Scaled FF Register. |
| **7** | Boost Control | Switch→6 Sec Timer→Scaled Field Current→Output through **AO**. | Moves a specific boost value into the **AO** register based on the MCP Boost Command. |
| **8** | Manual Field Control | Field control selector switch  
*manual or off*→Not in auto and No MCP Boost→Output thru **AO**. | CPT block used to send the manual field current data to the **AO** channel. |
22.2 Synchronous motor slipping.
This type of synchronous motor used an amortisseur winding for getting up to synchronous speed. This winding is essentially like a very short time rated squirrel cage induction motor winding. The winding can get the unloaded synchronous motor up to speed but cannot do anything with a loaded motor. When the motor slipped out of sync the protection did not activate and the amortisseur winding took all the load. Very quickly it overheated and the insulation failed.
# 24 Ladder Logic I/O List Mt Rawdon

![Table and Diagram]