Engineering Internship Final Report

The Pilbara Experience

An Internship with Rio Tinto Iron Ore Project Engineering

Prepared By Adam Raynor Jarvis (S/N 30320652)

On Friday, 14th November 2008

For Dr Greg Crebbin and Professor Parisa Arabzadeh Bahri

A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering/Bachelor of Commerce
Abstract

The 11kV distribution system at Paraburadoo mine site has been in service for the better part of the last forty years and has come to the end of its service life and requires replacing. These 11kV electricity assets include the 11kV bulk supply switchroom, a significant portion of the plant distribution, six distribution transformers and a shunt reactor. In addition a new administration/workshop building and wash pad is currently under construction at West Angelas mine site and requires power installed from nearby overhead power lines.

The purpose of my internship has been to write a Scope of Works and a Functional Specification for the replacement of the electricity assets at Paraburadoo and the installation of power at West Angelas. This was achieved by assessing the installation requirements, understanding the functionality of the electrical network in which they operate and consulting the relevant Australian Standards applicable to each installation whilst communicating with project stakeholders in order to facilitate the replacement and installation of these assets at both sites. Specifically the assets at Paraburadoo shall be replaced with contemporary switchgear, transformers and shunt reactors while at West Angelas the new buildings will receive power via new underground cable from nearby take-off poles to a kiosk comprising an LV switchboard.
Acknowledgements

I would like to publicly acknowledge and express my sincere thanks for the contribution that the following people have made which has made my internship possible:

a) Industry Supervisor, Noel Michelson for providing me with terrific support throughout the internship;
b) General Manager Project Engineering, Momcilo Andric and Project Manager Electrical Utilities, Geoff Leech for approving my placement with Rio Tinto;
c) Colleagues in the Electrical Utilities team in particular Ross George and Jamie Cullen for their help with my projects;
d) Rio Tinto Iron Ore Human Resources, Aleisha Cross and Vanessa Michelmore for organising the internship contract;
e) Professor Parisa Bahri and Dr Greg Crebbin at Murdoch University for organising the internship contract and their academic support throughout the internship;
f) The good people at Rio Tinto Iron Ore Project Engineering;
g) My colleagues at Murdoch University who I have had the pleasure of undertaking my degree with over the past five years; and
h) My friend, who was forced to proofread this report in an attempt to make it readable.
Table of Contents

ABSTRACT ...........................................................................................................................2
ACKNOWLEDGEMENTS ........................................................................................................3
TABLE OF CONTENTS ...........................................................................................................4
LIST OF FIGURES ................................................................................................................6
LIST OF TABLES ....................................................................................................................8
LIST OF EQUATIONS ............................................................................................................9
1.0 INTRODUCTION ............................................................................................................10
  1.1 THE INTERNSHIP ......................................................................................................10
  1.2 THE LIMITATIONS OF THE REPORT ....................................................................10
  1.3 THE SOURCES AND METHODS OF DATA COLLECTION ......................................10
  1.4 LITERATURE REVIEW ............................................................................................10
  1.5 THE REPORT ORGANISATION ..............................................................................15
2.0 RIO TINTO ...................................................................................................................16
  2.1 RIO TINTO IRON ORE ............................................................................................16
  2.2 RIO TINTO IRON ORE PROJECT ENGINEERING ...............................................17
3.0 IRON ORE MINING PROCESS .................................................................................18
  3.1 RESOURCE DEVELOPMENT ...............................................................................18
  3.2 MINE OPERATIONS ...............................................................................................18
  3.3 RAIL AND PORT OPERATIONS ............................................................................19
4.0 GREATER PARABURDOO .......................................................................................20
  4.1 MINE OPERATIONS ...............................................................................................20
  4.2 ELECTRICITY NETWORK .....................................................................................20
  4.3 CURRENT ELECTRICITY ASSET UPGRADE PROJECTS ...................................22
  4.4 RIO TINTO DISTRIBUTION ASSET CONDITION ASSESSMENT REPORT ........25
5.0 PARABURDOO 11KV RATIONALISATION PROJECT .............................................26
  5.1 OBJECTIVE ............................................................................................................26
  5.2 WHY IS THERE A NEED FOR AN UPGRADE? ....................................................26
  5.3 PROJECT SPECIAL FEATURES ..........................................................................28
  5.4 DESIGN CONCEPTS AND TECHNOLOGY ............................................................39
  5.5 REVIEW OF OTHER DISTRIBUTION SYSTEM DESIGNS ..................................54
  5.6 SCOPE VARIATION ...............................................................................................54
  5.7 FUTURE WORK, RESULTS AND OUTCOMES ......................................................55
6.0 OTHER PROJECTS .....................................................................................................56
  6.1 PARABURDOO 11KV TRAIN LOADOUT (SUB 6) RELOCATION .........................56
  6.2 PARABURDOO 33KV RATIONALISATION PROJECT ........................................57
  6.3 PARABURDOO R301 REACTOR REPLACEMENT ...............................................58
  6.4 WEST ANGELAS WASH PAD AND ADMINISTRATION BUILDING/WORK SHOP HV WORKS 64
7.0 CONCLUSION ............................................................................................................70
8.0 REFERENCES .............................................................................................................71
9.0 APPENDICES .............................................................................................................74
  APPENDIX A: MISCELLANEOUS DOCUMENTS .........................................................74
  APPENDIX B: PARABURDOO CLIMATIC DATA .......................................................75
  APPENDIX C: PARABURDOO ELECTRICITY NETWORK LAYOUTS ......................76
  APPENDIX D: PARABURDOO 33KV CABLE DETAILS ............................................85
  APPENDIX E: PARABURDOO 33KV AND 11KV CABLE INSTALLATION DETAILS ...86
List of Figures

FIGURE 1 RIO TINTO IRON ORE BUSINESS MAP (RIO TINTO IRON ORE (B), 2008 [ONLINE]) ......... 16
FIGURE 2 RIO TINTO IRON ORE OPERATIONS MAP .............................................................................. 17
FIGURE 3 PROXIMITY OF PARABURDOO (GOOGLE MAPS, 2008 [ONLINE]) ........................................... 20
FIGURE 4 PARABURDOO SINGLE LINE DIAGRAM ................................................................................. 21
FIGURE 5 REACTOR (R301) SINGLE LINE DIAGRAM ............................................................................. 21
FIGURE 6 GTG1 AND GTG2 UNITS AT PARABURDOO .......................................................................... 23
FIGURE 7 CONSTRUCTION OF THE 33kV SWITCHROOM AT PARABURDOO ........................................ 23
FIGURE 8 EXISTING PARABURDOO TOWN FEEDER ........................................................................... 24
FIGURE 9 THE ARC FLASH PHENOMENON (IEEE BLOG, 2008 [ONLINE]) .............................................. 26
FIGURE 10 AN EXAMPLE OF A CEEG KIOSK SWITCHROOM ............................................................ 31
FIGURE 11 KIOSK TRANSFORMER/LV SWITCHBOARD MADE BY TANIS IPS PTY LTD. ................. 31
FIGURE 12 UTILITIES WORKSHOP SINGLE LINE DIAGRAM ............................................................... 32
FIGURE 13 PARABURDOO NEUTRAL EARTHING RESISTOR ............................................................. 33
FIGURE 14 PARABURDOO NEUTRAL EARTHING TRANSFORMER .................................................... 33
FIGURE 15 PHASE DISPLACEMENT CAUSING RESIDUAL VOLTAGE (AGRAWAL, 2001, p.522) ...... 36
FIGURE 16 THREE PHASE FAULT LEVELS AT PARABURDOO (DIGSILENT, 2008, p.7) ................. 45
FIGURE 17 IEC 61850 OBJECT NAMES USE POWER SYSTEM CONTEXT (SISCO, 2007) ......... 48
FIGURE 18 DNP3.0 COMMUNICATION PROTOCOL (WIKIPEDIA, 2008 [ONLINE]) ....................... 49
FIGURE 19 ABB REF541 DIGITAL PROTECTION RELAY ................................................................. 51
FIGURE 20 AN REF 541 FEEDER TERMINAL USED FOR THE PROTECTION, CONTROL, MEASUREMENT AND SUPERVISION FUNCTIONS OF A UTILITY FEEDER (ABB, 1999, p.62) ........................................ 51
FIGURE 21 PHASOR DIAGRAMS OF INCOMING SOURCES (AGRAWAL, 2001, p.522) ..................... 53
FIGURE 22 11kV DISTRIBUTION POLE IN THE MIDDLE OF THE GTG3 CONSTRUCTION SITE ... 56
FIGURE 23 PROPOSED AND EXISTING CORRIDORS FOR 11kV TRAIN LOADOUT FEEDER ....... 57
FIGURE 24 T301 TRANSFORMER AND R301 REACTOR ...................................................................... 63
FIGURE 25 300kVA 33.0/433kV Dyn11 TRANSFORMER FOR WASH PAD ........................................ 65
FIGURE 26 EXISTING PARABURDOO ELECTRICITY NETWORK ...................................................... 76
FIGURE 27 EXISTING PARABURDOO 11kV SWITCHBOARD CONFIGURATION ............................. 77
FIGURE 28 PARABURDOO ELECTRICITY ASSET LAYOUT ................................................................. 78
FIGURE 29 PARABURDOO 11kV FEEDER LAYOUTS ............................................................................. 79
FIGURE 30 EXISTING PARABURDOO 11kV OVERHEAD AND CABLE LADDER FEEDERS .......... 80
FIGURE 31 OPTION A PROPOSED PARABURDOO ELECTRICITY NETWORK LAYOUT ............................. 81
FIGURE 32 OPTION B PROPOSED PARABURDOO ELECTRICITY NETWORK LAYOUT ............... 82
FIGURE 33 OPTION A PROPOSED PARABURDOO 11kV SWITCHROOM LAYOUT ............................. 83
FIGURE 34 OPTION B PROPOSED PARABURDOO 11kV SWITCHROOM LAYOUT ............................. 84
FIGURE 35 SPARE T311/T312 TRANSFORMERS ................................................................................ 100
FIGURE 36 T311/T312 TRANSFORMER NAMEPLATE ....................................................................... 101
FIGURE 37 33kV SWITCHBOARD INCOMER PANEL ........................................................................... 102
FIGURE 38 33kV SWITCHBOARD INCOMER PANEL CIRCUIT BREAKER AND AMPY POWER METER .............................................................................................................................................. 103
FIGURE 39 33kV SWITCHBOARD INCOMER PANEL WIRING ................................................................ 104
FIGURE 40 CH03 TAKE-OFF POLE FOR WASH PAD UNDERGROUND WIRING ......................... 106
FIGURE 41 ‘TAKE-OFF’ POWER POLE WHERE UNDERGROUND CABLE WILL FEED FROM FOR THE WASH PAD .............................................................................................................................................. 106
FIGURE 42 HV POWER LINE ROUTE FOR WASH PAD ...................................................................... 107
FIGURE 43 WASH PAD UNDERGROUND CABLE ROUTE ................................................................. 108
FIGURE 44 KIOSK LOCATION .............................................................................................................. 109
FIGURE 45 ROM1 TAKE-OFF POLE FOR ADMINISTRATION/WORK SHOP BUILDING UNDERGROUND POWER WIRING ...................................................................................................................................... 111
FIGURE 46 ROM DISTRIBUTION FEEDER LINE .................................................................................. 112
FIGURE 47 ROM1 AIR-BREAK SWITCH ............................................................................................... 113
FIGURE 48 ROM1 TAKE-OFF POLE TO UNDERGROUND WIRING ROUTE ..................................... 114
FIGURE 49 ADMINISTRATION/WASH PAD BUILDING UNDERGROUND WIRING ROUTE ............ 114
FIGURE 50 ADMINISTRATION/WASH PAD BUILDING UNDERGROUND WIRING ROUTE ............ 115
FIGURE 51 ADMINISTRATION/WASH PAD BUILDING PROPOSED KIOSK LOCATION ................... 115
FIGURE 52 FERRORESONANCE FUNDAMENTAL MODE ..................................................................... 116
FIGURE 53 FERRORESONANCE SUB HARMONIC MODE .................................................................... 116
**List of Tables**

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>11kV Switchroom Configuration</td>
<td>34</td>
</tr>
<tr>
<td>Table 2</td>
<td>Existing 0.433kV Switchboard</td>
<td>34</td>
</tr>
<tr>
<td>Table 3</td>
<td>Proposed 0.433kV Switchboard</td>
<td>35</td>
</tr>
<tr>
<td>Table 4</td>
<td>Generator Dispatch Cases (DigSILENT Pacific Pty Ltd, 2008)</td>
<td>46</td>
</tr>
<tr>
<td>Table 5</td>
<td>Rio Tinto Iron Ore Site Loads (DigSILENT Pacific Pty Ltd, 2008)</td>
<td>46</td>
</tr>
<tr>
<td>Table 6</td>
<td>Paraburdoon Climatic Data (Bureau of Meteorology, 2008 [online])</td>
<td>75</td>
</tr>
<tr>
<td>Table 7</td>
<td>Paraburdoon 33kV Cable Details</td>
<td>85</td>
</tr>
<tr>
<td>Table 8</td>
<td>Paraburdoon 33kV and 11kV Cable Installation Details</td>
<td>86</td>
</tr>
</tbody>
</table>
## List of Equations

1. **Equation 1** Earth Potential Rise ................................................................. 43
2. **Equation 2** EPR Voltage Profile .................................................................. 44
3. **Equation 3** Reactive Power Balance ............................................................. 59
1.0 Introduction

1.1 The internship
The engineering internship programme at Murdoch University has consisted of sixteen weeks of full-time work experience with the Project Engineering business unit of Rio Tinto Iron Ore (RTIO). The internship has been an alternative to full-time on campus study which has provided me with a valuable opportunity to complete a semester within the engineering industry as a capstone to my Bachelor of Engineering (Electrical Power and Industrial Computer Systems)/Bachelor of Commerce (Management) degree. The internship placement aims at providing exposure to the applied world of engineering design or research through a period of workplace employment, under the direction of an experienced engineer in order to gain practical problem solving experience (Murdoch University, 2008 [online]).

1.2 The limitations of the report
This submission is made in terms of the ENG450 Final Year Engineering Internship Study Guide. It documents my experiences in relation to the various ongoing work on the projects I have worked on with RTIO Project Engineering in the Electrical Utilities team.

1.3 The sources and methods of data collection
Primary sources include my experiences from meetings and interactions with clients, management, members of the Electrical Utilities team and external contractors. Secondary sources include technical articles from sources such as ABB and Schneider Electric whilst tertiary sources include text books used throughout my degree.

1.4 Literature review
Traditional final year projects for engineering students are based on a research topic which forms the basis for a thesis. In a thesis a literature review focuses on reviewing the “section of available documents, ideas, data and evidence written from a particular standpoint to fulfil certain aims or express certain views on the nature of the topic and how it is to be investigated” (Ferfolja and Burnett, 2002, p.1). Since the projects I have worked on throughout the course of my internship are of an industrial nature, the following is an adaptation of a literature review.

RTIO Project Engineering is a business unit within Rio Tinto that engineers and manages capital projects on behalf of clients (Pilbara Iron, Hamersley Iron and Robe River Iron). An overarching struggle facing the business unit at present is the ability of team members to integrate their already sound technical knowledge in delivering projects with traditional project management knowledge, skills and abilities. A capital project such as the rationalisation of the 11kV distribution system at Paraburadoo has a set of objectives which have been determined by the client. It is the responsibility of RTIO Project Engineering to deliver these projects to clients by managing constraints, dependencies and assumptions in order to deliver a solution that meets the client’s objectives. Objectives are established by the client but are then evaluated and
finalised through discussions with clients, management and other members of the project team. Constraints refer to limitations that have to be met in the projects delivery. Dependencies refer to related projects that need to be managed in parallel in order to deliver a global solution to multiple clients. For example, the Electrical Utilities team are currently in the planning process for a Static VAr Compensator (SVC) which is an electrical device responsible for reactive power compensation on HV transmission networks. A dependency for this project is the Network Manager project which aims at rolling out a new control system for the RTIO electricity network. Consequently the objectives of these two projects have to be met in parallel and hence their scope needs to be developed to allow for a proof solution to be delivered to the client. Assumptions are educated guesses on project issues which are unknown and need to be monitored to ensure the project is delivered correctly to the client. On this premise it is the responsibility of the project engineers to translate between the expertise of technical engineers and the requirements set by clients and the business people in order to deliver a proof solution. A discussion with an engineer in the Electrical Utilities team who specialises in project management has found that there are seven constraints in delivering projects, these include:

a) Meeting the needs of stakeholders such as clients, the business and engineers;  
b) Defining an appropriate scope that fulfils the clients need;  
c) Delivering the project within the agreed time;  
d) Delivering the project within the agreed budget;  
e) Delivering the project which adds value to the organisation;  
f) Delivering a quality solution; and  
g) Ensuring team satisfaction in order to maintain the longevity of the project team responsible for delivering project solutions to clients.

Overall, it is the role of the project team to deliver a project by eliminating problems however everyone cannot be pleased, which means that there is always a compromise. Another dimension in delivering projects is determining metrics for these objectives, these include:

a) How do you know when a particular objective has been met?  
b) Is there some measurement or some evaluation process that needs to be carried out?

Since projects are dynamic in nature it is hard to measure how the project is proceeding and to set standards for performance. The difference between projects and operations in a mining environment is that performance (such as mine production) is evaluated by outputs which are produced on a regular basis over short periods of time (e.g. tonnes produced per 24 hours) whereas projects take longer to deliver and produce varying intangible outputs which makes it hard for success to be measured. So how does this relate to the projects I have worked on during my internship?
Paraburadoo 11kV Rationalisation Project

Objective: develop a Scope of Works and Functional Specification which is a contractual document to engage a vendor to upgrade Paraburadoo’s bulk supply 11kV switchroom and distribution transformers.
Constraints: nil.
Dependencies: as a part of the upgrade the protection for the neutral earthing resistors will have to be upgraded because the fault level on the 33kV bus will be increased to a point where step and touch potential on feeders such as at the airport may exceed safe levels in the absence of an upgraded earthing system. The protection upgrade work will have to co-ordinate with the 11kV rationalisation project.
Assumptions: completion of the 33kV switchgear upgrade.

Paraburadoo 11kV Train Loadout Line Relocation

Objective: Relocate an approximate 300m section of the 11kV feeder to a corridor which is not in the way of the construction and future operation of the GTG3 generation facility.
Constraints: the corridors for the 33kV Town Feeder distribution line and the existing 33kV East Pit distribution line.
Dependencies: Completion of town feeder replacement project in order for electrical lines contractor to undertake the works upon its completion whilst they are still mobilised on-site.
Assumptions: nil.

Paraburadoo R301 Reactor Replacement

Objective: Replace the R301 Reactor that is connected in delta to the tertiary winding of the T301 transformer in the 220kV switchyard at Paraburadoo.
Constraints: EMC compliance for the new reactor installation and ground contamination clean up of the existing reactor.
Dependencies: Completion of the construction of the 33kV switchroom so contractors can perform the replacement works while they are still on-site.
Assumptions: nil.

West Angelas Wash Pad and Administration/Workshop HV Installation

Objective: Install HV power supply from nearby overhead lines to respective transformers housed in a kiosk containing the LV switchboard for the purpose of supplying power to the administration/workshop building and a wash down bay.
Constraints: cable route for the underground cable as per agreement between Project Supervisor and the Civil Engineer responsible for the building design.
Dependencies: Completion of underground drilling and trenching for underground cable by an on-site drilling contractor.
Assumptions: nil.
Since the Electrical Utilities team are involved in delivering capital projects to clients who are based in the Pilbara region of Western Australia, the evaluation on performance ranges across the following key accountabilities (Rio Tinto Iron Ore (f), 2008):

**Health, Safety and Environment**
- Ensure the project complies with and is delivered to Rio Tinto standards and policies for HSE;
- Demonstrate strong personal commitment to HSE in the workplace;
- Participate in HSE induction and training programmes;
- Have knowledge and experience of HSE policies, standard procedures and statutory requirements;
- Apply and implement appropriate HSE risk analysis processes from initiation stage followed by identification, evaluation, management, reporting and updating stages; and
- Leveraging the broader organisation (internally and externally) for HSE value creation through sharing knowledge, experience, skills and resources.

**Knowing the Business of Projects**
- Understanding and applying wide professional knowledge, experience, expertise and skills to all phases of the project;
- Understanding the particular characteristics of a project and applying sound judgement at each phase of the project development and execution to the handover;
- Seeing and focussing on the big picture, developing fit for purpose and project value creating outcomes through the project life cycle;
- Identifying, monitoring and managing key issues and relationships at all phases of the project life cycle; and
- Keeping abreast of innovation and best practice in the electrical engineering field and applying this knowledge for successful execution of allocated projects.

**Optimising and Sustaining Value**
- Ensuring that effort is focused on delivering sustainable value for allocated tasks/projects;
- Applying rigorous analysis and assessing a wide range of options to build the business case for the allocated tasks/projects;
- Ensure appropriate consultants, contractor and suppliers selection, engagement and management for allocated tasks/projects; and
- Prioritising and sequencing the required work/tasks to optimise value throughout the project.
Providing Electrical Engineering Expertise

- Ensuring a broad base of electrical engineering knowledge and expertise to allow balanced and informed decision making;
- Understanding key electrical engineering drivers in order to optimise technical solutions and minimise technical risks;
- Sourcing appropriate technical reviews, expertise and knowledge within and outside the department to optimise the technical solution; and
- Ensuring electrical engineering integrity of the allocated tasks/projects in order to deliver robust and sustainable electrical engineering systems to optimise the asset performance.

Business Focussed Collaboration

- Leveraging the broader organisation for value creation through sharing knowledge, experience, resources and skills;
- Sharing and seeking out knowledge, best practice and resources across Rio Tinto Iron Ore;
- Building positive and trusting relationships across Rio Tinto Iron Ore;
- Valuing and drawing on other’s skills and experience; and
- Thinking and acting in the interest of Rio Tinto Iron Ore.

Building Productive Stakeholder Relationships

- Identifying, developing and sustaining productive relationships with all stakeholders to deliver the best business outcome;
- Identifying the full range of key stakeholders;
- Using constructive communication, influencing and negotiation to engage and obtain buy in from stakeholders;
- Building a positive reputation through dealing, openly, sensitively and consistently with stakeholders; and
- Actively addressing conflict and focussing on achieving ‘win-win’ outcomes.

Financial Management

- Applying financial/cost analysis rigour to business analysis and decision making;
- Taking and managing considered financial/cost risks;
- Using accurate and complete customer information to improve projects that add value;
- Understanding the difference between capital and operating expenditures;
- Developing the appropriate contracting strategy for the allocated projects/tasks;
- Understanding the financial/cost drivers for each party to a contract; and
- Preparing the capital and operating costs estimates for the allocated tasks/projects.
Delivering the Project

- Defining and communicating a clear vision for the project;
- Developing and implementing robust and practical project development and implementation plans, documents and standards;
- Generating accurate and reliable cost estimates to facilitate effective project section and cost forecasting;
- Applying objective, data-driven problem solving and sound judgement to decisions about project planning and implementation;
- Implementing project controls in managing the project to specific scope, budget, schedule and quality standards;
- Ensuring effective allocation, utilisation and deployment of physical and human resources;
- Implementing effective change management tools and processes; and
- Ensuring that plant meets agreed standards for safety, operability, reliability and maintainability from handover.

1.5 The report organisation

This report provides an account of my internship with RTIO Project Engineering in the Electrical Utilities team. First an overview of Rio Tinto and how Project Engineering fits in with the Iron Ore group is given. Secondly an overview of the Iron Ore mining process which leads into a description of the Greater Paraburadoo operations and the existing electrical projects which are currently in place. Next is an analysis of the Paraburadoo 11kV Rationalisation Project which contains a detailed discussion of the upgrade requirements. Furthermore towards the end of the internship an expansion in the scope of the project was identified which has seen the aim of the project encapsulate the refurbishment of much of the Paraburadoo plant 11kV distribution system. An overview is also given into the other projects I have worked on at Paraburadoo and West Angelas mine sites. Lastly the appendices provide the reader with a variety of ancillary information pertinent to the internship.
2.0 Rio Tinto

Rio Tinto is a mining and exploration company which mines and processes the earth’s mineral resources such as aluminium, copper, diamonds, energy products, gold, industrial minerals and iron ore (Rio Tinto (a), 2008 [online]). Rio Tinto is an international mining group consisting of Rio Tinto plc (a publicly listed company with headquarters in London) and Rio Tinto Limited (listed on the Australian Stock Exchange with headquarters in Melbourne). The two companies are joined in a dual listed company’s structure as a single economic entity, called the Rio Tinto Group (Rio Tinto (b), 2008 [online]). Rio Tinto concentrates on the development of first class ore bodies into large, long life and efficient operations, capable of sustaining competitive advantage through business cycles (Rio Tinto (b), 2008 [online]). The group’s activities are spread across Australia, North America, South America, Asia, Europe and southern Africa (Rio Tinto (b), 2008 [online]).

2.1 Rio Tinto Iron Ore

RTIO is headquartered in Perth, Western Australia and is a global supplier of iron ore, iron ore pellets, iron ore concentrates and high quality pig iron (Rio Tinto Iron Ore (a), 2008 [online]). RTIO consists of wholly-owned subsidiaries and joint venture initiatives which manage mining and processing operations in North America, South America and Australia, with development projects located in Africa and India (Rio Tinto Iron Ore (b), 2008 [online]) as shown in Figure 1.

![Figure 1 Rio Tinto Iron Ore Business Map (Rio Tinto Iron Ore (b), 2008 [online])](image)

The Pilbara region of Western Australia comprises mines, ports and rail as shown in Figure 2.
A map of the major mineral and resource projects in Western Australia can be found in Appendix A: Miscellaneous Documents which puts the iron ore sites in context of the mining and resources industry in Western Australia (Department of Industry and Resources, 2008 [online]).

2.2 Rio Tinto Iron Ore Project Engineering

RTIO Project Engineering is responsible for the capacity expansion and upgrades undertaken by Pilbara Iron in response to an increase in demand for Iron Ore. Project Engineering works across the Pilbara in mines, ports, rail and power supply infrastructure and is responsible for taking projects from conceptual studies through to construction and upon completion handover to Pilbara Iron, Robe River Iron and Hamersley Iron operations. Project Engineering is based in Perth in the Quadrant Building located at 1 William Street in the Perth CBD and consists of multiple project teams across a broad range of engineering disciplines. For the purpose of my internship I have been based in the Electrical Utilities team, which is responsible for the delivery of high voltage power capital projects across all RTIO sites.
3.0 Iron Ore Mining Process
This section briefly describes the activities involved in finding, mining and processing iron ore in the Pilbara region of Western Australia.

3.1 Resource Development

3.1.1 Exploration and Evaluation
This involves the identification and quantification of ore bodies through means of geological, geophysical and metallurgical techniques that mainly involves drilling in remote areas to sample ore (Rio Tinto Iron Ore (g), 2008).

3.1.2 Metallurgical Assessment
The data from the exploration and evaluation activities is logged, mapped, analysed and interpreted through models (Rio Tinto Iron Ore (g), 2008).

3.1.3 Mine Planning and Scheduling
This involves the development of detailed plans on which ore bodies to mine and in what sequence to deliver the required quality of iron ore at an appropriate cost (Rio Tinto Iron Ore (g), 2008). This process commences many years before a mine is developed and continues on an operational basis once the mine is developed.

3.2 Mine Operations

3.2.1 Drill and Blast
Areas of the mine are selected for open-pit mining using the mine plan and identified areas are tagged and holes are drilled in an appropriate pattern by the drill rigs (Rio Tinto Iron Ore (g), 2008). These drill holes are then filled with an explosive such as ANFO (Ammonium Nitrate/Fuel Oil) and then charged, which sees the resulting blast break the material into a suitable size for digging (Rio Tinto Iron Ore (g), 2008).

3.2.2 Load and Haul
Once the target areas have been blasted then the broken material is loaded for transport by face shovels, excavators or front-end loaders into haul trucks. Overland conveyors are also used to transport partially crushed feed at sites where there are long distances between the pits and process plants (Rio Tinto Iron Ore (g), 2008).

3.2.3 Process
The processing of the ore ranges from the simple crushing and screening to a standard size, through to production processes that enhance its quality by removing impurities by differences in particle density, size gravity or size separation from both wet and dry process techniques (Rio Tinto Iron Ore (g), 2008).
3.2.4 Stockpile and Rail-Load Out
Once the ore is processed then it is stockpiled and blended to meet product quality requirements, before being reclaimed and conveyed to rail load-out for transport to port facilities (Rio Tinto Iron Ore (g), 2008).

3.3 Rail and Port Operations

3.3.1 Rail
The ore is railed up to 460km to the coast along a privately owned rail system, where a train consists of up to 230 ore cars and is over 2.4km long (Rio Tinto Iron Ore (g), 2008).

3.3.2 Ore Car Dumping
Once the train arrives at the port the ore cars go through the car-dumper where the ore flows out into bins which are discharged onto conveyors (Rio Tinto Iron Ore (g), 2008).

3.3.4 Stockpile
The ore is stockpiled according to product type and the quality control plan. The travelling stackers create 250m long stockpiles and rotary bucket-wheel reclaimers later reclaim the ore which is conveyed to the ship loader (Rio Tinto Iron Ore (g), 2008).

3.3.5 Ship-Loading
Vessels are loaded at the berths alongside the ore wharf where lump-ore is re-screened to remove undersize material. Reclaimed ore is conveyed along the wharf and the ore is loaded into the vessel’s holds by travelling, slewing and luffing ship loaders (Rio Tinto Iron Ore (g), 2008).
4.0 Greater Paraburdoo

4.1 Mine Operations
Paraburdoo is situated approximately 1500km north of Perth and 79km south-south-west of Tom Price in the Pilbara region of Western Australia as shown in Figure 3. The mine site is accessible via road from Paraburdoo Township.

Figure 3 Proximity of Paraburdoo (Google Maps, 2008 [online])

Paraburdoo mine site is formally known as Greater Paraburdoo mine operations run by Pilbara Iron. The Paraburdoo mine site is owned by Hamersley Iron and production commenced in 1972. The Channar mine which is located nearby is owned by Hamersley Iron in joint venture with the members of the Chinese steel industry and commenced operation in 1990. The Eastern Range mine also located nearby is owned in joint venture with Baosteel and commenced operation in 2004. These mines produce hematite ore in lump and fines. Paraburdoo receives ore from Channar and Eastern Range by conveyor for processing and transport. Fine ore is upgraded in the Paraburdoo Fines Processing Plant. The ores are blended with other ores at the port.

4.2 Electricity Network
The high voltage (HV) reticulation across all Rio Tinto Iron Ore sites can be seen in the single line diagram (drawing # E-001-58523) which is available in Appendix A: Miscellaneous Documents. Paraburdoo receives its electricity from two (the third is currently under construction) LM6000 SPRINT Gas Turbine Generation Plants and a Frame 5 Gas Turbine Generation Plant. Power is also received from the 220kV transmission line from Mount Tom Price terminal. This is shown in Figure 4 below.
Distribution throughout the Paraburdoo mine site and township is reticulated at both 33kV and 11kV with a total maximum mine demand of 25MW. The configuration of both distribution systems can be seen in their respective single line diagrams (drawing # E-001-3048 and E-001-46307) which are available in Appendix A: Miscellaneous Documents.

Figure 5 shows the single line diagram for the R301 Reactor which is currently offline. This means there is no technique in place to provide an inductive load to compensate for the capacitive load of the transmission line from the Mount Tom Price terminal as well as the site generation facilities. It is connected in delta to the tertiary winding of T301. It is also used for
the energisation of the 220kV transmission line in the event of system collapse, which will be discussed later in the report.

The 33kV feeders are connected to the existing 33kV switch yard which takes supply from the 220:33kV transformer (T301) and the Frame 5 Gas Turbine Generation plant injecting power via dual 15MVA, 11:33kV transformers (T313 and T314). At the time of the internship the rationalisation of the 33kV switchgear into a switchroom was in progress. As a result the new switchroom will receive supply from T301, GTG3 and the Frame 5 Generation Plant whilst GTG1 and GTG2 are connected through tie-ins at 220kV. The new 33kV switchroom shall be responsible for supplying the township, west pit, east pit, T311, T312 and two spares.

The 11kV feeders are connected to an indoor 11kV switch room which is supplied from the 33kV switch yard via two 33/11kV transformers (T311 and T312). Both the 11kV and 33kV distribution systems include distribution class Neutral Earthing Resistors (NER) which is designed to limit the current flow to earth under fault conditions (Schneider Electric, 2008). The 11kV switch room supplies feeders throughout the Paraburdo mine site, which are then stepped-down to 0.433kV or 3.4kV for plant use. The 11kV distribution system consists of radial feeders and four rings interconnected by a Ring Main Unit (RMU MB558). The 11kV switchroom is also connected to a Neutral Earthing Transformer (NET), which is responsible for providing an earth reference point and fault level mitigation for the Frame 5 generation plant transformers.

4.3 Current Electricity Asset Upgrade Projects
The following are brief descriptions of the current capital projects in progress at Paraburdo being engineered and managed by the Electrical Utilities team.

4.3.1 Gas Turbine Generator 3 (GTG3)
Currently the company is installing a third gas turbine at Paraburdo Power Station. The new generation plant (GTG3) is being constructed adjacent to the GTG1 generation plant at Paraburdo. Figure 6 below shows the GTG1 and GTG2 units.
4.3.2 Paraburdoo 33kV Rationalisation (P33R) Project

The installation of GTG3 has induced the need for a new prefabricated 33kV Switchroom which is currently under construction as shown circled green in Figure 7. These works are included in the Paraburdoo 33kV Rationalisation Project (P33R).

4.3.3 Town Feeder Replacement

The 33kV distribution feeder to Paraburdoo town ship has reached the end of its service life and is being replaced. The recent failure of five poles on the town feeder due to termite damage as shown in Figure 8 has brought the need for a new town feeder to a head. The railway CTC (Centralised Traffic Control) substation is being converted to solar and so the use of the existing 22kV railway distribution line has become redundant and provides an ideal route for the new town feeder corridor.
Figure 8 Existing Paraburdoo Town Feeder
4.4 Rio Tinto Distribution Asset Condition Assessment Report

ABB Australia Pty Ltd is in the process of evaluating the condition of all Rio Tinto Iron Ore electricity assets. To date they have performed a visual assessment at Paraburadoo, Tom Price, Channar, Brockman, Marandoo and West Angelas mine sites in order to “determine the current state of the distribution utility assets for Rio Tinto in the Pilbara to determine future actions around maintenance and replacement” (ABB Australia Pty Ltd, 2008, p.1). The result of the visual assessment has been an interim report for Stage 1 of the project outlining the condition of the distribution assets at these sites. Stage 2 will review the assets in the coastal region and Stages 3 and 4 are to provide future engineering and maintenance recommendations. The main conclusions drawn from the assessment of Paraburadoo’s 11kV distribution include:

- Transformers generally appear to be circa 1975 and in very poor condition;
- Almost all units are leaking creating ground contamination;
- Almost all units have leaks sourced from ancillaries, quite a few from HV and LV cable boxes with a few also from the lid gasket;
- No indication of recent maintenance;
- Units at sub 7 (fines plant) were built in 1995 but as a group are the worst of all;
- Sub 3 has the newest units from 2003 and are in excellent condition;
- Electromechanical protection relays on metal-clad switchgear appears to be same age as transformers (1975) and operation appears sound;
- RMUs also appear sound but are leaking in some places with some showing significant leaks from cable termination boxes;
- Overall there is no evidence of recent maintenance and the equipment is old and should be considered at the end of its service life;
- Cables are mostly paper insulated lead cable and many are leaking from termination boxes and should be considered at the end of their service life;
- Many cables are showing evidence of previous repair work; and
- Bus work is generally in good condition.

The Rio Tinto Distribution Substation Asset Condition Assessment Report provides a solid foundation for the rationalisation of the 11kV distribution system at Paraburadoo mine site.
5.0 Paraburadoo 11kV Rationalisation Project

5.1 Objective
Upon commencement of the internship the purpose of the P11R Project was to facilitate and implement the replacement of the existing 11kV switchroom with a new switchroom containing metal enclosed (ABB ZSi) switchgear as well as replacing the 0.433kV switchgear for the utilities workshop with a separate kiosk switchroom containing a self-bunded transformer and an LV switchboard. The project also aims at replacing the T311, T312, T313, T314, Aux 1 and Aux 2 transformers. These works fall under phase one of the project since towards the end of the internship a need to replace the plant’s 11kV distribution system was identified between mine operations and Project Engineering. The amendment of the scope of the upgrade of the plant distribution is discussed later in the report.

5.2 Why is there a need for an upgrade?
Rio Tinto Iron Ore electricity assets in the Pilbara are in the process of being replaced because (ABB Australia Pty Ltd, 2008):

a) These assets have been exposed to the extremes of the mine site environment and generally have operated in an under-maintained state;
b) These assets have an assessed remaining life of between four to seven years;
c) A number of these assets have been identified as either being extremely close to failure or inoperable in their current state; and
d) Critical mine operations distribution assets need immediate attention to ensure reliability.

The problem concerning the existing switchrooms (both 11kV and 0.433kV) involve its arc flash protection capability. An arc fault is a high power discharge of electricity between two or more conductors which can be initiated by a low power arcing fault (a few amps) whilst rapidly increasing from several hundred amps to thousands of amps (The Arc Fault Homepage, 2006 [online]). The arc flash phenomenon is shown in Figure 9 below.

![Figure 9 The arc flash phenomenon (EEE Blog, 2008 [online])](image)
There is no direct calculation to establish arc fault levels however they can be estimated through the use of known minimum and maximum bolted three phase fault levels and their maximum clearing times. This provides the user with a known incident energy level [cal/cm²] for an arc fault in open air which determines boundary distances for unprotected personnel and the working distance for qualified personnel working on energised equipment (Inshaw and Wilson, 2004; Walls, 2005). Since research into arc flash protection has only been carried out over the past few years it is indicative that old electrical equipment was never designed to protect against arc faults. As a result it is beneficial for Rio Tinto Iron Ore to replace the existing 11kV switchroom not only because it is at the end of its service life as diagnosed by ABB Australia Pty Ltd but also to protect site personnel with the best PPE (Personal Protective Equipment), reduce insurance premiums and increase system reliability. If this project was not approved then it should be noted that the company is exposing themselves to non-compliance fines, costs involved with lost productivity, increased equipment repair costs, medical expenses for injured workers, legal costs and most importantly the potential for loss of life in the event of an uncontrolled arc flash (Inshaw and Wilson, 2004; Walls, 2005).

The transformers should be replaced because they are all reaching the end of their service life as diagnosed by ABB Australia Pty Ltd. Their replacement is also recommended because some of these transformers contain Polychlorinated Biphenyl (PCB) in the oil which poses an environmental, health and safety (EHS) risk to workers. After consultation with the Pilbara Iron Networks Supervisor at Dampier it has been confirmed that T311 and T312 both contain no PCB contaminants while T313 has 6ppm and T314 has 11ppm (parts per million). There is no legal limit on the amount of PCB in transformer oil however there are conditions on storage, handling, transport and disposal of the oil. The future for a contaminated transformer means the following processes need to be executed (Email from Pilbara Iron Networks Supervisor, 23rd September 2008) [sic]:

a) Leave as is keep on operating, monitor and attend to any leaks, dispose of contaminated oil using a licensed disposal company.

b) Remove oil, refill with new oil, and test for PCB leaching out of the windings over a period of about 2 yrs, after that time the rate of PCB leaching out reaches an equilibrium between the windings and the oil. Dispose of the original oil using a licensed company.

c) Remove transformer from service. It is to be scraped. Remove oil, send oil and empty transformer to licensed disposal company.

Prior to 1970, PCBs were in widespread use as a dielectric fluid since it was not flammable, however, under incomplete combustion, PCBs can form highly toxic products such as furans (BCD Technologies, 2008 [online]). Furan is a heterocyclic organic compound and several studies have shown that exposure to Furan increases the risk of several types of cancer in humans. The World Health Organisation has determined that Furan is a human carcinogen and
the US Department of Health and Human Services has also determined that Furan is known to cause cancer (National Pollutant Inventory, 2008 [online]). Companies such as BCD Technologies utilise Base Catalysed Dechlorination and High Temperature Plasma Arc techniques to treat both pure PCB and oils contaminated with PCB (BCD Technologies, 2008 [online]). As a result, when T313 and T314 are removed from site the use of PCB clean up procedures shall be followed to ensure a safe working environment at Paraburdoo.

Overall the replacement of these assets will increase the reliability and safety of Paraburdoo’s electricity network and shall complement the other electrical upgrade projects in place at the current time.

### 5.3 Project Special Features

#### 5.3.1 Climatic Conditions

Paraburdoo is a mining town located in the Pilbara region, which endures harsh conditions with soaring temperatures and low and erratic rainfall. This exposes all mining assets to extreme conditions which need to be taken into account when designing and constructing the new P11R project assets, particularly when operation and maintenance programmes are developed. Please refer to Appendix B for Paraburdoo Climatic Data. This is a primary reason why all switchrooms are fitted with air-conditioning in order to maintain a suitable temperature for the switchgear. Ambient temperature directly affects the sizing of cables due to the “current-carrying capacity dependant upon the method of installation and the presence of external influences, such as thermal insulation, which restrict the operating temperature of the cable” (AS3008, 1998, p.12). This Australian Standard applies to cables less than 1kV and there is a constraint concerning its application to voltages higher than this. It was mentioned by an engineer from Maunsell Aecom in an ENG455 lecture that an industry ‘rule of thumb’ was to apply a de-rating factor to the cable by dividing the minimum cable size by 0.6 for cables used in installations higher than 1kV. It will be up to the discretion of ABB Australia Pty Ltd to decide whether this technique applies to the calculation of the size of the various cables for the P11R project assets.

#### 5.3.2 Transformers

Drawing E-001-46307 in Appendix A show that the 11kV switchroom receives its supply from T311 and T312 transformers. Due to the increase in site load, these transformers are to be rated at 25MVA as opposed to the existing 9/12MVA ONAN/ONAF ratings. ONAN and ONAF refer to the cooling class of transformers which is described below (Widup, 2003, pp.1-2):

- **First letter – the type of oil**
  - O: mineral oil or synthetic insulating liquid with fire point <= 300°C
  - K: insulating liquid with fire point > 300°C
  - L: insulating liquid with no measurable fire point
- **Second letter – how the oil is internally circulated**
  - N: natural convection flow through cooling equipment and in windings
o $F$: forced circulation through cooling equipment (i.e. coolant pumps) and natural convection flow in windings (also called non-directed flow)

o $D$: forced circulation through cooling equipment, directed from the cooling equipment into at least the main windings

• Third letter – how the oil is externally cooled
  o $A$: air
  o $W$: water

• Fourth letter – what is used to cool the oil
  o $N$: natural convection
  o $F$: forced circulation [fans (air cooling) or pumps (water cooling)]

Currently T311 and T312 are both have a Yd1 vector grouping, which is used because there is no problem with the third harmonic in its voltages as they are consumed on the $\Delta$ side of the transformer (Chapman, 2005). This type of transformer is also used because they are suited for handling unbalanced loads as any imbalance is redistributed on the $\Delta$ side (Chapman, 2005). However this type of transformer does have one problem concerning the 30o phase shift of the secondary side voltage, which means that when they are in parallel the magnitude and direction of the phase shift must be equal (Chapman, 2005). During a phone meeting with ABB Australia Pty Ltd it was discussed that a Y:Y transformer vector grouping arrangement could be used as this has advantage of being able to use a tertiary winding connected in delta to supply the switchroom light and small power, whilst mitigating against any third harmonic components of voltage by circulating a current flow within the winding (Chapman, 2005). Tertiary windings are generally rated at one-third of the apparent power rating of the actual transformer (Chapman, 2005) and so act as a suitable source for switchroom light and small power. However it was discussed with ABB Australia Pty Ltd that using two auxiliary transformers would be a more cost-effective measure of supplying power to the switchroom through a distribution board, which can also supply the light and small power to the 33kV switchroom and 220kV relay room. If ABB Australia Pty Ltd specify that it is suitable to use the Y:Y vector grouping then the neutrals of the both sides of the transformer shall be grounded as it provides a return path for any current imbalances in the load. This is used to mitigate the unbalanced transformer load circuits where voltages can become severely unbalanced (Chapman, 2005). Since the tertiary winding won’t be used for T311 and T312 then a more likely vector grouping would be $\Delta$Y since Y:Y is rarely used in practise and $\Delta$Y has no problems concerning third harmonic components in its voltage. The vector grouping of the new transformers must have a phase shift rating of 30o to match the existing transformers (e.g. Dyn1) to avoid any circulating currents occurring during cutover. The ramifications of this are discussed in section 5.3.5 (loading considerations when paralleling transformers) of the report. Towards the end of the internship it was discovered that in 2007 RTIO had in fact purchased two spare transformers for T311 and T312 which are currently in a lay-down yard at Paraburadoo as shown in Appendix L. There are concerns over the use of the spares because they are the same vector grouping as the existing T311 and T312 transformers and they also contain aerial conductors, which pose as a lightning strike hazard in the switchyard and
so underground cables are preferred. In the existing 11kV distribution system the earth fault level is restrained through the use of 11kV earthing transformers with neutral earthing resistors. If T311 and T312 are replaced with the spare transformers in the lay-down yard then there needs to be an earthing transformer and NER for each bus section. On the contrary it could replicate the existing 11kV system and use two 11kV feeders from each bus to connect to a single earthing transformer and NER. Both T311 and T312 will require a separate 90Ω NER. Overall the 11kV plant load is now at 14MVA and so it has been recommended that new transformers be purchased with an apparent power rating increased to 25MVA each to account for future growth patterns at the mine site.

The existing two Frame 5 transformers have several replacement options. The first option is to have a Δ:Y vector grouping connected to the 33kV switchboard in the event that the 11kV switchboard is not load and fault current rated. The ABB ZSt switchgear has a rated busbar current of 1250A to 4000A. The Frame 5 produces on average 18MW to 19MW. The output of the Frame is influenced by ambient air temperature and air pressure only. The ONAN/ONAF ratings of the transformers do not apply to the limitation of gas turbine units. The nameplate of the Frame 5 is 25MVA (20MW at 0.8PF). For a 20MW generation power injection (assuming 0.8 PF) the current is 1312A at 11kV and 437A at 33kV. If the connection of the Frame 5 is to remain at 33kV then ABB Australia Pty Ltd are to specify the apparent power rating for the new Frame 5 transformer based on the generation capability whilst taking into account the Paraburdoo climatic conditions given in Appendix B. The second option is to connect the Frame 5 straight onto the 11kV switchboard which would eliminate the need for T313 and T314 completely and avoid any system outages resulting from transformer faults. For this option to be evaluated the Paraburdoo power system model currently being compiled by DigSILENT Pacific Pty Ltd needs to be used to determine whether the fault level of the generation plant can be handled by the switchboard. The Frame 5 connection options are discussed later in the report.

The vector grouping and sizing of the auxiliary transformer for the utilities workshop shall be the responsibility of ABB Australia Pty Ltd. Figure 10 shows a picture of a kiosk switchroom made by China Electric Equipment Group (CEEG), which is able to house a transformer and the LV switchboard.
Figure 10 An example of a CEEG kiosk switchroom

Figure 11 below shows a kiosk enclosing a transformer/LV switchboard on a skid. This option is more cost-effective because it is cheaper, made locally in Perth and is similar to many other kiosk transformer/LV switchboard installations across RTIO sites, which allows site electricians to become familiar with the equipment for operational and maintenance purposes.

Figure 11 Kiosk transformer/LV switchboard made by Tanis IPS Pty Ltd

The single line diagram for the utilities workshop switchboard is shown below in Figure 12.
Neutral Earthing Resistors (NER) are used in AC distribution networks to limit the current that would flow through the neutral wye point of a transformer or generator in the event of an earth fault (Fortress Resistors, 2003 [online]). The rating of the NER is chosen so that the fault current is limited to that necessary to operate the protection relays within the required time (Fortress Resistors, 2003 [online]). The neutral earthing resistor at Paraburdo is shown below in Figure 13. The functionality of the earthing system at Paraburdo is discussed later in the report.
Figure 13 Paraburdoo Neutral Earthing Resistor

Figure 14 below shows the Neutral Earthing Transformer at Paraburdoo which is used to provide an earth reference and fault level mitigation for the Frame 5 generation plant in the event of an earth fault so the protection can operate in the required time.

Figure 14 Paraburdoo Neutral Earthing Transformer

5.3.3 General arrangement of P11R Assets

Please refer to Appendix C for figures showing the existing and proposed layouts of the assets to be constructed as a part of the P11R project. At present the T313 and T314 transformers are to be connected to the new 33kV switchroom. Both T311 and T312 transformers are to be connected to
the 11kV switchboard from the 33kV switchboard. The physical location of the 11kV switchroom is yet to be decided as the final layout of the works resulting from the rationalisation of the 33kV distribution system will determine where the 11kV switchroom goes. The 0.433kV switchroom is to be built as a separate installation to the 11kV switchroom as a kiosk switchroom housing the auxiliary transformer and LV switchboard. The next section addresses the configuration of the 11kV incomers and feeders.

5.3.4 Incomer and Feeder Configuration

Table 1 shows the incomer and feeder configuration for the existing 11kV switchroom.

<table>
<thead>
<tr>
<th>Feeder Configuration</th>
<th>Inco Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loadout</td>
<td>Overhead</td>
</tr>
<tr>
<td>Spare</td>
<td>-</td>
</tr>
<tr>
<td>Spare</td>
<td>-</td>
</tr>
<tr>
<td>Neutral Earthing Transformer Tx L/H Feeder</td>
<td>Underg. Radia</td>
</tr>
<tr>
<td>Stockpile</td>
<td>Cable ladder Ring</td>
</tr>
<tr>
<td>Services (Admin)</td>
<td>Underg. Radia</td>
</tr>
<tr>
<td>Aux Tx#2</td>
<td>Underg. Radia</td>
</tr>
<tr>
<td>Bus tie</td>
<td>-</td>
</tr>
<tr>
<td>Neutral Earthing Transformer R/H Feeder</td>
<td>Underg. Radia</td>
</tr>
<tr>
<td>Fines Plant</td>
<td>Cable ladder Ring</td>
</tr>
<tr>
<td>Truck shop</td>
<td>Underg. Radia</td>
</tr>
<tr>
<td>Sec/Tert Crusher</td>
<td>Cable ladder Ring</td>
</tr>
<tr>
<td>M.O.C.</td>
<td>Underg. Radia</td>
</tr>
<tr>
<td>Aux Tx#1</td>
<td>Underg. Radia</td>
</tr>
<tr>
<td>GTG1 Aux Tx</td>
<td>Underg. Radia</td>
</tr>
<tr>
<td>GTG2 Aux Tx</td>
<td>Underg. Radia</td>
</tr>
<tr>
<td>Spare</td>
<td>-</td>
</tr>
<tr>
<td>Spare</td>
<td>-</td>
</tr>
</tbody>
</table>

This will be the typical layout of the 11kV switchroom but with only two spares as shown in Figure 33 and Figure 34 in Appendix C. The cutover strategy is discussed later in the report. For further information on the 11kV and 33kV cable circuit start and finish points, nominal details and cable lengths, please refer to Appendices D and E. The layout of the existing 0.433kV switchboard is shown in Table 2 below.

<table>
<thead>
<tr>
<th>Feeder Configuration</th>
<th>Inco Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spare</td>
<td>From Aux Tx 2</td>
</tr>
<tr>
<td>Spare</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Existing 0.433kV Switchboard
There are many spares because this used to be a switchboard in a power station which had more ancillary electrical equipment than what is there now. Table 3 shows a proposed layout of the 0.433kV switchboard which sees a reduction to two spares and the removal of the LV feeders to the 33kV switchroom and 220kV relay room, as this will be fed off the distribution board supplied by auxiliary transformers 1 and 3, as shown in Appendix C.

<table>
<thead>
<tr>
<th>Feeder</th>
<th>Configuration</th>
<th>Incom</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>33kV Switchyard Dist Board DB1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spare</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relay room supply</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spare</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11kV switchroom air conditioner</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spare (out of service)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spare</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution board F</td>
<td>Undergroun</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution board C</td>
<td>Undergroun</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workshop DB-B</td>
<td>Undergroun</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undergroun From Aux Tx 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workspoon DB A</td>
<td>Undergroun</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressed Air Main Distribution Board</td>
<td>Undergroun</td>
<td></td>
<td></td>
</tr>
<tr>
<td>415V Dist Board#1 A DB-A Isolator</td>
<td>Undergroun</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold start (MCC open)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold start</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spare</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Proposed 0.433kV Switchboard
5.3.5 Loading considerations when paralleling transformers

Once the new 11kV switchroom is complete the power from the existing T311 and T312 transformers to the switchroom shall be cutover to the new transformers. There is an engineering issue here that needs to be addressed concerning the loading considerations when transformers operate in parallel. This will be an issue when one of the existing transformers is operating in parallel with one of the new transformers during cutover. In theory, the ideal conditions for the operation of transformers in parallel are (ABB, 2003):

- Identical turn ratios and voltage ratings;
- Equal percent impedances;
- Equal ratios of resistance to reactance;
- Same polarity;
- Same phase angle shift; and
- Same phase rotation.

If the turns ratios are not the same a circulating current will flow even at no load due to a residual voltage \(E_c\) as shown in Figure 15.

![Figure 15](image)

Figure 15 Phase displacement causing residual voltage (Agrawal, 2001, p.522)

If the percent impedance or ratios of resistance to reactance are different there will be no circulating current at no-load but the division of load between transformers when load is applied will no longer be proportional to their apparent power ratings (ABB, 2003). This is because the power divides between parallel-connected transformers inversely proportional to their impedance and a low-impedance transformer operated in parallel with a higher-impedance transformer will transfer a greater amount of the power and may be overloaded (Warne, 2005). Certain transformer connections, such as Y:Δ, produce a 30° shift between the line voltages on the primary and secondary sides. Transformers with connections that produce such a phase shift cannot be paralleled with other transformers not having this shift, such as Y:Y or Δ: Δ (ABB, 2003). Phase rotation refers to the rotation which the terminal voltages reach their maximum values. Any violation of these conditions lower the efficiency and reduce the maximum amount of load the combined transformers can carry (Schneider Electric, 2007). This part of the report
has discussed the theoretical limitations of the transformer operation, but what implications does this have in practice and ultimately for the new 11kV switchroom?

Electrical systems have been using paralleled transformers for many years to make power systems more reliable, provide better power quality, prevent voltage sags or add load requirements (Schneider Electric, 2007). In practice, good paralleling can be achieved when impedances of two transformers are within 7.5% of each other (ABB, 2003). Furthermore, in normal design, the ratio of resistance to reactance is generally small so this is a non-issue in terms of paralleling transformers. In addition, under any load condition, the current will be divided such that the product of impedance and current in one transformer is equal to the product of the impedance and current in the other (Schneider Electric, 2007). Transformers should not be operated in parallel when (Schneider Electric, 2007, p.2):

- **The division of load is such that, with the total load current equal to the combined MVA rating of the transformers, one of the transformers is overloaded;**
- **The no-load circulating currents in any transformer exceed 10% of the full load rating; and**
- **The combination of the circulating currents and full load current exceed the full load rating of either equipment.**

The concern for the installation at this stage of the project is when the new 11kV switchgear gets its power supply from the old transformers to the new transformers (T311 and T312). The power from the new transformers to the new switchroom is to be energised upon cutover and so the bus-tie shall be open to prevent circulating current and/or unwanted current division which would cause overloading on the existing T311 when the existing T312 gets cutover to the new T312. However, this decision has been made on the assumption that the new and old transformers are to be of different apparent power size, impedance and vector grouping. A discussion with an electrical engineer from RTIO Technical Assurance yielded that if the bus tie on the 11kV switchboard is open, the transformers are no longer in parallel so circulating currents cannot exist. The only constraint on the 11kV switchboard during cutover now is to ensure that the old transformer will not be overloaded with the bus tie open when the first new transformer is cutover. AS2374 gives a list of transformers with different vector groups that can be paralleled. Vector groups aside, the different impedances of the two transformers are what would set up the circulating currents, so opening the bus-tie during cutover will remedy this problem. The pre-conditions for the cutover include that if the old Frame 5 Generation Transformers are still in service then they need to be isolated in order to avoid earth fault tripping when the 11kV switchboard and the NET are offline.

### 5.3.6 Cutover strategy

Once the new assets have been built and are ready to be electrically cutover from the old to the new system, a switching programme must be followed in order to ensure a safe transition. This
needs to be verified by an engineer and/or electrician deemed competent in LV and HV switching operations, which means they are able to (Western Power Corporation, 2008 [online]):

- Describe the principles and concepts of switching operations;
- Demonstrate safe switching procedures;
- Identify and explain the purpose and principles of basic protection systems;
- Identify distribution system configurations and components;
- Interpret system diagrams when conducting switching operations;
- Interconnect and isolate high voltage switching apparatus;
- Test and earth high voltage apparatus; and
- Write and submit switching programmes.

Below is a brief description of some of the issues relating to the cutover of the new assets when performing HV switching (The Switching Committee, 2004):

- 50Hz electric fields
  - The National Health and Medical Research Council (NHMRC) provide exposure limit levels to electric fields.

- Magnetic fields
  - NHMRC provide exposure limit levels to magnetic fields, which need to be complied with.

- Isolation
  - It is the responsibility of the authorised person to ensure that there are systems in place to identify the risk and required action to safely isolate plant and equipment prior to any work commencing.

- Proving dead and earthing
  - Electrical isolation: work must not be carried out by direct contact with exposed HV conductors or exposed parts of HV equipment unless they have been isolated by authorised persons from all sources of electricity;
  - Mechanical isolation: this is done by isolating drives or removing and/or disconnecting shafts, couplings or linkages;
  - Hydraulic/pneumatic isolation: the apparatus is isolated from all sources of pressure or fluid by placing a physical barrier in the circuit such as closing a valve;
  - Testing (proving dead): live line test indicators of an approved type for the particular application must be used to prove that both high and low voltage lines and equipment are dead after isolating and prior to any earth system;
  - Low voltage earthing: all isolated LV circuits must be proven de-energised before they are worked on. A single main earth must be applied to the conductors being worked on while all phases must be earthed with the neutral being the first conductor to be earthed and the last to be removed; and
- 39 -

- Lock and tag system: these must be used as near as possible to a point of isolation and, in the case of where a switch can be remotely controlled additional tags must be fixed to all control points.

- **Operation of HV electrical apparatus**
  - Switching control: HV switching is to be controlled and co-ordinated and an authorised person is to be responsible for approvals concerning the HV switching.
  - Switching actions: two people must be present during switching operations except when the switching is done in accordance with documented procedures developed by the entities or under emergency conditions. A switching programme is to be developed which clearly identifies the operators, equipment and required actions prior to any HV switching.

- **Emergency HV switching**
  - Emergency switching actions are to be used in the event of an emergency to reduce risk, which clearly defines the processes to be put in place during emergency HV switching operations.

- **Energising of electrical equipment**
  - Ensure that all personnel are clear of the equipment and have been notified to treat the line or equipment as live and that it is safe to energise.

- **HV live line work**
  - The operator of the electricity infrastructure or equipment must ensure that the person engaged to carry out high voltage live line work is competent to carry out this work.

- **Switching interface protocols**
  - It is the responsibility of the authorised person to ensure appropriate procedures are prepared and used for switching at connections to or between transmission and distribution systems.

### 5.4 Design Concepts and Technology

#### 5.4.1 Switchroom layouts

The general layout of the 11kV and 0.433kV switchrooms is shown in Appendix C. The layout of the 0.433kV switchroom has already been discussed, however please refer to Appendix F for its further information regarding its arrangement. The 11kV switchroom is to be of the modular demountable, steel frame colour bond clad type, and shall be mounted clear of finished ground level to allow entry of all cabling and services through the floor of the buildings. Please refer to Appendix G for further information regarding its arrangement.

#### 5.4.2 Switchgear

This section gives an overview of the purpose of switchgear and discusses the exact type of switchgear to be used for the 11kV switchroom. Switchgear is “a term used to refer to
combinations of switching devices and their interconnection with associated control, protective
and measurement systems” (Laughton and Warne, 2003, p.1124). It allows the interconnection
of different parts of an electricity supply network through means of underground or overhead
line connections in order to allow the flow of electricity within that network (Laughton and
Warne, 2003). Another important aspect is its ability to clear any type of fault to ensure network
safety by protecting connected equipment and operational personnel (Laughton and Warne,
2003). Switchgear connected with transformers, underground and overhead lines together with
housings and structures is termed a substation (or switchroom) (Laughton and Warne, 2003).
Switchrooms typically comprise the following switching devices (Laughton and Warne, 2003;
Warne, 2005):

- **Disconnectors** (or isolators) are devices which consist of movable contacts capable of
  being mechanically closed to form an electrical circuit to other equipment. They also are
  capable of being mechanically opened to physically disconnect one part of a circuit from
  an adjoining part whilst providing an isolating distance.
- Switches are mechanical switching devices that are capable of closing against and
  interrupting load currents.
- **Switch disconnectors** are switches which in its open position provide the isolating facility
  required of a disconnector with interlocking and padlocking facilities provided.
- **Earth switches** are mechanical switching devices used to connect the disconnected and
  de-energised primary conductors of a circuit to earth and allow work to be undertaken on
  the earthed part of the circuit.
- Fuses are ‘one-shot’ devices capable of carrying the rated load current while clearing
  over-currents and short-circuit currents.
- **Fuse switches** are switches which are connected in series with a fuse or mounted on the
  moving contact system of a specially designed switch.
- **Contactors** are devices that are capable of performing the same switching duty as a
  switch and are capable of closing against a downstream short circuit when protected by
  an appropriate fuse.
- **Circuit breakers** are devices that are capable of making and breaking load and overload
  currents of the circuit in addition to the full-rated short-circuit current.

There are two main types of switchgear assemblies, these include (Agrawal, 2001, p.354):

- **Open type which exists without an enclosure and is used in an outdoor switchyard or
  mounted on a pole; and**
- **Metal enclosed type which is completely enclosed on all sides by sheet metal except for
  the operating handles, knobs, instruments and inspection windows.**

For the purpose of the P11R Project the switchgear is to be of the metal enclosed type and in
particular will be the ABB ZS1 air insulated switchgear suitable for medium voltage distribution.
A copy of the technical specification for the ABB ZS1 switchgear can be found in Appendix A. Some technical aspects of the switchgear which are of vital importance for selection concern the thermal current rating and the fault withstand levels, which for the ZS1 range are:

- Rated short-time withstand current: 31.5kA [3s]
- Peak current: 80kA
- Internal arc current withstand current: 31.5kA [1s]
- Rated busbar current: 1250-4000A

These will be discussed later when connection of the incoming sources are taken into account.

**Switchgear layout**

Figure 31 to Figure 34 in Appendix C show the two proposed layouts of the 11kV switchroom. The first option is to replace the 11kV switchboard in its existing format by having two sources of power supply from the T311 and T312 transformers (i.e. incomers) form the power control centre (PCC), which then distribute the power to the different load centres (i.e. feeders) in the form of Motor Control Centres (MCCs) and Distribution Boards (DBs). The second option is to connect the Frame 5 generation facility to the 11kV switchboard, which would mean the rated busbar current rating of the switchboard would need to be increased from 1200A to at least 2300A. The feasibility of connecting the Frame 5 at 11kV is discussed later in the report. Switchboards can have multiple layouts, some of these include (de Kock and Strauss, 2004, p.5):

- **Single busbar with one busbar section (no flexibility and low reliability);**
- **Single busbar with two sections (improved flexibility and reliability with highest fault level if section maker is closed);**
- **Single busbar with three sections (excellent flexibility and reliability); and**
- **Double busbar with one or more sections (good flexibility and reliability).**

The existing switchroom comprises a single busbar with two sections with the bus-tie (section maker) closed. This will be the same layout for the new switchroom. In addition the actual construction of the switchboard will be of the cubicle-compartmentalised type where each feeder is housed in a separate compartment of its own (Agrawal, 2001). This type of switchboard has the advantage of localising faults on feeders without affecting other parts of the supply network (Agrawal, 2001). Lastly the switchboard is of the type ‘form four’ which means it can compartmentalise any damage done by an arc fault to that particular switchboard cubicle.

**Design parameters for switchgear**

The following outlines the parameters concerning the design of a switchboard (Agrawal, 2001):

- Rated voltage should be chosen as the nominal system voltage at which the equipment operates (i.e. 11kV),
- Rated frequency which shall be 50 Hz,
- Rated insulation level consists of the power frequency voltage withstand level and the impulse voltage withstand level,
- Rated continuous current rating and permissible temperature rise,
- Rated short-time current rating or fault level of a system (breaking current for an interrupting device),
- Duration of fault, and
- Rated momentary peak value of the fault current (making current for an interrupting device).

Since the design of the switchgear will be the responsibility of ABB Australia Pty Ltd a discussion on its design will not be given here.

5.4.3 Transformers
The transformers for the P11R Project are to be built to RTIO specifications as per the company’s internal engineering standards, chiefly the ‘Power Transformers’, ‘Large Power Transformers’ and the ‘Electric Wiring and Materials for Major Equipment Installation’. Since these standards are propriety information, a discussion of their content will not be given.

5.4.4 Cable
Please refer to Appendices D and E for cable installation details for the P11R project. This will be to the ‘Electric Wiring and Materials for Major Equipment Installation’ standard. Since this standard is propriety information a discussion of its content will not be given.

5.4.5 Earthing
In early June 2008, Enerserve, performed earth system injection testing and resistivity testing in light of an upgrade of the 33kV at Paraburdoo mine site in order (Enerserve, 2008, p.1):

a) To assess safety criteria compliance of existing electrical infrastructure under earth fault conditions; and

b) To determine likely minimum fault current flows using different neutral earthing impedance options that may be installed as part of the proposed 33kV switchroom upgrade.

The actual content of the analysis cannot be given because it is the proprietary information of the consultants used for the earthing study, however the following is a summary of the findings from their report (Enerserve, 2008):

a) Retaining the existing earth fault limitation on the Paraburdoo 33kV power system, given the future connection of GTG3 and multiple transformers, would see unrestricted fault levels exceed 12kA. Removal of the fault level mitigation would result in non-compliant touch voltages for the earth faults on the 33kV system and the entire earthing system would need to be redesigned.
b) Single phase to ground faults can occur with varying fault resistances. Low resistance faults such as through an earth switch will result in a high fault level limited only by the source impedance and earthing system impedance, which are typically no more than a few ohms. High resistance faults can occur through arcing or transient faults such as a tree branch, which will likely be less than 50Ω.

c) The future arrangement of the Paraburadoo 33kV switchroom will be supplied by the 220:33kV transformer (T301), two Frame 5 Generation Plant 11:33kV Transformers (T313/314) and the future connection of the GTG3 11:33kV transformer. In light of this supply arrangement it has been recommended that there are two options for installing neutral earthing fault limitation on the 33kV system:
   a. A single neutral earthing resistor connecting the 33kV neutral point of all transformers to the switchroom earth grid; and
   b. An individual neutral earthing resistor for each 33kV transformer.

As a whole it was recommended that the 33kV system be fitted with feeder earth fault protection that is capable of detecting the lowest earth fault level across the Paraburadoo system through means of a single 90Ω neutral earthing resistor or multiple 90Ω or 180Ω neutral earthing resistors. In the event that the feeder relay settings are too coarse to detect high impedance earth faults on the Paraburadoo 33kV network, then it has been recommended to install SEF (sensitive earth fault) on the reclosers at the airport and the bore fields in order to reduce the risk of uncleared high impedance earth faults. From preliminary analysis of the injection testing at the 220:33kV substation, the EPR (earth potential rise) during a 220kV earth fault is not likely to exceed 300V, which will result in manageable and compliant hazards at the substation and downstream infrastructure (Enerserve, 2008). So what is EPR?

EPR occurs when a large current flows to earth through an earth grid impedance (NationMaster, 2005 [online]). The ground potential at the current injection site increases relative to a remote earth, with the potential decreasing with increasing distance from the injection point (NationMaster, 2005 [online]). EPR is typically cause by lightning strikes and short-circuit conditions at substations, power plants and along high voltage transmission lines. EPR is responsible for causing hazardous voltages tens of metres away from the location of the fault.

The calculation of the potential of the earth grid can be calculated using Ohm’s Law as shown in Equation 1 (NationMaster, 2005 [online]):

\[ V_{grid} = I_{f} \times Z_{grid} \]

**Equation 1** Earth Potential Rise

The EPR decreases at points outside the earth grid and so an estimate of the EPR at a distance from an earth grid relates to the analysis of a driven rod electrode, assuming the rod radiates contours of equipotential voltage in a homogeneous earth environment (NationMaster, 2005 [online]):
\[ V_r = \frac{\rho I}{2\pi r_x} \]

Equation 2 EPR Voltage Profile

Where \( r_x \) is a point beyond the edge of the earth grid, \( V_r \) is the voltage at distance \( r_x \) from the earth grid, \( \rho \) is the resistivity of the earth and \( I \) is the earth fault current (NationMaster, 2005 [online]).

As a result of the testing, it has been recommended that the 220kV, 33kV and 11kV earthing systems remain common bonded in order to retain the following system benefits (Enerserve, 2008):

a) Lower 220kV earth system impedance producing lower than otherwise EPR for a 220kV earth fault;

b) Lower EPR during 33kV and 11kV earth faults than on a separated earthing system; and

c) Decreased risk of non-clearing 33kV and 11kV faults.

Since this report was compiled for the 33kV rationalisation project, the major implications for the 11kV rationalisation project means that much of the fault current entering the 220:33kV switchyard earth grid is carried to earth by 11kV cable sheaths between T313/T314 and the Frame 5 as well as the cable sheaths between T311/T312 and the existing 11kV switchboard. An upgrade of the 11kV distribution system must ensure that robust connections are retained between the 220:33kV switchyard and the 11kV system. However, it should be noted that injection testing and resistivity testing is to be performed again for the 11kV switchboard and distribution system to ensure that the earthing system is compliant with the relevant earthing requirements with respect to safe step and touch potential and EPR requirements.

5.4.6 Connection of Frame 5 Generation Facility

Currently RTIO are in the process of developing a site-wide power system model through the DigSILENT Pacific Pty Ltd PowerFactory software, which is due for completion in December 2008. Once the model is online it is recommended to model the connection of the Frame 5 generation plant to the 11kV and 33kV switchboards to determine the implications on both the upstream and downstream fault level, load flows, transfer limits, generation dispatch and dynamic performance. An advantage of connecting the Frame 5 to the 11kV switchboard is that there is a power supply source feeding the bulk supply switchroom in the event of an outage from the 33kV switchboard feeder transformers (T311/T312) as a result of a transformer fault, an outage on the transmission line from Tom Price or an outage on any of the generation (GTG1, GTG2 or GTG3) units. So what are the implications of connecting the Frame 5 generation facility to either the 11kV or 33kV switchboard?
Firstly there is insufficient space in the 220kV switchyard to accommodate another generator tie-in for GTG3 let alone the reconnection of the Frame 5. Therefore the remaining options for tie-in lie in the 11kV and 33kV switchboards. The two most obvious concerns are the increased fault levels at 11kV, and as 33kV having the ability to fully export the capacity of the Frame 5 to the transmission system without violating operating conditions at either the 11kV or 33kV level. The fault levels of the Frame 5 need to be determined for an 11kV tie-in in order to ensure they comply with the fault rating for the ABB ZS1 air-insulated switchgear (31.5kA rated short-time withstand current [38], 80kA peak current and 31.5kA internal arc withstand current [18]). Interestingly a report conducted by DigSILENT Pacific Pty Ltd on the impact of the GTG3 generation facility has shown that both the sub-transient (19.64kA) and synchronous three phase fault (15.68kA) levels are within the fault withstand rating of the ABB ZS1 switchgear for the 11kV bus as seen below in Figure 16. However this should be treated as a guide only as contributions from T313/T314 don’t need to be taken into account for a direct connection to the new 11kV switchboard.

<table>
<thead>
<tr>
<th>3P Fault at Bus</th>
<th>Un</th>
<th>Ik&quot;</th>
<th>Sk&quot;</th>
<th>Ip</th>
<th>Ib</th>
<th>Sb</th>
<th>Ik</th>
<th>Ith</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kV</td>
<td>kA</td>
<td>MVA</td>
<td>kA</td>
<td>kA</td>
<td>MVA</td>
<td>kA</td>
<td>kA</td>
</tr>
<tr>
<td><strong>T301 220kV Terminals</strong></td>
<td>220</td>
<td>2.22</td>
<td>844.64</td>
<td>5.70</td>
<td>2.12</td>
<td>807.81</td>
<td>2.05</td>
<td>2.27</td>
</tr>
<tr>
<td><strong>Para 33kV Main Bus</strong></td>
<td>33</td>
<td>12.07</td>
<td>659.05</td>
<td>31.58</td>
<td>11.15</td>
<td>637.31</td>
<td>10.28</td>
<td>12.44</td>
</tr>
<tr>
<td><strong>LM6000GT Unit3 Bus 11kV</strong></td>
<td>11</td>
<td>32.42</td>
<td>617.63</td>
<td>84.32</td>
<td>26.39</td>
<td>502.75</td>
<td>24.42</td>
<td>30.30</td>
</tr>
<tr>
<td><strong>LM6000GT Unit2 Bus 11kV</strong></td>
<td>11</td>
<td>34.29</td>
<td>653.23</td>
<td>89.07</td>
<td>28.42</td>
<td>541.52</td>
<td>26.84</td>
<td>32.36</td>
</tr>
<tr>
<td><strong>LM6000GT Unit1 Bus 11kV</strong></td>
<td>11</td>
<td>34.29</td>
<td>653.23</td>
<td>89.07</td>
<td>28.42</td>
<td>541.52</td>
<td>26.84</td>
<td>32.36</td>
</tr>
<tr>
<td><strong>LM2500 GT0 11kV Bus</strong></td>
<td>11</td>
<td>19.64</td>
<td>374.14</td>
<td>50.31</td>
<td>16.66</td>
<td>317.47</td>
<td>15.68</td>
<td>18.55</td>
</tr>
</tbody>
</table>

*Figure 16 Three Phase Fault Levels at Paraburadoo (DigSILENT, 2008, p.7)*

Connection of the existing Frame 5 tie-in at the 33kV level has already been assessed and is within the fault withstand rating of the ABB ZX1 gas-insulated switchgear (62.5kA peak withstand current, 25kA rated short-time current [38], 25kA rated short-circuit breaking current of circuit breaker and 62.5kA rated short-circuit making current of circuit breaker). Another issue concerning the connection of the Frame 5 at 11kV is the busbar current rating. The minimal rated busbar current rating is 1250A which is not sufficient to withstand the 1312A from the Frame 5 and the two 1300A incomers from the proposed 25MVA T311/T312 transformers. The 11kV plant load has been rated at 14MVA, which means the supply current from T311/312 won’t be near 2600A, but future growth patterns for Paraburadoo need to be taken into account to avoid poor power system planning. As a result there needs to be a revision in the 1250A rated busbar current rating. If the maximum 4000A busbar current rating was chosen then a busbar cooling system would need to be installed on the new switchboard. If the 14MVA 11kV plant load was chosen then this would require 735A in addition to the 1312A from the Frame 5, so a busbar current rating of approximately 2100A would be sufficient. Table 5 shows that Paraburadoo is expected to have the same load level in 2013 so the latter assumption seems valid. This is to be the decision of ABB Australia Pty Ltd as they are the design engineers, however if a 4000A busbar rating was chosen then I believe a decision needs to be made whether RTIO upgrades to
the ABB ZX1 gas insulated switchgear to cater for the higher busbar current levels. This decision will be made on the price of each connection and in particular on the net benefit it serves to RTIO. These fault and load current levels are the main concern, however there are other implications relating to the operation of the Frame 5 as part of the Paraburndoo generation capability and its relationship with power stations at Dampier and Cape Lambert on the coast. This relates to the load flows of each of the generation units at Paraburndoo with respect to the generation dispatch cases at Dampier (four generators) and Cape Lambert (three P1 alternators) power stations as shown in Table 4, and applied against the different load cases shown in Table 5, as evaluated by DigSILENT Pacific Pty Ltd, on a study on the connection of GTG3 to the 33kV switchboard.

<table>
<thead>
<tr>
<th>Table 4 Generator Dispatch Cases (DigSILENT Pacific Pty Ltd, 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Machine</strong></td>
</tr>
<tr>
<td>Dampier 1</td>
</tr>
<tr>
<td>Dampier 2</td>
</tr>
<tr>
<td>Dampier 3</td>
</tr>
<tr>
<td>Dampier 4</td>
</tr>
<tr>
<td>Paraburndoo 1</td>
</tr>
<tr>
<td>Paraburndoo 2</td>
</tr>
<tr>
<td>Paraburndoo 3</td>
</tr>
<tr>
<td>Paraburndoo 4</td>
</tr>
<tr>
<td>Cape Lambert</td>
</tr>
<tr>
<td>Cape Lambert</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5 Rio Tinto Iron Ore Site Loads (DigSILENT Pacific Pty Ltd, 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site</strong></td>
</tr>
<tr>
<td>Brockman</td>
</tr>
<tr>
<td>Cape Lamb</td>
</tr>
<tr>
<td>Dampier</td>
</tr>
<tr>
<td>Hope Down</td>
</tr>
<tr>
<td>Pannawoni</td>
</tr>
<tr>
<td>Paraburndoo</td>
</tr>
<tr>
<td>Tom Price</td>
</tr>
<tr>
<td>West Angel</td>
</tr>
<tr>
<td>Yandi</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Another consideration in the event of the Frame 5 being connected to the 11kV switchboard is the ability of T311 and T312 to withstand reverse power flows for the purpose of generation back onto the grid with respect to their protection schemes being able to handle the additional power flows. This is something that needs to be followed up with the design engineers.
5.4.7 Switchroom Control and Protection

Glover, Sarma and Overbye (2008) states that protection systems have three basic components: instrument transformers, relays and circuit breakers. Protection is an important part of an electrical system. For the P11R Project, the Scope of Works states:

a) The Contractor shall integrate the switchgear into the Network Control System (through switches, routers, CAT5, fiber etc) by updating the Network Manager System locally at Paraburdoo, the ROC and coastal power station;

b) Equipment communications within the switchgear building shall be based upon the IEC 61850 standard protocol;

c) The Contractor shall ensure connectivity to the MicroSCADA system located in the 11kV building by interfacing it to the 11kV switchgear;

d) The communications system shall be designed to communicate to the Network Manager via the DNP3.0 communication protocol. It shall be updated and integrated into the Network Manager system; and

e) The Contractor shall install an ABB RTU560 Remote Terminal Unit with redundant power supplies and communication cables, and run fiber optic cable from the 11kV switch room building to the 33kV switch room building, which is fed from the 220kV relay room building.

The remainder of this section will discuss the switchroom control and protection system components for the 11kV switchroom based on the scope of works and the functional specification. This section initially reviews concepts and technology used in the design of the switchroom control and protection system whilst incorporating aspects of the 33kV distribution system upgrade at Paraburdoo, which is akin to the P11R Project.

IEC 61850 Overview

A new substation automation system is currently being rolled out in new substation, switchyard and switchroom installations across all RTIO sites. This system is the MicroSCADA system by ABB, which is based upon the newly created IEC 61850 Substation Automation standard. The traditional approach to substation automation uses standardised RTU (remote terminal unit) protocols which were designed for data transmission over serial protocols (Sisco, 2007). However IEC 61850 uses protocols such as TCP/IP and Ethernet to provide a cost-effective means of high-speed communications within a substation. IEC 61850 provides “a standardised framework for substation integration that specifies communications requirements, the functional characteristics, the structure of data in devices, the naming conventions for data, how applications interact and control the devices for the data and how conformity to the standard should be tested” (Sisco, 2007, p.1). These models are then mapped to a specific set of protocol profiles that are optimally used for each functional area of the system such as data access,
supervisory control, protection oriented messaging and transducer interfaces (Sisco, 2007) as shown in Figure 17.

![IEC 61850 Object Names Use Power System Context](image)

**Figure 17** IEC 61850 Object Names Use Power System Context (Sisco, 2007)

The first three parts of the standard identifies the general and specific functional requirements for communications in a substation (Mackiewicz, 2007). The major transformation with this standard is the ability for it to adopt ‘abstracting’ of data items which means it creates data items/objects that are independent of any underlying protocols (Mackiewicz, 2007). This allows the mapping of data objects and services to any other protocol that can meet the data and service requirements (Mackiewicz, 2007). Data objects consist of common pieces such as Status, Control, Measurement and Substitution where Common Data Classes define common building blocks for creating larger data objects (Mackiewicz, 2007). The final step is the mapping of the abstract data objects and services into an actual protocol (Mackiewicz, 2007). Section 8.1 defines the mapping of the abstract data object and services onto the Manufacturing Messaging Specification (MMS) while sections 9.1 and 9.2 define the mapping of the Sample Measured Values (unidirectional point-to-point and bi-directional multipoint accordingly) onto an Ethernet data frame (Mackiewicz, 2007). There is a significant amount of configuration work required to put all the pieces together and have them work which is done through an XML based Substation Configuration Language (SCL) (Mackiewicz, 2007). SCL allows the formal description of relations between the substation automation system and the substation (or switchroom). As a result IEC 61850 provides a model for how power system devices organise data which is consistent across all devices (Mackiewicz, 2007). For example if a new instrument transformer was installed into an IEC 61850 protection relay then the relay can detect this module and assign it a measurement unit automatically. Since the author won’t be involved in developing the ABB MicroSCADA system an in-depth analysis of the protocol won’t be given.
DNP3.0 communication protocol

DNP3.0 is better known as the Distributed Network Protocol which is used in process automation systems in electrical utility type industries. DNP3.0 is used as the communication protocol between different types of data acquisition and control equipment and the SCADA system. DNP3.0 uses the term outstation to denote remote field devices and the term master to denote control system computers (Curtis, 2005). The protocol provides the rules for remotely located computers and master station computers to communicate data and control commands. DNP3.0 allows outstation computers to gather data for transmission to the master such as (Curtis, 2005, p.1):

a) Binary input data that is useful to monitor two state devices such as ‘circuit breaker closed’ or ‘circuit breaker tripped’ conditions;

b) Analog input data that conveys voltages, currents, power, reservoir water levels and temperatures;

c) Count input data that reports energy in kilowatt hours or fluid volume; and

d) Files that contain configuration data.

The master station issues control commands that the form of (Curtis, 2005, p.1):

a) Close or trip a circuit breaker, start or stop a motor and open or close a valve; and

b) Analog output values to set a regulated pressure or a desired voltage level.

Collectively DNP3.0 is a protocol designed for the transmission of data acquisition information and control commands from one computer to another for SCADA applications.
P11R Project Typical Switchroom Control and Protection Functional Description

As mentioned in section 4.3 (current electricity asset upgrade projects) of this report, the new 33kV switchroom for the P33R Project is currently being built. The new switchroom for the 33kV distribution system at Paraburadoo is also being constructed with the ABB MicroSCADA system. The technical specification for the switchroom control and protection system for the proposed 11kV switchroom can be found in Appendix H. A discussion on the detailed design aspects of the control and protection scheme won’t be given as I am forbidden from disclosing it to a third party. This is because it is the proprietary information of ABB Australia Pty Ltd and not RTIO.

ABB RTU560

The ABB RTU560 is a remote terminal unit used in electric utility applications for remote control, communication and automation in substations. The remote control capability is to monitor and control the plant by providing a hardwired connection to the plant or through data acquisition via intelligent electronic devices (IEDs). The data is then sent through to the higher level control system through the unit’s multi processor architecture to achieve high performance data processing. The binary I/O interface for 110-220V DC requires no interposing relays. At the network level a different communications protocol such as DNP3.0 is employed. The RTU560 can convert substation protocols to network protocols and vice versa. The unit can also interface to a variety of protection and control devices as well as other automation products. The Human Machine Interface (HMI) integrated into the RTU560 allows for local control and monitoring. For example disturbance records and load profiles are easily stored in the RTU560 and transmitted on the communications network when requested. The RTU560 can communicate with different hierarchical levels of a network control system. At the station level it can communicate with sub RTU’s or with any other intelligent electronic devices (IED’s). In addition to standard protocols such as DNP3.0 and the various IEC standards the RTU560 can communicate with protocols such as Modbus. For communication with sub RTUs and IEDs such as the REF541 protection relay protocols such as Modbus, SPA-Bus and Sinaut 8FW can be used. The connection of the these communication lines can be carried out in several ways through direct links with RS 232-C interfaces for local communication, voice frequency telegraphy over leased telecommunication lines or power line carriers, dial up modem, fiber optic cables and digital communication networks. The RTU is also compliant with IEC 61850 which means that the new 11kV switchroom can interface with remote control applications and operate with parallel I/O connections, serial IED connections via IEC, DNP3.0, Modbus or SPABUS and station bus via IEC61850. It is also possible to integrate IEC61850 gateway, time, server and integrated HMI in the one RTU560. For further information relating to the ABB RTU560 please refer to the technical guide in Appendix A. A discussion on the design for the communications for the 11kV switchroom cannot be given because the design information given to RTIO by ABB is not available for disclosure to third parties and thus unable to be discussed in this report.
**ABB REF541 Protection Relay**

The protection for the 11kV switchboard is to be conducted by the ABB REF541 digital relay, which is designed for the protection, control, measurement and supervision of medium voltage networks.

![Figure 19 ABB REF541 Digital Protection Relay](image)

This relay incorporates a range of feeder terminal functions inclusive of protection, measurement, disturbance, power quality, control, fault locator, condition monitoring, general, communication and standard functions. For further information consult the ABB REF541 protection relay user guide in Appendix A.

![Figure 20 An REF 541 feeder terminal used for the protection, control, measurement and supervision functions of a utility feeder (ABB, 1999, p.62)](image)

Figure 20 above shows a single line diagram for a utility feeder which shall be the typical layout for all plant feeders supplied by the new 11kV switchboard at Paraburadoo. The neutral point of the supply network is earthed via a low resistance. The scheme is also fully applicable to other types of low-impedance earthed networks where the neutral point is effectively earthed. The following is a summary of the recommended protection requirements for this type of utility feeder general arrangement (ABB, 1999, pp.65-67):
a) 3I > 50/51: multiple stage three-phase overcurrent protection, low-set, high-set and instantaneous available
b) I0 > 50N/51N: multiple stage earth-fault protection, low-set, high-set and instantaneous stage available
c) SEF 51N: low-set stage sensitive earth-fault protection to operate in the event of a high resistance earth fault in effectively or low-impedance earthed networks
d) 3Iaf > 68: inrush detection based on the 2nd harmonic content of phase currents applied for preventing possible unnecessary operation of over-current or earth-fault protection during transformer switching-in to start cold load pick-up logic
e) ΔI > 46: phase discontinuity protection
f) f < 81U: under frequency protection/load shedding scheme
g) 0 → 1 79: multiple-shot auto re-closer
h) CBFP */62: circuit-breaker failure protection
i) MCS: measuring circuit supervision
j) TCS: trip circuit supervision
k) CBCM: circuit-breaker condition monitoring
l) P: active power measurement, indication and supervision
m) 3I: three phase current measurement, indication and supervision
n) 3U: three phase voltage or phase-to-phase voltage measurement, indication and supervision
o) E: energy counter, forward or reverse active/reactive energy
p) R: annunciating, event generating and value recording functions
q) △: disturbance recorder
r) △△: MMI/MMIC display
s) △△: local and remote control interface
t) △△: bay-oriented interlocking logic

Since ABB Australia Pty Ltd is going to be contracted as the design engineers for the 11kV rationalisation project then it is their responsibility to devise and configure the REF541 protection system suitable for the feeders on the 11kV switchboard. The incomers from T311/312 have will have their protection system in the 33kV switchroom through the REF542 protection relays. The existing construction of the new 33kV switchboard has the Frame 5 connected with the REF542 module. If the Frame 5 was going to supply the 11kV board then an incomer with an appropriate generator protection scheme shall be used.

5.4.8 Power System Synchronisation

Please refer to Appendix I for the power system synchronisation specification. Note that the specification was written for the T311/T312 incomers only. If the Frame 5 is to be connected to the 11kV switchboard then this would require synchronisation equipment as well.

Synchronisation is required for the parallel operation of incoming supplies to a switchboard to ensure that their terminal voltage and phase sequence is the same as what is on the 11kV bus.

Synchronisation is used in order to ensure that the voltage, frequency and phase displacement of the incoming sources are equal as shown in Figure 21.
Figure 21 Phasor diagrams of incoming sources (Agrawal, 2001, p.522)

This is further explained by Agrawal (2001, p.521) below:

a) The phase sequence of the incoming machine must be the same as that of the existing source;

b) The terminal voltage, $E_t$, of the incoming source must be almost the same as that of the other source, $E_o$, or the bus, $V_b$;

c) i.e. $E_t=E_o$ or $V_b$ and

d) $\Delta V=E_t-E_o$ or

e) $\Delta V=E_t-V_b$ where $\Delta V$ is the difference in magnitude of the two voltages (permissible variation of 1% within $V_b$ or $E_o$)

f) The frequency of the incoming source, $f_t$, must be almost the same as that of the other machine, $f_o$, or the bus, $f_b$ (permissible variation: $\Delta f$=within 0.15Hz)

g) To check the phasor difference, if any, between $E_t$ and $E_o$ or $V_b$ to check $\Delta \theta$. $\Delta \theta$ gives rise to the residual voltage $EC$, which is responsible for the circulating current $I_c$ (permissible variation: $\Delta \theta$ is within $\gamma$).

The synchronisation system of the 11kV switchboard shall consist of both ‘check synchronisation’ and ‘auto-synchronisation’.

The purpose of the check-synchronisation relay is to check the accuracy of the manual synchronising by checking if $\Delta f$, $\Delta V$ and $\Delta \theta$ between the incoming source and the bus. When these quantities fall within the permissible limits the relay unlocks the incomer circuit breaker which means the source can be synchronised manually. Check synchronisation is a preferred method because it is a safety precaution for manual synchronising to double check the pre-set quantities ($\Delta f$, $\Delta V$ and $\Delta \theta$) which prevents inadvertent synchronisation (Agrawal, 2001) due to
the lead times involved with closing breakers after receiving a synchronisation pulse signal. This is why check synchronisation is advantageous over manual synchronisation because it is able to assess the incoming sources more accurately.

Larger installations (generally 500kVA and above) require other methods of synchronisation because manual methods are likely to cause fault conditions due to heavy circulating currents as a result of the higher Δf or Δθ than permissible. Furthermore auto-synchronisation is required particularly in times when the operator is not available. Auto-synchronising compares f₀ and E₀ of the incoming source with the source to control the frequency and voltage to preset values. This can be achieved through an auto-synchronising relay which can monitor the phase shift (Δθ) to perform perfect synchronisation even without an operator. A normally open contact of the relay is wired in the closing circuit of the interrupting device of the incoming source. The relay sends out an early signal to account for the lead time of the closing circuit breaker in close the contact as soon as Δf, ΔV and Δθ fall within their pre-set values (Agrawal, 2001). Auto-synchronising relays are generally solid-state or microprocessor based.

5.4.9 Metering
Please refer to Appendix J for the power and energy metering specification. The end user has specified that they want to know the ‘maximum demand’ and ‘monthly MWh consumption’ for each outgoing circuit which is to be sent to the MicroSCADA system. This is to be measured through means of AMPY 5300 revenue meters.

5.5 Review of other distribution system designs
11kV switchrooms have been installed at Hope Downs and Brockman 4 mine sites, however information pertaining to their design is unavailable as this was performed through another RTIO business unit and information relevant to the design belongs to the EPCM (Engineering, Procurement and Construction Management) firms who built those switchrooms as a turnkey project.

5.6 Scope Variation
On 28th October 2008, another site visit was carried out at Paraburdoo, this time with the intent of expanding the requirements of the P11R Project to refurbish the 11kV plant distribution system in addition to the replacement of the bulk supply 11kV switchroom as per the original project requirements. In attendance was the General Manager of Project Engineering, the Project Manager of the Electrical Utilities group, an Electrical Project Engineer from the Electrical Utilities group, the Senior Substation Sales Engineer from ABB Australia Pty Ltd, the Electrical Engineering Superintendent for Paraburdoo, the Electrical Projects Supervisor for Paraburdoo and myself. Since this additional expansion in the project requirements was decided only towards the end of the internship, it shall be completed next year when I return to the company. A discussion on the technical requirements will not be given as the entire 11kV distribution system was not covered during the site visit and will be completed next year.
5.7 Future Work, Results and Outcomes

The Scope of Work and Functional Specification has been written and is waiting for internal review before it is finalised and sent to the vendor for an official quotation. However this shall depend on confirming the connection options for the Frame 5 generation plant when the RTIO power model is handed over by DigSILENT Pacific Pty Ltd. Once the quotation is received I will be able to attach this to the Capital Expenditure Application to get the funds from Rio Tinto for the project to proceed.

As a result of the site visit on 28th October with the Electrical Utilities Project Manager, Electrical Utilities Project Engineer, Project Engineering General Manager, Engineer from Vendor, Paraburdoo Electrical Engineering Superintendent and Paraburdoo Electrical Projects Supervisor, the Scope of Works and Functional Specification needs to be written in order to encapsulate the plant distribution upgrade work as subsequent phases to the existing 11kV switchboard upgrade.
6.0 Other Projects

6.1 Paraburdoo 11kV Train Loadout (Sub 6) Relocation

A 300m section of the 11kV Train Loadout (Sub 6) distribution feeder is to be relocated because it lies in the middle of the GTG3 construction site as shown in Figure 22.

![Figure 22: 11kV Distribution Pole in the middle of the GTG3 Construction Site](image)

An on-site meeting on 21st August 2008 with an electrical lines contractor identified a suitable corridor for the 300m section of the train loadout feeder which is shown in Figure 23 below. RTIO will stand a new pole adjacent to the first Eastern Corridor Feeder pole and build a new steel pole line parallel to that feeder for about 150m, before dog-legging right briefly to hit the ABS switch installed earlier this year. Ladder cables were considered, however this is likely to be more restrictive on access, more expensive and would require mechanical barriers without any major benefits. For the time being the first pole of the new section will be fed from a slack span off the H-pole on the top of the hill. In the long term, this will be replaced with a short cable section as part of the 11kV switchroom works in which RTIO plan to remove all wooden H-poles and overheads into the to-be-redundant 33kV yard.
As this is a non-urgent project compared to the other works currently undertaken at Paraburadoo, it has been forecasted that the relocation will most likely occur in January 2009 upon completion of the town feeder replacement project. Once the line is relocated, the old section of line shall be decommissioned and removed from service.

**6.2 Paraburadoo 33kV Rationalisation Project**

**6.2.1 HV submission**

One of the initial tasks of the internship was to write the HV submission to the Department of Consumer and Employment Protection – Energy Safety for the HV works concerning the rationalisation of the 33kV switchroom and GTG3 construction. Section 7.4 Submission of Proposal of the Western Australian Electrical Requirements states that all details of proposed HV installations certified as complying with all the *Electricity (Licensing) Regulations 1991* requirements by a professionally qualified electrical engineer must be submitted to the network operator prior to equipment purchase and construction commencement. The following details are to be included in the submission (Department of Consumer and Employment Protection – Energy Safety, 2008, pp.42-43):

- A single line diagram showing all principal components and detailed information such as the transformer voltage levels and winding configurations.
- Loading details, including maximum expected demand, load characteristics, duty cycles, large motor starting details, other disturbing load details and special requirements.
- Where the main switch is one or more HV switch-fuse units (on a common busbar):
  - Rated current of all fuses;
  - Rated breaking current of fuses;
  - Make and type of fuses;
  - Current-time characteristic curves.
In the instance where the main switch is a circuit breaker (or similar, such as a re-closer) details on the protection system must be given such as a control and protection schematic diagram of the incoming circuit breaker(s) or vacuum contactor(s), details of protection relays used, including make and type, setting range and characteristic curves drawn for the selected settings. Any subsequent change must also be notified to and accepted by the network operator before the change is implemented. Since the submission made by RTIO to the Department of Consumer and Employment Protection – Energy Safety is confidential information, a discussion on its content won’t be given in this report.

6.2.2 Relay testing at Maddington
Please refer to Appendix M to view photos of the relay testing. As a minor activity of the internship I was able to take part in the testing of the REF 542 protection relays installed in the new 33kV switchroom. This included working alongside the RTIO Project Engineer and the ABB Commissioning Engineer to test the wiring for the synchronisation of the incomer panels on the switchboard. This included using the ABB software to go online with the protection relay to open and close the breaker in addition to verifying the wiring between the incomer panels and the synchronising module. Although I was only available for one day of the testing it shows what an important part pre-testing and commissioning plays in checking an installation before it goes to site.

6.3 Paraburdoo R301 Reactor Replacement
The R301 Reactor at Paraburdoo is currently offline which means there is no technique in place to provide an inductive load to compensate for the capacitive load of the transmission line from the Mount Tom Price terminal. Shunt reactors are used to absorb reactive power and reduce over voltages during light load conditions, switching and lightning surges (Glover, Sarma and Overbye, 2008). DigSILENT Pacific Pty Ltd is currently performing a study on whether the reactor is needed. As already stated the R301 reactor is connected in delta to the tertiary winding of the 45MVA 220:33kV T301 transformer at Paraburdoo. Reactors are used in transmission systems in order to (Grigsby, 2001):

a) Reduce the electromechanical loading and thermal stresses windings to extend the service life of the transformer and its associated equipment;
b) Improve the stability of primary bus voltage during a fault on a feeder;
c) Reduce the current-interrupting duty of feeder circuit breakers;
d) Reduce line-to-line fault current to levels below those of line-to-ground faults or vice versa;
e) Protect distribution transformers and all other downstream power equipment from propagation of voltage transients due to faults and/or circuit breaker operations; and
f) Reduce the requirement for downstream protection devices such as reclosers, sectionalizers and current limiting fuses.
High voltage transmission lines generate large amounts of leading reactive power when they are lightly loaded and absorb large amounts of reactive power when they are heavily loaded. As a result if a transmission line is operating under reactive power balance then the system voltage cannot be maintained at rated values.

Reactive Power Balance = Total Line Charging – Line Reactive Losses

Equation 3 Reactive Power Balance

If the power balance is not equal to zero then the line must be compensated (Grigsby, 2001). Under a heavy load the power balance is negative and capacitive compensation (voltage support) is required whereas under light load the power balance is positive and inductive compensation is required (Grigsby, 2001). The use of shunt reactors absorb reactive power which lower voltage on a system and are used on systems lightly loaded transmission lines which produce higher operating voltages. Therefore shunt reactors provide inductive reactive compensation which mitigates the high charging current of transmission lines which limit switching surges during energisation or reclosing (Grigsby, 2001). The primary driver from a RTIO point of view for the reactor replacement is due to the energisation of transmission grid in the event of system collapse. A paper on the energisation of an unloaded transmission grid as part of the restoration process has found that a “potentially sustained non-harmonic oscillation may appear when energising the whole grid at a time” (Kuisti, 2003, p.1). The concept has been compared to Ferroresonance which results from the saturation of a ferrous core of an inductive component in a power system which increases the inductance relative to capacitance (Dugan, 2000).

Ferroresonance is a non-linear resonance phenomenon that affects power networks. The abnormal rate of harmonics results in transient or steady state over voltages and over currents is dangerous and hazardous for electrical equipment (Ferracci, 1998). Power networks consist of saturable inductances such as power transformers, inductive voltage transformers and shunt reactors in addition to capacitances such as cables, long lines, capacitive voltage transformers, capacitor banks and even metal-clad substations (Ferracci, 1998). The Ferroresonance phenomenon results in more than one steady state response for the same set of network parameters (i.e. for a nominal voltage supplying a constant load). System operations such as transients, lightning over voltages, energising or de-energising of transformers or loads, occurrence or removal of faults can initiate Ferroresonance (Ferracci, 1998). The following behaviours in a power system are typical of the effects of Ferroresonance (Ferracci, 1998, p.10):

- **High permanent line-to-line and/or line-to-ground over voltages**;
- **High permanent over currents**;
- **High permanent distortions of voltage and current waveforms**;
- **Displacement of the neutral point voltage**;
• *Transformer heating (in no-load operation)*;
• *Continuous and excessive loud noise in transformers and reactors*;
• *Damage of electrical equipment*; and
• *Apparent untimely tripping of protection equipment*.

Since Ferroresonance is a non-linear harmonics problem there is no direct way to model it mathematically so electrical engineers are required to analyse system behaviours in order to evaluate its presence in power networks. Some of the above behaviours are not purely the result of Ferroresonance such as in the case of displacing the neutral point voltage which may result from a line-to-ground fault. A simple diagnosis can be undertaken by comparing curves taken from a power system’s data acquisition system with the typical Ferroresonance curves shown in Appendix R. It is recommended to note the system actions that were in place at the time of the proposed Ferroresonance such as tripping of reactors and load shedding. The next step is to evaluate whether the following three conditions are present (Ferracci, 1998, p.10):

• *Simultaneous presence of capacitances with non-linear inductances*;
• *Existence in the system of at least one point whose potential is not fixed (isolated neutral, fuse breaking, single phase switching)*; and
• *Lightly loaded system components (e.g. unloaded power transformers) or low short-circuit power sources (e.g. generators)*.

If any one of these conditions has not been evident in a system then it is highly unlikely Ferroresonance has occurred. An observation of some historical RTIO transmission network events can be found in Appendix S. So what are the implications for the Paraburadoo power system in light of the replacement of the R301 reactor?

The (Kuisti, 2003) study found that the saturation behaviour of power transformers leads to a non-harmonic oscillation in the voltage which gives rise to over-voltages which do not exceed the basic insulation level (BIL) but do cause overheating of transformers. The use of shunt reactors connected to the tertiary winding of a power transformer acts as an ideal inductance which when the voltage level in the grid is low, the non-harmonic oscillation decays fast (Kuisti, 2003). An increase in the size of the inductance provided by a shunt reactor increases the decay rate of the non-harmonic oscillations. The non-harmonic oscillations occur because of the harmonic resonance from the current injection of the saturated power transformers which produce harmonic components of voltage since impedance of the grid seen by the transformer is high at one of the harmonic frequencies (Kuisti, 2003). According to the study the non-harmonic oscillation attenuates quickly if the voltage level and the saturation of transformers are reduced by sufficient shunt reactor overcompensation in the energised grid. The overcompensation limits transformer inrush current due to the equivalent source impedance of the shunt reactor. Once the transmission grid is energised the voltage level has to be raised, which can be achieved by
disconnecting shunt reactors or switching additional power lines online before generators or loads can be connected to the grid. Operationally it is also recommended to by-pass all series capacitors and interconnecting lines on the energised grid as it increases the equivalent source impedance as seen from the transformers. In essence the voltage level of a reenergised transmission grid depends on the level of shunt reactor compensation. It can be achieved by disconnecting redundant lines or using shunt reactors connected to the tertiary winding of power transformers in order to attenuate the non-harmonic oscillations. In the case that shunt reactors cannot be used the end-to-end length of an unloaded transmission grid should not exceed 1000km to avoid a sustainable non-harmonic oscillation. However the length of the transmission line from the Mount Tom Price Terminal Substation to the Paraburadoo 220kV switchyard is approximately 80km so this should not be a problem. Therefore the following procedure is recommended to reenergise the 220kV transmission line from the Mount Tom Price Terminal in the event of a blackout (Kuisti, 2003, p.6):

a) Switch all shunt reactors online;
b) Disconnect transformers without shunt reactors;
c) Disconnect lines not required for the energisation to increase the equivalent source impedance of the shunt reactor;
d) By-pass all series capacitors to increase the impedance between transformers and the source to decrease the current of saturated transformers;
e) The grid is energised in one to three parts with no generation or load online between successive generations; and
f) When the whole grid has been energised the voltage is increased to the nominal level by switching additional power lines online or by disconnecting shunt reactors.

However an interim recommendation from DigSILENT Pacific Pty Ltd has stated that the R301 shunt reactor is not in fact needed which may be explained by the future implementation of the SVC unit but RTIO will have to wait until their report is submitted in order to analyse this decision.

**General arrangement of R301**
The new R301 reactor is of the air-core type and is to be installed onto the HV bushings of the T301 (220:33kV) transformer connected in delta to its tertiary winding as shown back in Figure 5. The reactor is rated at 10MVA and 11kV and is currently in the Project Engineering lay-down yard at Paraburadoo awaiting installation.

**Replacement Work Constraints**
ABB Australia Pty Ltd is to perform all civil and electrical works relating to the replacement of the R301 reactor. There is one major constraint in what seems a simple replacement job on-site in terms of the evaluation of electromagnetic field levels around the future air-core reactor in the 220kV switchyard. Among all the LV and HV electrical assets throughout RTIO air-core reactors
are the biggest sources of low frequency electromagnetic fields. An electromagnetic field has two components, an electric field and a magnetic field. An electric field exists when two objects have a voltage difference between them such as between a power line and ground below it. A magnetic field exists when current flows through a wire such as power lines. There has been much conjecture as to whether electromagnetic fields are hazardous to individuals and so US National Institute of Environmental and Health Sciences have found (Electricity Supply Association of Australia, 2001, pp.3-4):

*The scientific evidence suggesting that ELD-EMF exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer, childhood leukaemia and chronic lymphocytic leukaemia in occupationally exposed adults... On balance, the scientific evidence does not indicate that exposure to 50Hz electric and magnetic fields found around the home, the office or near power lines is a hazard to human health and at this stage any action to reduce exposure must rest with the individual.*

As a result of the adverse publicity of electromagnetic fields with respect to public health the contractors responsible for the replacement works are measuring and/or modelling the EMF in proximity to the air-core reactors, comparing their results against national and international safe exposure limits and providing recommendations for placement of the new reactor and whether modifications are required to the switchyard fencing. The Australian National Health and Medical Research Committee’s guideline recommends the following set of limits for human exposure to power frequency EMF (Western Power Corporation, 2006, p.5):

a) *For continuous 24 hour per day exposure for the general public, 1000mG;*
b) *For whole working day for occupational purposes, 5000mG; and*
c) *For a few hours per day for the general public, 10 000mG and for occupational purposes, 50 000mG.*

In order to determine the power frequency magnetic field, measurements should be taken at one metre above the ground surrounding the site of the proposed reactor as well as in several radial directions from each compound. The measurements in the radial directions are made to determine (Magshield Pty Ltd, 2003):

a) The rate of the EMF reduction with distance away from the reactors;
b) The radial direction from the reactor compound in which the EMF is the highest; and
c) If there is any other EMF source within the switchyard other than the reactors that emit comparable to the reactors EMF.

The results from such measurements hence determine reactor and switchyard compound fencing requirements with respect to safe exposure levels for personnel working on-site.
My role in the project was to manage the ground contamination clean-up left by the existing reactor installation as a result of reactor oil leaking into the ground, which can be seen in Figure 24. There is the potential that hydrocarbons and/or PCBs exist within the soil beneath the reactor. If contamination exists within the soil there is potential that groundwater is also impacted. The clean up involves an initial soils investigation to determine if soil contamination exists beneath the reactor once it has been removed. This involves excavation beneath the reactor to a depth of 2m below ground level where soil samples will be taken and sent to a laboratory for testing while the excavated soil will be sent to the Paraburadoo land farm for remediation. Since the excavation works are to take place in the 220kV switchyard several important RTIO standard work procedures will have to be carried out. These include:

a) Permit to work;
b) Critical lift form for the removal of the existing reactor using a crane;
c) HV vicinity access form to allow works to occur in an area where live overhead HV conductors are present;
d) Job hazard analysis to ensure the tasks involving excavation of the soil is carried out safely; and
e) Pre-start meeting to discuss safety matters of the job before the work is carried out.
Project Outcomes
The reactor is awaiting installation and the environmental clean-up requires commencement however RTIO are waiting an opportunistic time to get into the switchyard to perform the works. Once a time becomes available, the removal and replacement of the reactor can take place along with the environmental clean-up of the contaminated ground.

6.4 West Angelas Wash Pad and Administration Building/Work Shop HV Works

6.4.1 West Angelas Mine Site
The West Angelas mine opened in 2002 and is owned and operated by Robe River with support services provided by Pilbara Iron (Pilbara Iron, 2006 [online]). West Angelas produces Marra Mamba fines and lump ore, which is crushed and screened into discrete products on site. An expansion program is underway to increase annual production capacity to 25Mt (Pilbara Iron, 2006 [online]).

6.4.2 Project Purpose
The Principal Mechanical Engineer for West Angelas is currently project managing the construction of a new administration and work shop building and a light and heavy vehicle wash pad for the site. I was handed over this project from a Graduate Electrical Engineer in the Electrical Utilities team who had done some work on the project mainly relating to the procurement of a 1000kVA 33:0.415kV transformer for the wash pad. The design tasks have been outsourced to GHD Pty Ltd who had prepared preliminary HV design. My role was to design and organise the installation of HV power from the sites existing distribution network to both installations. Please refer to Appendices N and P for an aerial view of the wash pad and administration/work shop building.

6.4.3 Wash Pad
The equipment required for this part of the installation consisted of a transformer, a kiosk comprising the LV switchboard, 50mm² HV cable and modifications to the distribution power pole, and its earthing system, where the HV installation was to originate. In the Osborne Park ABB transformer factory, Rio Tinto had a 300kVA 33:0.433kV Dyn11 transformer in stock which had been in service at Cape Lambert, as shown in Figure 25. The installation images can be found in Appendix N.
As a result of the factory inspection and the assessment of the transformer’s data sheet it was deemed suitable for use in the wash pad installation. There were three preliminary options for its installation at the mine site. The first option, to install it as a pole-top transformer on an H-pole, was not pursued as it poses as a lightning strike risk as well as a hazard for electricians working on the transformer due to ‘working at heights’ related risks. This option was prepared by GHD and was not pursued by Rio Tinto because it would mean there would be a 150m cable run at LV which would require a larger cable size (240mm²) than the HV run (50mm²) which would be more costly due to the larger amount of copper in the cable. As a result, option one was dismissed. The second option was to install the transformer in a transformer bund which is generally used for transformers of larger size (e.g. 1MVA+). This option was dismissed because the use of a transformer bund would mean the transformer, LV switchboard and cables are exposed to high-pressure water sprays from the wash pad. The third option was to install the transformer into a kiosk enclosing the LV switchboard. This option was chosen because the kiosk is easily relocatable, which is beneficial because there is going to be construction nearby after the wash pad is completed, and in the event that the transformer is in the way it can be easily relocated. Another benefit is the IP rating of the kiosk enclosing the transformer and the LV switchboard. The IP rating refers to the Australian Standard responsible for defining the degrees of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72.5 kV. As a result, option three was pursued. The next step was to purchase a kiosk that could house both the transformer and LV switchboard. I visited the Industrial and Mining Manager
from Tanis IPS Pty Ltd to have a discussion on the requirements for the kiosk. As a result of my discussion I sent through the appropriate Rio Tinto standard drawing for a kiosk, the 300kVA transformer general assembly drawing and the single line diagram for the wash pad in order to get a quote for Tanis to construct the kiosk and LV switchboard. The quote was received within a week and the purchase order was put through and now the kiosk is currently under construction. The next step was to determine the installation requirements.

6.4.4 Wash Pad Installation Requirements
In order to determine the installation requirements I had to first look at the project drawings developed by GHD with respect to the HV installation as well as find Rio Tinto drawings on the West Angelas distribution network. Since I could not find any Rio Tinto pole layout drawings (later attributed to Rio Tinto’s acquisition of Robe River in 2000 when over two thousand drawings were lost) I had to use the company’s GIS system to view an aerial shot of the wash pad site and view the nearby 33kV distribution line from where GHD had proposed to connect the HV line. The aerial shot of the wash pad site can be viewed in Appendix N. The next step was to visit site to physically determine the underground line route from the power pole to the location of the kiosk. Figure 40 to Figure 44 in Appendix Q show the layout of the underground HV cable route to the kiosk for the wash pad. An on-site meeting with the Project Supervisor and the civil underground drilling contractor led to the determination of a cable route from the CH03 distribution pole to the proposed location of the kiosk adjacent to the wash pad.

6.4.5 Wash Pad Design Issues
Since the author had never designed or installed an underground cable before, I had to perform research into the relevant Australian standard (AS3000: Wiring Rules) to determine design requirements for an underground cable installation. Firstly AS3000 defines underground wiring as “a system of installation wiring in which cables are buried in soil, either directly or in a wiring enclosure beneath the surface of the ground” (2007, p.38). As per AS3000 it has been determined that the underground wiring for the wash pad has been classified as category B which means there needs to be mechanical protection provided for the cable. A category B underground wiring installation system is where cables are enclosed in medium-duty insulating conduit with additional mechanical protection or where sheathed cables are buried direct in the ground with mechanical protection (AS3000, 2007). AS3000 outlines various methods of mechanical protection for category B underground wiring. As a result, the underground wiring is to be steel wired armoured and shall be in a conduit where the cable is buried under the road in between the distribution pole. Furthermore the cable is to be termite nylon sheathed or double brass taped for protection against termites. Another consideration is the depth of cover of the cable. Table 3.6 in AS3000 states that the minimum depth of cover for category B wiring buried elsewhere external to a building is 500mm. In addition the Rio Tinto minimum depth of cover for HV cable is 1m as well as having a ribbon in between the cable and the surface in order to indicate that a HV cable is buried below. Another design issue is the proximity of the HV cable to other service lines such as a water pipeline, telecommunications cable and fire system supply
pipeline. AS3000 states in section 3.9.84 ‘near non-electrical services’ that where wiring is installed close to non-electrical services they shall be arranged so foreseeable routine operation carried out on the other services will not cause damage to the electrical services. Therefore it is recommended that the underground wiring be enclosed in conduit in order to prevent any water leaking from the water pipeline coming into contact with the HV cable. The size of the cable was calculated through the use of the relevant Australian Standard (AS3008 Electrical Installations – Selection of Cables). Since this standard is used for the sizing of cables up to 1kV a derating factor of 0.6 is used which is calculated by dividing the cable size by 0.6. This is an industry rule of thumb which was recommended by a guest lecturer from Maunsell in Semester One 2008 in ENG455 Operation and Control of Power Systems. A cable size of 10mm² was calculated which increased to 16mm² with the use of the Maunsell derating factor. Since the minimum cable size one can procure from a vendor for HV use is 50mm², this will be size of the wash pad underground cable conductor (copper) size which requires a conduit size of 100mm².

Modifications to the CH03 pole need to be completed in order for the HV cable to be able to take-off from the pole into the ground for the underground cable run. GHD have already provided Rio Tinto with a design for modifications to the pole. This will be given to the contractor responsible for performing the HV installation works on-site. The design will not be published in this report as it is the intellectual property of Rio Tinto. In addition, all metal parts of the take-off pole (CH03) such as insulator pins, braces, eyebolts and stay wires are to be common bonded together and earthed onto one common earth rod at the base of the pole. Terasaki circuit breakers are to be installed on the primary and secondary side of the transformer and LV switchboard by the contractor to protect the HV and LV cables. Lastly an air-break switch and drop-out-fuses (DOF) shall be installed on the take-off pole (CH03) in order to have a point of HV isolation in the event of any necessary servicing of the line or transformer.

6.4.6 Technical query on degree of protection

The project officer asked me to look into a quotation provided by a vendor for the supply and installation of a hydrocyclone (an oily water separation system) for the wash pad, where two prices had been given for compliance with Australian Standards and secondly a quote for compliance with Rio Tinto standards. The reason for this investigation was that there was a significant cost difference between the two and also compliance with Australian standards would be legally sound but cheaper whereas compliance with Rio Tinto standards would be more expensive but would ensure compliance and standardisation of the installation within site operations. In order to reach a decision over what option to pursue I had to research the relevant Australian Standard (AS60529:2004 Degrees of protection provided by enclosures) and the relevant Rio Tinto standard (SS-E125 Supply of Electrical and Instrumentation Equipment for Mechanical Enclosures). AS60529 provides an overview of the various degrees of protection where an IP rating is given. The first numeral in the IP rating indicates both protection of persons against access to hazardous parts and protection of equipment against ingress of solid foreign objects such as dust. The second numeral in the IP rating indicates the protection of equipment against ingress of water. The Australian Standard merely defines the varying rates of
IP protection whilst the Rio Tinto standard specifies that outdoor enclosures housing electrical equipment must be rated to IP66D, which means the hydro cyclone enclosure must be ‘dust tight’, be able to withstand powerful water jetting and prohibit access inside the enclosure against hazardous parts with a wire. I found by looking through the quote that ensured compliance with Rio Tinto standards that it only quoted compliance to IP56 which meant it did not comply. As a result of discussions with the Project Officer and the Principal Mechanical Engineer, it was decided that the IP56 rating was sufficient as it still provided protection against entry of dust in sufficient quantity to interfere with satisfactory operation of equipment as well as protection against heavy seas or strong jets of water from all practicable directions (AS1939, 1990). I followed this up with the Engineering Superintendent in the Electrical Utilities team and it was recommended to review the Rio Tinto SS-E125 standard as IP56 would suffice in this instance while the recommended IP66D for outdoor enclosures may be too high and costly to the business.

6.4.7 Administration/Workshop Building
Please refer to the installation images in Appendices P and Q for the aerial photo and installation images for the administration/workshop building. The equipment required for this part of the installation consisted of a transformer, a kiosk comprising the LV switchboard, 50mm² HV cable and modifications to the distribution power pole and its earthing system where the HV installation was to originate. When the project was handed over to me the transformer had been ordered (1000kVA 33:0.415kV Dy1 ONAN manual tap change transformer) from ABB in Brisbane with a lead time of 20 weeks. Similar to the wash pad installation the meeting I had with the Mining and Industrial Manager from Tanis IPS Pty Ltd was to follow up a quote for the kiosk that could house the 1000kVA transformer and the LV switchboard. As a result of my discussions, an issue relating to the form type of the kiosk and LV switchboard needed to be resolved. The switchboard needed to be type tested to form 4 which meant it was able to compartmentalise any damage done by an arc fault in the switchboard as per AS3439:2002 (Low-voltage switchgear and control gear assemblies - Type-tested and partially type-tested assemblies).

6.4.8 Administration Building/Work Shop Installation Requirements
In order to determine the installation requirements I had to first look at the project drawings developed by GHD with respect to the HV installation as well as find Rio Tinto drawings on the West Angelas distribution network. I had to look at the pole layout drawing and use the company’s GIS system to view an aerial shot of the administration building/work shop site and view the nearby 33kV distribution line where the underground wiring could be sourced. As per Appendix P and drawing W133-E-801 in Appendix A, the original plan was to use PS02 as the take-off pole when the project was handed over to me. However this was dismissed because this distribution line supplies a significant portion of the mine and any disruption would have a significant impact on production. So the use of ROM1 as the take-off pole was chosen in order to minimise disruption to the mine. Figure 45 to Figure 51 in Appendix Q show the layout of the
underground HV cable route to the kiosk for the administration/work shop building. An on-site meeting with the project supervisor and the civil underground drilling contractor led to the determination of a cable route from the ROM1 distribution pole to the proposed location of the kiosk adjacent to the wash pad as shown in Figure 51.

### 6.4.9 Administration Building/Work Shop Design Issues
All design issues discussed in 6.4.5 (wash pad design issues) apply to the design of the HV wiring to the transformer kiosk, however the ROM1 take-off pole already contains an air-break switch so there is no need to install a new one.

### 6.4.10 Project Outcomes
The 1MVA step-down transformer is under construction in ABB’s Queensland factory while the kiosks comprising the LV switchboards for both the wash pad and the administration/wash pad building are under construction as well. The 300kVA transformer has been delivered from the ABB Osborne Park Factory to the Tanis IPS factory in Welshpool for the remainder of the construction of the wash pad kiosk. The Scope of Works for the installation of these HV assets on-site has been written, but I am awaiting the works schedule from the Principal Mechanical Engineer in order to provide this to the contractor. Overall, I have enjoyed this project because it has been a nuts and bolts job requiring me to assess what needs to be done and deliver the project as a part of a wider solution.
7.0 Conclusion

Overall, I have enjoyed the internship with Rio Tinto Iron Ore Project Engineering. My initial expectation was to work purely on Paraburdoo 11kV Rationalisation however I got to do a lot more. The General Manager told me “if you don’t see, you don’t learn”, which I think is very true, as it important to go to site to assess what the engineering requirements are for a project as opposed to being based purely in the office. I have enjoyed the opportunity to work constructively with the various project stakeholders and perform works that deliver a solution to their requirements. I believe I have enhanced my practical knowledge of power systems in a mining environment and in particular distribution throughout a mine site. This has lead to the development of technical competencies in ‘engineering practice’ and ‘engineering planning and design’ as per the Engineers Australia professional development programme requirements. This also extends to the development of process competencies, in particular ‘self management in the engineering workplace’ and ‘engineering project management’. I believe I have further developed my communication, initiative and problem solving skills through discussions with project engineers, clients, managers and contractors/vendors by listening to what they want out of a project and by providing a way to implement a feasible solution. And finally, I am pleased to say that the internship has put my degree in perspective by using skills across both engineering and commerce, which means it has been a good thing after all!
8.0 References


ABB Australia Pty Ltd, 2008, Rio Tinto Distribution Substation Asset Condition Assessment Stage 1 – Interim Report, ABB Australia Pty Ltd, ABB Office Unknown.


AS1939, 1990, Degrees of protection provided by enclosures for electrical equipment (IP Code) - Wallchart 1, Standards Australia, Homebush.


Magshield Products International Pty Ltd, Evaluation of Electromagnetic Field Levels Around Air-Core Reactors in Dampier and West Angelas at 220kV Substations, Magshield Products International Pty Ltd, Hampton.


Rio Tinto Iron Ore (e), 2008, Iron Ore Production in the Pilbara, Rio Tinto Iron Ore, Perth.


Schneider Electric, 2008, Neutral earthing resistors and transformers, Schneider Electric, Auckland.


9.0 Appendices

Appendix A: Miscellaneous Documents

WA Major Mineral and Resource Projects Map
E-001-58523
E-001-3048
E-001-46307
W-133-E-801

ABB UniGear ZS1 Air Insulated Switchgear Catalogue [available electronically in CD]
ABB RTU560 Remote Terminal Unit Technical Guide [available electronically in CD]
ABB REF 541 Protection Relay Technical Guide [available electronically in CD]
Appendix B: Paraburdoo Climatic Data

Site name: PARABURDOO AERO  
Latitude: 23.17 °S  Longitude: 117.75 °E  
Elevation: 424 m

Table 6 Paraburdoo Climatic Data (Bureau of Meteorology, 2008 [online])

<table>
<thead>
<tr>
<th>Statistic Element</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean maximum temperature (°C)</td>
<td>40</td>
<td>38</td>
<td>33</td>
<td>32</td>
<td>29</td>
<td>25</td>
<td>24</td>
<td>27</td>
<td>31</td>
<td>35</td>
<td>38</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td>Highest temperature (°C)</td>
<td>47</td>
<td>46</td>
<td>44</td>
<td>39</td>
<td>36</td>
<td>32</td>
<td>32</td>
<td>34</td>
<td>38</td>
<td>44</td>
<td>44</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>Lowest temperature (°C)</td>
<td>16</td>
<td>18</td>
<td>11</td>
<td>10</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>4.4</td>
<td>8</td>
<td>13</td>
<td>16</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Mean rainfall (mm)</td>
<td>44</td>
<td>78</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4.4</td>
<td>8</td>
<td>13</td>
<td>16</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Highest rainfall (mm)</td>
<td>203</td>
<td>257</td>
<td>16</td>
<td>11</td>
<td>11</td>
<td>33</td>
<td>26</td>
<td>37</td>
<td>15</td>
<td>597</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest rainfall (mm)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>
Appendix C: Paraburdoo Electricity Network Layouts

Figure 26 Existing Paraburdoo Electricity Network

*Upon P33R completion
Figure 27 Existing Paraburdo 11kV Switchboard Configuration
Figure 28 Paraburdo Electricity Asset Layout
Figure 30 Existing Paraburdo 11kV Overhead and Cable Ladder Feeders
Option A: Proposed Paraburdoo Utility Layout

Figure 31 Option A Proposed Paraburdoo Electricity Network Layout
Figure 32 Option B Proposed Paraburdoo Electricity Network Layout
Figure 33 Option A Proposed Paraburdoo 11kV Switchroom Layout
Figure 34 Option B Proposed Paraburadoo 11kV Switchroom Layout
## Appendix D: Paraburdoo 33kV Cable Details

### Table 7 Paraburdoo 33kV Cable Details

<table>
<thead>
<tr>
<th>CIRCUIT</th>
<th>END 1</th>
<th>END 2</th>
<th>NOMINAL DETAILS</th>
<th>CABLE</th>
<th>LENGTH</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>T301 33kV Incomer</td>
<td>T301 33kV cable termination</td>
<td>33kV switchboard</td>
<td>1/3 x 1-co 19.1/33kV XLPE/PVC 300mm² C</td>
<td>1 x 3</td>
<td>3 x 8</td>
<td>Run in new conduits</td>
</tr>
<tr>
<td>Frame 5 33kV incomer</td>
<td>33kV bus structure at T / T314</td>
<td>33kV switchboard</td>
<td>1/3 x 1-co 19.1/33kV XLPE/PVC 300mm² C</td>
<td>1 x 3</td>
<td>3 x 5</td>
<td>Run through switchyard on ladder / conduit</td>
</tr>
<tr>
<td>GTG3 generator transformer 3 incomer</td>
<td>33kV terminal (in cable box)</td>
<td>33kV switchboard</td>
<td>1/3 x 1-co 19.1/33kV XLPE/PVC 300mm² C</td>
<td>1 x 3</td>
<td>3 x 1</td>
<td>Run through switchyard on ladder and GTG on ladder / conduit</td>
</tr>
<tr>
<td>T311 33kV feeder</td>
<td>33kV bus structure at T311</td>
<td>33kV switchboard</td>
<td>1/3 x 1-co 19.1/33kV XLPE/PVC 300mm² C</td>
<td>1 x 3</td>
<td>3 x 5</td>
<td>Run through switchyard on ladder / conduit</td>
</tr>
<tr>
<td>T312 33kV feeder</td>
<td>33kV bus structure at T312</td>
<td>33kV switchboard</td>
<td>1/3 x 1-co 19.1/33kV XLPE/PVC 300mm² C</td>
<td>1 x 3</td>
<td>3 x 5</td>
<td>Run through switchyard on ladder / conduit</td>
</tr>
<tr>
<td>West Pit 33kV feeder</td>
<td>in-line joint with existing cable feeder in pit switchyard</td>
<td>33kV switchboard</td>
<td>1/3 x 1-co 19.1/33kV XLPE/PVC 300mm² C</td>
<td>1 x 3</td>
<td>3 x 3</td>
<td>Run in conduit at end of trench; size allow in-line</td>
</tr>
<tr>
<td>Town 33kV feeder</td>
<td>in-line joint with existing cable feeder in pit switchyard</td>
<td>33kV switchboard</td>
<td>1/3 x 1-co 19.1/33kV XLPE/PVC 300mm² C</td>
<td>1 x 3</td>
<td>3 x 3</td>
<td>Run in conduit at end of trench; size allow in-line</td>
</tr>
<tr>
<td>East Pit 33kV feeder</td>
<td>new cable termination on existing 33kV overhead line pole south of switchyard</td>
<td>33kV switchboard</td>
<td>1/3 x 1-co 19.1/33kV XLPE/PVC 300mm² C</td>
<td>1 x 3</td>
<td>3 x 3</td>
<td>Run through switchyard on ladder / conduit</td>
</tr>
</tbody>
</table>
### Appendix E: Paraburdoo 33kV and 11kV Cable Installation Details

#### Table 8 Paraburdoo 33kV and 11kV Cable Installation Details

<table>
<thead>
<tr>
<th>CIRCUIT</th>
<th>END 1</th>
<th>END 2</th>
<th>NOMINAL DETAILS</th>
<th>NOMINAL RUN LENGTH</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame 5 11kV incomer</td>
<td>Existing 11kV cable in trench near T313</td>
<td>11kV switchboard</td>
<td>2/3 x 1-6.35/11k/400mm2</td>
<td>2 x 3 x 7</td>
<td>In-line joint w/existing cables in trench near T313/T314</td>
</tr>
<tr>
<td>New T311 3 feeder</td>
<td>33kV cable of new T311</td>
<td>33kV switchboard</td>
<td>1/3 x 1-19.1/33k/300mm2</td>
<td>1 x 3 x 2</td>
<td>Run through switchyard in conduit; recover redundant cable from old T311</td>
</tr>
<tr>
<td>New T311 1 incomer</td>
<td>11kV cable of new T311</td>
<td>11kV switchboard</td>
<td>2/3 x 1-6.35/11k/400mm2</td>
<td>2 x 3 x 6</td>
<td>Run through switchyard on new ladder / conduit</td>
</tr>
<tr>
<td>New T312 3 feeder</td>
<td>33kV cable of new T312</td>
<td>33kV switchboard</td>
<td>1/3 x 1-19.1/33k/300mm2</td>
<td>1 x 3 x 2</td>
<td>Run through switchyard in conduit; recover redundant cable from old T312</td>
</tr>
<tr>
<td>New T312 1 incomer</td>
<td>11kV cable of new T312</td>
<td>11kV switchboard</td>
<td>2/3 x 1-6.35/11k/400mm2</td>
<td>2 x 3 x 5</td>
<td>Run through switchyard on new ladder / conduit</td>
</tr>
<tr>
<td>MOC 11kV feeder</td>
<td>existing 11kV cable in trench near CB3611</td>
<td>11kV switchboard</td>
<td>1/3 x 1-6.35/11k/240mm2</td>
<td>1 x 3 x 3</td>
<td>In-line joint w/existing cable run tail from switchboard conduit / ladder to existing trench</td>
</tr>
<tr>
<td>TRUCKSHOP 11kV feeder</td>
<td>existing 11kV cable (ex MOC feeder) in trench near CB3611</td>
<td>11kV switchboard</td>
<td>1/3 x 1-6.35/11k/240mm2</td>
<td>1 x 3 x 6</td>
<td>In-line joint w/existing cable run tail from switchboard conduit / ladder to existing trench; use recovered cable from MOC feeder; join to existing TRUCKSHOP feeder cable in old 11kV cable basement</td>
</tr>
<tr>
<td>TRUCKSHOP AUX TX 1 loop</td>
<td>TRUCKSHOP 11kV RMU</td>
<td>New AUX 11kV RMU</td>
<td>1/3-6.35/11k/240mm2</td>
<td>1 x 100m</td>
<td>Route to be determined; possibly loop back from TRUCKSHOP sub to old 11kV cable basement</td>
</tr>
<tr>
<td>Location</td>
<td>Current Configuration</td>
<td>New Configuration</td>
<td>Action</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------------------</td>
<td>-----------------------------</td>
<td>---------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUX TX 1 11kV</td>
<td>New AUX TX 1 11kV RMU</td>
<td>11kV switchboard</td>
<td>Run through switchyard in ladder, then through existing trench to old 11kV cable basement; in joint to existing AUX TX 1 feeder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEM WORKSHOP SEC CRUSHER 11kV</td>
<td>existing (recently installed) cable at ladder structure on 11kV switchboard</td>
<td>11kV switchboard</td>
<td>In-line joint with existing (recently installed) cable; run tail from switchboard conduit / ladder to new ladder structure up to (recently installed) 11kV ladder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FINES PLANT 11kV</td>
<td>existing 11kV cable (ex MEM feeder) in trench near CB362 bay</td>
<td>11kV switchboard</td>
<td>In-line joint with existing cable; run tail from switchboard conduit / ladder to existing trench; use recovered cable from MEM feeder; join to existing FINES PLANT feeder cable in old 11kV cable basement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STOCKPILE 11kV</td>
<td>existing (recently installed) cable at ladder structure on 11kV switchboard</td>
<td>11kV switchboard</td>
<td>In-line joint with existing (recently installed) cable; run tail from switchboard conduit / ladder to new ladder structure up to (recently installed) 11kV ladder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUX TX 2 11kV</td>
<td>existing 11kV cable (ex STOCKPILE feeder) in trench near CB362 bay</td>
<td>11kV switchboard</td>
<td>In-line joint with existing cable; run tail from switchboard conduit / ladder to existing trench; use recovered cable from STOCKPILE feeder; join to existing AUX 2 feeder cable in old 11kV cable basement</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| PLANT            | existing (recently installed) 11kV | 11kV switchboard           | In-line joint with existing 11kV switchboard }
<table>
<thead>
<tr>
<th>WORKSHOP / LOADOUT feeder</th>
<th>installed) cable at ladder structure on hill</th>
<th>switchboard</th>
<th>6.35/11kV/240mm2</th>
<th>existing (recently installed) cable run tail from switchboard conduit / ladder to new ladder structure up to (recently installed) 11kV ladder</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADMIN / WORKSHOP / FUEL FARM 11kV feeder</td>
<td>existing 11kV cable (ex PLANT W'SHIP / LOADOUT feeder) in trench near CB362 bay</td>
<td>11kV switchboard</td>
<td>1/3 x 1 x 6.35/11kV/240mm2</td>
<td>In-line joint with existing cable run tail from switchboard conduit / ladder to existing trench; use recovered cable from PLANT W'SHIP feeder; join to existing ADMIN feeder cable; join to existing 11kV cable basement</td>
</tr>
<tr>
<td>FUEL FARM AUX TX 2 loop</td>
<td>Extended FUEL FARM 11kV RMU</td>
<td>New AUX 11kV RMU</td>
<td>1/3-core 6.35/11kV/240mm2</td>
<td>Route to be determined; possibly looped back from FUEL FARM sub to 11kV cable basement to AUX TX 2</td>
</tr>
</tbody>
</table>
Appendix F: 0.433kV Kiosk Switchroom Functional Specification

1. Fully self contained bund capable of holding the maximum capacity of the oil in the transformer tank;

2. Cable box on HV and LV terminals;

3. Switchgear and transformer to be in the same compartment;

4. Kiosk access shall be via bolt-on removable panels or doors with pad-lockable handles;

5. The sheet steel shall be first quality, include coating of adequate gauge to ensure rigidity of panels. The sheet steel shall be at least 3m thick;

6. Other steel components shall be hot dip galvanised after fabrication;

7. The transformer shall be capable at operating in the following climatic conditions:
   a. 1050W/m² solar radiation horizontal area
   b. 90% relative humidity
   c. Dusty atmosphere containing fine abrasive particles
   d. 50 degrees Celsius maximum ambient temperature

8. HV and LV cable access shall be side entry;

9. The kiosk shall be provided with an integral earth bar connected to all equipment and panels;

10. The earth bar shall allow the flow of fault current without any restriction;

11. The star connected HV winding shall be directly connected to the earth bar;

12. The earth bar shall be a minimum of 25mm x 6mm;

13. The kiosk enclosure shall have an external M10 “frame earth” stud complete with nut, locknut and washer located close to the bottom of the enclosure frame; and

14. IP56D minimum.
Appendix G: 11kV Switchroom Building Functional Specification

The building shall:

a) Be designed and constructed to be suitable for the Pilbara region of Western Australia;
b) Comply with the Building Code of Australia as a non-habitable Class 10 Structure without disabled access and with landings and stairs to AS1657;
c) Be structurally designed to relevant Australian Standards to carry the imposed floor loads of all equipment likely to be installed including switchgear, battery racks, panels, etc;
d) Be constructed from non-combustible materials
e) Be separated from oil-filled devices as follows:
a)  
< 2000litres : 5m
b)  
≥ 2000litres : 15m
f) If these distances cannot be met, fire barriers must be installed.
g) Provide approved fire retardant barriers to shield cables beneath the building from potential fires from disassociated oil-filled devices
h) Be air conditioned with “Split Type” dual redundant air conditioner units to maintain temperature at not greater than 25°C. (The air conditioners shall be cycled each 24 hours by the Station RTU);
i) Be effectively sealed against ingress of dust and water under specified environmental conditions, pressurisation fans are not required;
j) Include an airlock at the normal entry point, in which the Fire Isolation Panel, Substation HMI and a telephone handset shall be located;
k) A separate room for batteries and eyewash;
l) Include, in addition to normal and emergency access doors suitable access for addition and removal of equipment such as circuit breakers, control room equipment and test & maintenance equipment;
m) Comply with the following Standard Specifications:
   • SS-C116 Metalwork for Buildings
   • SS-E114 Control Rooms and Electrical Equipment Rooms

The following building services shall be provided:

n) Lighting and small power;
o) An eye wash facility in the immediate vicinity of the batteries;
p) Fire detection and alarming system for Switchgear Building (“VESDA” type or similar);
q) Fire suppression system (FM200 or similar);
r) Arc Flash Detection and Elimination/Suppression;
s) Normal and emergency access doors; and
t) Security access point to be installed by the Company
u) Desk, chair, whiteboard and steel locker in the Switchgear building.

Wall space shall be allowed for notice boards, key cabinets, signage and the like.
The Contractor shall supply all access platforms, stairs, etc associated with the building.
Appendix H: Switchroom Control and Protection Functional Specification

Protection Systems
The Contractor shall specify the types of protection schemes required for the works. Protection systems shall be provided in accordance with good Industry Practice. For general guidelines regarding current “Industry Practice” on transmission assets in the NWIS, refer to the WPC Technical Code for Electricity Transmission.

11kV Incomer (Supplied in 11kV switchgear portion)
In addition to the protection provided from the Transformer protection panel, one REF541 is included at each incomer for main protection. This provides incomer over current and earth-fault protection. Each REF541 also includes CB control & interlocking.

CB Protection (Supplied in 11kV switchgear portion)
For each Circuit Breaker, protection and monitoring functions including CB fail and trip circuit supervision are included in each REF541.

Protection Coordination
The Contractor shall calculate and apply all necessary protection settings for the new 11kV relays at Paraburdoor.

Trip circuit and trip supply monitoring
Each protection tripping circuit shall be supervised with an alarm provided through the control system to indicate an open circuit condition or loss of tripping supply voltage.

Protection Sensitivity
Protection relay settings shall be selected to provide adequate sensitivity for minimum fault levels. In terms of current settings, an accepted practice is to ensure adequate sensitivity for faults down to one third of minimum phase-to-phase or phase-to-earth fault currents.

Fault location and disturbance recording
All Intelligent Electronics Devices (IEDs) shall incorporate Time Stamping via a local GPS clock signal.

SCADA and Communications Systems
The 11kV switchgear shall be integrated into the new MicroSCADA system to provide as a minimum the following functionality:
a) Monitoring of all alarms from each panel and from each item of equipment;
b) Data logging of electrical data including maximum demand, M/kWh, Volts, Frequency, Power Factor, MW, VArS, Amps etc;
c) Monitor status of position of all primary equipment including, Circuit Breakers, Isolators, Earth Switches, etc;
d) Remote control of CBs and other equipment from Dampier, Paraburdoo or other locations as specified by the Engineer;
e) Provision for future expansion; and
f) Communicate to the Network Manager via DNP3.0 over TCP/IP.

The system shall be designed and installed in a manner that is suitable for a high voltage substation environment.

The Contractor shall install an ABB RTU560 Remote Terminal Unit and run fiber optic cable from the 11kV switch room building to the 33kV switch room building (which is fed from the 220kV relay room).

**Paraburdoo Switchgear**

Equipment installed in the Paraburdoo switchgear building is to provide functionality equivalent to that of the existing systems installed elsewhere in the Pilbara Iron Power System. In general the system shall provide:

a) Control, indication and operational alarms on the Network Manager; and
b) Control, indication and operational alarms on the MicroSCADA HMI system at Paraburdoo.

The works at Paraburdoo necessary to achieve the above functionality shall include:

a) Equipment communications within the switchgear building shall be based upon the IEC 61850 standard protocol, and
b) Communications to the Network Manager shall be via DNP3.0 over TCP/IP.

**Control Hierarchy**

Specific points to note are as follows:

a) Site Control is ‘taken’ by personnel at site by operation of a soft switch on the MicroSCADA which provides an input to the RTU;
b) Operation of the Site Control Switch disables all commands that originate from outside the substation, and switches the local SCADA HMI from ‘View Only’ into ‘Control’ mode;
c) While in ‘Site Control’, all alarms and indications shall continue to be available on the greater SCADA system;
d) Check Sync Over-ride function is required;
e) The push buttons, to be located on the relevant circuit breaker protection & control panels in the relay room, will normally be inactive, but will become active once an associated Local/Remote switch has been selected to ‘Local’ control. ‘Local’ in this instance means ‘at the
panel’, whereas ‘Remote’ means ‘further away’ - such as the site SCADA station, or the greater SCADA system;
f) The status of Local/Remote and Local/Remote/Disconnect switches shall be indicated to the RTU. On selection of ‘Local’, the SCADA shall disable both Open and Close commands for that particular circuit breaker, and shall provide visible on-screen indication that remote control for that circuit breaker has been inhibited; and
g) The Sync Check Over-ride function must be initiated as two concurrent site actions and must be configured so it cannot be left in the ‘over-ride’ state. Note: it shall not be implemented within logic controllers such that it could be initiated from other than site.

**Circuit Breakers**

All operator-instigated actions shall result in simultaneous operation of all three poles; only certain automatic protection system actions will result in independent single pole operation.

The circuit breakers may be operated by:

a) Protection Relay HMIs;
b) Remote operator control via SCADA system; and
c) Automatic tripping by action of the associated protection schemes.

**Operation from Switchgear Building**

Each circuit breaker protection and control panel shall be fitted with an IED with its own HMI that shall enable REMOTE-LOCAL, OPEN, CLOSE and SYNC CHECK OVER-RIDE functions to be selected from the IED’s HMI to control the permissible actions as follows:

a) In REMOTE, trip/open and close signals from a source remote to the circuit breaker protection and control panel will be enabled; operation of the OPEN, CLOSE and SYNC CHECK OVER-RIDE function will be disabled.

b) In LOCAL, operation of the OPEN, CLOSE and SYNC CHECK OVER-RIDE functions will be as follows:

a. Depressing the respective CB OPEN HMI key will send an open signal to the circuit breaker;

b. Depressing the respective CB CLOSE HMI key will send a close request to the synchronising scheme, and a close signal will only be issued to the circuit breaker once the voltage across the circuit breaker is assessed by the synchronising scheme as acceptable;

c. Depressing the respective CB CLOSE and SYNC CHECK OVER-RIDE HMI keys simultaneously will send a close request to the circuit breaker, irrespective of the voltage difference across the circuit breaker.

c) The LOCAL selection does not interfere with trip/open and close signals from Relay Room protective relays or SCADA.

**Operation by SCADA system**

Remote control operation of circuit breakers from the **MicroSCADA** shall operate as follows:
a) Site Control is ‘taken’ by personnel at site by selecting the Site Control soft key on MicroSCADA. The status of the Site Control key will be mapped to the station’s hot stand-by RTU560;

b) Operation of the Site Control Switch soft key disables all commands that originate from off-site, and switches the local MicroSCADA HMI from ‘View Only’ into ‘Control’ mode;

c) While in ‘Site Control’, all alarms and indications shall continue to be available within the station’s hot stand-by RTU560 and be available for transfer to the network control system;

d) Dedicated push buttons are required for open and close operations of all circuit breakers;

e) A separate push button is required for Check Sync Over-ride;

f) The push buttons, to be located on the relevant circuit breaker protection & control panels in the relay room, will normally be inactive, but will become active once an associated Local/Remote switch has been selected to ‘Local’ control. ‘Local’ in this instance means ‘at the panel’, whereas ‘Remote’ means ‘further away’ - such as the site MicroSCADA station, or the network control; and

g) Outdoor circuit breakers shall also be equipped with a Local/Remote/Disconnect switch within their control cubicle. ‘Local’ in this instance means ‘at the circuit breaker’, whereas ‘Remote’ means ‘further away’ - such as the Control/Relay Room or the site MicroSCADA station, or the network control
Appendix I: Power System Synchronisation Functional Specification

The Contractor shall supply and install Check Synchronisation and Auto Synchronisation functions to manage closing of two (2) 33kV circuit breakers (CB3614 and CB3623) which are connected to the incoming sources. All other feeders shall have Check Synchronisation functionality.

The Check Synchronisation scheme will prevent a circuit breaker from being closed if the systems on either side are not in synchronism, but will allow for ‘dead bus’ close. The Auto Synchronisation scheme will provide for synchronisation at 11kV of the Paraburadoo system.

All other feeders and bus-tie shall have Check-Synchronisation functionality.

Backup Synchro-Check Scheme
This scheme is essentially a manual close scheme with synchro-check permissive. Each circuit breaker close signal shall be directed to the bay control relay of the breaker to be closed. The CB ‘close’ command will be executed on the proviso that a ‘permissive’ is given by the synchro-check function.

The synchro-check function shall monitor the VT voltages on both sides of the breaker selected for closing. The synchro-check function shall also incorporate a dead bus/dead line feature that will be activated automatically within the synchro-check relay with no requirement for operator selection.

Auto Synchronising Scheme
The Auto Synchronising Scheme shall be implemented using a single Auto-Sync Relay and an RTU-based voltage selection scheme which provides for the appropriate voltages to be switched to the Auto-Sync Relay once a circuit breaker is selected for closing. Other required interlocks such as:

a) The selected circuit breaker is open;

b) The miniature circuit breakers MCBs of the VTs to be selected are closed; and

c) No other circuit breaker has been selected for synchronising shall also be incorporated to ensure proper operation of the scheme.

Once the Auto-Sync Relay is initiated, sufficient information shall be provided to the network operator to enable manual synchronisation.
When the conditions are within the specified limits, the synchroniser shall perform a synchro-
check then send a close signal to the circuit breaker. Automatic dead line/dead bus functions
shall also be included in the synchroniser without the need for operator selection.

While the synchronising process is in progress, a “Sync In Progress” indication shall be
incorporated into the SCADA system.

If a circuit breaker trips or closes during this stage, a STOP signal shall be issued to the Auto-
Sync relay and the synchronising scheme shall then be made unavailable for a twenty-second
time duration. A manual stop feature shall also be provided within the MicroSCADA system and
shall be actioned by selecting the circuit breaker and issuing a trip command. A
“Synchronisation Unavailable” signal will be generated during any time-out period and displayed
to the Network Operator on the MicroSCADA system. Selection of any circuit breaker is disabled
for this duration. At the end of the twenty-second delay the synchronising scheme reverts to
normal operation.

If any synchronising activity is in progress for more than 4.5 mins, a STOP signal shall be
activated, resetting the synchronising process. If the operator wishes to resume the
synchronising process, the process must be re-commenced.
Appendix J: Power and Energy Metering Functional Specification

The metering for the 11kV switchboard shall meet the end user’s requirements of being able to measure and record at least the maximum demand and MWh on a monthly basis to the MicroSCADA system on each outgoing 11kV circuit. Check Metering is not required.

Performance Requirements for Revenue Metering:

a) Maximum allowable overall error at 50% load and greater: 1.5% for active power; 3.0% for reactive power;

b) Minimum acceptable class or standard of components: 0.5CT/VT; 1.0 Meter (Wh); 2.0 Meter (VARh); and

c) Clock error: ±10 seconds per month.

Design Requirements for Revenue Metering installation (which may comprise CTs, VTs, wiring, links, fuses and interposing equipment) must comply with the following requirements:

a) The CT core and CT secondary wiring forming part of the revenue metering installation must not be used for any purpose other than revenue metering;

b) The VT supply to each revenue metering installation must be separately fused and located in an accessible position as near as practicable to the VT secondary winding;

c) If more than one VT supply is available, a voltage changeover scheme must be provided; and

d) Secondary wiring must be by the most direct route and the number of terminations and links must be kept to a minimum.

The Contractor shall supply and install AMPY 5300 revenue meters (with a pulse output to measure kWh/MWh) wired to the RTU. The Contractor shall also run TCP/IP cable to the communications switch.
Appendix K: Cable Functional Specification

Cables and Marshalling Boxes
All cables and cable installation practices shall comply with Standard Specification SS-E101 Electric Wiring and Materials for Major Equipment Installations unless specifically amended by this scope of work.

The Contractor shall provide a Cable Schedule showing the type and length of each cable installed and drawings of the cable routes giving the identification marks for the cables.

Power Cables
Direct buried cables shall be adequately protected against termite attack with either double brass tape, Nylon jacket outer sheath or a combination of both.

Secondary Cables
All secondary cabling shall comply with Standard Specification SS-E122 Wire Colour Code except as outlined in this section.

a) All 415V and 240V power circuits will have 2, 3, or 4 cores with an earth conductor;
b) All cables running through the substation (unless excluded for the function in question such as optic fibres) shall be screened, with the screen earthed at both ends. Indoor data cable screens shall be earthed at one end only. This applies to CT and VT cable shields that will be earthed at both ends;
c) Earth bars shall have independent earth connection to main earth;
d) All wiring within cubicles shall use 1.5 sq. mm wire except for CT and earth circuits which shall use 2.5 sq mm wires, and that 1.0 sq. mm wire may be used where equipment can only accommodate this size of wire;
e) All wiring except that for CT circuits, VT circuits, and earth wires shall be grey stranded flexible wire. All CT, VT, and AC supply wiring shall be of the phase colours red, white, blue and black. Earth wires shall be green/yellow; and
f) Unless the receiving equipment is unsuitable, all wires shall be terminated with the use of lugs.

All substation cabling shall comprise double brass taped, PVC/PVC insulated, nylon jacketed cables. All cables within buildings and equipment shall be PVC/PVC.

Cable Trenches and Conduits
A main trench shall lead from the Switchgear building cable basement to service the outdoor equipment. Final cable runs to individual equipment from the main trench shall be installed in PVC conduit.

The main trench shall be equipped with galvanised steel checker plate covers which shall have sufficient strength to serve as a pedestrian way or traffic way as required. The trench shall be set into the ground and finished just proud of the aggregate surface and shall be drained to the storm water drainage system by gravity.

As an alternative to a main cable trench, all cable runs may be installed in conduit provided that:

a) At least one spare conduit is provided between the Control Room and the first Bay Marshalling Cubicle;
b) At least one spare conduit is provided between adjacent Bay Marshalling Cubicles; and

c) At least 20% spare capacity is provided in all other conduits.

Marshalling Boxes
All marshalling boxes shall comply with Standard Specification SS-E120 Electrical Enclosures. In addition:

a) All field marshalling boxes which contain active devices (including circuit breaker control panels) shall be fitted with 240V AC anti-condensation heaters; and
b) All field marshalling boxes shall be finished as natural stainless steel.
Appendix L: Spare T311/T312 Transformers

Figure 35 Spare T311/T312 Transformers
Appendix M: 33kV Switchroom Relay Testing at Maddington

Figure 37 33kV switchboard incomer panel
Figure 38 33kV switchboard incomer panel circuit breaker and AMPY power meter

AMPY power meter
Figure 39 33kV switchboard incomer panel wiring
Appendix N: West Angelas Wash Pad Aerial Photo
Appendix O: West Angelas Wash Pad Installation Photos

Figure 40 CH03 take-off pole for wash pad underground wiring

Figure 41 “Take-off” power pole where underground cable will feed from for the wash pad
Figure 42 HV power line route for wash pad
Figure 43 Wash pad underground cable route
Figure 44 Kiosk location
Appendix P: West Angelas Administration/Workshop Building
Aerial Photo
Appendix Q: West Angelas Administration Building/Workshop Installation Photos

Figure 45 ROM1 take-off pole for administration/workshop building underground power wiring
Figure 46 ROM distribution feeder line
Figure 47 ROM1 Air-Break Switch
Figure 48 ROM1 take-off pole to underground wiring route

Figure 49 Administration/wash pad building underground wiring route
Figure 50 Administration/wash pad building underground wiring route

Figure 51 Administration/wash pad building proposed kiosk location
Appendix R: Ferroresonance

Illustration of Ferroresonance Characteristics (Ferracci, 1998, p.8):

Figure 52 Ferroresonance fundamental mode

Figure 53 Ferroresonance sub harmonic mode

Figure 54 Ferroresonance quasi-periodic mode

Figure 55 Ferroresonance chaotic mode
Appendix S: RTIO Power System Events

The following events occurred during the commissioning of the first GTG1 generation facility back in March of 2006. Please refer to the Paraburdoo 33kV and 11kV single line diagrams to understand which circuit breakers and isolators are being discussed.

A system collapse occurred on Thursday 2nd March 2006 at 11:35AM, the following describes the events that occurred:

- Frame 5 on @ 5MW
- Closed 3921 to energise T302 from grid
- 3611 tripped on earth fault
- Neutral current settings for T301 need reviewing
- Paraburdoo line volts increased
- Tom Price reactor was tripped by operator
- System voltage increased to very high levels
- Transformers set to manual taps
- Circuit breakers began opening on over voltage protection
- All inland load lost except Paraburdoo

Figure 56 System Collapse
Figure 57 System collapse voltages

Figure 58 System collapse voltages
Figure 59 System collapse PLC ladder logic
**Harmonic resonance** occurred on Monday 14th March 2006 at 4:57pm, the following describes the events that occurred:

- Frame 5 on
- Paraburdoon islanded
- T302 energised from LM6000
- Closed 3921 to energise T301, R301 and transmission line
- Resonant condition set up, extremely high voltages and currents observed
- Hi-set over current trip from Toshiba Overall Dif/REF relay and Main Tx Dif/REF relay
- 3921 and 3362 opened

![Figure 60 Harmonic resonance currents](image-url)
Figure 61 Harmonic resonance currents

Figure 62 Harmonic resonance fault currents and voltages
A **Dead Bus Close** occurred on Wednesday 15th March 2006 1:59pm, the following describes the events that occurred:

- Frame 5 on
- Paraburadoo islanded
- T302 energised from LM6000
- 3921 closed to energise T301 and R301 only
- 3911 remained open, 220kV line dead
- Attempted sync at 3611
- Existing logic saw and dead line and permitted a dead bus close
- LM6000 and Frame 5 closed together out of sync
- Toshiba Overall Dif/Ref relay tripped on Hi-set over current opening 3921 and 3362

**Figure 63** Dead bus close Citect SCADA tags
Figure 64 Dead bus close fault currents

Figure 65 Dead bus close ladder logic
Figure 66 Dead bus close ladder logic