University of Southern Queensland

Faculty of Health, Engineering & Sciences

Implementation of a condition monitoring program for High Voltage (HV) assets for the Santos GLNG Project

A dissertation submitted by

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Abstract

Electricity supply to Santos' existing field operations in the Surat Basin is currently provided by diesel and/or gas motor driven generator sets. This has the disadvantages of poor reliability, high diesel costs and the unwanted consumption of gas that could otherwise be sold to market.

Part of the Santos GLNG Project includes the 'electrification' of the Coal Seam Gas (CSG) fields and processing plants. Electrical equipment such as large power transformers, HV switchgear, HV motors and Motor Control Centres (MCCs) will be installed to power the expanding gas gathering and processing infrastructure. Due to the remoteness of these assets and the critical role they will play in the CSG process, it is essential that they are highly reliable. It is intended to employ condition monitoring technologies to aid in achieving this.

A literature review was conducted in order to research current CM technologies applicable to HV plant and equipment. From this, identified techniques were evaluated to determine those most applicable and/or suitable for use in this particular application. A selection methodology was then used to identify critical equipment for inclusion in the condition monitoring program. All of this resulted in the development of a CM strategy which is intended to be implemented in a CM program when the project is fully operational.

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Limitations of Use

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

Date

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Table of Contents

List of Figures

List of Tables

Chapter 1

INTRODUCTION

1.1 Santos overview

Founded in Adelaide in 1954, Santos Ltd. is a leading oil and gas producer and exploration company, supplying Australian and Asian customers. Its name is an acronym for South Australia Northern Territory Oil Search.

With its origins in the Cooper Basin, located in the remote corners of South Australia and Queensland, Santos operates in all mainland states and the Northern Territory. It also has an exploration led Asian portfolio, with a focus on three core countries: Indonesia, Vietnam and Papua New Guinea.

Santos has delivered major oil and gas liquids businesses in Australia. It is one of Australia's largest producers of gas to the domestic market (15%) and has the largest exploration and production acreage position in Australia of any company. From this base, Santos is pursuing a transformational Coal Seam Gas (CSG) to Liquid Natural Gas (LNG) strategy with interests in four LNG projects, including the Gladstone Liquid Natural Gas (GLNG) Project, the geographical location/s of which are shown in Figure 1.1.

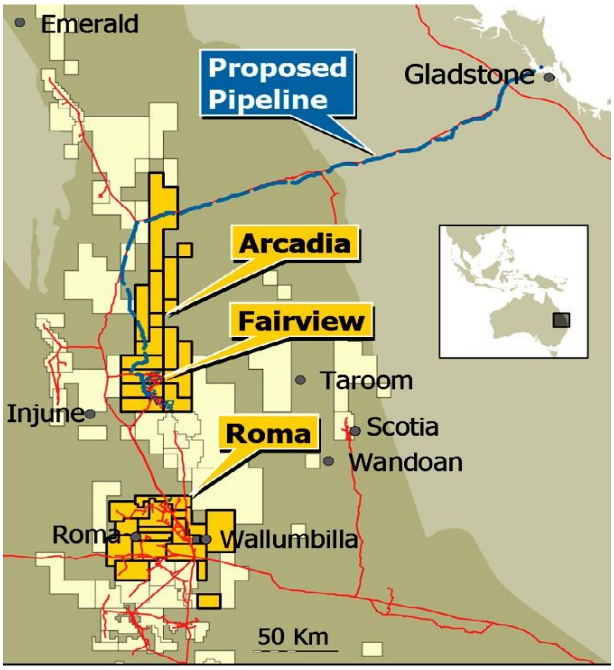


Figure 1.1 – Santos GLNG Project

1.2 Project background

Electricity supply to Santos' existing field operations in the Surat Basin is currently provided by diesel and/or gas motor driven generator sets. This has the disadvantages of poor reliability, high diesel costs and the unwanted consumption of gas that could otherwise be sold to market. Part of the Santos GLNG Project includes the 'electrification' of the Coal Seam Gas (CSG) fields and processing plants, known in the upstream operations as Hub Compressor Stations (HCS). Fairview Hub Compressor Station 4, currently under construction, is shown in Figure 1.2 below. This will initially be achieved by utilising Gas Turbine Alternators (GTAs), followed by the ultimate development of connection to the high voltage grid, currently being augmented into the Surat Basin by the Queensland Transmission Utility, Powerlink.

Figure 1.2 – Fairview Hub Compressor Station 4 (F-HCS-04)

This development will represent a major organisational change for Santos. From an engineering perspective, new plant and equipment such as large power transformers, HV switchgear, HV motors and Motor Control Centres (MCCs) will be installed to power the expanding gas gathering and processing infrastructure. Due to the remoteness of these assets and the critical role they will play in the CSG process, it is essential that they are highly reliable. It is intended to employ condition monitoring technologies to aid in achieving this, by monitoring key equipment parameters and being alerted to developing failures.

1.3 Project aims

Briefly, the scope of this project is to develop a condition monitoring program for High Voltage (HV) assets for the Santos GLNG Project and investigate/illustrate the effects such a program has on improving equipment reliability and associated availability. The ultimate goal of such a program is that it will initiate preventative actions to improve equipment reliability and mitigate the risk of future breakdowns.

Chapter 2

CONDITION MONITORING

Condition monitoring can be defined as the process of monitoring a parameter of condition in plant and equipment, such that a significant change is indicative of a developing failure. It relies on systematic data collection and evaluation, often by advanced signal processing methods and algorithms, to identify changes in performance or condition of a system, or its components. This allows maintenance to be scheduled, or other remedial actions to be taken to avoid the consequences of failure, before the failure occurs.

It is most frequently used as a predictive maintenance (PdM) or condition-based maintenance (CBM) technique, and has the advantage of determining the condition of equipment while in operation, thus maintaining unit availability. Condition monitoring also offers the following advantages:

- Improved reliability
- Decreased replacement costs
- Reduced system downtime
- Improved spares management
- Increased maintainability
- Enhanced performance
- Economical plant operation

The human senses (sight, hearing, smell, touch) are one of the simplest, yet most effective condition monitoring techniques. The ‘intuitive insight’ provided by these often matches, and in some cases may exceed the results, in terms of accuracy and speed of diagnosis, obtained by technology. It is therefore an invaluable skill set, particularly for plant and equipment operators to possess. Other examples of condition monitoring include:

- Vibration analysis
- Oil analysis (lubrication, Dissolved Gas Analysis (DGA))
- Thermography
- Partial Discharge
- Motor current analysis

- Specialist vendor packages

It is important to note that condition monitoring does not prevent failure – it detects and predicts it. Moriarty (2010) suggests that condition monitoring is a powerful tool to establish reliability risk management and should be considered as an essential component of an organisation’s reliability improvement strategy. The consequences of catastrophic equipment failure, including financial loss, environmental incidents and public reputation, provide adequate justification for industrial companies to employ condition monitoring on their operating assets.

2.1 Dissolved Gas Analysis (DGA)

Fluid Analysis (FA) relates to the collection of fluid (e.g. oil, coolant) samples from equipment; conducting laboratory analysis to detect such things as wear metals, contaminants and changes in physical/chemical properties; then using this information to determine equipment condition, assisting in predicting failure. It is capable of detecting the following incipient failures or conditions:

- Solid particle or water contamination
- Wrong oil added to equipment
- Poor engine running conditions
- Oil condition as the basis for change, rather than time
- Component degradation such as bearings, gears, reciprocating parts
- Fuel injector or seal failure

Dissolved Gas Analysis (DGA)

A subset of Fluid Analysis is the collection of oil samples from oil insulated electrical equipment such as transformers and circuit breakers. The oil has two important functions; cooling and electrical insulation. With normal use of the transformer, the oil starts degrading due to various factors such as ageing, overheating and environmental conditions. Any deterioration in the oil can lead to the premature failure of the transformer.

When the oil is subjected to high thermal and/or electrical stress, gases are generated due to decomposition of the chemical bonds in the hydrocarbon molecules of the mineral oil. The seven (7) ‘key’ gases generated are Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), Acetylene (C_2H_2), Carbon Dioxide (CO_2) and Carbon Monoxide (CO).

The energy required to break the chemical bonds can be due to overloading or the result of an electrical fault. The four basic conditions or types of fault which can occur in a transformer are:

- Arcing or high current break down
- Low energy sparking or partial discharges
- Localized overheating or hot spots
- General overheating due to inadequate cooling or sustained overloading

Different types of faults will generate different gases, depending on the temperature and amount of energy. Table 2.1 shows the typical gases generated under the four basic fault conditions.

Table 2.1 – Gas generation guide

Condition	**Gases Generated**
High current arcing (fault)	Hydrogen (H_2); Acetylene (C_2H_2)
Partial Discharge/Corona	Hydrogen (H_2); Carbon Dioxide (CO_2); Carbon Monoxide (CO)
Localised overheating (hot spots)	Methane (CH_4); Ethane (C_2H_6)
General overheating (overloading)	Carbon Dioxide (CO_2); Carbon Monoxide (CO)

The chemical analysis of these gases, in particular the concentration (expressed in parts per million (ppm)), will provide useful information about the condition of the oil and the identification of the type of fault in the transformer. Depending on the individual unit's specifications and operational requirements, removal of an oil sample may be done with the transformer energised or de-energised. The oil sample is analysed in the laboratory using Gas Chromatography (GC) techniques. This process is commonly referred to as Dissolved Gas Analysis (DGA). Pandey and Deshpande (2012) consider it to be the most important oil test for insulating liquids in electrical apparatus.

These generated gases will initially dissolve in the oil and cannot be seen by the naked eye. As the volume of generated gases increases, more of these gases will dissolve into the oil. There will come a point when the oil will be totally saturated with the dissolved gas, and any further increase in gases cannot be contained as dissolved gas in the oil. The excess gases will come out as free gas, contained in the head space of the transformer tank.

Along with oil, the windings of oil-filled transformers use paper insulation (cellulose). If this becomes weakened, the consequence of a fault current may be severe; the inevitably high forces on the windings may result in mechanical failure of the insulation and consequent inter-turn short-circuits. In order to assess the rate of degradation of the paper insulation, the furfural level in the oil can be measured. The organic compound furfural is a colourless oily liquid; a by-product of the chemical reaction that occurs when paper is exposed to high temperature, in the presence of water. Zhang and MacAlpine (2006) suggest that the relationship between furfural and mechanical strength of the paper is well established and therefore the level of paper degradation as well as the condition of the oil can be assessed from the same oil sample removed from the transformer.

Early diagnosis and periodic monitoring of the condition of oil-filled electrical equipment used in generation, transmission and distribution of electricity can improve reliability and availability. DGA is a unique condition monitoring tool and has given significant benefits in the form of major reductions in unscheduled transformer failure, reduced maintenance and reduced cost of repairs. However, some inaccuracy is always associated with laboratory DGA measurements of transformer oil; which may affect the gas ratios, concentration differences and other calculations upon which transformer condition assessment and fault diagnosis by DGA are based.

2.2 Thermography

Thermography relates to the use of infrared heat camera equipment to detect variations and discrepancies in the thermal signature of electrical equipment. This identifies such things as abnormal loading conditions, high resistance joints or ‘hot spots’, which are often the first indications of impending failure. It is also capable of detecting the following incipient failures or conditions:

- Levels of liquids and solids in vessels
- Rubbing components in rotating equipment
- Hot spots in furnaces, boilers, heat exchangers
- Hot/cold zones on storage tanks, vessels and rotating equipment

All electrical and moving mechanical equipment generates thermal energy (heat) in the form of infrared electromagnetic radiation. Infrared, meaning ‘longer than red’, has a wavelength range of approximately 700nm – 1mm. This is outside that of visible light (400nm – 700nm); therefore it cannot be seen by the human eye. A thermal imaging camera, an example of which is shown in Figure 2.1 below, is used to detect and record infrared electromagnetic radiation. The images are presented pictorially as in Figure 2.2, with different colours representing different absolute temperatures. This simple method provides a very effective way of recognising heating concerns, allowing preventative maintenance to be scheduled in a timely manner, generally without interruption to production purposes.

Figure 2.1 – FLIR brand thermal imaging camera

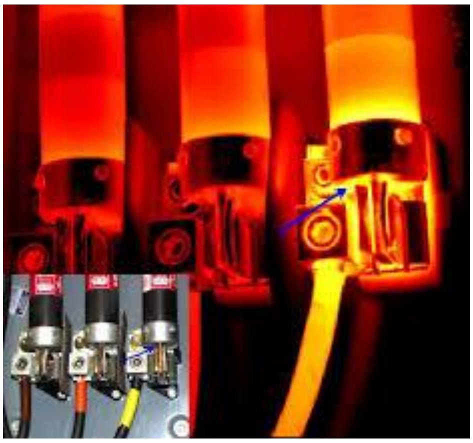


Figure 2.2 – Thermographic image of fuse cartridge assembly

For electrical equipment, this heat loss is often directly proportional to the square of the current passing through it, multiplied by the resistance (I^2R). Also, as equipment ages, it will generally deteriorate, increasing heat dissipation and emitting a greater amount of electromagnetic radiation.

As discussed, this type of heat can be detected with an infrared camera, defining temperatures, which can then be calculated as “Delta – T” (change in temperature) temperatures. Reporting formats will then categorise “Delta – T” temperatures by means of defining the urgency of corrective action. A suggested approach by Smith (2001) is illustrated in Table 2.2 below.

Table 2.2 – Corrective maintenance guide due to “Delta – T”

Delta – T Classification	**Action Required**	**Category**
0°C to 10°C	Possible fault developing. Continue monitoring for possible deterioration.	Monitor
10°C to 20°C	Corrective measures should be scheduled.	Next shut down
20°C to 40°C	Corrective measures required urgently.	Urgent
40°C and above	Corrective measures required immediately.	Immediate

There are many opportunities for the use of thermographic imaging inspections, with possible applications in the electrical, mechanical and chemical fields. It is important to have a direct line of vision when scanning equipment to ensure absolute and meaningful results are attained. Once another medium is in place that obscures the equipment being investigated, the readings and results are less conclusive and assumptions must be made to determine the real effect.

Thermographic imaging inspections are a very effective service in detecting heat and determining acceptable operating conditions of plant and equipment. Its non-destructive/non-intrusive nature means that it is widely used within the electrical maintenance and installation industries.

Depending on the risk, exposure and type of plant and equipment routine, thermographic imaging inspections should take place at least every six months, or twelve months where there is a reduced risk.

2.3 Partial Discharge

Partial discharge (PD) is an electrical discharge event that occurs within the insulation of medium and high voltage electrical systems. They are the result of electrical breakdown of air pockets (voids) within the insulation. If allowed to continue, these discharges will eventually erode the insulation, resulting in insulation failure and probable equipment failure which is often catastrophic in nature. Cables, switchgear, transformers and motors/generators suffer the greatest losses from insulation failure.

PD Measurement

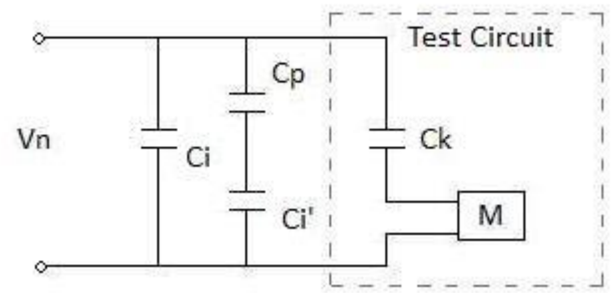


Figure 2.3 - Partial discharge equivalent circuit with test circuit

- Vn - voltage source
- Ci - capacitance of the insulation system
- Cp - capacitance of an air cavity in the insulation due to degradation
- Ci' - capacitance of the rest of the insulation around the air cavity
- Ck - capacitance of the coupling capacitor
- M - measuring system hooked up in series

At some inception voltage, the electromagnetic field is strong enough to bridge the void in the insulation and a partial discharge occurs. After the breakdown of the air gap, the rest of the insulation around the air cavity (Ci') now sees the full voltage Vn and therefore the charge across Ci' increases. This extra charge must be provided by all of the parallel capacitances around it (i.e. Ci and Ck) or the voltage source (though it is usually too slow to react). Therefore, the capacitances Ci and Ck discharge a short pulse into Ci' to provide the extra charge. In doing so, the voltage across all the capacitances reduces and the voltage source Vn reacts by charging all of the capacitances in the system (including the air cavity) back to the normal voltage Vn.

Partial discharge testing is done by directly measuring the short pulse discharged into Ci' by the coupling capacitor Ck. In the equivalent circuit, the measuring system is represented by a single box M, but in practice, this includes the coupling device, connecting cables, measuring device, etc.

It should be noted that any pulse measured by M is not the actual partial discharge, but an apparent charge caused by the discharge of Ck into Ci'. It is not possible to directly measure the partial discharge, but the apparent charges can be used to infer the level and frequency of partial discharge activity in the insulation system.

Offline Partial Discharge testing, as the name suggests, is carried out with the equipment out of service. It offers a significant advantage over other technologies because of its ability to measure the system’s response to a specific stress level and predict its future performance without causing a fault. Offline testing is also known for its ability to pinpoint the exact defect location on field-aged equipment, enabling the asset manager to accurately plan for maintenance and repair.

Online Partial Discharge testing is performed while the equipment is energized at normal operating voltages. The testing is conducted during real operating conditions, under typical temperature, voltage stresses, and vibration levels. It is a non-destructive test and unlike Offline testing, does not use over voltages that could adversely affect the equipment. Online Partial Discharge testing is relatively inexpensive compared to offline testing that requires interruption of service and production. For critical facilities that operate 24x7, this is the best solution for identifying insulation condition.

Data obtained through Partial Discharge Testing and Monitoring can provide critical information on the quality of insulation and its impact on overall equipment health. This is because partial discharge activity is often present well in advance of insulation failure.

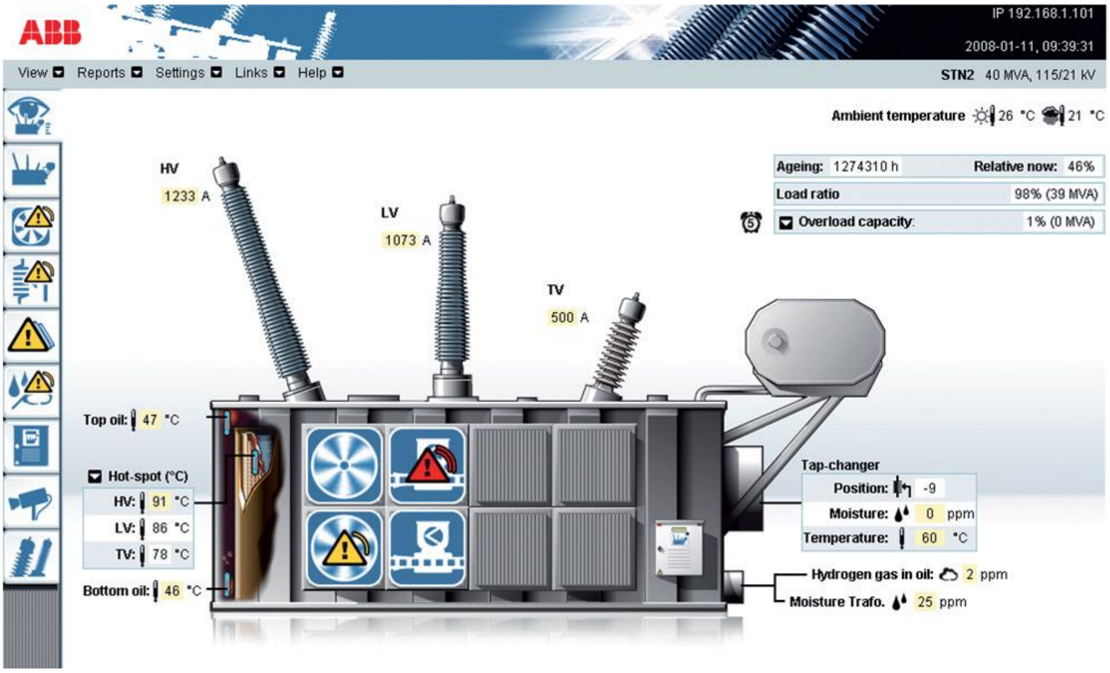
Partial discharge breakdown of insulation produces light, heat, smell, sound and electromagnetic waves. These characteristics are very useful, as it means that non-intrusive methods can be utilised for the detection and measurement of partial discharge. Indeed, most modern practical methods of partial discharge detection on switchgear involve the detection of sound (ultrasonics) and electromagnetic waves (Transient Earth Voltages (TEVs)). Both of these can be done from outside the equipment, are non-intrusive and do not require the integrity of the equipment to be compromised.

2.4 Proprietary/Vendor CM packages

ABB's TEC (Transformer Electronic Control) is a ‘bolt-on’ IED (Intelligent Electronic Device) module that provides total transformer monitoring. It converts data obtained from other IEDs and sensors into a user friendly online health status indicator. A model of the transformer and its working conditions is generated, and then by comparing the measured values with the parameters calculated by the model, the system is able to early detect malfunctions and discrepancies.

TEC has built-in monitoring of temperatures, currents and tap-changer parameters, including advanced thermal models for both the transformer and the tap-changer. These models do not only calculate hot-spot temperatures according to IEC and IEEE standards, but also model the complete thermal behaviour, allowing comparison between measured thermal behaviour and expected thermal behaviour.

The end customer has a single user friendly web interface for all the monitoring equipment as well as a single source for setup of protocol communication to SCADA systems. This is shown in the Figure 2.2 below.



IP 192.168.1.101
2008-01-11, 09:39:31
STN2 40 MVA, 115/21 kV
Ambient temperature 26 °C 21 °C
Ageing: 1274310 h
Relative now: 46%
Load ratio 98% (39 MVA)
Overload capacity: 1% (0 MVA)
HV 1233 A
LV 1073 A
TV 500 A
Top oil: 47 °C
Hot-spot (°C)
HV: 91 °C
LV: 86 °C
TV: 78 °C
Bottom oil: 46 °C
Tap-changer
Position: -9
Moisture: 0 ppm
Temperature: 60 °C
Hydrogen gas in oil: 2 ppm
Moisture Trafo. 25 ppm

Figure 2.4 - TEC web graphical user interface (GUI)

Chapter 3

CM PROGRAM DEVELOPMENT

3.1 System Overview

The ‘upstream’ portion of the Santos GLNG Project is currently comprised of two areas - Fairview and Roma. This is illustrated in Figure 1.1. The term upstream refers to the following:

- extraction of gas from the coal seams
- gathering of gas
- processing (compression) of gas at a compressor station or ‘hub’

It is then transported 420km, via the Gas Transmission Pipeline (GTP) to Gladstone, where it is converted to Liquid Natural Gas (LNG), before being exported to overseas markets.

It is important to note that the proposed condition monitoring program with which this dissertation is concerned applies to the plant and equipment in the upstream portion of the project. This is primarily due to the author of same being employed in the Upstream Operations business unit.

The power infrastructure in the management area consists of gas turbine electrical power generators located at the hub compressor stations (identified as F-HCS-04, F-HCS-05 and R-HCS-02). The power from these generators is distributed and reticulated from the hubs to electrical equipment at well sites (an 11kV electrical distribution system). In the Fairview area, 33 kV links between the hub compressor stations will be installed to facilitate sharing of spare generator capacity and also power the Fairview compressor station three(F-CS-03).

The 33kV systems are used for power transmission via overhead conductors from Fairview hub compressor station four (F-HCS-04) to Fairview hub compressor station five (F-HCS-05) and from Fairview hub compressor station four (F-HCS-04) to Fairview compressor station three (F-CS-03). The lines between compressor stations with generators are less critical than the compressor stations without generators. The compressor stations without generating capacity are dependent on electrical power being transmitted via the line and all the electrical driven equipment will cease to function if the line fails.

The 11kV systems are used for power distribution via overhead conductors from the compressor station to the well pads. The lines' architecture is a radial arrangement; similar to a tree structure with the main trunk branching out to individual well pads in the field, distributed over a relatively large area. When the line, or part of it fails, all the electrical driven equipment downstream of the failure will cease to function.

The assets consist of approximately 450km of electrical distribution lines in total (a combination of 11kV and 33kV lines). This electrical transmission infrastructure is constructed above ground with typically 12 to 14 m high poles, with a maximum height of 18m. Spacing between poles is typically 80 to 200m. Approximately 90% of the power lines are constructed in road and pipeline easements., with varying widths of between 10 and 25 m.

The electrical equipment is designed to operate continuously in the conditions particular to the location in which equipment is installed for the design life of the facilities. The minimum design life of major electrical equipment is 25 years. However, electricity infrastructure is subject to an array of weathering events, such as lightning strikes and vegetation interference, which may reduce its lifespan.

3.2 Methodology

The PdM equipment list and sampling frequencies will be selected by various methods at the various sites. The usual basis for selecting a machine for application of a particular PdM technology is:

1. Criticality
2. Machine type
3. Technology applicability and general effectiveness
4. Duty (0-100%).

The sampling frequency is set by the criticality and machine type. For example, the taking of oil samples from a large power transformer will occur more regularly than, say, a thermography scan on the contacts of an LV motor isolator. The reasons for this include:

1. The transformer is the source of power. Transformer failures can be catastrophic and may cause damage to ancillary equipment. It could also possibly mean the loss of supply to downstream equipment.
2. Time taken to replace/repair transformer far greater than simple module replacement of equipment such as an LV motor isolator module. Delivery lead time of new unit/spares may also be excessive.
3. Cost of replacement transformer can be in the millions of dollars and availability not guaranteed.

Where equipment or equipment type is subject to a Reliability Centred Maintenance (RCM) review, the application of PdM technologies should be determined by the Failure Modes of the equipment that are able to be mitigated by a PdM technology. That is, the RCM review should identify where a technology is to be applied, and the frequency at which the data is to be sampled. The application of PdM technology would then be based on:

1. Criticality of the equipment
2. Failure Mode to be mitigated
3. Whether the technology can be applied to mitigate the Failure Mode
4. Sampling frequency is set by the P-F interval and/or Mean Time Between Failure (MTBF) of the failure mode, modified by the duty of the equipment.

The Failure Mode is linked to the PdM activities with the Failure Modes Effects Analysis (FMEA) for equipment types subjected to a RCM review. This is to be maintained to enable the continuous improvement of the PdM programs. For instance, if a particular failure occurs that could have been detected and/or prevented by a PdM program active for that machine, the details from this failure can be reviewed against the original basis for application of the PdM technology and subsequent changes made. Such changes could also be applied across fleets.

Chapter 4

CRITICAL EQUIPMENT

Equipment considered for inclusion in the condition monitoring program will be predominantly primary plant. Primary plant is classed as all equipment which can be connected to HV levels (e.g. transformers, circuit breakers, isolators, motors etc.) and any equipment directly associated with the major plant (e.g. Buchholz relays on transformers, SF_6 gas pressure switches on circuit breakers etc.).

As with other essential components in the power system, the failure of primary plant quite often means that associated equipment and other infrastructure also sustain damage, or at the very least need to be taken out of service to repair the fault. Equipment outages such as these are undesirable. The costs involved in repairing damaged elements can be substantial and the time taken to return them back to service can be lengthy. The first step in mitigating this is the identification of critical equipment. For this project, the following has been identified for inclusion:

4.1 Transformers

Figure 4.1 - 11kV/33kV 16MVA YNd1 transformer

Figure 4.2 - 11kV/415V 2.5MVA Dyn11 transformer

These transformers are essentially distribution transformers. The larger units (16MVA) are used to step up the 11kV output from the Gas Turbine Alternators (GTAs) and supply the 33kV interconnect feeders that run between each of the gas processing plants. The 2.5MVA units are used to supply the plant Low Voltage (LV) reticulation systems (i.e. 240V/415V). These include administration buildings, workshops, plant lighting, LV Motor Control Centres (MCCs) etc.

4.2 HV switchgear (11kV & 33kV)

Figure 4.3 - 11kV Vacuum Circuit Breaker (VCB) board

Figure 4.4 - 11kV Vacuum Circuit Breaker (VCB) showing internal arrangement, including cable connection

Figure 4.5 - 33kV Gas Insulated Switchgear (GIS) board

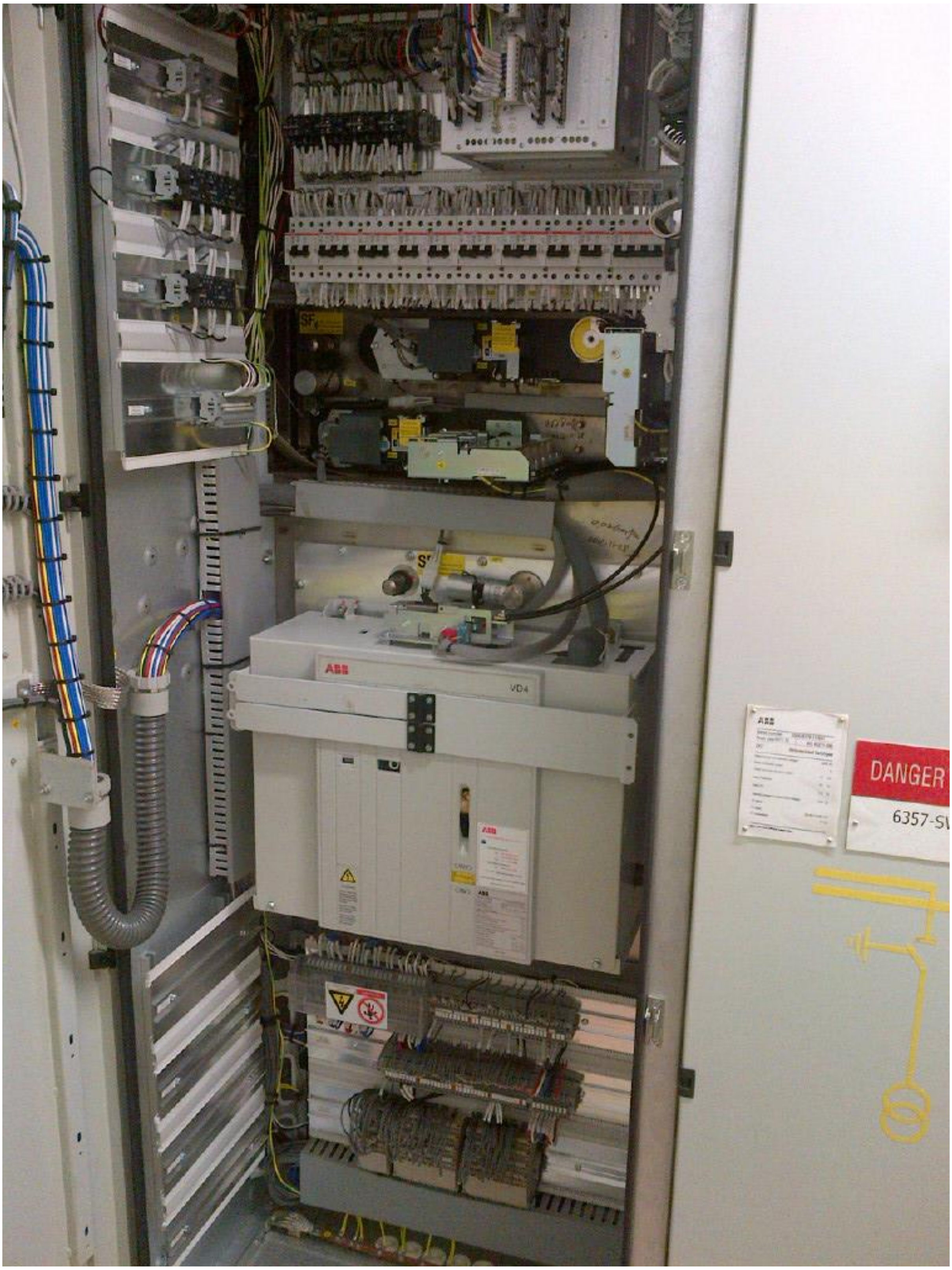


Figure 4.6 - 33kV Gas Insulated Switchgear (GIS) board showing internal arrangement

This switchgear is used for the 11kV reticulation systems within the plants and the 33kV interconnect feeders that run between the plants.

4.3 11kV electric motors

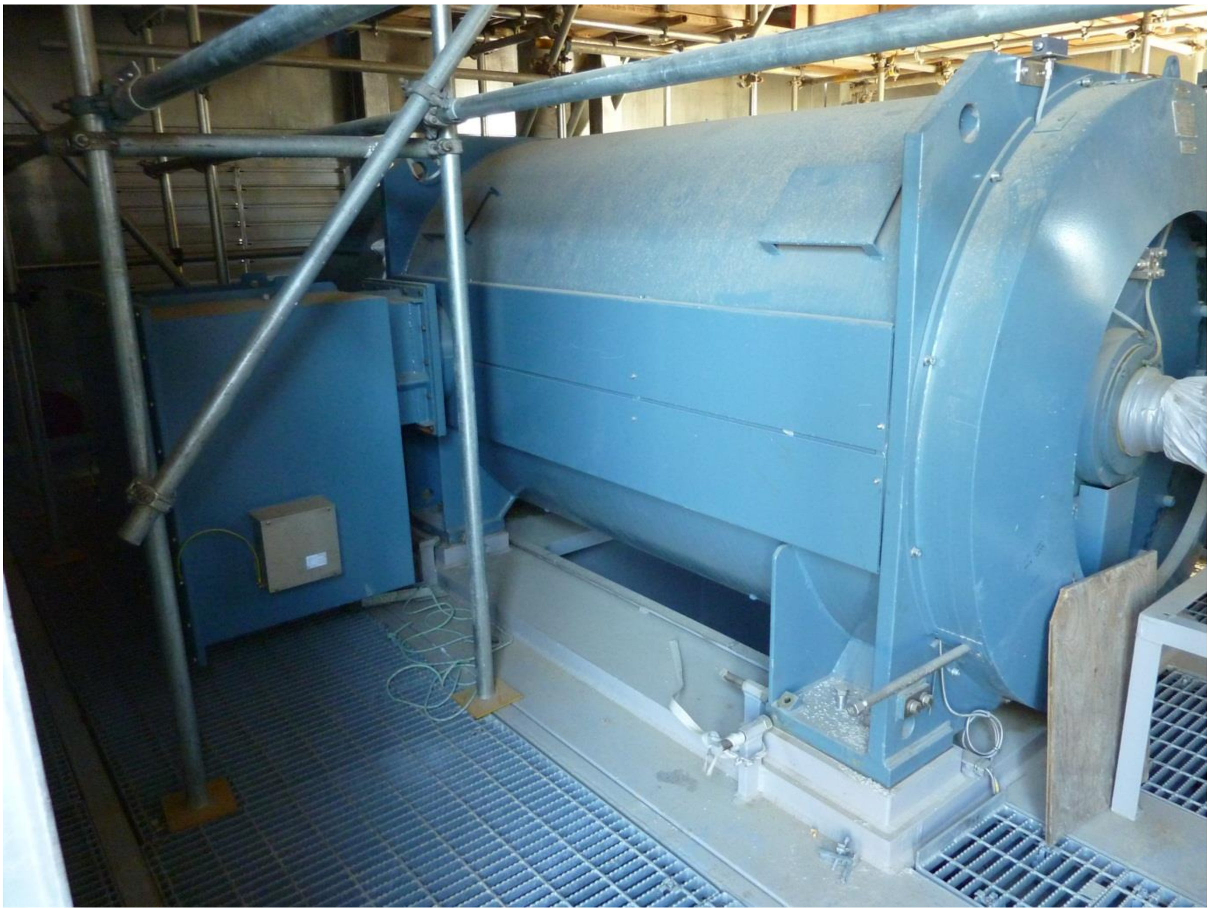


Figure 4.7 - 11kV 2.675MVA electric motor

These are the large three phase electric drive motors used to drive the gas screw compressor packages at each of the hubs.

4.4 Overhead transmission lines and pole top transformers

Figure 4.8 – Typical 11kV/415V pole top transformer installation

Chapter 5

CM STRATEGY

Table 5.1 – Condition Monitoring strategy

Equipment type	**Strategy Summary**
Transformers	
11kV/33kV 16MVA	Operator Essential Care (OEC) Annual thermography 12 monthly oil sampling DGA Partial Discharge (acoustic emission as a result of DGA) TEC (retrofit vendor module)
11kV/415V 2.5MVA	Operator Essential Care (OEC) Annual thermography 12 monthly oil sampling DGA
HV switchgear	
11kV VCB	Operator Essential Care (OEC) Annual thermography Partial Discharge (acoustic emission/ultrasonics) Protection relay interrogation
33kV GIS	Operator Essential Care (OEC) Partial Discharge (acoustic emission/ultrasonics) Protection relay interrogation
11kV electric motors	
11kV 2.675 MVA	Operator Essential Care (OEC) Annual thermography Partial Discharge (retrofit vendor module) Motor current analysis Vibration monitoring (existing Mechanical initiative)
OH transmission lines	
11kV & 33kV	Ongoing patrol and repair following faults Annual thermography 4 yearly offline check and overhaul if required, earthing checks
Pole top transformers	
11kV/415V (up to 500kVA)	Annual thermography 4 yearly offline check as part of line works

The selection methodology explained in Chapter 3 was used to identify the critical equipment for inclusion in the condition monitoring program. The applicable CM techniques reviewed and presented in Chapter 2 have been applied to the critical equipment, producing the CM strategy as shown in Table 5.1. The time intervals used in the strategy are based upon industry standards, previous equipment knowledge and vendor specific recommendations.

It is noticeable that Operator Essential Care (OEC) is a recurring CM activity in the strategy. OEC involves the use of the human senses i.e. sight, hearing, smell, touch, to not only assess the condition of equipment, but also identify potential emerging issues. It is the author's considered opinion that these are some of the simplest, yet most effective techniques for the condition assessment of plant and equipment. Indeed, it is well known in industry that an experienced and intuitive operator who knows their plant and can quickly detect abnormal conditions or developing failures is invaluable.

Chapter 6

ROLES, RESPONSIBILITIES AND RESOURCES

6.1 Roles and Responsibilities

This Research Project was work based and sponsored by my employer, Santos Ltd. As part of this, it was a stipulation that some work be carried out to identify the necessary roles, responsibilities and resources required for the implementation and ongoing administration of such a program. While this is not a technical component of the project, it is a fundamental starting point to one of the programme tasks listed in the Project Specification (Appendix A) i.e. develop workflows – so the data path is designed from machine to engineer to corrective action.

This is a complex process and requires all personnel to not only have role clarity for themselves, but also understand the roles and responsibilities of others in the process. This ensures a smooth workflow, promotes collaboration and increases awareness of who the subject matter experts are, thus saving time in the event of a fault or emergency situation. This is particularly important for third party personnel and/or providers who may not be in regular contact with permanent company personnel. An example of this may be an independent contractor providing thermography services.

The workflows are still being devised and drafted and will not be included in this dissertation. This is primarily due to the program being in its infancy stages, with the majority of roles not yet fully defined, recruited for or filled. Along with this is the training requirements; the gaining of new skills and competencies that will enable personnel to carry out the duties required of a condition monitoring technician or professional. As can be appreciated, this piece of work takes considerable time, firstly to organise and then to facilitate using either in-house resources, a vendor who has supplied the particular equipment or a third party recognised training provider.

The following roles and their responsibilities are deemed the necessary minimum for the proposed condition monitoring program. A summary table is also included in Appendix B.

Program Owner

The program owner is responsible for implementing and administering the CM program for the technology they represent.

Responsibilities:

- Acts as Santos specialist for the PdM technology
- Responsible for monitoring developments in technology
- Implement program and be first point of contact for equipment performance and general program related issues
- Liaise with assets to ensure that data collection is conducted as scheduled and to sufficient quality
- Develop reports for their technology
- Set training requirements for their PdM for all who need to be involved or aware of the program
- Develop plans to achieve desired practice in their technology
- Maintain and update Condition Monitoring (PdM) Strategy document
- Demonstrate benefits to customers through value engineering.

Principal Engineer

The Principal Engineer is the subject matter expert and technical authority for their particular field of engineering.

Responsibilities:

- Advise on specific technical problems arising from CM program
- Review new technologies for implementation
- Maintain an overview of PdM results in their area of expertise
- Advise program managers on specific scopes, coverage of PdM for their area of fleet responsibility
- Maintain and update Condition Monitoring (PdM) Strategy document.

Condition Monitoring Reliability Engineer

Co-ordinates the continuing development of the CM program, and advises Program Owners on strategy development and data management. They may also be the Program Owner.

Responsibilities:

- Maintaining and tracking PdM improvement plans
- Co-ordinating with Program Owners, reporting requirements
- Developing the best method for integrating PdM program into Strategy Management System
- Auditing PdM programs and identifying improvements
- Managing introduction of new technologies
- Measuring effectiveness of programs and working with Program Owners to maximise
- Maintain and update Condition Monitoring (PdM) Strategy document.

Asset Reliability Engineer

The Asset Reliability Engineer is responsible for the implementation and governance of the CM program by Asset type.

Responsibilities:

- Act as a site-focussed point of contact for resolution of technical problems
- Ensure CM program in their area is up to date in terms of equipment to be surveyed and if it is not, understand the risks
- Review PdM status summary reports on a regular basis to enable governance of the PdM program
- Report on program use via KPIs at Asset Governance Forums and seek rectification actions on variances
- Collection of data to determine effectiveness of the PdM Program
- Steward the work selection prioritisation of work orders arising from the PdM program to ensure action is taken in the recommended timeframe. Timeframes will be based upon estimated time to failure.
- Ensure data collection is executed through stewardship of compliance reports

- Ensure any program roadblocks are identified and acted upon, escalating if appropriate.

Maintenance Supervisors

Usually field-based personnel, the Maintenance Supervisors are responsible for tradespeople and operators and all maintenance activities carried out by those resources.

Responsibilities:

- Provide a list of names of maintenance personnel to be trained, arrange coverage for them, and maintain development plans for PdM training for their personnel
- Provide resources for PdM programs such as VA, FA
- Ensure PdM site activities (data collection and corrective actions) are carried out within reasonable timeframe.

Program Technician/Engineer

The Program Technician is responsible for analysing and sometimes collecting PdM data for their technology. They are responsible for generating corrective actions from their analysis. They may also be the Program Owner.

Responsibilities:

- Analyse results and create actions
- Enter corrective actions in CMMS system
- Produce reports resulting from analysis
- Provide training to data collectors.

External Service Provider

An External Service Provider may be engaged to collect data, analyse and/or report on results as part of an existing PdM program if there is a resource shortfall in that program or specialist skills are required. They may also supply specialist training.

Responsibilities:

- Collect PdM data, analyse and/or report as required
- Make recommendations to the Program Technician/Engineer that could be translated into corrective actions
- Conduct formal, specialised PdM training.

6.2 Resources

Broadly speaking, the options for manual routine collection of CM data at any site are:

- External consultant or specialist engaged to collect data
- Dedicated PdM resource from within the Operations Group, or the relevant program ownership group
- Local Asset-based resources. With this group, a further 3 options exist:
  - Single resource only allocated to PdM data collection (champion)
  - Selected resources (2-3 personnel) per shift trained to conduct PdM data collection
  - All personnel trained to collect PdM data and allocated to the task on a rotational basis.

The data collection resource will vary depending on the qualification requirements of the CM program (e.g. the Thermography program), or the complexity and conditions of individual sites (e.g. the Oil Analysis program). The data collection resource will be negotiated between the Program Owner and the Asset Team Leader to establish the best option for the business.

The Program Owner will determine the training requirements for personnel involved or required to perform functions in the CM program. They will also be responsible for the selection of training sources for the delivery of courses.

Chapter 7

CONCLUSION

7.1 Project summary

This project seeks to implement a condition monitoring program for High Voltage (HV) assets for the Santos GLNG Project.

A literature review was conducted in order to research current CM technologies applicable to HV plant and equipment. From this, identified techniques were evaluated to determine those most applicable and/or suitable for use in this particular application. A selection methodology was then used to identify critical equipment for inclusion in the condition monitoring program. All of this resulted in the development of a CM strategy which is intended to be implemented in a CM program when the project is fully operational.

It should be noted that on-line condition monitoring is the preferred mode. It's non-destructive and non-intrusive nature, coupled with the advantages of maintaining unit availability and minimal human involvement and/or interaction make it a very appealing option from an economic and most important safety perspective.

The logistics of implementing such a program are complex, particularly around the areas of processes, personnel and training. As part of the agreement of undertaking this work based project, roles, responsibilities and resources have been clearly defined. This will aid in the identification of workforce numbers, provide role clarity and responsibilities and identify knowledge gaps and the subsequent training required to increase knowledge and gain the required competencies.

7.2 Further work

Further investigation into the possible retrofitting of vendor specific IED modules such as TEC for transformers and MACHsense for electric motors is required. These units serve as a 'single source of truth', performing calculations and analysis on operating parameters such as temperature, voltage, current, pressure etc. to give an indication of overall equipment health.

APPENDIX A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111 / ENG4112 Research Project Part 1 and 2
PROJECT SPECIFICATION

FOR: **CHRIS LANIGAN**

TOPIC: Implementation of a condition monitoring program for High Voltage (HV) assets for the Santos GLNG Project.

SUPERVISORS: Dr Nolan Caliao
Nathan Robertson, Santos Ltd.

ENROLMENT: ENG4111 – S1, Ext, 2013
ENG4112 – S2, Ext, 2013

PROJECT AIM: To develop a condition monitoring program for HV assets and investigate/illustrate the effects such a program has on improving equipment reliability and associated availability.

SPONSORSHIP: Santos Ltd.

PROGRAMME: **Issue A, 13th March 2013**

1. Research current condition monitoring technologies used for HV plant and equipment;
2. Identify critical plant and equipment to be included in program;
3. Critically evaluate condition monitoring technologies and determine those applicable to identified assets;
4. Compare off-line to on-line condition monitoring and the advantages/disadvantages of each;
5. Develop workflows – so the data path is designed from machine to engineer to corrective action;
6. Submit an academic dissertation on the research.

As time permits:

7. Quantitative analysis (e.g. financial) of employing equipment condition monitoring vs. not employing.

AGREED:

_______________ (Student) _______________ , _______________ (Supervisors)

___ / ___ / ___ ___ / ___ / ___ ___ / ___ / ___

APPENDIX B – Roles, Responsibilities and Resources

Role	**Responsibilities**	**Vibration Analysis**	**Fluid Analysis**	**Thermography**	**Partial Discharge Testing**
Program Owner	Manage program – routes, frequency of data collection, equipment to be monitored, set alerts, reporting to asset governance.	Condition Monitoring Reliability Engineer	Lubrication - Condition Monitoring Reliability Engineer (Elec Equipment – Principal P&CS Reliability Engineer)	Principal P&CS Reliability Engineer	Principal P&CS Reliability Engineer
Program stewardship for each Asset Area	Overview and stewardship of equipment, training needs met, rounds completion and compliance, actions arising from Condition Monitoring are ranked and acted upon.	Asset Reliability Engineer	Asset Reliability Engineer	Asset Reliability Engineer	Asset Reliability Engineer
Data collection	Collect equipment condition data, samples. Carry out data collection to pre-defined routes. Upload to host data system (e.g. AMS suite)	VA Technicians Trained Santos maintenance personnel	Varies by site but typically trained maint techs, plant operators, production operators	Thermography technician	Specialist Service Provider (e.g. ABB)
	Allocation of personnel to collect data.	Maintenance supervisor	Maintenance supervisor	Principal P&CS Reliability Engineer	
Equipment specification data for the program	Provide equipment specific information such as type, power, bearing information, rotating components information etc.	Asset Reliability Engineers – as needs basis	Lubrication Reliability Engineer	Thermography technician	Specialist Service Provider

Role	**Responsibilities**	**Vibration Analysis**	**Fluid Analysis**	**Thermography**	**Partial Discharge Testing**
Reporting	Report on equipment condition – acceptable, marginal, and unknown. Tracking of overdue actions. Health of program – compliance, roll out.	Condition Monitoring Reliability Engineer	Lubrication Reliability Engineer	Thermography technician	Data analysis and report preparation by Specialist Service Provider
	Reporting to asset governance forums.	Asset Reliability Engineers	Asset Reliability Engineers	Asset Reliability Engineers	TBA
Training	Set training requirements and arrange training for practitioners and recipients of information.	Training requirements, arrange or run training sessions - Condition Monitoring Reliability Engineer Nomination of personnel to be trained, coverage, development plans – Maintenance supervisors	Training requirements, arrange or run training sessions -Lubrication Reliability Engineer Nomination of personnel to be trained, coverage, development plans – Maintenance &/or Operations supervisors, depending on which teams are taking samples	Principal P&CS Reliability Engineer	Not Required

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