School of Mechanical, Industrial and Aeronautical Engineering

An investigation into the Impact of emphasis on profitability and security of electricity supply as compared to Total Asset Management in a Power Plant

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the Masters in Engineering Degree to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University

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ABSTRACT

Asset owners are faced with the challenge of making operational decisions that are consistent with strategic objectives of the company. Staying in the forefront of Asset Management to optimize long term profitability and sustainability often have conflicting objectives and more so for an ageing asset. In 2008, South Africans saw the highest load shedding events ever experienced in the country as the power utility, Eskom cut electricity supply to houses. The government, in its bid to ensure a year-on-year economic activity, decided to operate assets in the power Industry to their maximum capacity while waiting for new capacity that will be provided by the new built Power Plants to be commissioned. Balancing conflicting objectives of Total Asset Care is a challenge in itself for asset managers, adding an Asset Management environment where profitability and reducing the risk of load shedding in the short term takes precedence over Total Asset Care, adds a totally new dimension.

The objective of the research was to investigate, using a single case study, the impact of a focus of ensuring security of electricity supply to the National Grid or profitability as opposed to Total Asset Management in a Power Plant. A single case study with embedded units was used for the research. The study was considered within the context of the Asset Management strategy used in the Power Plant under study and the environment in which it operates. Literature review revealed that the Power Utility adopted PAS 55, currently considered as the best practice in Asset Management in industry, in 2010. Following this, the subject of the research is to investigate the actual Asset Management practices, dictated by operational indicators as compared to the Power Utility Asset Management Requirements and thus PAS 55.

Power Plant Key Performance Indicators (KPI's) were used as the central focus of the analysis section. This is because KPI's not only gives information about the performance of the Power Plant; it also indicates the means of achieving such a performance. 17 year operational data from the Power Plant was used in the analysis. The data was collected from archiving systems in the Power Plant. The data collected included information about operations, availability, reliability, risk management, asset renewal, asset configurations and modification. Analysis of data employed both qualitative and quantitative techniques. The objective of the analysis was to use KPI's to determine how asset managers in such power utilities manage conflicting objectives of short-term performance and long term sustainability, asset utilization and asset care, capital investment and operating cost in the light of current electricity capacity challenges in South Africa.

The analysis showed that the performance of the Power Plant regarding availability is amongst the best in the world. The availability average is above 90% as compared to an average industry figure

of 83%. The load factor is also very high, with an average of 77% as compared to the industry average of 64%. This particular Power Station under study is used for grid frequency regulation. In summary, the analysis highlighted that the asset is operated at higher utilization factors, higher load factors close to operating limits and with limited maintenance opportunities. The key finding in the investigation is that prior 2001, the Power plant built a considerable maintenance backlog and it has not been able to recover from that. The plant started showing signs of distress from having limited maintenance opportunities after that. The distress was further exercebated by a decrease in reserve margins. In addition, the asset is not renewed timeously (to make it more available, instead of taking it down for replacements) and all systems supporting Asset Management are showing signs of deterioration. The current high asset availability levels, as indicated by the analysis might be giving a false sense of security to customers, regulators and investors in South Africa, however the current means of achieving good production performances are not sustainable.

The impact of the current asset care regime will eventually lead to premature plant deterioration and the signs are already visible as shown by the incident management system. The current environment is a breeding ground for creation of future problems about premature asset deterioration in an effort to obtain short term gains. This means that by the time new built capacity is commissioned, the current assets might not be able to sustain current production levels because of deterioration. This will lead to a situation where this new capacity will not serve the intended purpose of relieving current shortages but compensate for losses resulting from deteriorating assets. This will eventually lead to a condition where the country will remain in a state of lack until something drastic is done e.g. building a number of high capacity nuclear plants.

A focus on Total Asset Management on the other hand inherently takes care of long term sustainability of production levels. The analysis of the data shows that even though the power utility has adopted the best practices in Asset Management currently available in the market i.e. PAS 55, asset operational data paints a different picture. This is attributed to the fact that the day-to-day running of the plant contradicts the strategic objectives of the utility i.e. the line of sight between strategy and operation is blurred. An Asset Management system that does not support the strategic objectives of the organization is fruitless. The recommendation was that the utility reviews the appropriateness of its Asset Management strategy taking into account, the current status of the asset, operational environment and all supporting systems with the objective of aligning to world best practice. Currently the world best practice in Asset Management is PAS 55. Adoption of the standard without operational proof of adherence and certification is not sufficient. Adherence to the standard and certification on the other hand gives assurance to all stakeholders that the asset will deliver personnel safety, environmental safety, profit, security of supply as well as positive public opinion.

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LIST OF ABBREVIATION AND DEFINITIONS

DME: Department of minerals and Energy.
GDP: Growth Domestic Product.
ESKOM: Electricity Commission of South Africa.
AM: Asset Management.
PMB: Project Management Based.
SBM: Systems-Based Methods.
DSS: Decision Support System.
BRICS: Brazil, Russia, India, China, South Africa.
BSI: British Standard Institute.
PAS: Publicly Available Specifications.
KPI: Key Performance Indicators.
WEC: World Energy Council.
EAF: Energy Availability Factor.
UCF: Unit Capability Factor.
UCLF: Unplanned Capability Loss Factor.
PCLF: Planned Capability Loss Factor.
OCLF: Other Capability Loss Factor.
SSR: Successful start-up rate.
MCR: Maximum Continous rating.
UAGS: Unplanned Automatic Grid Separation.
GLF: Generation loss factor.
SADC: South African Development Community.
SAPP: Southern African Power Pool.
NERSA: National Energy Regulator of South Africa.
HMI: Human Machine Interface.
PLC: Programmable logic controller.
DCS: Distributed Control Systems.
HP: High Pressure.
IP: Intermediate Pressure.
LP: Low pressure.
MW: Megawatt.
UNIPEDE: the International Union of Producers and Distributors of Electrical Energy.
IEEE: Institute of Electrical and Electronics Engineers.
NERC: North American Electric Reliability Corporation.
EUROELECTRIC: The Union of Electricity Industry in Europe.
UF: Utilization Factor.
UMS: Utility Asset Management.
NARUC: National Association of Regulatory Utility Commissioners.
BU: Business Units
SAIIA: South African Institute on Internal Affairs
ICA: The infrastructure Consortium for Africa
C&I : Control and Instrumentation
OEM : Original Equipment Manufacturer
MRM: Management Review Meeting
EE : Electronic & Electrical

Power Utility/Utility in this document refers to the organization that operates and owns the Power Plant (asset) being studied. The nature of the utility is that it operates a number of similar assets known as Business Units

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1. INTRODUCTION

1.1. Background

Asset owners are faced with the challenge of making operational decisions that are consistent with strategic objectives of the company. The asset owner is the person or group of people who have been identified by management as having responsibility for the maintenance of the confidentiality, availability and integrity of that asset. The asset owner may change during the lifecycle of the asset (ISO 17799, 2000). More and more asset owners are expected by stakeholders to make decisions that are repeatable, transparent and competent in the context of environments in which they operate (Doloi & Jaafari, 2006).

Staying in the forefront of Asset Management to optimize long term profitability and sustaining the current production levels to ensure security of supply often have conflicting objectives and more so for an ageing asset. Conflicting objectives such as long versus short term benefits, expenditure versus performance, planned versus unplanned downtime as well as capital versus operating expenditure have to be managed on a daily basis (BSI PAS 55, 2008). Furthermore, the asset in its nature is complex integrating different disciplines including technical and management issues (Sun, et al. 2008).

When such a physical asset is operated in an environment where good Asset Management practices are secondary to profitability and security of electricity supply, asset care is compromised. Good Asset Management practices seeks to optimize long term returns on investment on the asset without compromising some aspects of asset care for short term benefits (BSI PAS 55, 2008). Realizing considerable profit margin in the short term is always tempting for many organisations however this temptation threatens the very core of Asset Management. Failure to manage the asset in a manner that balances short term benefits and sustainability of the asset over its life-cycle will ultimately results is considerable losses for the organisation. The research report investigates the impact of emphasis on profitability and guaranteeing security of power supply to the National Grid as compared with total Asset Management in a Power Plant.

1.2. Problem Statement

Availability of reliable electricity supply is a pillar of contemporary economies in any developing and developed countries (Vaccaro, et al, np). Security of supply and thus healthy electricity reserve margins are particularly important for developing countries such a Brazil, Russia and India. This is required in order to sustain the required year-on-year GDP growth. Through their research to investigate the relationship between cycles of electric power and the economic growth in China based on Maximum Entropy Method, Yong, et al (2006) showed that electricity investment is the Granger Causality of both GDP and installed electricity capacity. This implies that electricity investment can be used to predict both electricity capacity and GDP in the future. In Economics, the word *x (t)* is Granger causal for *y (t)* if *x (t)* helps predict *y (t)* at some stage in the future (Sorensen, 2005, page 2).

South Africa, as one of the notable emerging economies is no different to other BRICS countries. BRICS is an international political organisation of leading emerging market countries consisting of Brazil, Russia, India, China and South Africa, which are all deemed to be at a similar stage of newly advanced economic development(SAIIA, 2010). Electricity consumption in South Africa has been increasing at a high rate to keep up with growth while putting a lot of strain on dwindling reserve margins. Electricity investment and hence management of electricity infrastructure will determine if South Africa will be able to keep up with the required growth (Newbery at al, 2008).

In 2008, South Africans saw the highest load shedding events ever experienced in the country as the power utility, Eskom cut electricity supply to houses in a bid to ensure stability of the national grid. The Industrial sector was also not spared power cuts as several mines and manufacturing companies had to reduce production to assist with stabilizing the national grid. Investors showed concern over the ability of the country to deliver sufficient power. In its detailed reply to the public " National response to South Africa's Electricity Shortage" regarding the load shedding, the department of mineral and energy (DME, 2008) compiled a report highlighting interventions being taken by all stakeholders involved in electricity generation, transmission and distribution, to ensure that the risk of load-shedding is reduced.

The report highlighted the state of electricity reserve margins in South Africa including the strategy the DME was adopting to lower the risk of load shedding in the short term. The electricity consumption and demand was increasing at 4.3 % and 4.9% year-on-year for off-peak and peak period periods respectively. This resulted in electricity margins declining beyond a minimum requirement of 15%. Reserve margin is the amount of unused available capability of an electric power system at peak load for a utility system as a percentage of total capability. This is required to ensure reliability and security of supply in case of capacity disturbances. Moreover it allows for some generating units to be taken out of service for maintenance without increasing the risk of load shedding. Reserve Margins deteriorated continually from 25% in 2002 to between 8-10% in 2008 and are still decreasing (DME, 2008). These margins are significantly less compared to Asian countries like Malaysia, Thailand and Indonesia with reserve margins of 45%, 25%, and 26 % respectively (Malaysia Today online, 2011).

Dwindling reserve margins have significantly increased the risk of National Grid collapse and hence load shedding. According to the report by DME (2008) if the national grid were to collapse due to supply interruptions it would take at least days or even week to restore. Following this, among other strategies, the report highlights that operating assets (generating plant) at high load factors and reducing planned maintenance opportunities for these assets will be adopted.

The strategy adopted by DME since the 2008 has essentially placed stability of the grid and reduction of risk of load shedding above good Asset Management practices. While this might lower the risk of load shedding in the short term it significantly threatens long term security of supply thus increases the risk in the long term. In an organisation where a physical asset such as a Power Plant is central to the organisation achieving its business goal, a sound Asset Management strategy is critical. Amongst others, sustainability is a key factor of a good Asset Management strategy. Failure to address issues of sustainability with strategies being adopted puts the organization strategic objectives at risk.

1.3. Classification of the asset

The asset is a fossil-fuel power generation plant supplying electricity to the National Grid in South Africa. The combined units are designed to generate approximately 4000 MW. The asset has a total of six boiler-turbine sets operated independently from each control room. In the control room, unit operators have the ability to control and monitor the process remotely by a Human Machine Interface (HMI). The entire process is controlled and monitored by Distributed Control Systems and Programmable Logic Controllers (PLC's). The asset belongs to a power utility that has a number of assets in their portfolio. Similar assets have the same Asset Management strategy which is managed centrally. Each power station is then responsible to adopt and utilize centralised business processes locally. Figure 2 shows the general arrangement a Power Plant.

1.2.1 Primary Energy

The asset is fired with low quality coal having a calorific value of approximately 17.5 – 21.0 MJ/Kg and an ash content of about 32 % to 40%. The fuel is transported from the mine using overland conveyor belts through coal stock-yard to coal bunkers in the boilers. Coal transport and stock yard forms an integral part of the entire process.

1.2.2 Water

The asset consumes less than 0.2 l/kWh. The significantly less water consumption as compared to similar plants with an average consumption rate of 2.5 l/kWh is attributed to the cooling mechanism. The asset is dry cooled using atmospheric air where there is no direct contact between the cooler (air) and the coolant (water)

1.2.3 Combustion

For combustion to occur in the boiler coal, air and ignition fuel are required. Coal is pulverised using the milling plant to increase the total surface area for combustion. Force draught fans are used to add secondary air into the boiler for combustion. The combustion process produces coarse and fine ash. Coarse ash collects at the bottom of the boiler and conveyed to the dump. Fine ash is carried by flue gas which is cleaned using electrostatics to capture the ash particles. After the cleaning the fine is collected and conveyed to the ash dump.

1.2.4 Boiler

The boiler consists of hundreds of steel piping and is used to convert chemical energy in coal to thermal energy in a form of steam which is required by the turbine. Water circulates inside the steel piping that absorbs heat produced by combustion through conduction and convection. Water is supplied to the boiler using three boiler feed pumps each with 50% capability. During emergency situations each pump is able to supply 429 litre of water per second at speeds of about 5 862 r/min. The Water is pre-heated to 247 °C using LP and Hp heaters before it enters in to the boiler. The Maximum Continuous rating of the each boiler is 577 kg/s with super-heated steam temperature and pressure of 540 °C and 17.24 MPa respectively. The boiler uses a reheater and has an ability to bypass 100% of its steam via the bypass facility

1.2.5 Turbine

The asset uses the tandem compound reaction type turbines. Each turbine train has a High pressure (HP), Intermediate pressure (IP) and Low pressure (LP) turbines .The turbines are connected to the same shaft. The HP turbine has a single flow while the IP and LP turbines have a double flow. Steam from the boiler enters the turbine via the stop and governor valves. The turbine converts thermal energy in steam to mechanical energy. Steam enters the turbine at pressures and temperature of 16.1 MPa and 540 °C for HP turbine and 3.89 MPa and 540°C for IP turbine respectively. After the steam is used in the turbine it is condensed and re-used in the process. The cooling water used in the condenser is pumped from the cooling towers using two cooling water pumps each with a capacity of 50%. The cooling water is cooled via the cooling towers using an indirect dry cooling system.

1.2.6 Generator

The maximum output of each generator is 729 MW with a power factor of 0.9 at full load and a terminal voltage of 22 kV at 50 Hz. The optimised maximum continuous rating (MCR) is 686. From the 686 MW an approximated 46 MW is used to power the plant auxiliaries. The generator is hydrogen cooled. The output of the generator is connected to the National Grid via a 400 kV breaker.

1.4. Hypothesis

By conducting a single case study on a Power Plant in South Africa, which is perceived to be driven by profitability and security of electricity supply the following hypothesis can be tested.

- A focus on Total Asset Management inherently ensures sustainable profitability and asset performance over the useful life of the asset.
- A reduction of the risk of load shedding by reducing maintenance opportunities and operating the asset at high load factors is not sustainable.

1.5. Research questions

The following research will answer basic questions relating to the state Asset Management at the reference plant:

1. What is the long-term impact of focusing on profitability and security of supply instead of total Asset Management for a Power Plant that effectively depends of physical assets to achieve their business goals?
2. How does Asset Management information of a profit driven organisation compare with global best practices in Asset Management?

1.6. Objectives

The objective of the research is to conduct a single case study on a fossil powered plant by performing the following:

- Investigating different Asset Management methods/policies in the power industry.
- Investigating the Asset Management regime adopted by the Power Plant under study.
- Analysing key performance indicators for the Power Plant. Key performance indicators give information about the performance of the Power Plant and the means of achieving such a performance. The means of achieving performance gives an indication of the state of Asset Management and the principles applied thereof.
- Benchmarking the state of Asset Management of the Power Plant with Similar Plants around the world.
- Concluding on the state of Asset Management at the Power Plant.
- Making recommendation on how Asset Management at the plant can be improved,

1.7. Synopsis of methodology

The research methodology to employ in the report is a combination of quantitative and qualitative analysis. The research approach was to compare planned Asset Management regime as opposed to the actual Asset Management regime and make recommendations to reduce the deviation. Moreover the analysis compares the current Plant Asset Management Philosophy at the Power Plant with world best practice and makes relevant recommendation. Refer to figure 1.

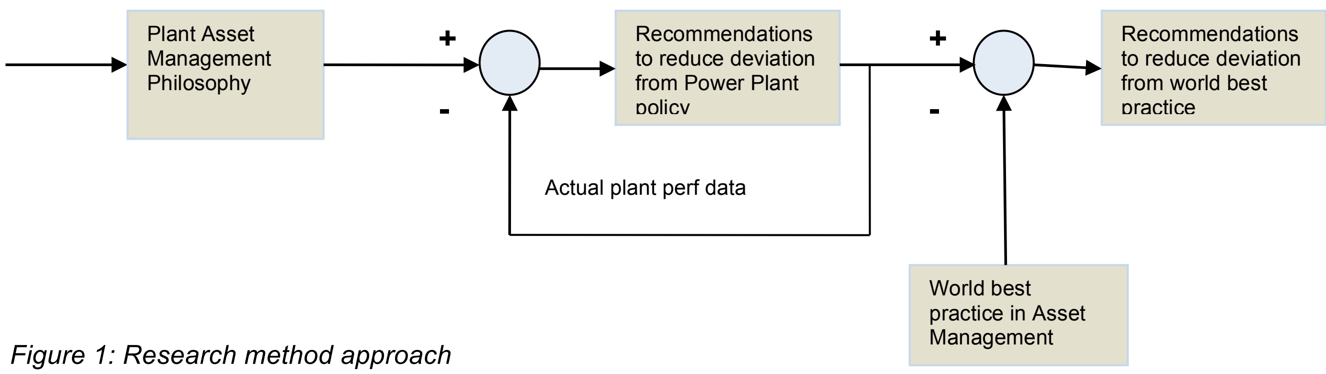


Figure 1: Research method approach

Plant Asset Management philosophy is provided by the existing Asset Management System at the Power Plant. Actual Asset Management Regime is indicated by actual performance data from computerised systems as dictated by the Key Performance indicators. In a case where the Power Plant has not adopted world best Asset Management Policies as per world standards (currently PAS 55), additional recommendation will be made to reduce the deviation.

1.8. Assumptions, Constrains and limitations

The asset owner allowed this study to proceed provided no references are made to the power utility or its employees. Because of this, acknowledgements of people who contributed to the report cannot be made. The data that was utilised for the analysis was obtained from computerised systems. In some cases, relevant data was not available because of different reasons given by the Power Plant. This also applies to benchmarking information from worldwide database system provided by World Energy Council. In general, the analysis was performed within the limits of data available from the Power Utility and WEC database. The study had to extensively depend on quantitative analysis even though in some cases, where the information collected was insufficient to make conclusions, qualitative research method, in the form of interviews would have assisted to drive a point across. The scope of the study will only cover aspects of physical Asset Management excluding related human assets.

1.9. Chapter outline

The objective of chapter 1 was to systematically formulate the problem to be addressed by this research report. It gives the background of the problem, problem statement, and description of the asset under study, hypothesis, research questions and objectives. The chapter also briefly outlines the research approach to be followed in the report.

2. LITERATURE REVIEW

The primary purpose of an Asset Management System is a sustainable asset performance over the lifetime of the asset. The performance in considered within the boundaries of statutory requirements of occupational health and safety, technical regulations regarding the asset as well as environmental requirements. The literature review is divided into four sections. The first section gives an overview of the industry and context in which the asset is operated. The second section gives an overview of the asset and the current management regime. The third and fourth sections outline the performance indicators that will be used to evaluate the performance of asset.

2.1 Introduction to Asset Management

An asset is a plant, machinery, property, buildings, vehicles and other items and related systems that have a distinct and quantifiable business function or service (BSI PAS 55-1, 2008). Asset Management is then defined as a systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets, and their associated performance, risks, and expenditures over their lifecycles for the purpose of achieving its organisational strategic plan (BSI PAS 55-1, 2008). The objective of Asset Management is to ensure that asset owners get value for money over the lifecycle of the asset by ensuring reliable operation, sustainable operation, renewal of the asset, safe operation of the asset and cost effectiveness amongst others.

In industry, assets vary according to their level of complexity. Mostly, industrial assets are complex, interdisciplinary and long term based. The assets depreciate and degrade over time requiring renewal/ replacement in order to reach end of life profitably. Furthermore failure of the asset during its active operating life often leads to extreme consequences. In the power industry for instance, failure of critical assets in generation, transmission and distribution may lead to load shedding and in extreme cases collapse of the national grid which leads to a total black-out. On December 27 1983 (Evert Agneholm, 1996) a disconnecting switch in a 400 kV substation near Enköping, Sweden failed due to overheating. This caused the substation's busbar protection to trip all circuit breakers, then most of the 400 kV lines carrying hydro power from northern Sweden were disconnected and the few remaining lines tripped due to overload within a few minutes. As a result, mains frequency and voltage rose in northern Sweden until safety systems tripped most of the generating equipment. On the contrary, southern Sweden suffered from sinking voltage and frequency until most equipment tripped there. For a short time, the whole country except parts supplied by small independent utilities, suffered from the blackout. It took up to 24 hours to restore full service because most of the nuclear power stations were emergency stopped and needed several hours to restart. A good Asset Management philosophy is proactive in determining asset deficiencies that have adverse negative impact on production and National Grid Stability. Using a good Asset Management approach such incidents can be prevented

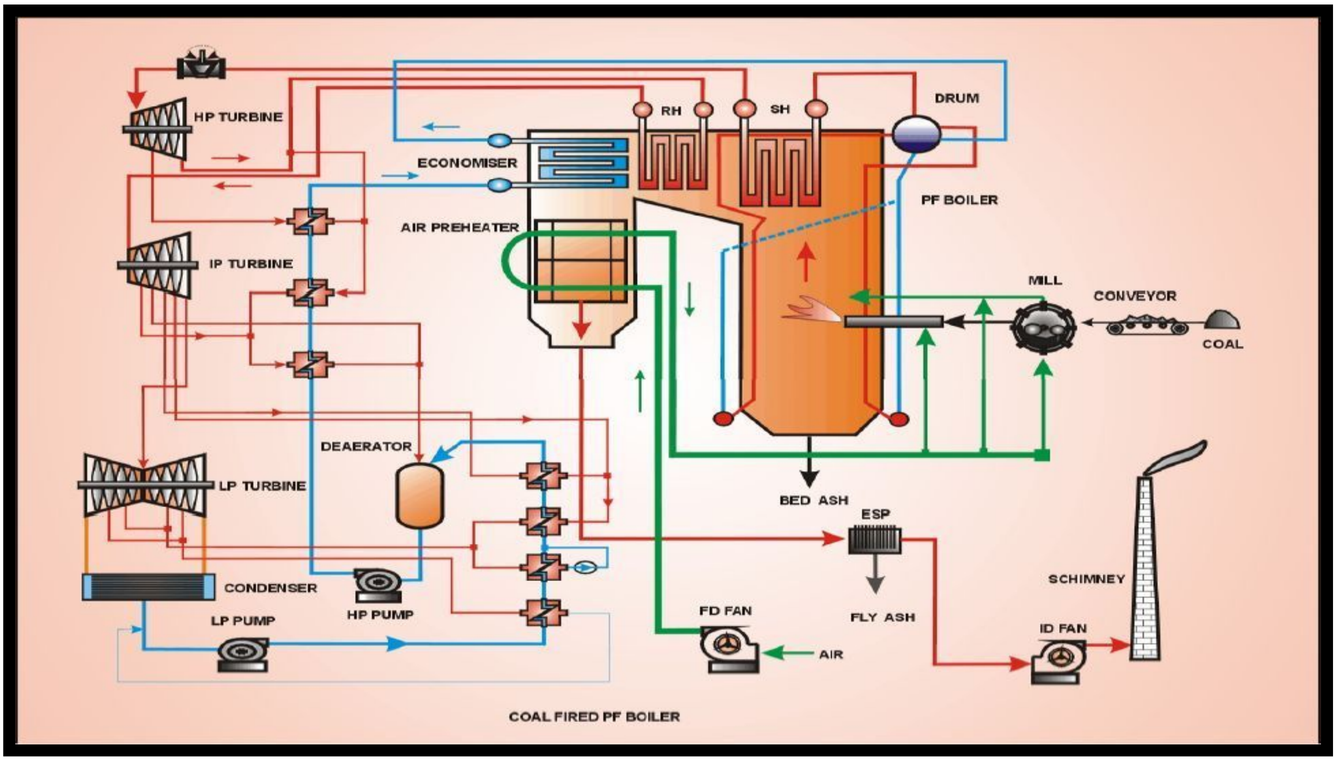


Figure 2: Coal Fired Power Plant Schematic (PSE Consulting, 1997)

Electricity infrastructure includes assets for generating, transmitting and distributing electricity. Figure 2 above depicts a schematic of a power generating plant showing critical assets. Strategic as well as operating decisions about the asset will ensure that the asset is operated optimally with less power outages over its lifecycle. Following this, a sound Asset Management model will provide asset owners with adequate support and information to make integrated decisions that supports strategic, tactical and operational objectives.

2.2 Background of the Electricity Supply Industry in South Africa

2.2.1 Power Supply shortfalls in perspective

Electricity generation and supply in South Africa is dominated by the State owned utility of South Africa, ESKOM. ESKOM provides about 96% of South Africa's electrical power and more than 60% of Africa's. Other electricity generators include 1% by the municipality and 3% by independent power producers. ESKOM owns the entire transmission network. Distribution of electricity to consumers is between ESKOM, the municipality and other licensed distributers. Generation is primarily coal-fired, but also includes a nuclear power station at Koeberg, two gas turbine facilities, two conventional hydroelectric plants, and two hydroelectric pumped-storage stations. The company also owns and operates the national transmission system. Electricity consumption profile is shown in Figure 3. The consumption splits indicates approximately 70% of electricity is used for industrial and commercial activity that contribute to year-on year GDP. This might explain why the authorities in South Africa have decided to reduce the risk of load shedding at the expense of Total Asset Management in order to keep up with year-on-year GDP growth.

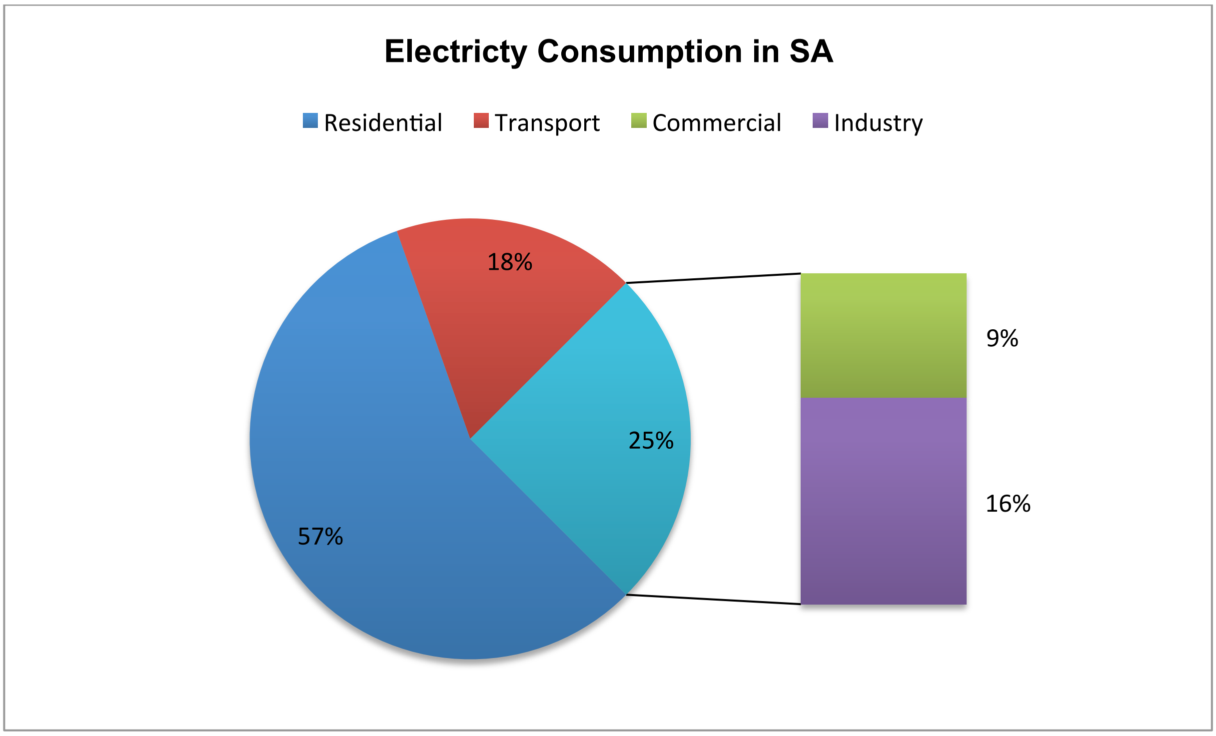


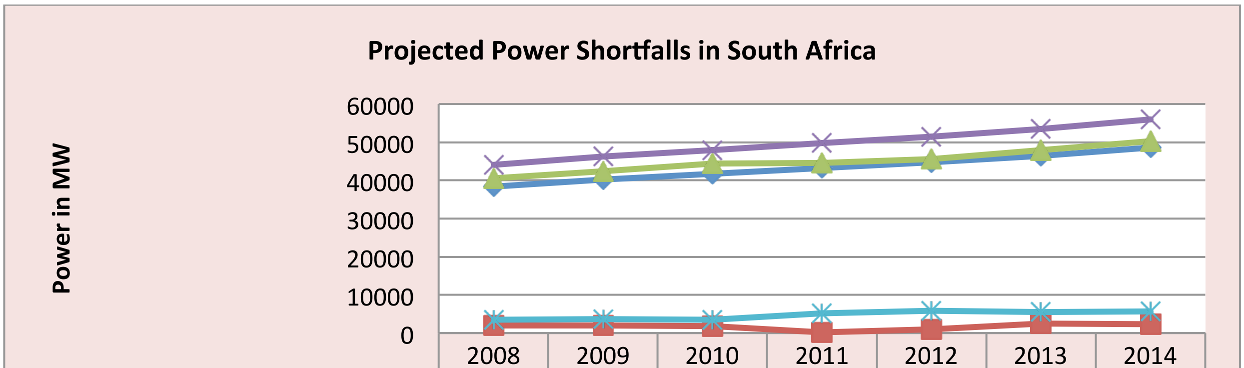
Figure 3: Electricity consumption profile in South Africa (H Fawkes, 2005)

The National Electricity Regulator has been supervising ESKOM's progress towards government targets, which aim to bring electricity to the entire country. Nearly half of rural households in South Africa still do not have power. Seventy percent of South Africa's population have access to electricity, well above the SADC average of around 20 %. In Sub-Southern-Africa, the access rate to electricity is generally low (3-40 %). Table 1 shows the electrification rate in some of the regions in Africa (ICA, 2008).

Region	Electrification rate
North Africa	27 – 99%
West Africa	4-40%
Central Africa	3-35%
East Africa	5-25%
Southern Africa	7-70%

Table 1: Electrification rates in some of the regions in Africa (ICA, 2008)

The Southern African power utilities are experiencing electric power shortages during peak demand periods because of inadequate reserve margins. Apart from utilities in Mozambique, no other utility in the SADC region is reported to have been spared load shedding in the past recent years. Infrastructure development and maintenance of the existing infrastructure is essential. High economic growth of more than 5% in most of the SADC member countries in recent years had resulted in unprecedented growth in electricity consumption and demand. Other factors attributed to the electricity deficit is opening of new mines Figure 4 shows the projected forecast of supply shortfalls in South Africa (EE Publishers,2008).



	2008	2009	2010	2011	2012	2013	2014
Demand Forecast (MW)	38287	40158	41671	43238	44665	46430	48624
New Plant (MW/Y)	2024	1915	1892	181	1003	2422	2363
Year end capacity MW	40548	42463	44355	44536	45539	47961	50324
Ideal reserve margin @ 15%	44030	46182	47922	49724	51365	53395	55918
Shortfall (MW)	3482	3718	3566	5188	5826	5433	5594

*Figure 4: Projected Power Shortfalls in South Africa (*EE Publishers,2008*)*

Southern African Power Pool (SAPP) has identified the following as the main contributors to the electricity supply deficit (SAPP, 2009):

- High Economic growth of more than 5% in most of the SADC member countries in recent years which has resulted in unprecedented growth in electricity consumption and demand.
- Opening of new mines in the region due to high demand of base metals that has resulted in high world market prices.
- Inadequate investment in generation and transmission infrastructure over the last 20 years.
- Sluggish response to early warning signals about future electricity capacity requirement to cope with GDP growth.

2.2.2 Model for Electricity Industry Structure in SA

The electricity industry structure in South Africa is vertically integrated monopoly (ENERGY FUTURES AUSTRALIA, 2004). Except for 1% and 3% electricity generation by the municipality and independent power producers respectively all the electricity business functions are controlled by the state electricity utility ESKOM. The functions include generation, transmission and distribution of electricity. There is virtually no competition at all levels. The utility's main objective is to provide South Africa with Electricity even though it also supplied some electricity to the SADC region. The government body, NERSA regulates the utility to prevent any monopoly abuse. Figure 5 shows structure of electricity supply in South Africa

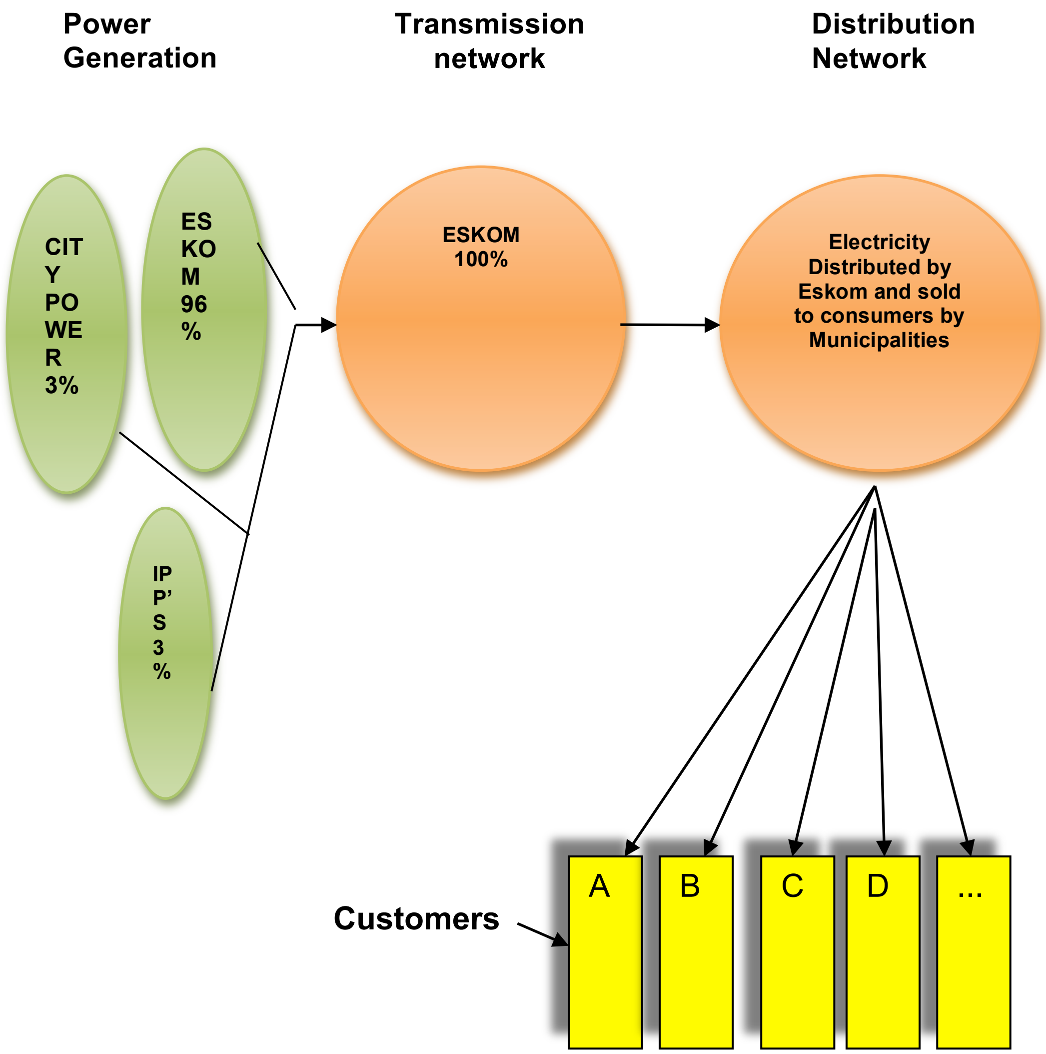


Figure 5: Electricity Industry Structure in South Africa

The three different business units namely: generation, transmission and distribution operate as independent business entities. This is despite the fact that they all belong to the same asset portfolio and are centrally managed by the same people. There exist legally binding contracts between the different business entities in terms of supply and demand of electricity. There are often different conflicting priorities between the three business units which affects respective businesses. The management of the entire business chain is about optimizing conflicting objectives and finding the best possible trade offs.

2.3 Overview of industry research conducted on Asset Management

A diverse number of research projects to develop Asset Management models/frameworks for managing complex assets such as those found in the industry have been undertaken. The following literature review outlines four research projects undertaken to formulate complex Asset Management tools using different methods.

2.3.1 Research Project 1

Industrialization in Britain primarily driven by the introduction of the double-acting Watt Steam Engine, which was developed between 1763 and 1775 necesitated a shift from manual-base labour to machine-based-labour. This was necessary to enable mass manufacturing.. The inherent nature of machines is that they need to be maintained in order to operate optimally. The cost of maintenance increased significantly in the beginning of the twentieth century as mass production became prominent. Strategies were developed to decrease maintenance cost through better management in order to compete in the market and make profit. In 1945 Reliable Centred Maintenance was introduced. The introduction brought many advantages that saw increase in profit margins and most importantly collection of maintenance data for further analysis and improvement of strategies. (Jan Myburg, 2009)

Even with development of advanced maintenance stratergies, incidents were still very prominent. This forced the industry and regulatory bodies to rethink what the minimum requirements for a good physical Asset Management plan. On July 6, 1988, a gas production platform operating in the North sea exploded. The explosion and resulting fire killed 167 men and led to insurance losses of about £ 1.7 Billion. A public inquiry into the incident recommended an establishment of an industry standard for minimum requirements for maintenance of physical assets. This gave birth to PAS 55 which was first released in April 2004. (Jan Myburg, 2009)

PAS 55 is a publicly available Specification on optimal management of physical assets. Published by the British Standard Institution it gives guidance and a 28 Point requirements checklist of good practices in physical Asset Management. The standard is applicable to industries where a physical asset is used as a means of generating income such as a Power Plant, oil refineries, water utilities etc. PAS 55 is getting a lot of interest and shows promise to become a defacto word-wide specification for any organization seeking to demonstrate a high level of professionalism in whole life cycle management of physical assets.

PAS 55 does not define the ideal Asset Management strategy but rather provides a set of minimum requirements to which the Asset Management system should conform to. It also does not prescribe a totally new Asset Management system approach; it requires a sound understanding of the principles behind the standard that can be adapted to the existing Asset Management regime for improvement. This standard was one of its kind at the time and is still considered the model standard for Asset Management. The standard is produced in two parts i.e. PAS 55-1 and PAS 55-2 which focuses on specifications and application of specifications respectively. Overview of PAS 55 process flow is shown in figure 6. The objective of the standard is to achieve synergy between organisational strategic direction and day-to-day activities of managing physical assets. The model seeks to achieve the following:

- Make a sustainable profit for shareholders over the life-cycle of the asset;
- Guarantee security of supply for customers;
- Sustain the health of the asset over its life-cycle;
- Improve Risk Management Methods;
- Compliance with Environmental and Safety Regulations.

The standard achieves its goal by answering questions such as:

- How best to operate the asset;
- How best to maintain the asset;
- How best to renew/sustain the asset;
- How best to decommission or dispose of the asset.

The model described in the standard uses systems engineering techniques and methods to demonstrate that sustainable profitability is actively achieved within the management of the asset over the lifecycle.

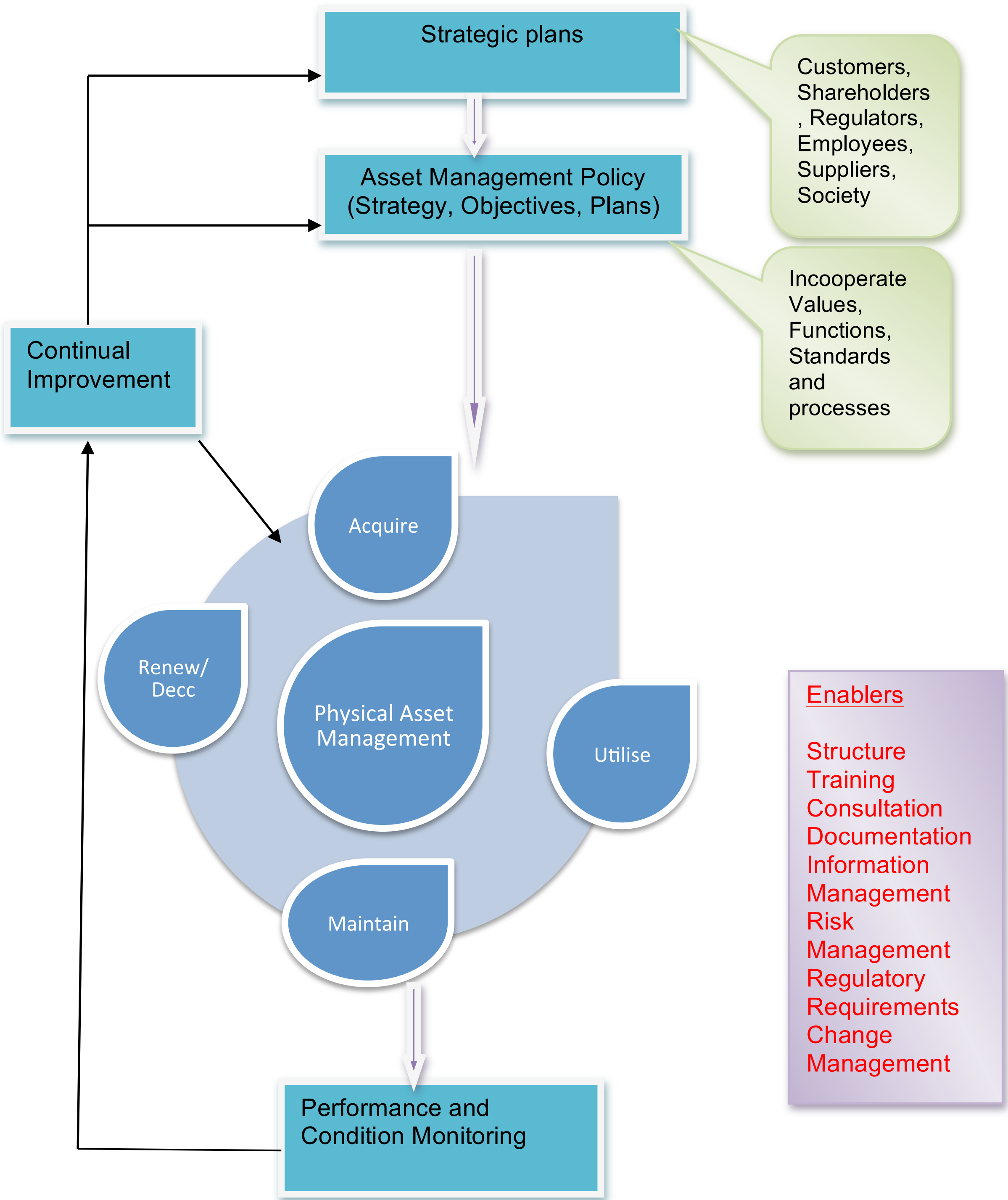


Figure 6: Asset Management Process Flow

2.3.2 Research Project 2

Any power generating plant has different assets which all work together to produce electricity. It is not uncommon to find that some assets are more susceptible to problems than others because of the conditions in which they operate. The economizer is very critical for efficient operation of any plant. In boilers, economizers (refer to figure 1) are heat exchange devices that heat fluids, usually water, up to but not normally beyond the boiling point of that fluid. Economizers are so named because they can make use of the enthalpy in fluid streams that are hot, but not hot enough to be used in a boiler, thereby recovering more useful enthalpy and improving the boiler's efficiency. They are a device fitted to a boiler which saves energy by using the exhaust gases from the boiler to preheat the cold water used to fill it Sun, et al. (2008).

Sun, et al. (2008), conducted a research to adopt the split Asset Management decision making process models for economizer maintenance management. The economizer is notoriously prone to expensive breakdowns and hence it was chosen to illustrate how the split Asset Management method can be applied to the industry. Efficient and effective decisions are required to ensure that potentially costly outages are avoided. Such decisions are complex incorporating interdisciplinary short term and long term decisions. To ensure that decisions are made taking an integrated approach and on a scientific basis, the group adopted a generic split AM decision making process for industrial applications. Using this process, a basic decision-making process which focuses solely on decision making activities is separated (split) from the decision-supporting information acquisition and generation processes which provide inputs for making decisions. In the report, the AM decision making process is defined as a set of interrelated activities and the sequence of these activities that are necessary to make optimal AM decisions, within the context of an organisational structure and resource constraints. The split AM method was traditionally not used for industrial applications. It was specifically developed to address the different time scales for different AM decision types. Using this method decisions to be made regarding the asset are classified according to time frames and relations between different time frames are taken into account in order to generate a decision making tool. This is a time based decision making tool. Through the research, Sun, et al. (2008), were able to successfully prove that with optimization split, AM decision methods can be extended and used for industrial application.

2.3.3 Research Project 3

In 2001, the University of Sydney undertook a number of research projects to better understand the practical aspects of managing complex assets such as power utilities and some manufacturing assets. The main drive for the research projects was because a number electricity generation assets were undergoing transition from regulated to de-regulated environments. A number of state owned enterprises were corporatized and or privatised to operate in deregulated environments. It was becoming increasingly important for competitive businesses to find optimal solutions in an environment where resources were becoming less and there was a growing need for value for money in areas of cooperate activities. To achieve optimal performance in the new environment required more understanding of market dynamics to achieve synergy across the value chain. One such project was done by Doloi, et al. (2006) to devise a systematic method of managing complex assets through Project-Based Methods (PBM). The research used an innovative approach using the theory of project based management and process simulation techniques applied to the value chain. Using this theory inputs from different departments in a value chain are integrated as part of a project. Different market opportunities are also evaluated and each opportunity is then treated as a project. To optimize the process, organisational projects are then mapped to market projects. This method requires a good understanding of the organisation and the market. Using these techniques it has been proven that synergy between long (asset health) and short term (operational) decisions can be achieved.

2.3.4 Research Project 4

Another research in this field was conducted at Loughborough University in the UK, (Faiz & Edirisinghe, 2009). The objective of the research was to develop a decision making tool for predictive maintenance in order assist asset owners to make informed decisions. The main objective of the research was to devise a Decision Support System (DSS) that will ensure that the assets are kept operational as long as possible without sacrificing reliability and safety. They utilised an asset-centric approach which puts emphasis on availability of information, at the right time, in the right format, before the right person (asset owner), against the right query and at the right level to ensure optimal decision making relating to the asset. The solution proposes an expert system combined with fuzzy logic to provide a better way of decision making in predictive maintenance of an asset. This method requires accurate and updated information about the asset at all times. The results are increased uptimes, reduction in maintenance costs, increased profits and thus enhancement in the reputation of the business to its customers.

2.4 The Current Asset Management regime/structure at the Power Utility

2.4.1 Asset Management Philosophy

The Power Plant under Study has formally adopted PAS 55 as a philosophy in 2010. To date, two documents that have been developed by the utility to align their Asset Management Philosophy with PA55. The first document outlines the principle behind Asset Management as per PAS 55: Part 1. The name of the document is called Plant Asset Management Policy Document. The structure and philosophy in the Policy Document is the same as specified by PAS 55: Part 1. The second document outlines the business processes required to achieve PAS 55 Asset Management principles as required by PAS 55: Part 2. The name of the document is Plant Asset Management Directives. This document is designed as a practical application of principles specified by PAS 55: Part 1. The directive is structured in accordance with PAS 55: Part 2 and is fully aligned to ISO 9001 Quality Management Standard. It also supports PDCA (Plan, Do, Check and Act). The compilation and implementation of the Asset Management System is currently centralised at the Utility head offices. The details of which aspects of the standard (PAS 55, 2008) is explored and analysed and utilised in this report is outlined in chapter 3.

2.4.2 Asset Management Organization in the Power Plant under study

Managing of an asset requires different levels of planning, decisions at different points in time and actions at different points in time alike. The highest level of decision making is at the top as shown in figure 7. Management at this level utilizes information from lower level to make decisions about the asset, personnel at this level is often not technical and can take wrong decisions about the asset if problems are not explained to them effectively. In an organisation that is not regulated this is the highest decision making body. In a regulated environment as is often the case, decisions about the asset at this level could be overruled for other reasons not related to the asset e.g. political reasons. The most critical task at this level is to ensure that the day-to-day decisions made about the asset is consistent with the strategic objectives of the business. The boundaries of the asset and management thereof are limited to the Power Plant even though the plant is part of a portfolio of other assets.

Line management is probably the most important implementation wheel of the organization. Planning at this level involves formulating philosophies that will ensure that the asset will remain profitable to the end of its life. The philosophies include operation of the plant, maintenance and renewal as well as al human related support structure required in the management of the asset. It ensures that formulated philosophies are implemented at the time they are supposed to be implemented. It also ensures that the plant is always operated within its limits. All employees at this level are technical, mostly engineers. Line management uses skills on the lower level to implement philosophies, maintain and operate the asset. In organisations that are geared more towards profit and to guarantee security of supply, such skills are prioritised towards production often leaving capital projects lagging behind.

The supervisors are responsible for the day-to-day running of the plant and ensure that production targets are realised. They also attend to any disruptions to production in a form of breakdowns. They work mostly with plant maintenance and operating procedures generated at upper levels. The main task at this level is to adhere to procedures. Decisions life-span at this level is very short. Personnel at this level make up the most number of employees in the Power Plant. The people include technicians, artisans and utility men. Failure to adhere to procedures at this level can manifests in a form of productions losses almost immediately but has long term consequences also. For example, if the asset is constantly operated outside of the limit, its life is reduced. Figure 8 show the detailed Power Plant organgram.

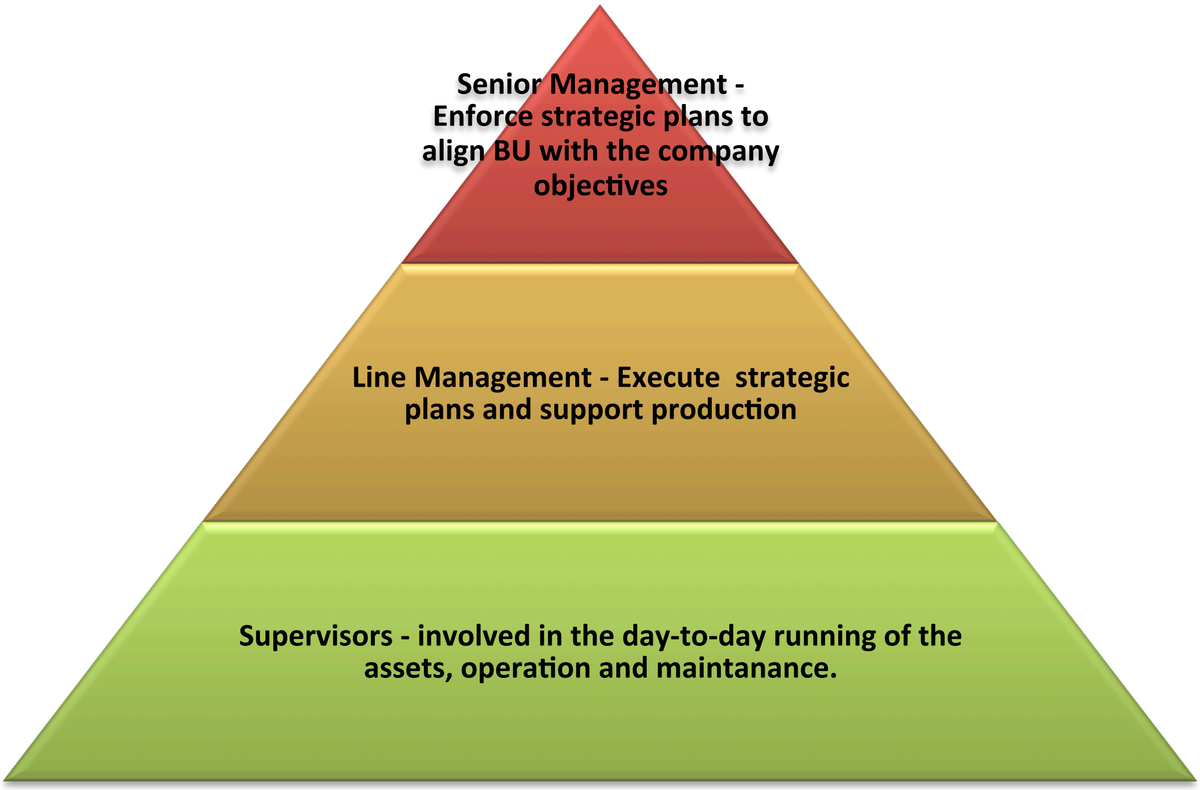


Figure 7: Power Plant Asset Management Pyramid

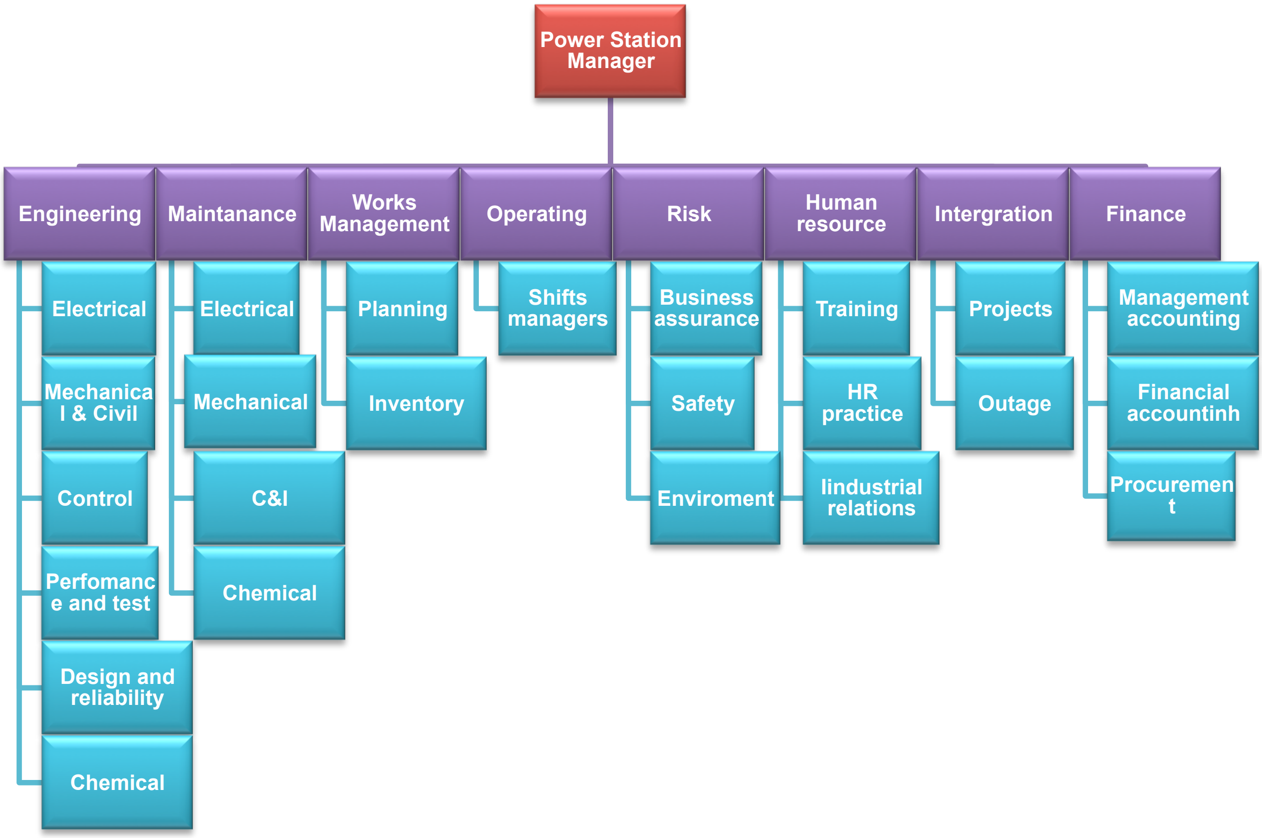


Figure 8: Power Plant current Asset Management Organogram

2.5 Comparative Framework for the Analysis

The comparative framework for the report uses the principles behind Asset Management. This comparison will be between the actual asset care principles applied in reality and documented principles that should be applied as per the Power Plant Asset Management Policy Document and directive which is aligned to PAS 55. As with any comparison, apples must be compared with apples. To achieve this, the actual principles being applied in reality are indirectly formulated by analysing the Key Performance Indicators. Formulation of actual principles being applied in reality requires comparison of the Power Plant KPI data with similar Power Plants around the world. The KPI's are outlined below:

Generating plant Key Performance Indicators has been a subject of research since the 1970's. WEC (World Energy Council) has a committee since 1974 that focuses on performance of generating plants and its has been collecting Power Plant availability statistics from various countries and uses the data to report on average indices for several groups of units (WEC,2010).

This data is then made available to the members for worldwide peer benchmarking. WEC uses a combination of standard sectoral indicators from NERC, UNIPEDE (the International Union of Producers and Distributors of Electrical Energy), IEEE and EUROELECTRIC ("ThePerf data base: Evaluation of performance indicators). The indictors cover availability, operations and reliability of the asset which indicates both the technical and financial performance of the asset. Profitability is maximised at higher reliability and availability.

Five Primary indicators are used to measure performance, the indicators are:

- Energy availability factor (EAF).
- Unit Capability Factor (UCF).
- Unplanned Capability loss factor (UCLF).
- Planned Capability loss factor (PCLF).
- Load Factor (LF).

In addition to the primary performance indicators, four additional secondary indicators are used, the indicators are:

- Unplanned Automatic Grid Separation per 7000 hours of operation (UAGS 7).
- Utilization factor (UF).
- Industrial Safety Accident Rate (ISAR).
- Successful start up rate (SSR).

2.6 Chapter outline

The literature review shows that the Power Plant under Study has already adopted PAS 55 as their Asset Management philosophy. It also shows that PAS 55 does not necessarily explicitly prescribe Asset Management principles to be followed. It merely specifies minimum requirements for optimal Asset Management strategy. This implies that Organization adopting PAS 55 have the flexibility to customise their Asset Management system as long they can substantiate and prove compliance with the principles. The challenge therefore becomes the ability of the organization to integrate the principles of PAS 55 within their already existing Asset Management Systems. Because of this, the comparative framework for the research will focus more on the evidence of compliance as dictated by Key Performance Indicators. PAS 55 will still be used as comparative frameworks in cases where it can be shown that there is are shortcomings in applying principles of PAS 55 by the utility.

3. RESEARCH METHODOLOGY

The type of research method employed in the report is a case study. Baxter, Jack (2008) defines a case study as a phenomenon of some sort occurring in a bounded context. Yin (2003) defines a case study as an empirical inquiry which investigates a contemporary phenomenon within real-life context when the boundaries between the phenomenon and the context are not clearly evident and multiple sources of evidence are used. The type of case study followed is a single case study with embedded units. The global issue is Asset Management, however this is influenced by different sub-issues which can be analysed separately e.g. operations, maintenance etc. The research methodology according to Davies et al (2007), which is followed in the report is outlined below:

3.1 Definition of the case

The case can be summarised as an analysis of business processes that supports Asset Management in a Power Plant with emphasis on the following:

- The type of principles applied to Asset Management.
- Available business processes that enables application of such principles.
- The evidence of application of such principles.

3.2 Definition of the context of the Case Study

The context of the case study is a Power Plant, owned and operated by a utility in South Africa. The environmental context is that of a country where the risk of load shedding because of electricity capacity deficits and low reserve margins is high. Furthermore, the authorities responsible for the electricity sector in South Africa, which also regulates the utility, have publicly announced that their strategy for reducing the risk of loading in a short term is to operate the asset at high load factors and limited maintenance opportunities (DME, 2008). The context can be summarised as Total Asset Management in a regulated environment.

3.3 Establishment of research questions

According to Yin (2003), a case study approach must be used when the study is to answer how and why questions. The study seeks to understand how a focus on profitability/security of electricity supply as opposed to Total Asset Management affects long term asset functional viability. This justifies using a case study as a research strategy

3.4 Determination of Data Sources

The following data sources were used:

- Documentation: this includes policies, directives, and procedures applicable to the Asset Management system.
- Archived data from computerised Systems: Plant Key Performance Indicators which gives an indication of the actual Asset Management principles.
- Direct/Participant Observation: The researcher is directly involved in the Asset Management process and some of observation made by the researcher, as a participant, will be used.

NB: All data used for the analysis is considered sensitive information. Following this the data will not be made available. Only summaries of data as shown on applicable graphs will be made available.

3.5 Collection of data

The method of collecting, coding and categorising data was determined. In some very rare cases the data collected was already in a form suitable for analysis, however, most of the raw data collected was sorted out and categorised to allow for analysis and comparison. A centralised database with information required for different sub-units of the analysis was created. Data which was not captured correctly in archived systems i.e. with missing data field were also captured and noted.

3.6 Determination of data analysis techniques

The study employed both qualitative and quantitative research analysis tools to analyse data. The base analysis method is quantitative in nature. Raw data was collected from Asset Management archiving systems and analysed. The objective of the analysis was to explore and expose coded/hidden information within the data. In analysing the data, the following themes were considered:

- patterns/trends/common features
- Repetition
- Links to the hypothesis
- Benchmarking with Similar processes from peers/ cross unit synthesis

In some instances where qualitative analysis was inconclusive or further exploration was required to converge to a conclusion, qualitative analysis in a form of direct/participant observation was employed. The researcher is directly involved with the Asset Management system at the Power

Plant, as a result some of personal direct observations and personal experiences were used to understand and make conclusions on coded information provided by raw data. Due to the nature of the sensitivity of the information being analysed, external participants other than the researcher could not be utilised. This negatively impacted the analysis, particularly in cases where further qualitative data was necessary to reach a holistic understanding of the phenomenon being studied.

3.7 Practical application of the research methodology

The study will use qualitative and quantitative research methods to analyse performance of the Asset Management system. In Control Theory, only what can be measured can be controlled (Norman NISE,2008). Following this, the measurement of actual asset care, which gives a set of actual Asset Management principles applied in reality, was formulated by analysing Key Performance Indicators. These formulated principles are then compared with power plant principles as outlined in the Utility Policy Document and PAS 55. The analysis will be achieved by performing the following:

- Analysis of seventeen year Asset Management historical data for a Power Plant in the form of KPI's is used. The information analysed included data about operation of the asset, maintenance of the asset, renewal of the asset, configuration and labelling of the asset , risk management, cross functional coordination, as well as other human related issues such as training and finance management.
- The actual Asset Management practices at the Power Plant, as dictated by the historical data was compared with the Power Plant Asset Management model to illustrate that focus on profitability and security of supply compromises sustainable asset health and hence long term profitability and security of supply.
- Based on the analysis, recommendations were made to align the Actual asset care practices with the Asset Management strategy at the Power Plant and world best practice as outlined in PAS 55-1 and PAS 55-2. The process flow is shown in figure 9.

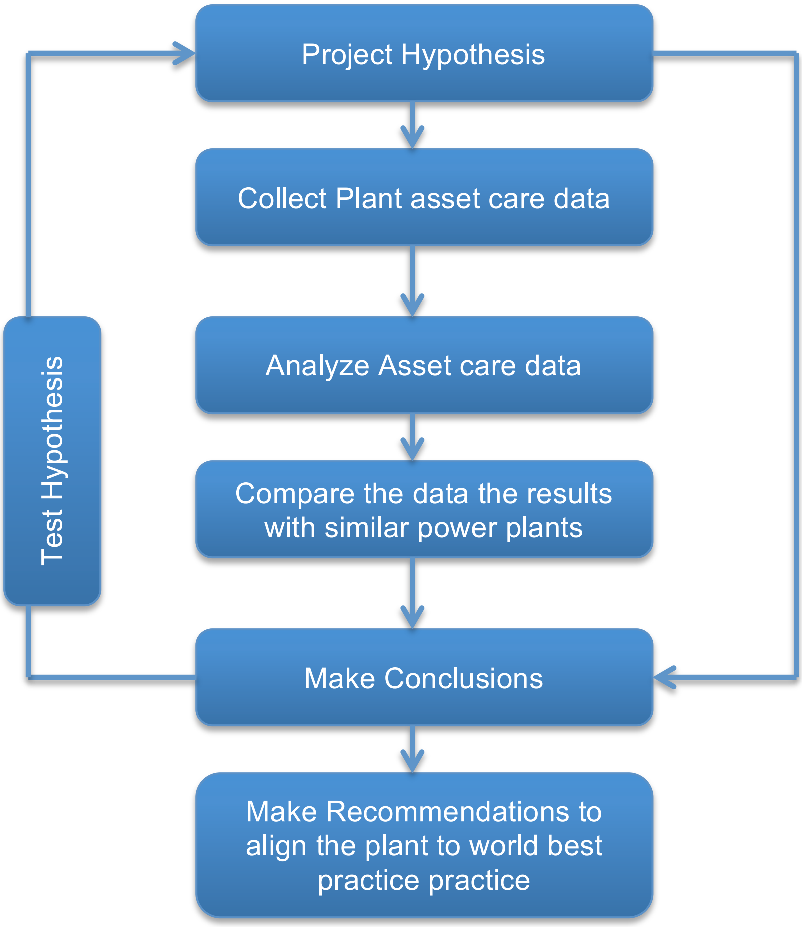


Figure 9: Research Methodology

Table 2 shows Asset Management focus/ checkpoint list areas in the Power Plant. The focus areas are taken from the Policy Document in the Power Plant. It also shows areas covered by the report and those which are not covered by the report. The choice of which area to cover was not dictated by the order of importance but rather availability of historical data in the Power Plant.

Covered by research

Not covered by research

ID	FOCUS AREA	ACTIONS REQUIRED	COLOUR CODE
1	Long term plant health	Monitored, Measured, Assessed and documented	
2	Plant Maintenance	Master plan for test, inspection and interventions developed and maintained, Effective planning and scheduling	
3	Incident Management	Effective allocation, Investigation and corrective actions	
4	Configuration Management	Documentation, record keeping and history maintenance	
5	Outages (PCLF)	Minimize downtime without compromising asset condition for t to run until the next maintenance intervention	
6	Operations	Operate the plant within design limits, document all processes	
7	Plant modifications	System to be established and effectively maintained	
8	Quality Control	Maintenance of quality control systems, effective procurement and materials control	
9	Plant classification	Established and maintained	
10	Reviews	Structures, processes to be set-up for business units to share experiences	
11	Safety, legal, Environmental regulations	Establish and maintain	

Table 2: Asset Management checkpoint list

4. ANALYSIS

In order to analyze actual performance of the asset, several indicators that give important information about the status of Asset Management were considered. The analysis is divided into two sections namely; profitability/security performance indicators and long term plant performance indicators. The latter is mostly concerned with long term asset health and forms the heart of Asset Management. The former is mainly concerned with the day-to-day performance of the asset and is used to evaluate the yearly performance of the Power Plant in terms of profitability, availability and reliability of power supply to the customers. The input data for the analysis was obtained from archive systems at the Power Plant and the output gives quantitative information about the actual status of asset care at the utility. The actual asset care data was then benchmarked against other similar data for other similar assets. Figure 10 gives an outline of the perfomance indicators used in the analysis.

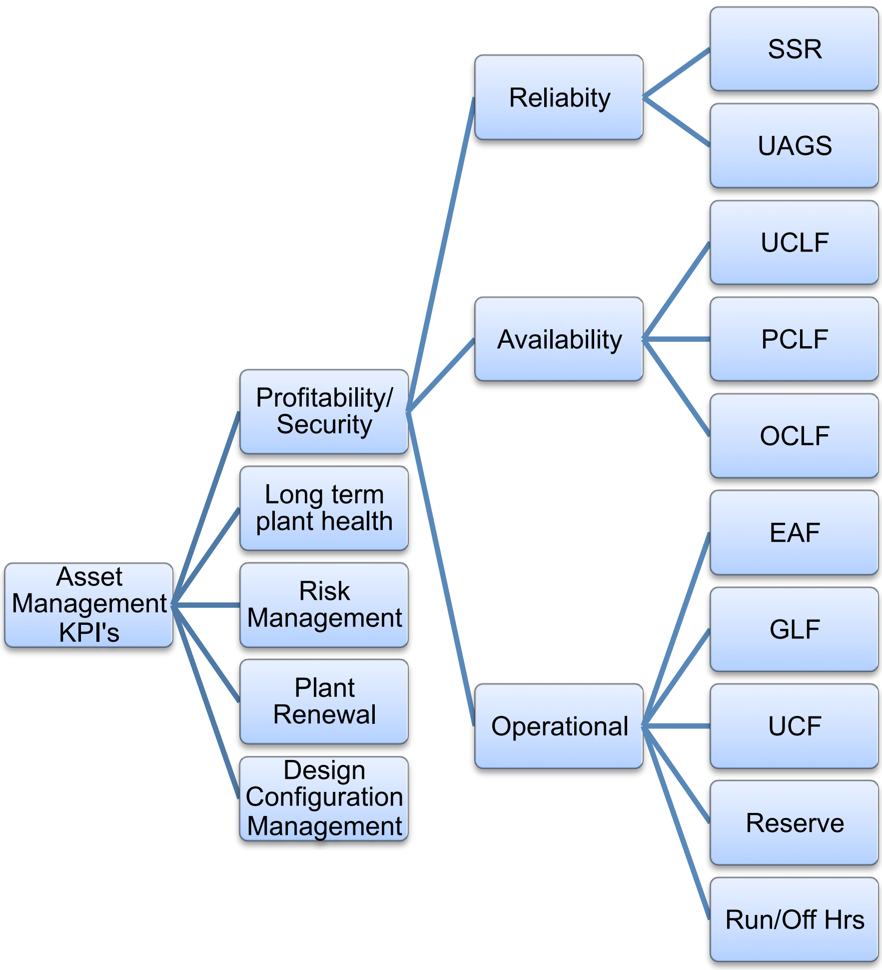


Figure 10: The structure of research analysis

4.1 Data Analysis

The Power Plant under study is comprised of six units which can be operated independently. The analysis was performed on average performance of all the units. Data was obtained from 1996-2012 fiscal years. Yearly performance was done according to financial year periods shown in Table 3.

Financial Year	Period
1996	1 April 1995-31 March 1996
1997	1 April 1996-31 March 1997
1998	1 April 1997-31 March 1998
1999	1 April 1998-31 March 1999
2000	1 April 1999-31 March 2000
2001	1 April 2000-31 March 2001
2002	1 April 2001-31 March 2002
2003	1 April 2002-31 March 2003
2004	1 April 2003-31 March 2004
2005	1 April 2004-31 March 2005
2006	1 April 2005-31 March 2006
2007	1 April 2006-31 March 2007
2008	1 April 2007-31 March 2008
2009	1 April 2008-31 March 2009
2010	1 April 2009-31 March 2010
2011	1 April 2010-31 March 2011
2012	1 April 2011-31 March 2012

Table 3: Performance Analysis Financial Year Periods

Exclusions to this performance analysis are statutory related performance indicators i.e. safety and environment. The main reason for this exclusion is that the Power Plant does not currently have a computerised database for such indicators.

NB: *All data used for the analysis is considered sensitive information. Following this the data will not be made available. Only summaries of data as shown on applicable graphs will be made available*.

4.1.1 Data Sets

Operational Indicators

For benchmarking, operational indicators information from WEC PGP database was used. The indicators analysed includes EAF, UCF, Machine running hours, GLF and cold reserve. The benchmarking information for EAF and GLF was obtained only from 2005 to 2009. The information used is from fossil powered steam turbine stations with capacity >600 MW. This classification is similar to the Power Plant under study as it has an (Maximum Continous Generation) MCR of 640 MW and uses steam turbines. For benchmarking of UCF however, quartile information was used. This is because similar information as used for EAF and GLF was not available. Quartile information classifies performance of Power Plants into four different categories ranging from low to world class. Data used to formulate the quartiles was obtained from all base loaded steam turbines < 500 MW from 2001-2005 (quartiles information for power plants with capacity > 500 MW could not be obtained from the database). There were limitation in terms of obtaining benchmarking data from power plants that matches up directly with the power plant under study. These limitations includes getting information for only limited number of years as well as from Power Plants with less capacity sometimes.

Table 4 shows data for deciles and quartiles for EAF, GLF and UCF. Figure 11 shows the classification.

Quartiles & Deciles for EAF

Percentile	Value
Min	36.35
d1	73.59
d2	78.96
Q1	80.63
d3	81.94
d4	84.62
Q2	86.84
d6	88.45
d7	89.83
Q3	90.4
d8	91.18
d9	93.44
Max	99.38

Quartiles & Deciles for UCF

Percentile	Value
Min	0
d1	74.42
d2	80.17
Q1	81.79
d3	83.16
d4	85.32
Q2	86.78
d6	88.22
d7	89.63
Q3	90.46
d8	91.3
d9	93.74
Max	100

Table 4: Quartiles and Deciles for EAF and UCF (WEC, 2010)

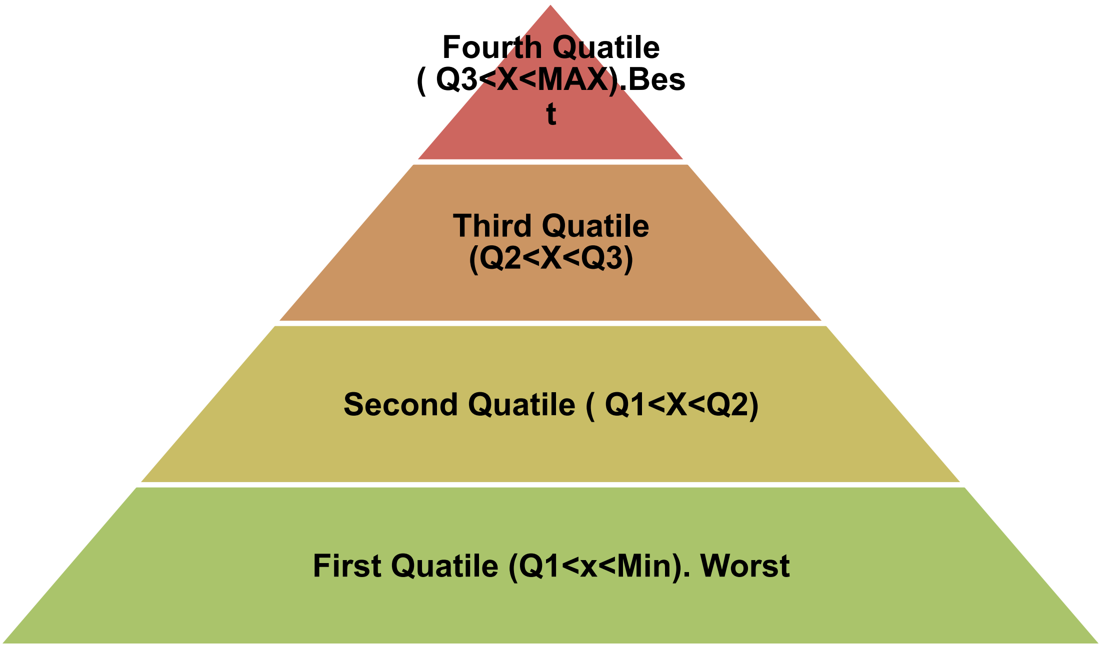


Figure 11: Benchmarking classification according to Quartiles and Deciles (WEC, 2010).

<u>*Energy Availability Factor (EAF)*</u>

EAF is the ratio of the available energy due to factors within and beyond management control over a given period of time to the maximum amount of energy (Maximum continuous rating) which could be produced over the same time period. A higher value of EAF as compared to peers average indicates that unplanned losses within management control and planned losses are minimized. Furthermore it indicates that unplanned events beyond management control are rare. EAF is calculated as shown in equation 1 below.

$$EAF = MAX_{Energy} - \overrightarrow{(P_{LOSS}\ (within\ management\ control)} + \overrightarrow{(P_{LOSS}\ (beyond\ management\ control)}\ )/\ (MAX_{Energy})\} * 100 \quad (1)$$

Where:

$$MAX_{Energy} = Unit\ Capacity \times No.\ of\ Units \times 24 \times No.\ days\ in\ a\ month$$

$$P_{LOSS}\ (within\ management\ control) = MW\ Capacity\ of\ losses\ within\ management\ control \times downtine\ of\ load\ loss$$

$$P_{LOSS}\ (beyond\ \ management\ control) = MW\ Capacity\ of\ losses\ beyond\ management\ control \times downtine\ of\ load\ loss$$

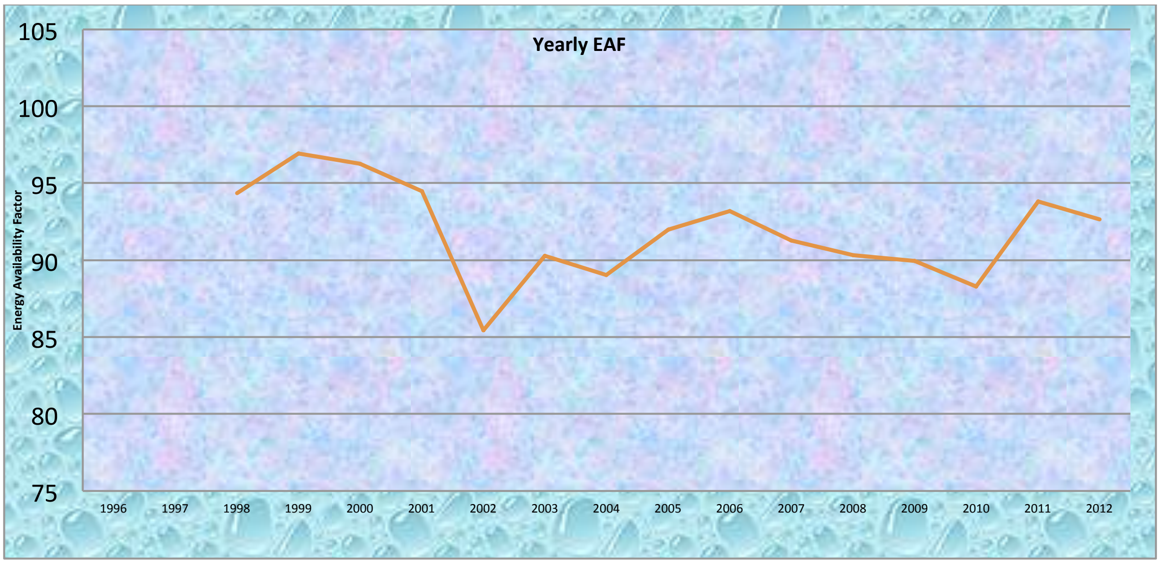


Figure 12: Yearly EAF

Fossil Steam Unit EAF, 600 -799 MW

	2005		2006		2007		2008		2009	
	#Units	EAF	#Units	EAF	#Units	EAF	#Units	EAF	#Units	EAF
TOTAL	158	85.57	143	83.89	140	83.84	142	83.58	141	83.26
Coal	127	86.35	119	84.85	116	84	117	84.92	114	84.71
Liquid	7	74.8	7	90.58	7	78.04	7	69.48	9	70.59
Gas	12	85.22	10	65.74	10	84.51	11	75.75	11	79.4

Table 5: *EAF benchmarking* (WEC, 2010).

Observations/Findings

- The power plant has a higher energy availability factor, well above the average from the database as shown in table 5.
- This essentially places the power in the first quadrant in terms of performamnce making it a world class power plant.
- The EAF has however dropped over the years, the power station recorder the high levels of EAF prior 2001, the highest EAF post 2001 is 93.8% as compared with 96.95 in 1995 and 94.49 in 2001.
- The perfomance since 2001 has not been consitent with the lower EAF of 85.44% being recorded a year after the highest performane of 94.49% in 2001.

Unit Capability Factor (UCF)

The performance indicator is the ratio of the available energy due to factors within management control over a given period of time to the maximum (Maximum Continuous Rating) amount of energy which could be produced over the same time period. A higher value of UCF as compared to peers average indicates that unplanned losses and planned losses are minimised. The main differences between EAF and UCF are that the former takes into account of losses due to circumstances beyond management control while the former only considers losses within management control. UCF is calculated as shown in equation 2:

$$UCF = MAX_{Energy} - \overrightarrow{(P_{LOSS}\,(within\ management\ control))/\,(MAX_{Energy})\}} * 100 \ldots\ldots(2)$$

Where:

$$MAX_{Energy} = Unit\ Capacity \times No.of\ Units \times 24 \times No.days\ in\ a\ month$$

$$P_{LOSS}\,(within\ management\ control) = MW\ Capacity\ of\ losses\ within\ management\ control \times downtine\ of\ load\ loss$$

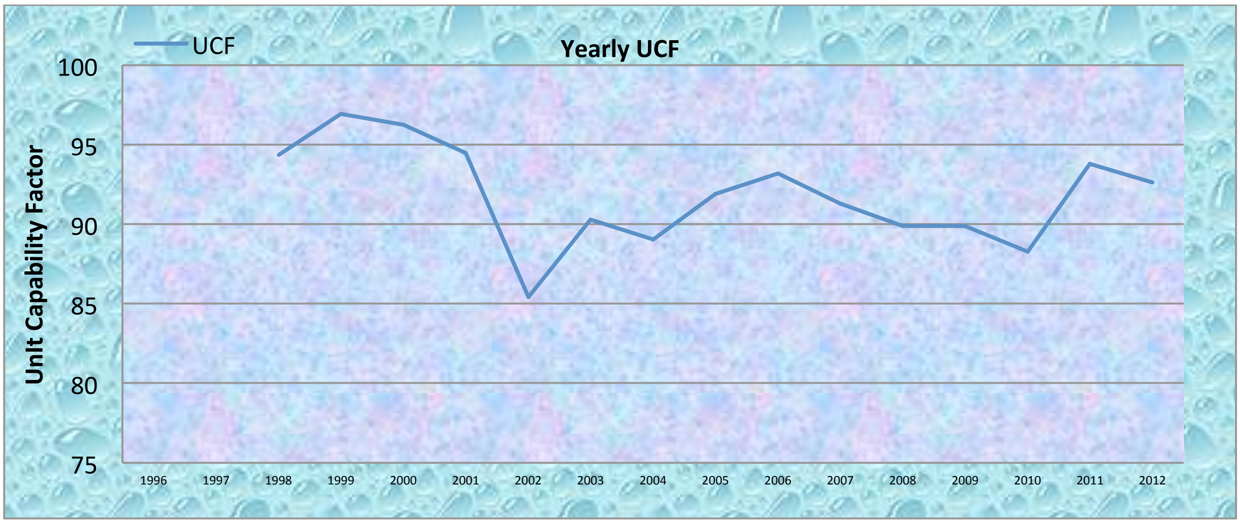


Figure 13 : Yearly UCF

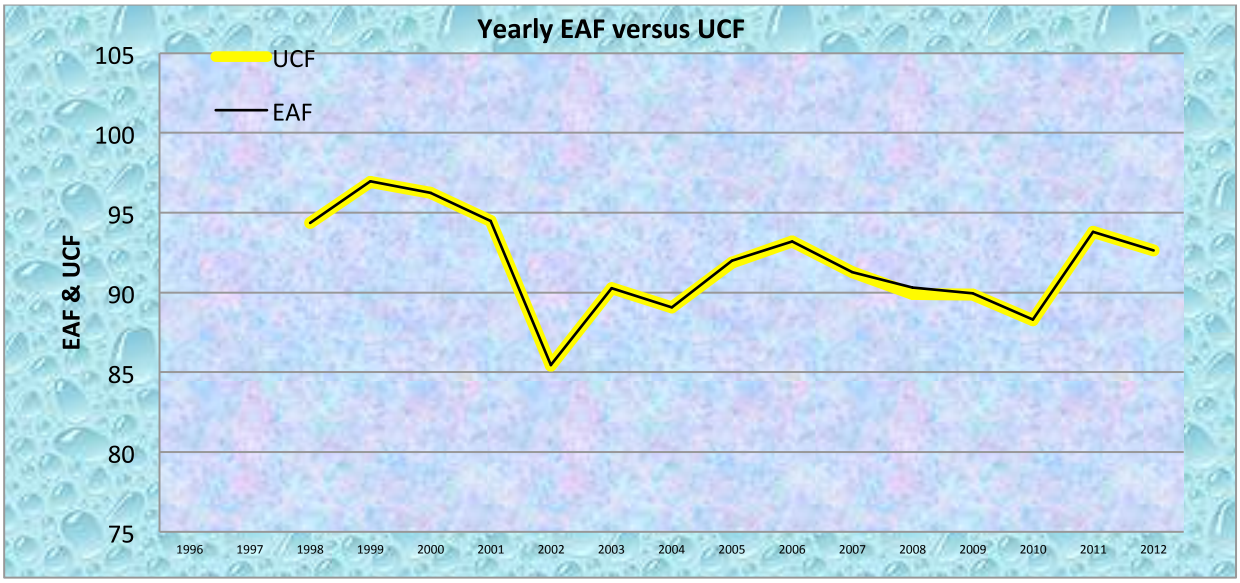


Figure 14: EAF versus UCF

Observations/Findings

- The power plant under study has a high Unit Capability Factor.
- In comparison with EAF, the data shows that the Unit Capability is rarely affected by the factor beyond management control. Factors that reduces UCF are within management Control.
- As compared to the Power Plant on the WEC database, the power plant under study is considered to be a world class perfomer, comfortably placed in the fisrt quadrant.
- There are however signs of decline in Unit capability Factor from 2001.
- Since the lowest recorded performance 85.44% in 2001, the power plant has not been able to return to the achieving very high UCF.

Generation Load factor (GLF)

Generation load factor is the ratio of energy produced over the period divided by electrical energy that would have been produced at maximum electrical capacity over the same period. Capacity in reserve storage is excluded. A higher value of GLF as compared to peers indicates that the asset is operated closer to operating margins and possibly stressed. GLF is calculated as shown in equation 6.

$$\boldsymbol{GLF} = \{\boldsymbol{NetEGen}\ (\boldsymbol{MWHrs})\times\mathbf{100}\}\ \div \{\boldsymbol{NetMaxCap}(\boldsymbol{MW})\times\boldsymbol{Time}\ (\boldsymbol{Hrs})\} \text{.........(Equation 3)}$$

Where

$$NetEGen = Nett\ Energy\ generated\ by\ the\ asset.$$
$$NetMaxCap = Nett\ Maximum\ Capacity\ generated\ by\ the\ asset.$$

Electricity price varies with load factor, the lower the factor the higher the price per kW. The higher price is because the producer still has to have the plant capacity available even though it is not fully used at low load factors. Load factor variations are determined by consumer electricity pattern

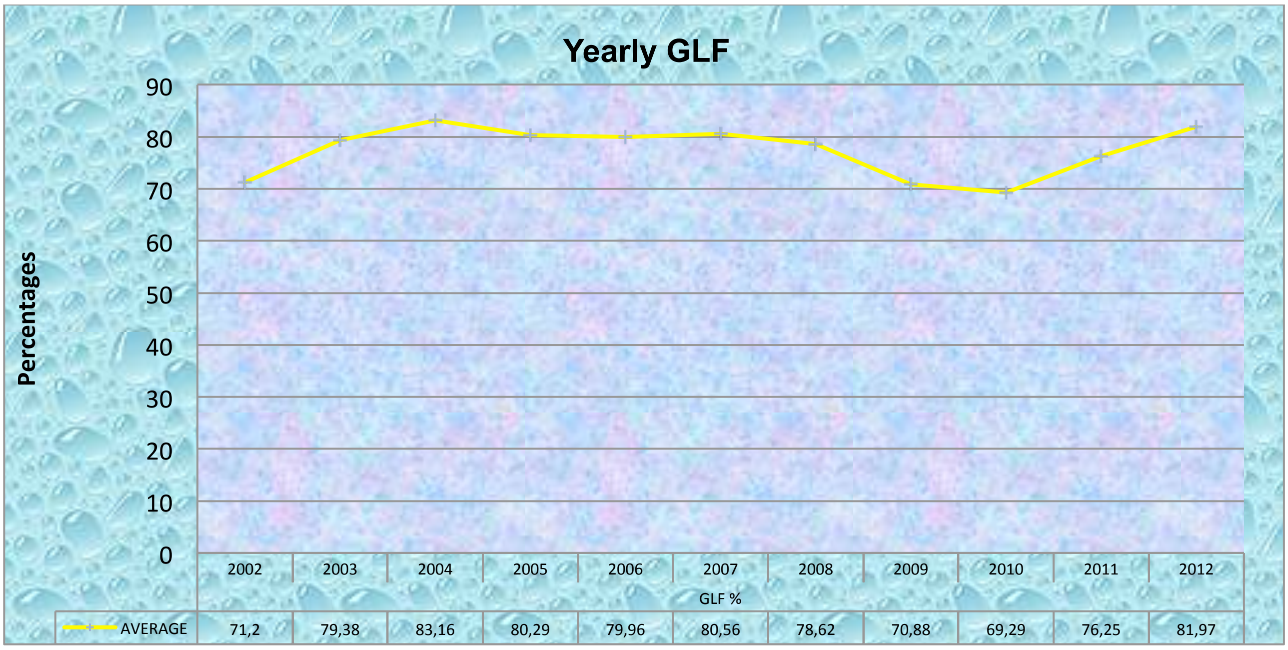


Figure 15: Yearly GLF

Fossil Steam Unit GLF, 600 -799 MW

	2005		2006		2007		2008		2009	
	#Units	GLF	#Units	GLF	#Units	GLF	#Units	GLF	#Units	GLF
TOTAL	158	65.5	143	64.82	140	65.65	142	62.44	141	60.5
Coal	127	72.23	119	70.85	116	72.93	117	68.76	114	68.19
Liquid	7	28.7	7	16.38	7	17.68	7	17.17	9	14.04
Gas	12	9.37	10	11.38	10	11.43	11	11.94	11	11.68

Table 6: *GLF benchmarking data* (WEC, 2010).

Observations/Findings

- Analysis for GLF was taken from 2002 as they were too many missing data void prior to this year.
- For any asset, a balance between under utilization of the asset and overutilization of the asset must be balanced in order to avoid premature ageing. The data shows that under-utilization is not a problem as the Power Station is operated with high load factors to fulfil grid demands.
- The average load factor of the power plants on the WEC database from 2005 to 2009 is 64%. This ensures that a good balance is achieved.
- In comparison, the power plant under study has a relatively high load factor. This is also because this power plant is used for frequency regulation of the national grid.
- During peak hours namely: between 05:00 & 09:00 AM in the morning as well as 04:00 – 09:00 PM, an emergency generation called EL 1 (Emegency Level one) is often declared which significatly contributes to the load factor. During this period, the machine is operated at loading greater than Maximum Countinous Rating approved by the OEM. This effect cannot be effectively shown by the data shown in figure 15, as the values used are averaged. This phenomenon can be observed clearly if data is analysed on a daily basis.

- The biggest problem is that since 2010 EL 1 is declared on a daily basis which means that the asset is operated outside of its operating parameters for an extended period which will result in premature ageing.

Cold Reserve

Cold reserve is energy that currently available but not operating. This is energy that is reserved and can be used in case of emergencies. Figure 17 shows how the cold reserve margin for the power plant is changing over the years.

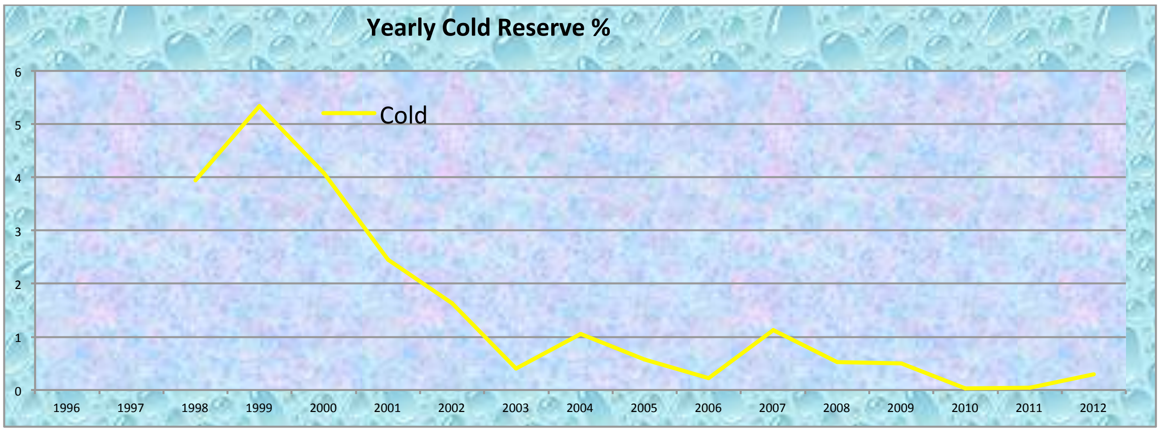


Figure 16: Average cold reserve

Observations/Findings

- Cold reserve margins have been declining from 1999 to the lowest point of 0 in 2010-2011 financial years.
- This shows that the Asset is operated closer to its limits to guarantee security of power supply to the National Grid
- Following this, asset failures are likey to affect the grid, impacting negatively on the public image of the company and hence putting asset managers under pressure to at times overlook asset health over security.

Running/off hours

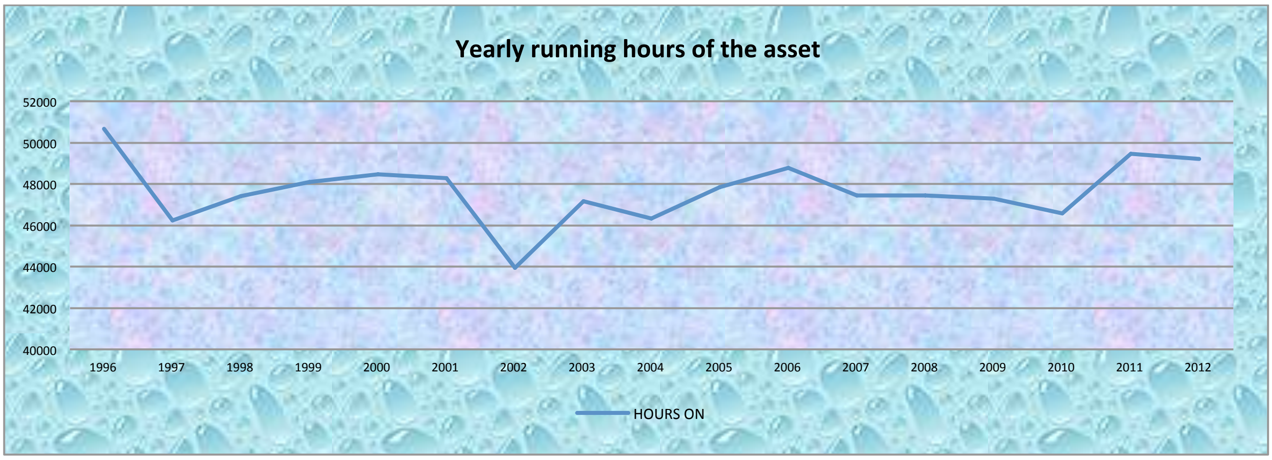


Figure 17: Yearly running hours

Observations/Findings

- Prior 2001 the power plant had very high operating hours.
- The operating hours dropped sharply from 2001 to 2002.
- The average operating hours has been decreasing since 2000.
- The asset is showing signs of strain since 2001, when the running hours are increased, it looks like the asset cannot cope and the running hours have to be decreased and then the circle starts again.
- The highest running hours since 2001 is 49466 as compared to a high of 50669 prior 2001 i.e in 1996.

Running/Off hours

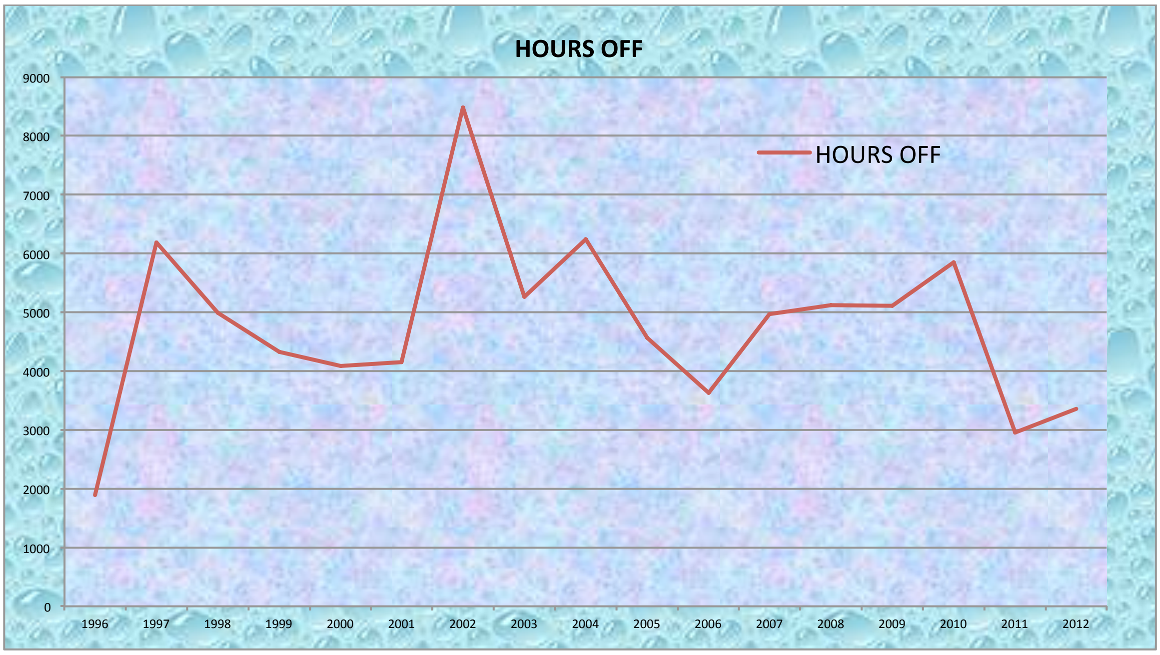


Figure 18: Yearly downtime hours

Observations/Findings

- Prior 2001, the asset had very low downtime, limiting maintenance opportunities on the asset (e.g 1891 in 1996) .
- Downtime required for maintenance doubled from 2000 to 2001 but has been decreasing since.
- The Power Station has not been able to reach low levels in the range of 1891 since 1996

Availability Indicators

Availability indicators shows how available the asset is to generate profit. Availability or unavailability of the asset is dependent on the losses in the system. Losses can either be due to planned activities such as maintenance, unplanned activities within management control or unplanned activities outside of management control. The asset generate more profit at higher availability. Generally, for any power plant, asset managers or their representatives together with the OEM uses different tecqniques to scientifically determine the number of downtime (outage) hours needed anually for preventative maintenance. Preventative maintenance ensures that the asset is continously renewed to sustain expected levels of perfomance. The information about the required downtime to renew the asset is used for planning of capital projects and budgetting.

For the asset under study the following preventative maintenance durations are required on an annual basis, namely:

- 1 General Overhaul (GO) = 42 days.
- 2 Interim repairs (IR) = 23x2= 46 day.
- 3 Boiler Tube Repairs (BTI) = 7x3 =21 days.

The above is based on a power plant with six units and the following requirements:

- A GO on each unit every six years.
- An IR on each unit every two years.
- A BTI on each unit every year (a BTI for a unit with an IR or GO for that particular year will be incooperated in the GO or IR, essentially there will be only three BTI).

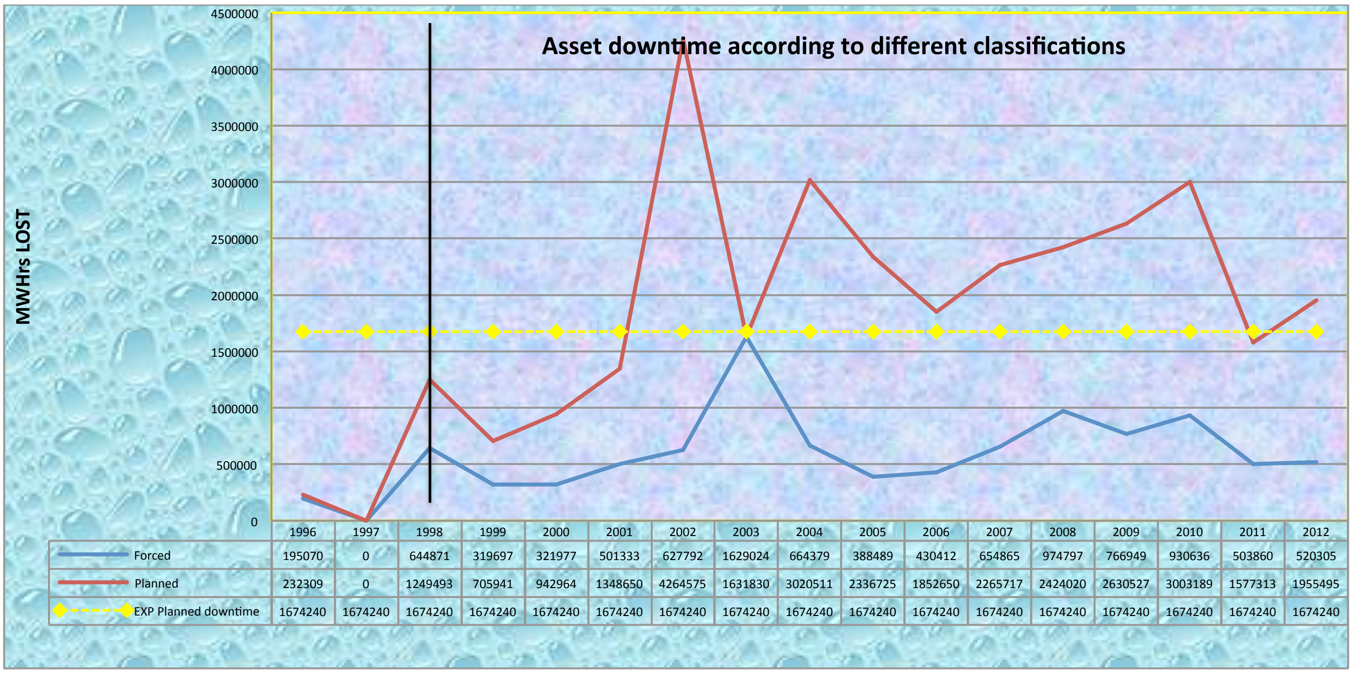
This means that on an annual basis a total number of 109 days is required. The asset produces a total of 686 MW of which 46 MW is used to supply the station internal auxilliaries. Only 640 is sent to the National Grid. This translates to 16,742,40 MWHrs annually.

Availability analysis achieves two objectives, namely:

1. Compares the station downtime against its own preventative maintenance strategy.
2. Benchmark availability indicators againts similar plants around the world. For this purpose percentages as opposed to the actual MWHrs will be used as the other plants have different sizes.

Graph 4 shows the asset downtime divived according different outage categories. This includes planned, unplanned but within management control (forced) as well as unplanned but outside of management control. The downtime is compared with the expected planned maintanace as determined by the Power Plant preventataive maintenance strategy.

NB: Data for 2007 finacial year is missing from the data set, this distorts trends from 2006 to 2008 financial year, following this, data before 2008 will not be used for analysis, that is indicated on Graph 4 with a solid black line



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Forced	195070	0	644871	319697	321977	501333	627792	1629024	664379	388489	430412	654865	974797	766949	930636	503860	520305
Planned	232309	0	1249493	705941	942964	1348650	4264575	1631830	3020511	2336725	1852650	2265717	2424020	2630527	3003189	1577313	1955495
EXP Planned downtime	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240	1674240

Figure 19: Yearly Asset downtime classification

<u>Observations/findings</u>

- Between 1998 and 2001, the total downtime average was below the expected planned preventative maitanance downtine, during this period, (three years), maintenance backlog was created.
- Maintenance backlog caused a strain on the asset as indicated by an increase in forced outages and the planned maintenance well above preventative maintenance strategy. This maintenance regime with creation of backlog could not be sustained, and in 2001 maintenance dowtime had to be sharply increased to the highest of 48,967, 81 MWHrs which represents 192.5% increase from the expected 16,742,40 MWHrs.
- Since 2001, the power station has not been able to recover from maintenance backlogs and the preventative maintenance downtime is continously above the expected downtime.
- Planned maintenance trend shows that there are unusually large deviations from the preventative maintenance plan. This shows that maintanace backlog is created to improve availability and when the forced outages increase because of inadequate preventative maintenance, planned maintenance are increased again to reduce the backlog and the cycle is repeated.
- The trend also shows that forced outage is indirectly proportional to planned preventative mainance downtime , for example between 2002 and 2004 planned maintanace was sharply decreased and in the same period forced outages increased, this is also the case

between 2003 and 2004 when the planned maintenance was increased, forces outages were decreased.

In order to compare availability of this power plant with other power plants, three indicators will be used in line with international standards. This indicators include PCLF, UCLF and OCLF. For benchmarking purposes operational indicators information from WEC PGP database were used. The benchmarking information for PCLF and UCLF was obtained only from 2005 to 2009. Benchmarking information for OCLF is not available.

Through years of collecting power plants perfomamnce data WEC has been able to classify perfomance of power plants according to four different categories referred to as quatiles, The information is shown in table 7.

Quartiles & Deciles for UCLF

Percentile	Value
Min	0
d1	1.94
d2	3.04
Q1	3.42
d3	3.97
d4	4.86
Q2	6.16
d6	7.34
d7	8.77
Q3	9.68
d8	10.89
d9	15.27
Max	91.33

Quartiles & Deciles for PCLF

Percentile	Value
Min	0
d1	2.08
d2	3.38
Q1	3.87
d3	4.36
d4	5.4
Q2	6.19
d6	6.99
d7	8.2
Q3	9.04
d8	9.93
d9	13.28
Max	100

Table 7: *Deciles and Quartiles for PCLF and UCLF* (WEC, 2010)

Unplanned Capability Loss Factor (UCLF)

Unplanned Capability loss factor is defined as the percentage of maximum energy generation that a unit in not capable of supplying to the National Grid because of unplanned energy losses. Energy losses are considered unplanned if they are not scheduled at least four weeks in advance. This refers to unplanned events that under management control e.g. load loss due to operating errors or inadequate maintenance. A low UCLF value indicates that the plant is reliably operated and highly available. UCLF is calculated as shown in equation 4.

$$UCLF = \{\overrightarrow{P_{LOSS}\ (within\ management\ control)}/MAX_{Energy}\} * 100 \qquad (4)$$

Where:

$$MAX_{Energy} = Unit\ Capacity \times No.of\ Units \times 24 \times No.days\ in\ a\ month$$

$$P_{LOSS}\ (within\ management\ control) = MW\ Capacity\ of\ losses\ within\ management\ control \times downtine\ of\ load\ loss$$

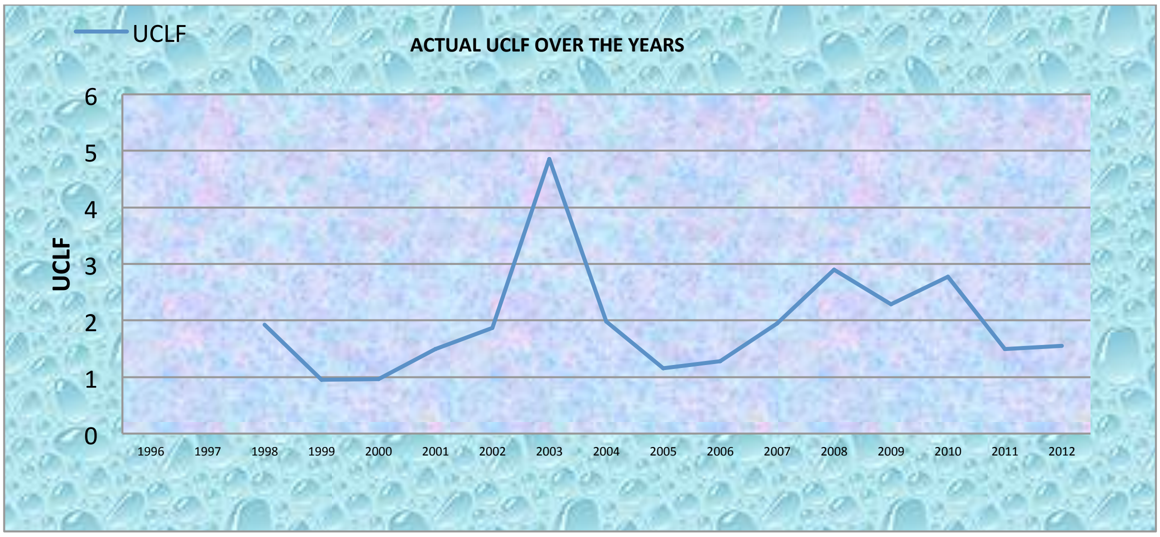


Figure 20: Yearly UCLF

<u>Observations/findings</u>

- The Power Station UCLF average is below 3 which puts this station perfomance in the first quadrant according to WEC classification.
- Following the above, this power station is considered as a world class perfoming station.
- Its only in 2003 when the station perfomed badly with a UCLF just below 5. During this period, the perfomance was placed in the second quadrand.
- Perfomance classification in this regards according to WEC classification does not take into account the means of achieving the low UCLF.
- The year 2002-2003 was a turning point for the power plant as the average UCLF became higher as compared to prior that period.

For this section of benchmarking, data from WEC database is used. UCLF variance from year to year is used to determinine if the yearly variance of the power plant under study compares with other power plants.

Fossil Steam Unit UCLF, 600 -799 MW

	2005		2006		2007		2008		2009	
	#Units	UCLF	#Units	UCLF	#Units	UCLF	#Units	UCLF	#Units	UCLF
TOTAL	158	7.21	143	7.06	140	7.78	142	8.18	141	9.25
Coal	127	6.92	119	7.44	116	7.86	117	7.72	114	8.7
Liquid	7	9.83	7	4.3	7	11.35	7	20.32	9	20.8
Gas	12	6.25	10	5.24	10	4.93	11	4.43	11	4.21

Table 8: UCLF benchmark (WEC, 2010).

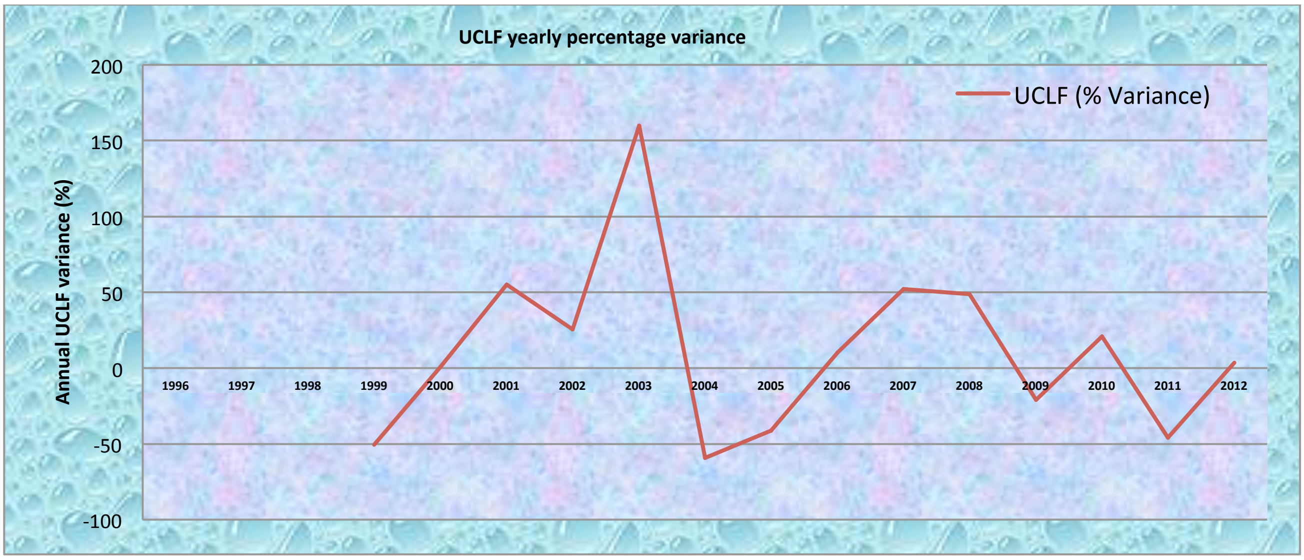


Figure 21: Yearly UCLF Variance

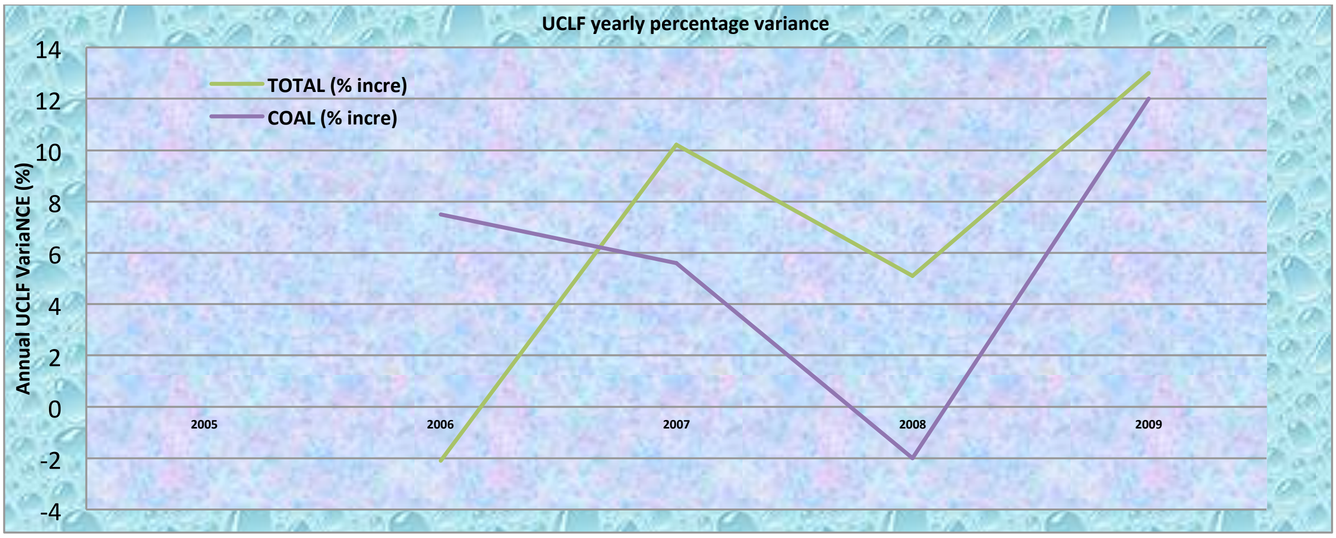


Figure 22: Yearly Percentage Variance

<u>Observations/findings</u>

- The higest and lowest variation in UCLF for the power plant under study is approximately 160% and -60 %. In comparison the higest and lowest variation in UCLF for the power plants on the WEC database is 13% and -2 % respectively.
- This shows that UCLF variation from year to year in unusually unsteady as compared to the pears. This is an indication of an irregular operation of an asset to achieve the required UCLF.

Planned Capability Loss Factor (PCLF)

Planned Capability loss factor is defined as the percentage of maximum energy generation that a unit in not capable of supplying to the National Grid because of planned energy losses. PCLF is determined by the maintenance regimen of the Power Plant. A relatively low value for PCLF as compared to the maintenance regimen may indicate that not enough opportunities are made available to perform perform maintenance activities. PCLF is calculated as shown in equation 3.

$UCLF = \overrightarrow{\{P_{LOSS}\ (preventative\ maintanance)/MAX_{Energy}\}} * 100$ ....(5)

Where:

$$MAX_{Energy} = Unit\ Capacity \times No.of\ Units \times 24 \times No.days\ in\ a\ month$$

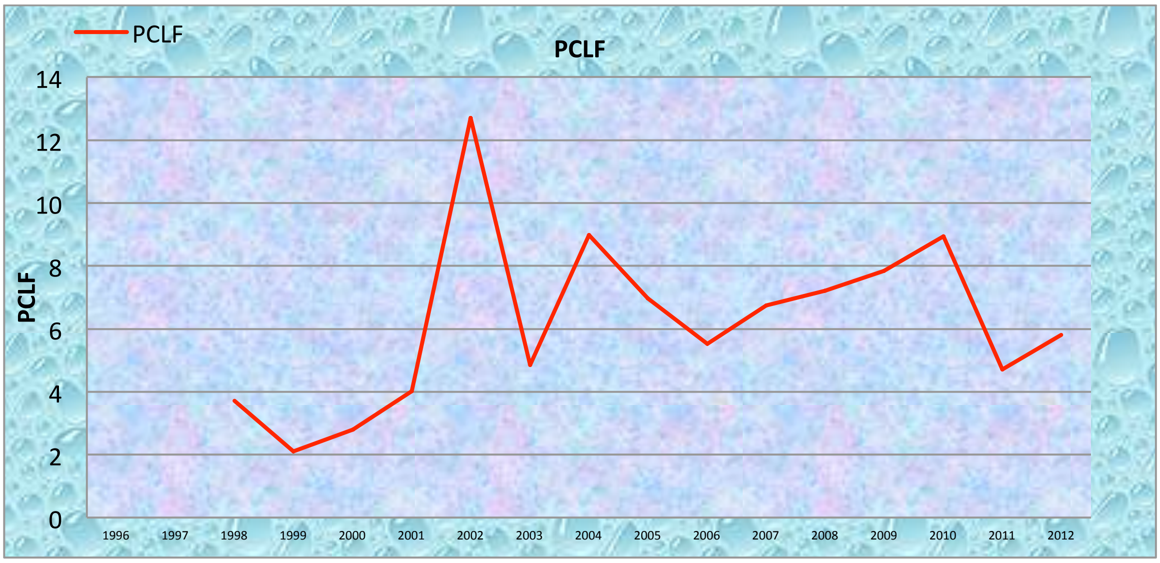


Figure 23: Yearly PCLF

Observations/findings

- Power plant perfomance in terms of PCLF is in the first and second quadrant according to WEC classification. The power plant was able to reach such level of perfomance because preventative maintanace downtime was kept way below the power plant preventative maintenance stratergy.
- According to the strategy which takes into account the ageing of the plant, plant perfomance in terms of PCLF should have an average of 4,7% which places the station in the fourth quadrant.
- From 2002 , the power plant consistently struggled to maintain such a perfomance.

	2005		2006		2007		2008		2009	
	#Units	PCLF	#Units	PCLF	#Units	PCLF	#Units	PCLF	#Units	PCLF
TOTAL	158	7.16	143	7.64	140	8.39	142	7.53	141	6.78
Coal	127	6.65	119	7.71	116	8.14	117	7.35	114	6.59
Liquid	7	15.37	7	5.12	7	10.61	7	10.2	9	8.61
Gas	12	8.53	10	9.01	10	10.56	11	10.06	11	7.31

Table 9: PCLF benchmarking (WEC, 2010).

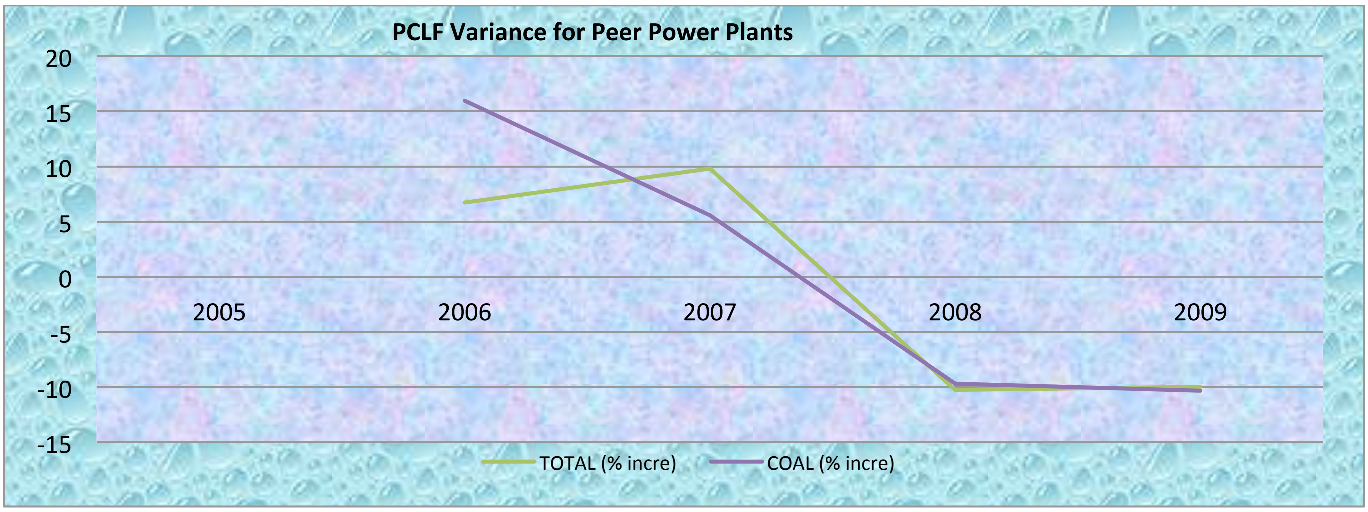


Figure 24: *Yearly % Variance Peers*

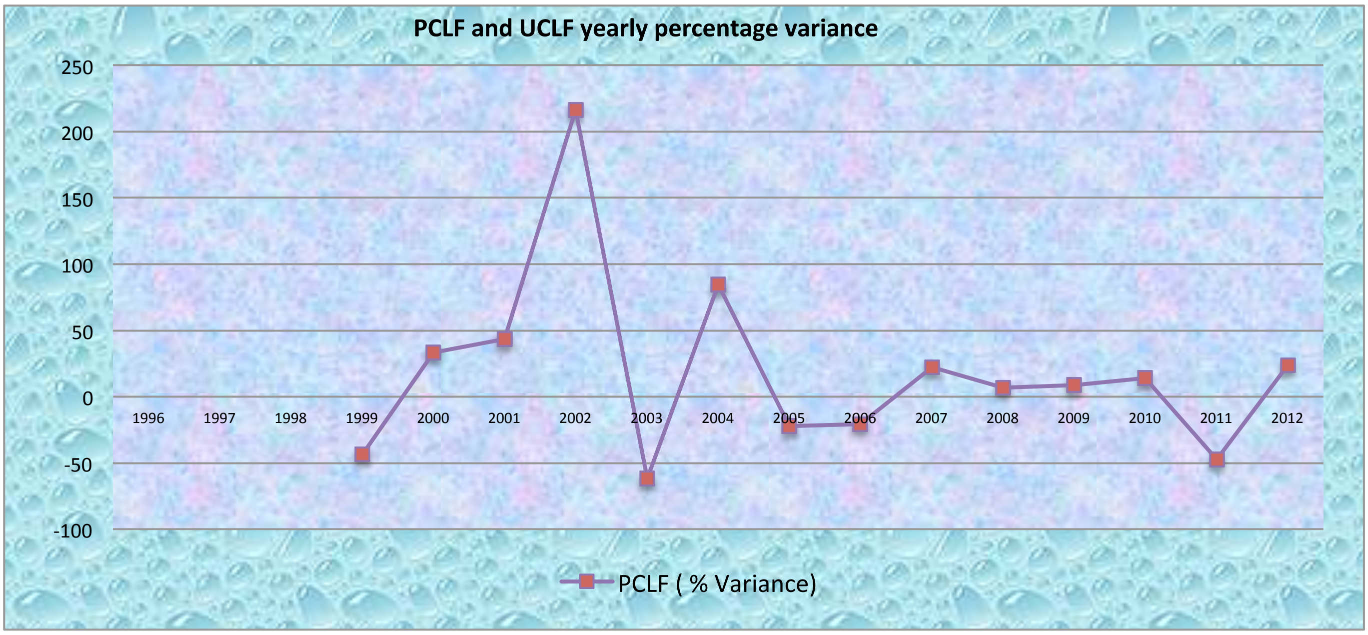


Figure 25: *Yearly % Variance Asset*

Observations/findings

- The higest and lowest variation in PCLF for the power plant under study is approximately 216% and -62 %. In comparison the higest and lowest variation in UCLF for the power plants on the WEC database is 16% and -10 % respectively.
- This shows that there is an obnormally high deviations from the planned maintenance as compared to peer power stations. This shows high irregularities in implementing the preventative maintenance strategy in order to regulate asset availability.

Other Capabilities Loss Factor (OCLF)

Other Capability loss factor is defined as the percentage of maximum energy generation that a unit in not capable of supplying to the National Grid because of unplanned energy losses. Energy losses are considered unplanned if they are not scheduled at least four weeks in advance. This refers losses associated to unplanned events that are beyond management control e.g. weather conditions. A low value of OCLF indicates that factors outside of management control are not significantly contributing to loss of capacity due to unplanned events. OCLF is calculated as shown in equation 7.

$$OCLF = \overrightarrow{\{P_{LOSS}\ (factors\ beyond\ management\ control)}/MAX_{Energy}\} * 100 \ldots\ldots(7)$$

Where:

$$MAX_{Energy} = Unit\ Capacity \times No.of\ Units \times 24 \times No.days\ in\ a\ month$$

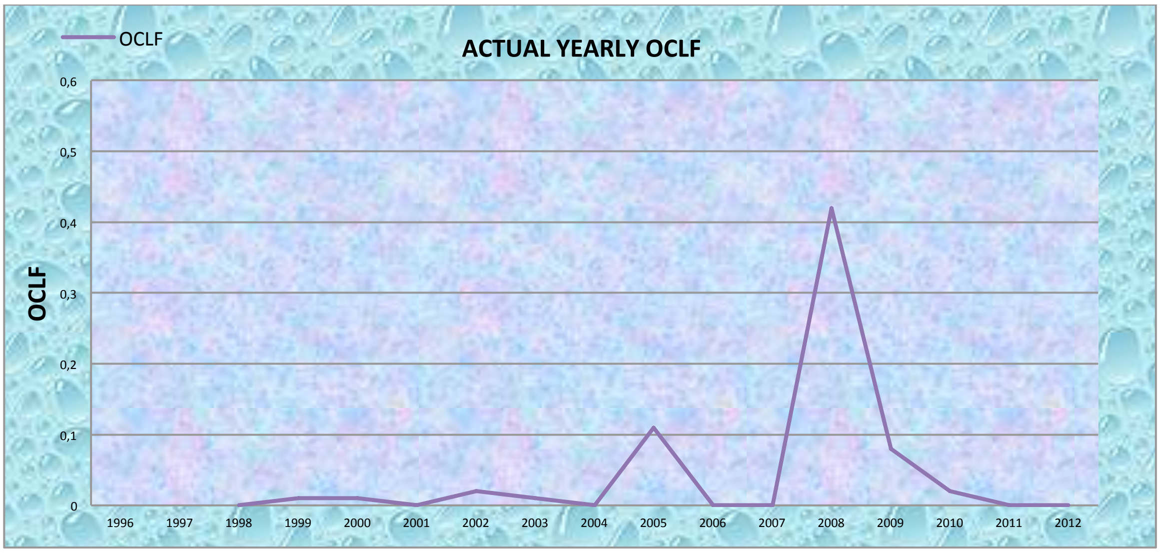


Figure 26: Yearly OCLF

Observations/findings

- OCLF is generally low except in 2008. This indicates that there are seldom factors that causes losses in the system due to factors that are beyond management control. Factors that causes losses in the system can be controlled by better management.
- In 2008 however the downtime due to OCLF added to an already stressed system. This is the year the country experienced extended loadshedding. Loadshedding is a function of other power plants within the business fleet. This could explain why even though from this power plant perspective, the worst unplanned outage occurred in 2003 from the fleet point of view, the worst unplanned outage occurred in 2008.

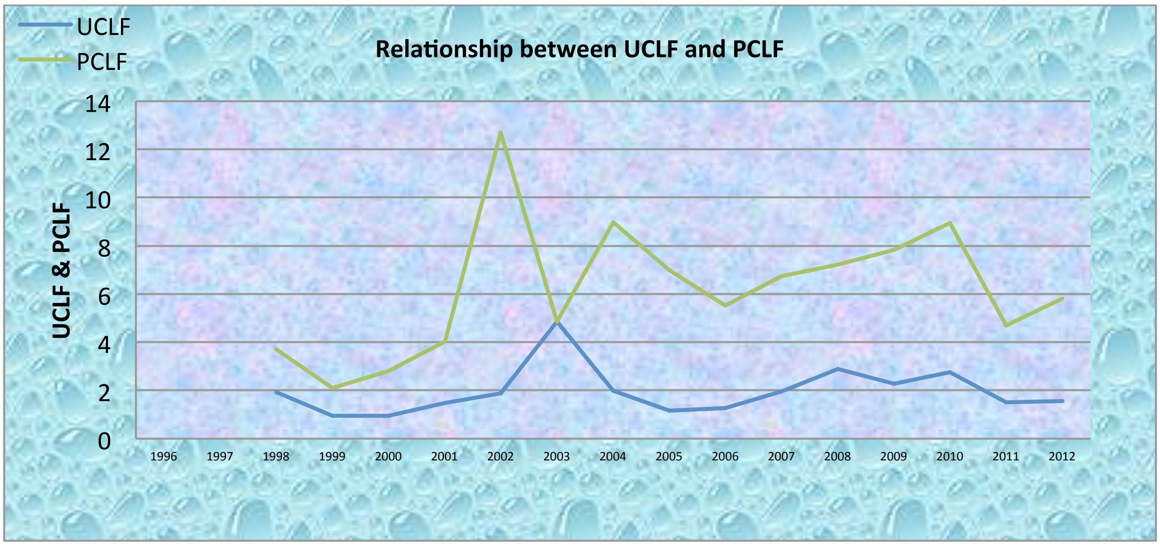


Figure *27: UCLF vs. PCLF*

Conclusions

- There is a direct relationship between planned maintenance and unplanned maintenance.
- If the asset is not renwed according to the preventative maintenance strategy, more breakdowns occurs.
- The first signs of power shortages were experienced in 2002 prior to which the asset was stressed by limiting maintenance opportunities and buiding up maintenance backlog.
- Planned Maintenance opportunities have consistently been decreasing from 2002, however the average value is higher than planned preventative maintenance strategy indicating that the asset cannot cope with expectations from asset managers.
- The data further indicates an unusual maintenance practice whereby planned maintenance opportunities are decreased as low as possible until an increase in unplanned Maintenance

opportunities becomes too high and the asset is forced down for maintenance because of intolerable number of disruptions.

- UCLF is controlled between 1.15% and 2.91% by varying PCLF. Decreasing UCLF by varying/compromising PCLF goes against the principles of asset management.
- Production losses due to circumstances beyond management control are very minimal except at the beginning of 2008.
- According to the quartiles and deciles, the Power Plant is considered to be one of the top performers because of minimal PCLF and UCLF however the means of achieving this performance is by compromising Asset Management.

<u>Reliability Indicators</u>

All generating units at the Power Plant are connected to the National Grid. Reliability indicators illustrate the level of service a Power Plant offers to the National Grid. The National grid operators buys reliability in order to ensure stability of the National grid and to improve competition amongst Power Plants connected to the Grid. Some Power Plants are only able to supply base load while others have an ability to assist with frequency control on the Grid. Two indicators will be used to measure reliability i.e. UAGS and SSR. For benchmarking SSR, data on figure 20 will be used. The data was obtained

	Category	Percentage
Weighted Average		91.4
	Best practice	100
A	Excellent	97.1
B	Good	94.3
C	Satisfactory	91.4
D	Poor	62.4
E	Very Poor	<62.4

Table 10: SSR benchmarking (UNIPEDE, 2008)

Unplanned Automatic Grid Separation

Unplanned Automatic Grid Separation indicates how often a generator connected to the national Grid is separated from it in both unplanned and automatic manner (all manual actions are excluded). This indicator takes the operating hours of the machine into account. The purpose of the indicator is to monitor reliability of services provided to the national grid and ultimately the customer. It also provides an indication of the reliability of maintenance and operation of the asset. UAGS is calculated as shown in equation 9.

$UAGS = \{Total\ Unplanned\ Automatic\ Grid\ Separations \times 7000\ Hrs\}/\{Total\ no.of\ operating\ hours\}$..(Equation 8)

Where

$Total\ Unplanned\ Automatic\ Grid\ Separations = the\ number\ of\ times\ the\ asset\ has\ been\ disconnected\ from\ the\ national\ grid\ in\ an\ unplanned\ manner.$

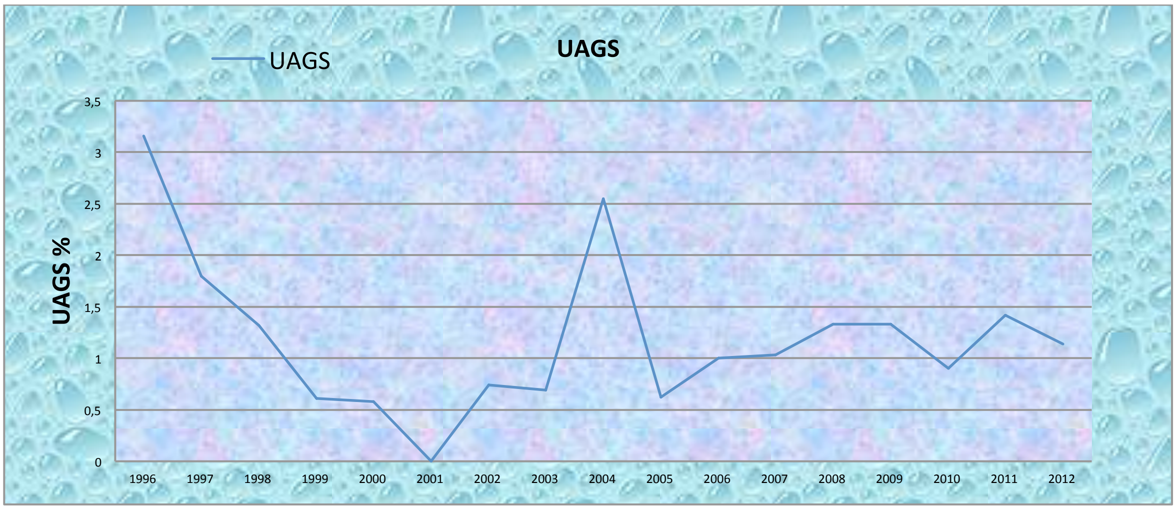


Figure 28: *Yearly UAGS*

Observations/findings

- Prior 2001, UAGS was high, it was notably the highest in 1996 at 3,16
- Efforts were put to reduce UAGS and it was at 0 in 2001, the same year when power plant experienced the worst power shortages.
- Following this, in 2001 the power plant was reliable in terms of power supply.
- Since 2001, the average UAGS was decreased as compared to the years before.
- The Power Plant in continually improving in terms of decreasing UAGS.
- This shows that realiabity of power supply to the grid in terms of low unexpected separation from the grid is excellent.

Successful Start-up Rate

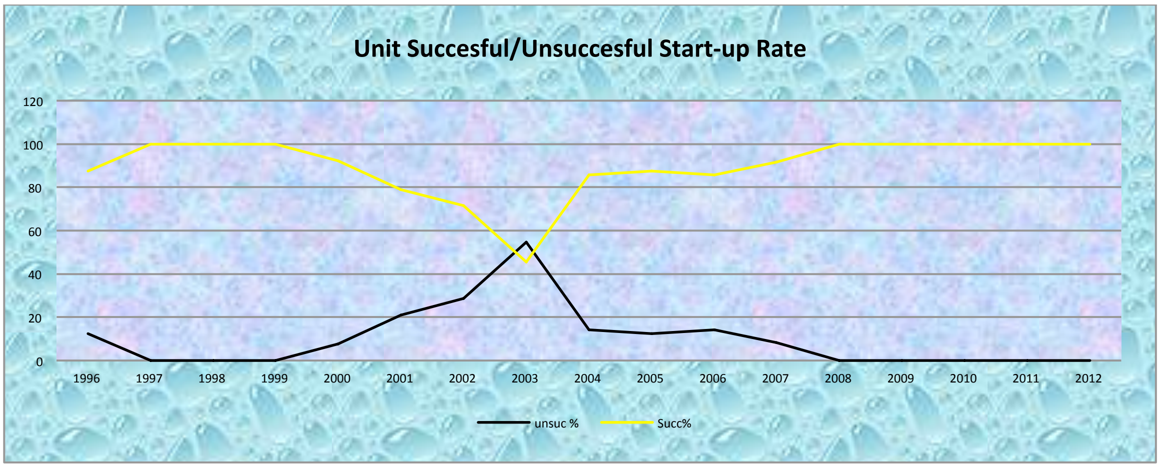
Successful Start-up rate is the ratio of number of successful start-ups to the number of contracted start-ups over a given time period. This indicator monitors how a Power Plant delivers on contractual agreement with the National Grid Operator. SSR is calculated as shown in equation 10.

$SSR = \{\{number\ of\ succesful\ Startups\}/\{Numbers\ of\ contracted\ startups\}\}\ x\ 100$.. (Equation 9)

$Number\ of\ sucessful\ startups = the\ number\ of\ times\ the\ asset\ was\ started\ up\ succesfully.$

$Number\ of\ contracted\ startups =$
$a\ total\ number\ of\ all\ contrated\ unit\ startups\ between\ the\ power\ plant\ and\ the\ National\ Grid\ Operator.$

NB: Contracted start-up is an agreement between the National Grid Administrator and the Power Plant. Successful start-up is considered to be 15 minutes before or after contracted time.



Figur*e 29: Yearly SSR*

Observations/findings

- Before 1999 the power plant success was very high.
- From 1999 to 2003 it dropped to a low of 45%.
- The power stattion put efforts to improve the success rate from 2003 to 2008.
- The power plant has been having a consitent 100% success rate for five consecutive years.
- This shows that realiabity of power supply to the grid in terms of succesful start-up rate is excellent.

Plant renewal (Plant Lifecycle Management)

Lifecycle planning is used to reflect different interventions required at different times during the operation of the asset to ensure that it is able to reach end of life profitably. Renewal is necessary to address deterioration in plant condition, environmental and safety requirements. For every plant area, there are currently indications from the OEM on when the particular plant areas will become obsolete or start experiencing wear and tear. This information is used in the planning process to determine when plant renewal projects should be implemented. A successful renewal project will be implemented within a scheduled time. Failure to implement renewal project as planned manifests themselves in the form of plant breakdowns and losses in production.

The Power Plant plans projects five years in advance through a process called technical planning. During this process, all projects that will ensure that the asset is renewed as per the technical requirements are budgeted for. The budgeting process is rigorous ensuring that only projects with a sound motivation are considered. The analysis will consider only capital expenditure as the other costs budgeted for during the technical planning process are considered as operational expenditure. The analysis will consider the following key points, namely:

- Whether the money requested by the Power Plant for capital spending on plant renewal projects is being spent in the right place and at the right time.
- There are generally three categories for capital projects i.e. Projects that are planned and are executed per plan, Projects that are planned but are not executed per plan and well as emergency projects that are not planned and not budgeted for.
- The Efficiency of the Power Plant in executing capital projects can be reflected by the yearly expenditure.
- A good balance in financial efficiency is achieved by achieving spending targets.
- The availability of resources from Engineering, projects and commercial to execute projects is very critical to ensure that spending targets are met.

Capital spending is planned according to the maintenance regimen. The maintenance regimen is divided into two sections i.e. day-to-day maintenance and periodical maintenance. Daily maintenance involves completing routine maintenance activities according to plant maintenance sheets. Maintenance personnel are required to complete routine maintenance sheets as well as attend to breakdowns. Breakdowns always take priority over routine maintenance activities because of the impact it has on production.

Periodical maintenance philosophy covers the scope of work to be performed on the plant as well as the frequency to avoid production disruptions in a form of breakdowns. The current maintenance philosophy is to overhaul each unit once a year for minor overhauls and every six years for a major overall. A minor overall lasts for 23 days while a major overall lasts for 42 days. In addition to the above maintenance opportunities, there are also boiler tube inspections that last for seven days.

With pressure to guarantee security of supply and hence profitability, some planned maintenance opportunities are either cancelled or the scope of work is reduced. Reducing the scope of work reduces the total downtime thus making the plant more available. A decrease in the number of planned maintenance opportunities results in an increase of the number of unplanned maintenance activities. To analyse Capital Spending, the power plant could only provide information for three years. The performance analysis is shown below:

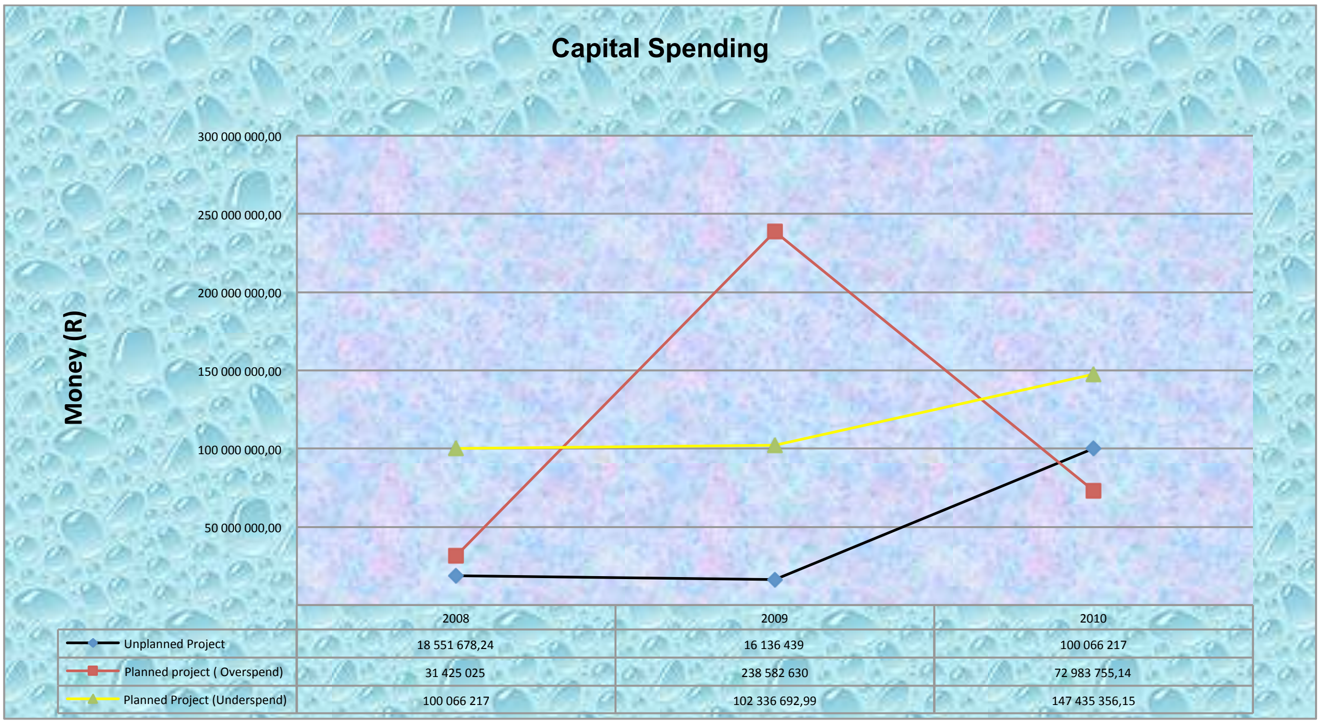


Figure 30: Capital Spending

Observations/findings

- Overspending due to emergency capital projects is increasing and it was the highest in 2009.
- Overspending on planned projects is increasing and the rate of increase rose sharply in 2009 and 2010.
- Under spending on planned projects is increasing and the rate of increase rose sharply in 2009 and 2010.

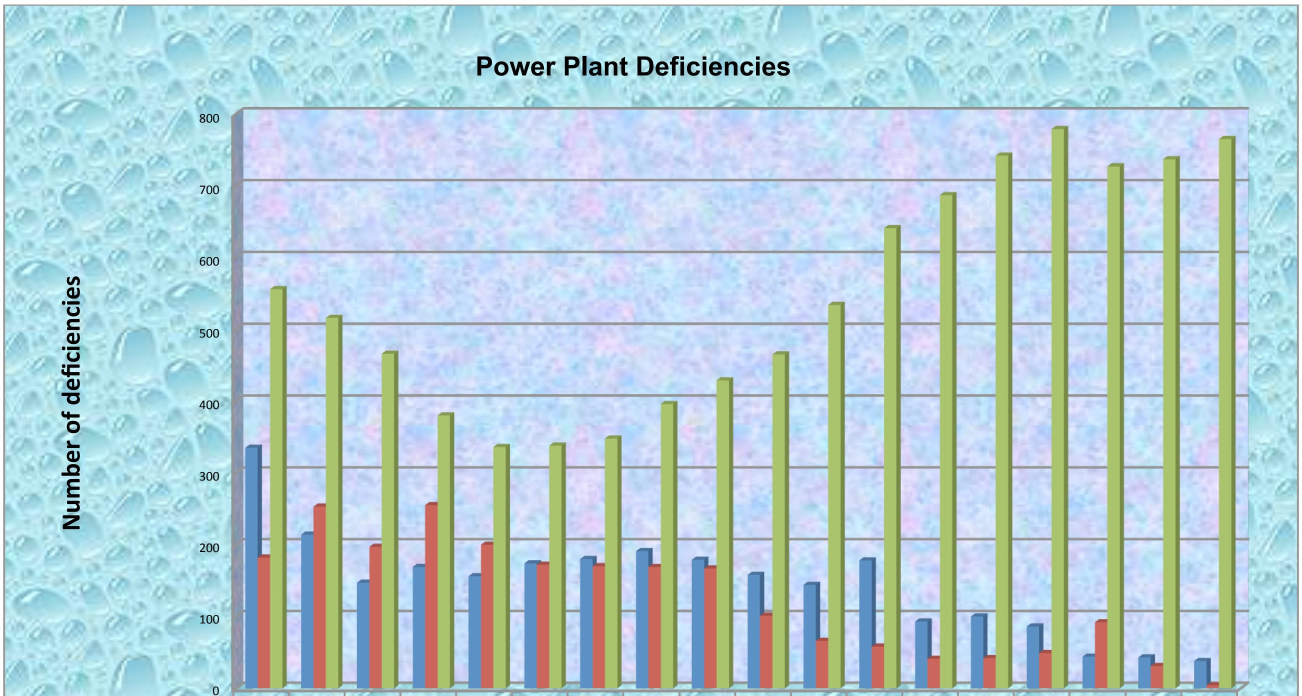
Conclusions

- Capital spending for only three years is limiting this analysis, data for at least ten years would provide a better analysis.
- There is direct correlation between making the units available for maintenance and capital spending because the plant needs to be available to implement the projects.
- Capital spending is planned according to the approved maintenance plan for the year. Contractual dates are also planned and negotiated with suppliers based on the maintenance plan. Following this, cash flow on capital project is always negatively impacted by changes in the plan.
- From PCLF analysis abovee, year 2009- 2010 had the highest PCLF since 2005. This could possibly signal that projects deferred from 2005 due to reduced PLCF were implemented in 2009. This could also signals that only projects that were considered critical were implemented and the less critical projects were deferred hence a sharp increase in overspending on some projects and under spending in other projects.

Plant Configuration (modification management)

Plant configuration is arguably the most important part of Asset Management even if it is often underestimated. If the configuration of the plant as per documentation does not reflect the true status of the plant, not only is it difficult to maintain and renew the plant, safety of personnel is compromised. In terms of plant renewal project, if the plant configuration is not accurate, projects are delayed and at times there is excessive overspending due to scope changes and reworks. Following this, the overal performance of the Deficiency Management System was analysed. Plant deficiencies are any abnormalities in the plant that can affect production or safety. The following indicators were used to measure the performance of plant configuration system:

- Backlog on plant deficiencies.
- Backlog on updating plant drawings per plant area.



	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Deficiencies raised	335	214	147	169	156	174	180	191	179	158	144	178	93	100	86	44	43	38
Deficiencies closed	182	253	197	255	200	172	170	169	167	101	66	58	41	42	49	92	31	4
Deficiencies outstanding	556	516	466	380	336	338	348	396	429	465	534	641	687	742	779	727	737	765

Figure *31: Power Plant deficiencies*

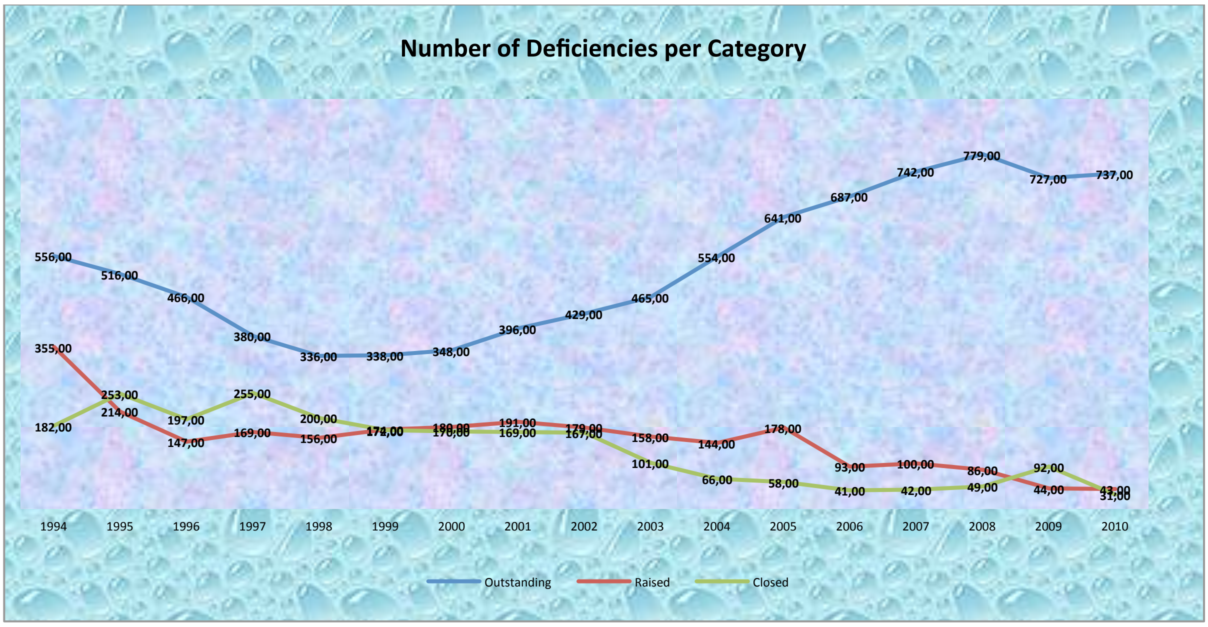


Figure 32: Number of deficiencies per category

<u>Observations/findings</u>

- Deficiency management system was established in 1991 and the earliest records available are from 1994.
- Between 1994 and 1998 the number of outstanding plant deficiencies were decreasing mainly due to the lower rate at which new deficiencies were raised. During the same period, the average rate of closing deficiencies was relatively hingher.
- There has been a systematic increase in a number of outstanding deficiencies since 2000. In the same period the rate of resolving (closing) deficiencies has been decreasing systematically.
- There was a sight improvement of resolving deficienciecies 2008 which is also supported by a slight drop in the number of outstanding deficiencies. This was also assisted by a slight drop in the number of new deficiencies being raised.
- There is an increased number of deficiencies raised from 2009 as compared to the years before.

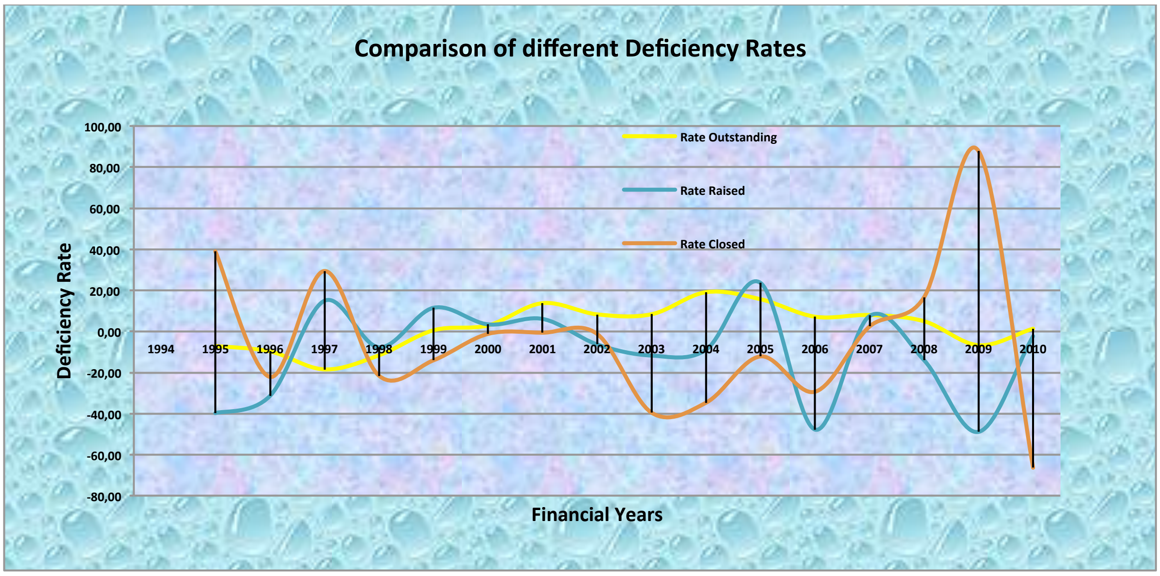


Figure 33: *Deficiency Comparisons*

Deficiency category	Number
> 11 years deficiencies	22
<11 years, > 9 years	64
< 9 years	69
Without a project leader	197
Total	**352**
Awaiting drawings	80
In progress and valid	447
Valid but no progress	159
Financial constraints	48
Can be closed in three months	64

Table 11: Deficiency Management System Statistics

Observations/findings

- Table 11 gives an insight as to why there are is an accumulation of a number of outstanding deficiencies. The main contributor is the slow pace at which deficiencies are being resolved.
- In addiction, the deficiency management system is not efficient as the average growth rate of the deficiency is increasing at about 7% but there is no focus to execute the deficiencies at a similar rate.
- A further analysis revealed that some deficiencies have not been allocated project leaders yet and hence lack of progress to resolve them. According to the System there are 197 projects with no project leaders allocated to them.
- There are also a further 155 projects which have been in the system for more than nine years without being resolved.

- Because of the inefficiencies with the process, a number of illegal modifications are done in cases of breakdowns in order to reduce downtime which make it difficult to control the system.
- The bottlenecks in executing Plant deficiencies and updating the plant accordingly include shortage of project management services, inefficient drawings department, lack of manpower in general.
- There is a discrepancy between the status of the plant and the documentation (drawings, manual etc) because of illegal modifications conducted in the plant.
- Lack of drawings that reflect the true status of the plant negatively impacts plant renewal projects, safety of personnel as well as training.
- Drawings are not properly listed making it difficult to search for drawings available on the system
- A committee which approves deficiencies and their execution thereof are not dedicated to the work as they are also assigned to other work.

Risk Management

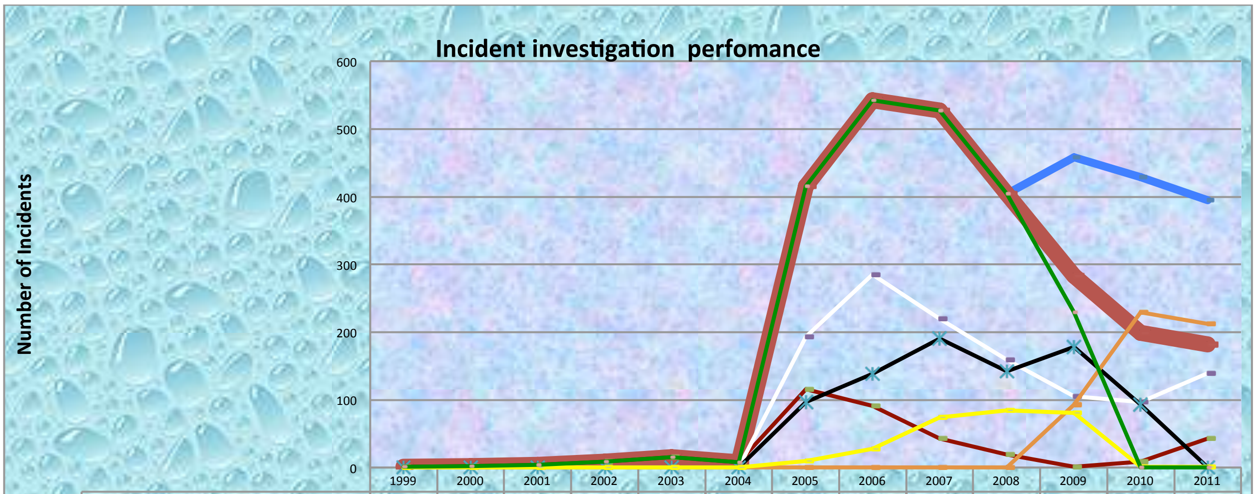
The risk management system at the Power Plant was established in 1997. There are two approaches used for risk management. One is a pro-active approach while the other is a reactive approach. The proactive approach involves indentifying risks that could potentially affect asset performance and hence production in the future. The reactive approach involves investigating incident that has already occurred. In both cases actions are generated to prevent the same incidents from re-occuring or that root causes of incidents are rectified to avoid re-occurrence. The increase in number of incidents may indicate that asset is not in a good condition due to reasons that can shown by further analysis. In some cases the incidents are due to human errors which might indicate a decline in training quality.

Risk Management analysis is done in two phases. The first phase analyses the effectiveness of the system. If an incident occurs and causes financial loss or equipment damage or threatens safety of personnel, the risk of the incident re-occurring exist until the incident investigation is completed and all actions to mitigate re-occurrence are completed. For the analysis, the following indicators were considered, namely:

- Incidents raised.
- Incidents investigated.
- Incidents investigates by the target date.
- Incidents that were investigated within a year from the target date.
- Incidents that took longer than a year to be implemented.

- Incidents awaiting investigation.
- Incidents not classified correctly (this constitutes error for this analysis).
- Incidents that are closed after all mitigating actions completed. The risk of re-occurrence ceases only when all the recommendations are implemented.

The second phase of the analysis classifies the top ten major plant incidents. The current management system uses codes to represent the root cause of completed incidents. This makes it possible to determine top contributors to plant incidents.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Incidents raised	1	2	4	9	15	8	416	542	527	404	458	429	395
Incidents investiged	1	2	4	9	15	8	416	542	527	404	283	199	182
Investigated on t <= target date	1	2	4	9	15	8	116	91	43	19	1	9	43
Investigated with target date<t<year	0	0	0	0	0	0	193	285	220	159	105	97	139
Investigation complete with t>365 days	0	0	0	0	0	0	97	138	190	142	178	93	0
Incidents ountstanding investgation	0	0	0	0	0	0	0	0	0	0	93	229	212
Not classified correctly	0	0	0	0	0	0	10	28	74	84	81	1	1
Incident closed (all actions completed)	1	2	4	9	15	8	416	542	527	404	229	0	0

Figure *34: Power Plant Risk Analysis*

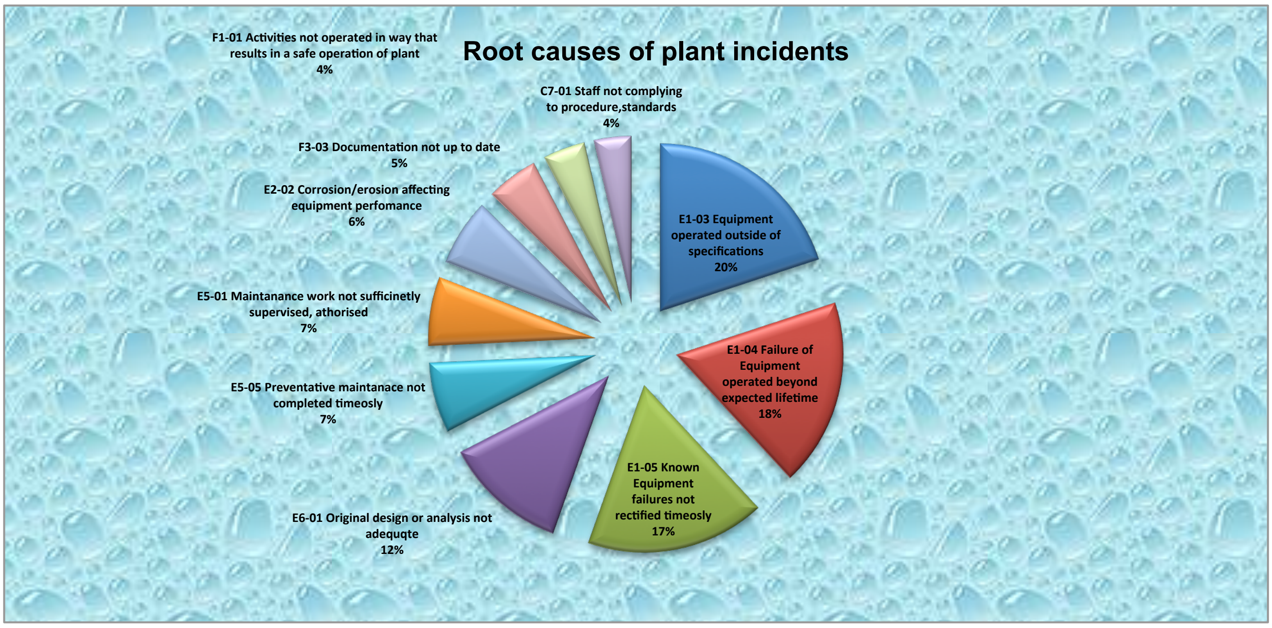


Figure 35: Root cause of incidents

The risk management system has been operating optimally from 1999 to 2004 as shown in figure 30. During this period incidents raised were investigated on time and the actions were completed on target. Plant risk exposure was significantly minimised.

- Analysis of GLF and reserve margins shows that the first signs of a tight National Grid were experienced in 2003.
- From 2004 the incident management system performance was very poor with number of incidents outstanding investigation reaching a peak of 229 in 2010. Incidents being investigated as per the target date decreased consistently since then.
- In cases where incidents are investigated, it takes longer to complete investigations. The longer it takes to investigate an occurrences, the higher the risk of re-occurrence.
- The accuracy of recording risk information into the risk management system has also increased as can be shown by the number of occurrences that are not classified correctly. The errors include not capturing dates etc.
- From 2005, the number of plant incidents raised increased sharply. Even though effort was put into implementing recommendations and closing occurrences, the inefficiencies in the system are still visible.
- Investigation into the top ten contributors to plant incidents revealed that certain equipments in the plant are operated outside of specifications.
- It also revealed that the equipment is operated beyond expected life, failures are not rectified immediately and preventative maintenance is not completed in time.

- This pattern is in line with the fact that the Unit is operated at high load factors and maintenance opportunities are limited.

4.1.2 Chapter Outline

Key Performance indicators have been analysed and observation have been made. Table 6 gives the deviation between Asset Management Policy Principles and hence PAS 55 and actual practices in reality. The evidence actual practices in reality is taken from and provided by the analysis in this chapter.

ID	FOCUS AREA	POLICY PRINCIPLES	ACTUAL PRACTICES
1	Long term plant health	Monitored, Measured, Assessed and documented	Monitored, Measured, Assessed and Documented.
2	Plant Maintenance	Master plan for test, inspection and interventions developed and maintained, Effective planning and scheduling	Planning and Scheduling not followed because of National grid capacity constrains, Maintenance regime compromised.
3	Incident Management	Effective allocation, Investigation and corrective actions	Investigations and actions not completed on time, information not captured correctly in some cases.
4	Configuration Management	Documentation, record keeping and history maintenance	System not maintained efficiently. Backlog very high.
5	Outages (PCLF & UCLF)	Minimize downtime without compromising asset condition for it to run until the next maintenance intervention	Downtime minimized at the expense of good asset care. Unplanned downtime increased due to breakdowns.
6	Operations	Operate the plant within design limits, document all processes	There is an increase in number of plant incidents due to sub-standard plant operation and operating it outside of design parameters.
7	Plant modifications	System to be established and effectively maintained	Modifications are raised but not closed and not closed. Drawings not updated timeosly
8	Quality Control	Maintenance of quality control systems, effective procurement and materials control	Not covered by the analysis
9	Plant classification	Established and maintained	Plant Classified and Maintained.
10	Reviews	Structures, processes to be set-up for business units to share experiences	Reviews (MRM) are Focused on profitability and not Total Asset Management
11	Safety, legal, Environmental regulations	Establish and maintain a Safety System	Not covered by the analysis

Table 12: Deviations between desired principles and actual principle

5. CONCLUSIONS

Effective Asset Management involves balancing out conflicting objectives related to the care and utilization of the asset in order to achieve required profits. The research was required to answer the following questions about Asset Management in the power station under study, namely?

1. What is the long-term impact of focusing on profitability and security of supply instead of total Asset Management for a Power Plant that effectively depends of physical assets to achieve their business goals?
2. How does Asset Management information of a profit driven organisation compare with global best practices in Asset Management?

To answer the above question, analysis of the power station performance had to be conducted to first prove if the Power Station under Study was profit driven. Utilization, performance and maintenance of the asset gives an indication of whether the management at the Power Plant is biased towards asset care or profitability and guaranteeing security of power supply to the customers. To quantify this, five categories as per PAS 55 were considered. The categories include: asset utilization, asset maintenance, asset renewal, asset modification and asset risk management.

5.1 Asset utilization

The asset care challenge is to strike a balance between taking care of the asset and using the asset to generate profit and hence ensuring security of supply to customers.. Asset utilization analysis shows that the Power Plant has moved beyond using the asset optimally by minimizing machines idle time, It is operating the asset at very high load factors closer to operating margings. Under-utilization of the asset is this case is not an issue because there are power shortages, the concern is overutilization of the asset. The combination of using the asset as much as possible, shown by higher EAF and operating the asset closer to its limits, shown by a higher GLF indicates that the asset is pushed to its limits in terms of utilization. Ideally if the asset has very minimal idling time it would be operated at average load factors in line with Maximum Continous Rating (MCR) with healthy margins. The negative effects of utilizing the asset in this way do not immediately manifest. Because of this, in the absence of online assessments tools that shows the deterioration of the machine as a result of the utilization regime, the false impression might be that because the asset is still running and producing the required power and hence profit, it can handle the stresses due to be operated in this manner. The balance between profitability and sustainability is not achieved as asset operated this way are susceptible to premature ageing. Long term profitability is sacrificed for short term gains. This is supported by the increasing in the number of modifications required as well as an increase in the number of incidents been reported in the system.

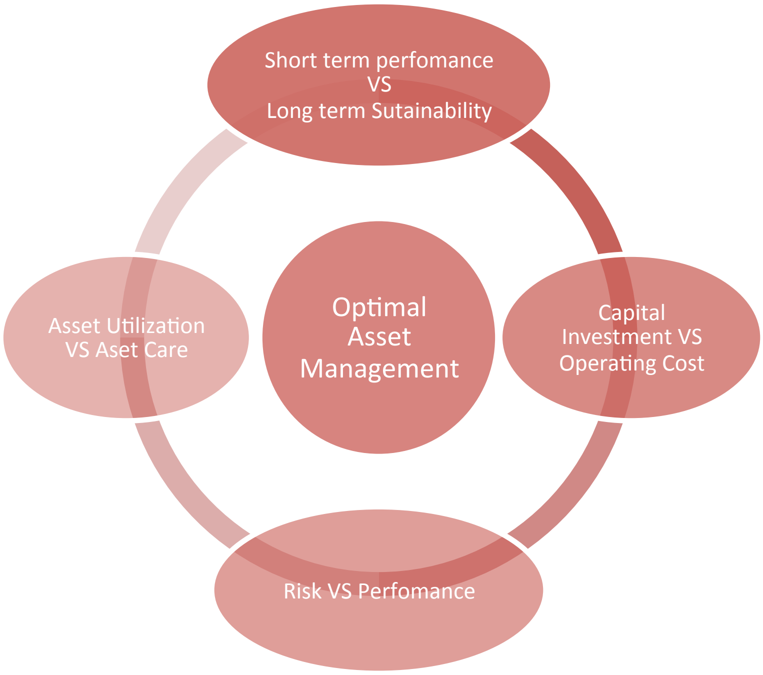


Figure 36: *Asset Management Conflicting Objectives*

5.2 Asset Maintenance

The maintenance regime of an asset needs to take into account of the utilization of the asset. As an example cars are maintained periodically according to the number of Kilometres they have travelled. If a car is used more it will have to be maintained more often than a car with a higher idle time. If an asset works harder (operates closer to limits and has minimal idle time), it needs to be maintained more often. The maintenance regime of the asset under study has not be reviewed in line with the operating regime in 2003 when the first signs of utilizing the asset harder was shown. Instead PCLF was decreased to make the asset more available. The irregularity of the PCLF also indicates that if the asset is forced to be taken down it takes longer for it to be returned back to service because of other consequential damages to the asset that might not have been anticipated. Short term availability and hence profitability takes precedence over maintenance. The impact of this is shown on the increases time taken to implement modification to plant because of deficiencies. Furthermore, analysis of the incident management systems indicates that the third highest contributor to plant incidents is because known equipment failures are not rectified in time. Prior 2001, in addition to operating the asset closer to its marging, maintenance opportunities were limited building a maintenance backlog. The data shows that this asset utilization regime could not be sustained and since then asset managers have been struggling to clear the backlog. The stress on the asset is futher ecercebated by growing demand for electricity.

5.3 Asset Renewal

The asset renewal strategy is formulated according to the operating and maintenance regime of the asset. If the operating and maintenance regimes changes, the renewal strategy must be ratified as such. Capital spending of renewal projects indicates that even with the original asset renewal strategy, the spending is not according to what is planned. The irregularity is capital spending is due to the fact that the Power Station prioritises attending to breakdowns to renewing the asset in time. The incident management system shows that the second most contributor to plant incidents is that asset components are operated beyond their expected lifetime. Further analysis shows that most of the projects being deferred to allow that asset to run are electronic in nature. It is difficult to predict the deterioration rate of electronic equipments, the closest prediction there currently is a bathtub curve which shown how failure rate shown in figure 24. Following this, the false comfort that an electronic system is still operating even after it is obsolete and the deterioration cannot be quantified gives the decision makers false confidence to defer electronic project. While this is not a big problem when an asset is operated manually, it is a problem for a highly automated asset. In a highly automated environment, electronic system performs control and protection functions, failures of such systems will render the asset inoperable. This seemingly pattern of running the asset to failure is in line with pushing the asset to its limit to get economic gains in the short term. The impact is that renewal project is rushed when the asset stands because of failures. This results in inadequate analysis of technical requirements, poor contracts being issued to external contractors, reworks and overspending on budgets. The incident management system shows that the fourth most contributors to plant incidents is that the original design or analysis was inadequate. The three year data about capital spending is not sufficient and if more data could be obtained, this point could be supported better.

5.4 Asset Modification

The golden rule of Asset Management is to know the status of the asset at all times. Following this, the quality of information about the asset is critical. When an asset is new, it is issued with relevant documentation and drawings. Modifications to the asset for any other reason should also ensure that the relevant documentation is modified to reflect the status of the plant. The analysis of the deficiency modification system indicates that updating of relevant documentation after modifications are done is poor. This is shown by the time it takes to resolve and close modifications. A modification is considered closed after it is completed and all the relevant documentation has been updated. The advantage for the power station is that even though the turn-over of staff is higher, people who have been working in the Power Plant from commissioning, mostly in their 50's are still available. Management of the quality of information has shifted from being system based to people based. The analysis also indicates that information is often not captured correctly making it difficult for people to search and access information. The inefficiencies in executing modifications/projects could be attributed to the poor quality of Asset Management information systems. The analysis further shows that there is focus of implementing modifications that has a immediate negative impact on plant availability and not necessarily the paperwork that goes with the modification. There are also deficiencies in the system that are valid but there is no progress because the deficiencies do not immediately negatively impact the asset.

5.5 Asset Risk Management

The original aim of the risk management system was to have a standardised methodology of managing asset risk. While the system worked well in the first five years of implementation, the analysis shows that a lack of focus on the system resulted in the backlog of incidents investigations and the closure thereof. The analysis also reveals that the rate of capturing information incorrectly has also increased. Furthermore the information in the system is not used to review causes of plant incidents to minimize the risk of re-occurrence. An optimised Asset Management system requires that asset information from computerised systems be captured correctly but most importantly be used to optimise the Asset Management system. The true benefits of the system is not truly realised when the information is not used for optimization. The mean time to investigation of incidents is too long; the analysis shows that some incidents take more 365 days before they are investigated. Until an investigation into an incident is completed and all the actions are closed the risk of re-occurrence is high.

Analysis of historical data about the operation of the asset has been able to provide essential information about the state of Asset Management at the Power Plant. It shows that operating the asset harder to have short term gains will be negated in the long term by unplanned failures. This means that short term gains cannot be sustained. This is supported by the following,

From analysing the data, it clear that prior to the year 2001, a maintenance backlog was created by limiting plant renewal opportunities and operating the asset closer to its limits to maximixe profitability. During this period, the country enjoyed a very reliable electricity supply with almost no load shedding. After 2001, the asset is struggling to sustain the perfomance and the maintenance backlog is not cleared. On the contrary the backlog is accumulating. The Perfomance is slightly sustained by reducing the reserve margins to zero. The asset is also showing strain due to the increased number of plant incidents as a result of limited maintenance opportunities. Supporting systems such as deficiency management system and risk management have also shown signs of deterioration from 2001 as the consequences of placing profitability above asset management began to show. The bias towards guaranteeing the security of supply is further shown by considerable improvemnts in the numbers of successful start up rate and UAGS reduction. The same improvents are unfortunately not translated into other aspects of Asset Management. This means of asset utilization and care where no balance is reached is not sustainable. This analysis validates the following hypothesis

"By conducting a single case study on a Power Plant in South Africa, which is perceived to be driven by profitability and security of electricity supply the following hypothesis can be tested.

- A focus on Total Asset Management inherently ensures sustainable profitability and asset performance over the useful life of the asset.
- A reduction of the risk of load shedding by reducing maintenance opportunities and operating the asset at high load factors is not sustainable."

6. RECCOMMENDATIONS

PAS 55 is on the verge of becoming a fully fledged ISO standard. Companies around the world who have adopted PAS 55 across all sectors are rapidly picking up the potential benefits through higher reliability, stable and cost-effective asset performance, improved customer service and enhanced relationships with customers. The UK regulator, OFGEM, has mandated that all UK utilities to be compliant with the specifications of PAS 55. The compliance to the standard is shown through certification. OFGEM has advised Network Companies that certification would help provide assurance of long-term asset stewardship and establish greater clarity of Asset Management policy and processes that underpin investments decisions. Dutch regulator, DTe has also stated that PAS 55 is an appropriate answer to the regulatory requirements set on utility distribution companies. PAS 55 certification would provide assurance to a growing number of regulators around the globe (North and South America, Europe and Asia) who have expressed interest and encouraged their utility charges to consider adoption of PAS 55 (UMS Group, 2012).

The Power Plant under study has adopted the principles of PAS 55 and currently has an Asset Management strategy and directive. The objective of the strategy as mentioned in the directive reads "the objective of the Plant Asset Management Directive is to mandate minimum life cycle

Asset Management principles to be adopted to achieve a safe, reliable, cost effective and sustainable management of asset". Data about the operation of the Power Plant clearly contradicts this objective as the asset is not being operated in a sustainable manner. If the principles of any standard being adopted are not applied entirely, true benefits cannot be realized. The recommendation is that the Power Plant re-launches the Asset Management system with a special emphasis on system enablers, implementation, control and review.

PAS 55-2:2008 4.1 "General Requirements" states " An organization seeking to establish an Asset Management system that conforms to PAS 55-1 should determine its current position with regard to its Asset Management by means of review. This is all part of ensuring an environment where an Asset Management System can flourish. In the absence of such an environment such a system may fail. Some of the system enablers include the following:

- Reviewing the current status of the plant in terms of design information, risk management, performance management, operations, maintenance, finance and spares handling. This is to ensure that the baseline for implementing the system is current.
- Reviewing the organisational structure to ensure that it supports implementation of the system.
- Reviewing information systems to ensure that the quality of data used is reliable. This includes checking if the information is captured correctly and the systems are reliable.
- Reviewing the skills of the personnel required to support the system at all levels.
- Ensuring that consistent information about the intention of the Asset Management system communicated to the employees.

Implementation

Implementation of PAS 55 is not straightforward. This is because the principles applied must be integrated within the existing Asset Management structures. The challenge for the asset manager is to ensure compatibility between PAS 55 principles within the existing systems. Where contradictions exist, such contradictions must be identified, recorded and rectified. In a Utility with a number of business units, the enablers of Asset Management in a form of business processes must be decentralised. This will ensure that an umbrella approach is not taken for all asset and specific challenges and uniqueness of each business unit are addressed individually. The power Utility needs to pay special attention to Asset Management Enablers e.g. authority, set out in PAS 55-1:2008 and demonstrate compliance if implementation is to succeed.

Control and review

Many systems are implemented correctly with the best on intentions but turn to collapse as time elapses, to ensure that the system continues to operate appropriately after implementation, maintenance effort is required. Information collected by the Asset Management System is only useful if it is used for optimization and improvement of the system. The Organization must be able to interrogate the collected data and continuously compare with its peers in order to stay at the forefront of Asset Management. In the absence of control and review measures, the system cannot be appropriately optimised to reach the state of maturity.

7. REFERENCE LIST

He Yong-xiu, Wang Wei He, Qun Wang, Da-wei Bus, 2006. Research on Relationship between Cycles of Electric Power and the Economy Growth in China Based on Maximum Entropy Method [internet]: China (Published in 2006).Available at:
http://ieeexplore.ieee.org/xpl/mostRecentIssue
[Accessed 8 July 2011]

Department of minerals and Energy, 2008. National response to South Africa's Electricity Shortage interventions addresses electricity shortages [internet]: South Africa (Published in 2000) Available at
http://www.info.gov.za/otherdocs/2008/nationalresponse_sa_electricity1.pdf
[Accessed 26 June 2011]

UMS Group, 2010. PAS 55 Overview, Global perspectives and Implications for the US, NARUC Winter Meeting [Internet]: America (published in 2010) Available at:
http://www.narucmeetings.org/Presentations/PAS55%20Presentation%20rev1.pdf
[Accessed 26 January 2011]

Malaysia Today online, 2011. Pua-why-pay-for-high-power-reserve-margins [Internet]: Malaysia, (Published in 2011)
Available at: http://malaysia-today.net/mtcolumns/newscommentaries/41372-pua-why-pay-for-high-power-reserve-margins
[Accessed 28 June 2011]

Alfredo Vaccaro, 2005? Reliable Electric Power for Developing Countries [Internet]: USA (IEEE.org) Available at:
http://www.ieeehtc.org/files/Reliable_Electricity_Challenge_Description.pdf
[Accessed 01 July 2011]

Bent E. Sorensen, 2005, ECONOMICS 7395: Granger Causality [Internet]: Houston, 2005
Available at:
http://www.uh.edu/~bsorense/gra_caus.pdf
[Accessed 15 July 2011]

South Africa Institute of Internal Affairs, 2010, BRICS [online]: (Updated August 2011)
Available at: http://en.wikipedia.org/wiki/BRIC
[Accessed 9 August 2011]

Evert Agneholm, 1996. The restoration Process Following a Major Breakdown: Technical Report No. 230 L. Department of Electric Power Engineering [Internet] Goteborg Sweden. Retrieved from
http://webfiles.portal.chalmers.se/et/lic/AgneholmEvertLic.pdf
[Accessed 9 August 2011]

British Standards Institution, 2000. Information Security Management Systems – Specifications with guidance for use (ISO 17799) [Internet], UK (Published, 2000) Available at:
http://iso-17799.safemode.org/index.php?page=asset_owner
[Accessed 9 August 2011]

Yong Sun, Warwick Robinson, Lin Ma and Colin Fidge, 2008. Adopting the Split Asset Management Decision-Making Process Model for Economiser Maintenance Management [Internet]: Australia (2008). Available at:
http://sky.scitech.qut.edu.au/~fidgec/Publications/sun08b.pdf
[Accessed 24 May 2011]

SAPP, 2009. Overview of the South African Power Pool: SADC-SAPP-RERA Investor Roundtable [Internet] Zambia. Available at:
http://www.sapp.co.zw/docs/SAPP%20Overview
[Accessed 24 May 2011]

H Fawkes, 2005. Energy Efficiency in South Africa Industry: Journal of Energy in Southern Africa. Vol 16 No 4 [Internet] Cape Penitsula. Available at:
http://erc.uct.ac.za/volume16/16jesa-fawkes.pdf
[Accessed 24 May 2011]

H. Doloi and Professor A. Jaafari, 2006. Managing Complex Assets through Project Based Management Project Management Programme Department of Civil Engineering [internet]: Sydney (Published, 2006). Available at:
http://www.zulanas.lt/images/adm_source/docs/2%20HDoloi_AJaafari-full%20paper-ENG.pdf
[Accessed 30 June 2011]

R.B Faiz and A. Eran, 2009. Decision Making for Predictive Maintenance in Asset Information Management [Internet] Edirisinghe (Published, 2009). Available at:
http://www.ijikm.org/Volume4/IJIKMv4p023-036Faiz422.pdf
[Accessed 24 June 2011]

Democratic Alliance, 2008. Electricity Sector Reform, DA discussion document, [internet] South Africa. Available at:
http://www.da.org/docs/Electricitysectorreform_document.pdf
[Accessed 24 June 2011]

D. Newbery and A. Eberhard, 2008. South Africa Network Infrastructure Review: A paper written for the National Treasury and the Department of Public Enterprises, Government of South Africa. Cape Town.

Terry Wireman, 2005. Developing Performance Indicators for Managing Maintenance, Copyright 2005, Industrial press, Inc, New York, NY.

Benjamin S. Blanchard, Wolter J. Fabrycky, System Engineering and analysis (second Editions), prentice hall international series in industrial and systems engineering, 4th edit.

Norman S. Nise, 2008. Control System Engineering (Fifth Edition), John Wiley & Sons, Printed in the United State of America, 2008.

R.K Yin, 2003. Case study Research: Design and Methods (3rd Edition). Thousand Oaks CA: Sage.

Jan Myburg,2009?. Investigating PAS 55: Developing Asset Management system elements to improve your shutdowns [internet] South Africa. Available at
http://saama.org.za/media/DIR
[Accessed 24 June 2011]

The infrastructure Consortium for Africa, 2008. Power Supply Situation in Africa: Background Paper prepared for ICA Annual Meeting March 2008 [Internet] Tokyo. Available at:
www.icafrica.org/fileadmin/documents/Tokyo/Background_paper_power_suply_situation_in_Africa_FINAL.pdf.
[Accessed 15 October 2011]

P Baxter and S. Jack, 2008. Qualitative case study methodology: Study and design implementation for novice researchers. The qualitative Report, 13 (4), 544 – 599 [Internet]. Available at:
http://www.nova.edu/ssss/QR/QR13-4/baxter.pdf
[Accessed 15 February 2012]

W. M Davis and T.J Beaumont, (2007). Case Studies: Research Methods, Teaching and Learning Unit, Faculty of Business and Economics, the University of Melbourne [Internet] Australia. Available at:
Http://tlu.fbe.unimelb.edu.au/
[Accessed 15 February 2012]

ENERGY FUTURES AUSTRALIA, 2004. Generic models for Electricity Industry Structure, [Internet] Australia. Available at:
http://www.efa.com.au
Accessed 10 February 2012]

Dawson, ion, Catherine, 2002. Practical Research Methods [Internet], New Delhi (Published, 2000)

UNIPEDE, 2008. Statistical data on the performance of fossil-fuelled Power Plants: General Report (1990-1997). Ref: 1998-514-002 [Internet] France. Available at:
http://www.documentation@unipede.org.
[Accessed 15 February 2012]

World Energy Council, 2010. Performance of Generating Plant: New Metrics for Industry in Transition [Internet] United Kingdom. Copyright World Energy Council. Available at:
http://www.worldenergy.org
[Accessed 09 February 2012]

EE Publishers, 2008. The future generation capacity and reserve margin outlook [internet] South Africa. Copyright World EE Publisher. Available at:
www.eepublisher.co.za
[Accessed 09 September 2012]