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THE EFFECT OF PLANT AVAILABILITY ON LIFE CYCLE PERFORMANCE OF COAL FIRED POWER STATIONS

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Abstract

This paper seeks to identify production and maintenance problems that are related to key availability factors such as times to failure (reliability), repair times (maintainability) and waiting times (maintenance support) and use them as a yardstick for adjudging the efficacy of Availability Centred Maintenance, (ACM) using the Pareto analysis for the significant failures. It also explores the possibility of import substitution, and spare part interchangeability and the implementation of internationally recognised standards such as, ISO 9000, ISO 14 000, use of Pareto analysis to establish the unavailability and downtime cost significance regime. The research then recommends the possible use of FMECA to those statistically or maintenance significant (ABC) items. The paper further recommends the implementation of softer aspects of maintenance management such as performance based contracts, benchmarking and identification of training needs.

Keywords: Availability Cenred Maintanance, Availability, Pareto Analysis, ISO

Introduction

In the today's competitive world, industries are compelled to use the most appropriate production and maintenance strategies in order to achieve set goals and survive in business. Competition in the power industry in Zimbabwe is growing fast with the creation of the Southern African Power Pool and the proposed privatisation of the power industry[1] . Zimbabwe currently can produce 80 % of its electrical power needs but actually produces 65% because of unavailability problems[2]. Hwange power station can produce 40% of the country's power needs but actually produces 30% because of plant unavailability or partial availability which makes units fail to achieve full load.

The other three coal-fired thermals namely Bulawayo, Munyati and Harare power stations could produce a combined 20 % of the country's power needs but actually produce between 0 and 5% as they are down most of the time due to aged plant equipment and unavailability of coal. The latter is caused by long distances involved in transporting the coal from Wankie Colliery Mine in Hwange to the three destinations. it is Production costs at these three old thermals are 3 to 5 times those at Hwange and Kariba and actually cheaper to import than to produce from these old stations. They have not been de-commissioned since 1975 as there are no back-up stations that will cater for the downtime period.

Kariba' hydroelectric power station can produce only 35% of Zimbabwe's power needs because of high plant load factors and high plant availability. This is because hydroelectric power plants have considerably fewer auxiliaries than coal fired power stations. Hydroelectric power plants for instance do not have a boiler and associated auxiliaries. They also do not have coal and ash plants or water treatment plants. Their turbine plant has fewer auxiliaries than those found in thermal power plants hence hydroelectric power plants are easier to maintain compared with coal-fired power stations[3].

Although power can be imported from neighbouring countries namely South Africa, Mozambique, Zambia and DRC, Zimbabwe struggles to import the 35 % shortfall because of an acute shortage of foreign currency. Maximum plant availability at Hwange power station would mean only a shortfall of 25% has to be met by imports.

Against this background, it is clear that life cycle profitability of power stations in general and coal fired power stations in particular depends on plant availability[4]. For power stations, the costs of unavailability due to breakdowns or partial loading of unit, easily erodes benefits achieved by high combined efficiency of the boiler and turbine plants[5]. Power stations the world over, enter into Power Purchase Agreements with the bulk customer, such as Gridco in the case of Hwange power station. The power station is penalised if it fails to deliver what it would have declared to Gridco say, for the next 24hrs. This is meant to offset what Gridco pays if it arranges for emergency imports from neighbouring countries as a result of the breakdowns. Emergency imports are more expensive than pre-arranged or contractual imports. This arrangement forces Hwange power station to reorient its maintenance effort towards increasing plant reliability, plant maintainability and maintenance support in order to maximise plant availability[6]. The most important factor that determines plant or equipment availability is maintenance. Maintenance however needs to be organised and controlled in an effective manner in order to translate into high plant availability and associated high production volumes and profitability,(Moubray 1998.)

Measures that improve plant availability would greatly benefit coal fired power stations such as Hwange thereby avoid loss making and improve their profit margins.

The objective of this study was to identify causes of plant unavailability and how they affect life cycle performance of coal fored power stations. The study also identifies equipement that requires special attention and recommends ways to improve plant availability and system life cycle performance.

Methods

The study involved analysis of current maintenance management system and the current status of the plant.Maintanace management practices and operations were assessed to measure plant reliability. ABC analysis was used to identify equipement requiring critical maintenance management systems. Ways of increasing system reliability were also identified.

RESULTS AND DISCUSION

Performance analysis

The records show that on average the station has 11 unplanned automatic grid separations (UAGS) per month against a target of 5 per month. This gives a measure of reliability of equipment, which could be poor due to various factors including maintenance practices as well as operations practices. Resource utilisation in terms of kg/kwh generated is in excess of the target for diesel, water, coke oven gas (COG) and coal. For diesel, water and COG this is due to numerous UAGS hence excessive usage during the raising or stabilisation of units. Poor coal firing rates are due to incomplete combustion such as due to poor optimisation of fuel air ratio by the operator, poor condition of mills, holed classifiers, poor state of burner diffusers high ash content in coal etc[8]. Works power gives the ratio of electric power used by the station production equipment over a given period to the total power generated over that period. It gives the level at which equipment that are supposed to be off service continue to run e.g. redundant equipment in parallel, or idling equipment etc[9]. It is a measure of poor or good management of power use by the station.

ABC analysis for years 1991 to 2001 show that tube leaks keep on appearing year after year as major causes of generation losses due to forced outages, see Fig 1 and 2.

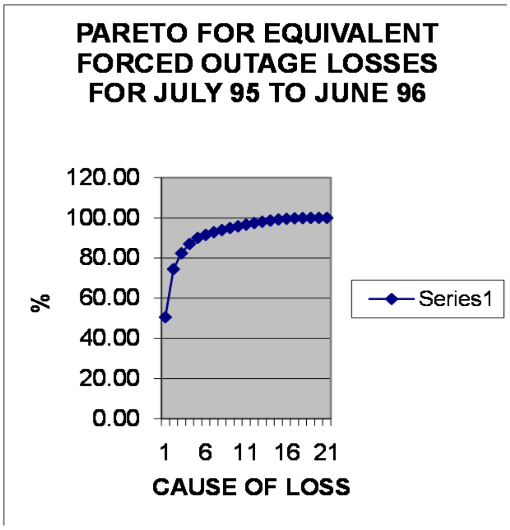


Fig 1: Pareto for equivalent forced outage losses for July 1995 to June 1996

Creep failures as a result of poor flow distribution on the boiler nose area is a major cause of forced outages for stage one units. The other major cause of tube leaks affecting both stage one and stage two units is erosion of economiser tubes. The erosive wear is due to poor distribution of flue gas across the gas pass as result of the geometry of the gas pass[10]. Changes in direction of flue gas cause it to impinge on tubes at areas where the gas pass changes direction and thus cause severe pitting. This phenomenon also causes gases to avoid parts of the cross section of the gas pass resulting in large volumes of gas passing through a small cross section. This increases flue gas speed hence erosive wear also increases. Design out maintenance is recommended. Baffles should be introduced to ensure that gases are distributed across the whole cross section of the flue gas[11]. Feed water heaters, major overhauls, ID fan vibrations, vacuum and milling plant problems are also common causes of generation losses due to forced outages, prolonged outages or partial loading of units for all the years from 1991 to 2001. Feed water heaters are taken out of service mainly due to leaks[12]. The main problem has been the shortage of money to replace the nest tubes, which are aged. For those heaters whose tubes have been replaced, fewer failures have been reported.

Major overhauls have been a major cause of downtime and associated production losses. This is due to delays caused by unavailability of spares especially those ordered abroad that have long lead times or due to deficiencies in the planning process where access or insufficient resources like time and manpower are allocated to activities due to poor or lack of work study. The planned outage duration is thus exceeded. ID fans vibrations and saturation as well as milling plant problems are featuring every year as items that contribute most to generation losses due to breakdowns (forced outages) or due to partial loading. ID fan impellers are subject to heavy erosive wear by the high speed and ash dust loaded flue gas. This introduces unbalance hence vibrations[13]. A design out solution is recommended in which ID fan impellers should be made up of anti-wear materials, be hardened or be coated with hard materials.

Bearing problems have also caused these vibrations. The white metal bearings used to be replaced with new ones once they are worn out but due to the shortage of foreign currency to import new ones, the old bearings are reconditioned. However the refilling process appears to be of poor quality on numerous occasions due to lack of skills and technology by Bulawayo Power station's workshops department who are tasked with this responsibility. It is hoped that with further training and acquisition of appropriate technology the reconditioned bearing would be of better quality. ID fans saturate due to blockages on the gas pass as a result of clinker formation which blocks the gas pass or due to increased fly ash burden in the flue gas. Saturation refers to a situation in which the ID fan vane is fully open and yet the fan fails to maintain the required low pressure in the furnace[12]. The solution to clinker formation is operational. Clinkering is a situation in which ash melts and thus ash particles glue to each other to form large particles called clinkers[4]. Controlling of furnace temperatures by the unit operator to below ash fusion temperatures prevents clinkering. This is usually done by monitoring burner tilts. The percentage of ash in coal if above normal causes an increased fly ash burden in the flue gas. This factor is controlled by the supplier of coal, which is Wankie Colliery and is managed by the coal contract signed by ZESA and Wankie Colliery. This contract however needs to be enforced as well as be reviewed as and when the need arises.

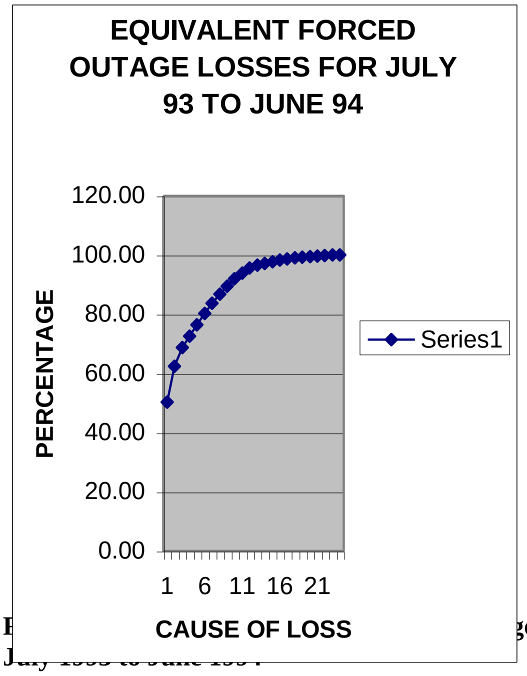
Problems associated with poor vacuum are partly due to insufficient cooling water supplies, ambient temperatures or humidity levels, cooling water pumps breakdowns, poor cooling tower performance, and occasional air ingress into systems under vacuum due to leakages or failures of the sealing system[14]. To begin with, a well-prepared diagnosis chart is needed in order to quickly identify the cause of poor vacuum and thus minimise waiting times and repair times. It must be noted that low vacuum automatically means reduced loads or no load at all as well as poor turbine efficiency. Additional cooling water pumps have been installed in parallel in order to increase reliability as well as increase cooling water flows especially in summer when both humidity and ambient temperatures are high.

Milling plant problems include feeder blockages, pulverised fuel leakages, breakdowns of mill auxiliaries such as PA fans, seal air fans and feeders, holed classifiers, bearing failures, mill breakdowns etc. The performance of stage one milling plant improved tremendously after this plant was placed on a service contract to an outside company.. The contract is performance based i.e. it is for one year, renewable subject to performance as opposed to the permanent ZESA maintenance crew whose employment contract is not strictly performance based. The stage 2 milling plant is not yet on a service contract and it continues to give problems. Some of the maintenance problems include leaks and holed classifiers are not worker performance related but need a design out solution. Most leaks are a result of pipe-work failures due to erosive wear and ceramic lining to reduce wear of the pipe-work.

In Fig 1. forced and equivalent forced outages for the period July 1995 to June 1996 were mainly vacuum, feed heaters, ID fan problems and extended outages.

More cooling water (CW) pumps have since been installed in parallel to improve both system reliability and quantities of cooling water. An additional cooling tower has also been installed. Failure to secure promised spares caused extended outages.

Mill vibrations wear due to worn out bearings that needed replacement but could not be replaced immediately due to shortages of spares.



F ... ge losses for July 1993 to June 1994

Major causes of forced and equivalent forced outage losses for July 1993 to June 1994 were boiler tube leaks, feed-heater tube leaks, major overhauls, mill feeder problems, mill vibrations, and blown mill seals. These problems seem to be endemic and premised on obsolescence of equipment, paucity of modern maintenance methods and scarcity of resources.

It is this poor performance which becomes the target of availability centred maintenance model proposed.

Although Hwange power station applies both condition based maintenance (CBM) and preventive maintenance and has a fairly well trained and experienced workforce it has failed to meet many of its performance objectives in terms of availability, load factor, rate of breakdowns (trip) or automatic grid separations, forced outage rate, planned outage rate etc because the current maintenance efforts and strategies are inadequate and hence the station often fails to meet customer power requirements due to plant unavailability. To begin with plant and individual equipment reliability was hardly reviewed. Only as recent as 2001 was the RCM concept of root cause analysis adopted. Plant modification meetings are now held every fortnight where engineers are allocated recurring plant problems that require design out maintenance to solve. This is a positive development that should see an improvement in plant and equipment reliability.

Faced with this seeming hubris of insoluble multifaceted and interlinked maintenance problems and possible solutions, the final maintenance model recommended was a hybrid of various maintenance practices, policies and maintenance management tools applied specifically to maximise plant and equipment reliability, maximise plant and equipment maintainability and maximise maintenance support performance aimed at achieving maximum plant availability at coal fired base load power stations. The maximised availability easily translates to high production volumes and profitability if the macro economic environment is favourable. The use of tools that aid maintenance management is very important. This area is neglected by many power stations and in particular Hwange. No Pareto analysis is carried out, say annually to identify equipment that contribute most to production losses due to unavailability, in which case more maintenance effort would be directed to items identified as critical, i.e. targeted maintenance to heighten availability performance. The maintenance effort might include reviews of maintenance policies and practices like frequencies of inspections or of preventive maintenance and design out maintenance including redundancy options. A more focused maintenance strategy that attempts to address the most fundamental maintenance factor that affects the company's overall goal is capable of meeting maintenance challenges at coal fired base load power stations. The overall goal of any business is profitability and the maintenance factor that ensures large production volumes associated with profitability at coal fired base load power stations is maximum plant availability. As the maintenance maxim goes, " A dollar saved in maintenance goes directly to profitability whereas a dollar invested in production might go to meeting overheads and other associated costs."

An availability centred maintenance strategy is probably therefore the answer to profitable business for coal fired power stations given the fact that such power stations have by far more auxiliaries when compared to other types of power stations such as gas or oil fired thermals, hydroelectric and nuclear power stations. Coal fired power stations thus have bigger maintenance loads. The availability centred maintenance strategy has to be holistic in order to be effective by taking into account key factors that determine availability namely reliability, maintainability and maintenance support. Maintenance engineering and maintenance management cannot be divorced hence availability centred maintenance should incorporate maintenance management techniques in order to adequately meet maintenance challenges at coal fired power stations.

The ACM strategy would incorporate both qualitative and quantitative methods in pursuit of its ultimate goal. Quantitative tools include maintenance performance indices such as load factor, availability factor, unit capability factor, planned outage rates, forced outage rates, unplanned capability loss factor, number of unplanned automatic grid separations per year, and ABC analysis etc. These should be used to evaluate the effectiveness of ACM so that appropriate adjustments can be made in addressing the maintenance shortcomings. These adjustments should be based on the concept of addressing root causes and finding lasting solutions as opposed to addressing symptoms. ACM should also incorporate the concept of continuous improvement.

To enhance the effectiveness of ACM, coal fired power stations should standardize their repair and work preparation methods so as to ensure quality repairs devoid of reworks. Reworks would tend to increase down times. Further to this adopting quality related standards such as ISO 9000 and ISO 14 000 would also assist in ensuring quality repairs to enhance equipment reliability.

Coal fired power stations have large dust burdens, and this tends to cause both mechanical and electrical faults if it enters equipment apart from being a health hazard to employees. Coal fired power stations also handle toxic materials like chlorine, explosive materials like hydrogen, fire hazards like propane and diesel etc hence an effective environmental management system would protect plant equipment from environmentally induced damages. These damages usually cause extensive damage to equipment requiring costly and long periods of repairs hence losses of production.

The ACM strategy would also incorporate procedurisation of all maintenance and operations activities as a way of enhancing reliability, maintainability and maintenance support. Repair procedures are a valuable resource to new employees and in cases of doubts for the experienced employees hence they assist to obtain quality repairs while operations procedures help prevent mal-operations especially those that can result in damage to equipment. As a way of enhancing maintainability and maintenance support, coal fired power stations should put in place a comprehensive spare parts reconditioning programme. They should also keep a database of plant items like motors, pumps, and compressors etc that are interchangeable. These measures would improve maintainability and maintenance support performances.

At the time of the study, no work study programme to determine standard times for completing given maintenance tasks was in place at Hwange power station. A work study assists in the planning of maintenance outages, identifying bottleneck maintenance activities, skills deficiencies and training needs of maintenance personnel. The workforce motivation programme that is in place has not born fruit because it does not adequately address both basic and high level needs of employee and harmonise them with organisational objectives. While basic needs like attractive salaries and job security are to some extend addressed, the other basic need namely acceptance by management is greatly neglected. Higher needs like self-fulfilment, opportunities to express ones abilities or creativity and self-esteem are totally neglected. Unless all the basic needs are met there is no need for worker to bother himself about higher needs. These deficiencies lead to poor utilisation of the workforce.

While production and maintenance performance indices are extensively used some important ones such as mean time to failure, mean time to repair or mean waiting times, number of reworks etc are not used. These if used further aid decision-making by management in terms of the direction of maintenance effort. Maintenance optimisation is greatly deficient in the sense that ABC analysis is not used to identify critical plant items to optimise maintenance activities like frequencies of inspections, overhauls or of preventive maintenance in order to minimise downtime and reduce costs. This would complement recommendations by the manufacturer and also to avoid a trial and error situation. No failure mode effect analysis is carried out on critical plant items and no group technology in terms of diagnosis charts for plant items with similar functions and failure modes are in place. While quite a number of commissioning sheets, operating, and maintenance procedures are in place, their quality leaves a lot to be desired as they are rarely reviewed in accordance with new performance standards or due to plant modifications. The computerised maintenance management system that is in place, although it is highly sophisticated and is on the station Local Area Network, does not show maintenance indices such as records of times to failure, waiting times, repair times, reworks. It only covers issues like permit requests, items due for preventive maintenance, plants due for overhauls or statutory outages among other few facilities. It has to be customised in order to cater for all maintenance management requirements.

In spite of the shortage of foreign currency problems in the country there is no deliberate policy to establish a vigorous spare parts reconditioning programme at the power station. Spares are being reconditioned on a reaction to crisis approach rather than on a proactive approach. It would be proactive to identify all spares that are being imported and decide if they could be reconditioned instead, by using the station's workshop or using workshops elsewhere in the country. Even for parts that are manufactured locally it makes sense to identify all parts that can be reconditioned and then compare the costs of reconditioning to those of purchasing a new spare. A spares import substitution programme is also required. Local producers or potential producers for spares currently being imported have to be identified and contracted. This is aimed at reducing lead times (waiting times) and beat foreign currency shortages.

Maintenance practices at Hwange power station need to be benchmarked with world-class power stations in developed countries. Benchmarking however should be carried out with extreme caution because economic, technological, social conditions and priorities etc in a third world country like Zimbabwe are different from a first world country. Strategic alliances with such power stations should also be established, especially with power stations in nearby South Africa. Such alliances are aimed at sharing resources like experiences about plant failures that are difficult to diagnose, sharing specialised skills or specialised repair equipment and scarce spares. This can contribute to improving plant availability.

RECOMMENDATIONS

In an attempt to implement an availability centred maintenance strategy that addresses maintenance shortcomings and improve productivity at coal-fired power stations and at Hwange power station in particular, somerecomemndations have been developed

There is need to

- Identify production and maintenance indices that are related to key availability factors like times to failure (reliability), repair times (maintainability) and waiting times (maintenance support) and use them as a quantitative monitoring tool of the effectiveness of ACM.

- Identify spare parts currently being imported but which can be reconditioned at the power station or at a workshop within Zimbabwe. This is meant to improve maintainability by improving spares availability eliminate lead times (waiting times) as well as alleviate the foreign currency shortage problem.

- Identify spare parts that are manufactured locally but can be reconditioned at the power station or at any workshop within the country and compare the cost of reconditioning with that of purchasing the new part in order to decide whether to recondition or purchase (make or buy decisions). This is meant to increase spares availability and encourage savings hence contribute to profitability.

- Have a database of plant items that are interchangeable so as to increase spare availability hence improve maintainability and reduce waiting times.

- Have maintenance, operations and commissioning procedures for all plant items to improve reliability, maintainability and reduce waiting times.

- Implement internationally recognised standards such as, ISO 9000, ISO 14 000 etc by targeting aspects that improve equipment reliability and maintainability.

- Put in place a spare parts import substitution programme by identifying local producers or potential producers of spares currently being imported in order to improve spares availability hence maintainability and also reduce lead times (waiting times).

- Apply ABC (Pareto) analysis on an annual basis to identify the group of items that contribute say 80% to unavailability losses due to forced outages or partial loading of units. This is meant to review maintenance policies on these critical items and apply long term solutions like re-design, increasing redundancy or change FTM frequency in or to increase equipment or system reliability.

- Apply FMECA on items identified by ABC analysis in order to determine root cause of failures hence choose appropriate maintenance policies and practices that can eliminate or contain the failure modes. Design out maintenance, CBM, change of FTM frequency can be used to increase reliability.

- Apply mathematical models that optimise maintenance such as decision diagrams for items whose FTM frequency is proving difficult to determine especially if the items are identified as critical by ABC analysis. This is aimed at improving reliability.

• Draw performance based contracts for senior staff, which are renewable subject to satisfactory performance. This is meant to encourage pro-activeness and productivity.

• Draw performance standards for each and every employee, which are to be used to appraise their performance. The standards should be measurable, objective, aligned to productivity and profit making and based on activities the particular employee influences directly.

• Benchmark power station maintenance practices with those of world-class power stations and establish strategic alliances with nearby power stations in South Africa to share experiences, specialised repairing equipment and specialised skills.

• Review and renegotiate service contracts with all subcontractors with the view of minimising maintenance costs and replacing management style contracts with performance-based contracts.

• Implement work study techniques that develop simpler, better quality, easier, safer, faster and cheaper work methods/ procedures aimed at improving productivity, identifying training needs, producing standard times for maintenance activities hence assist planning of outages.

• in the case of equipment that keep on appearing on the critical list year after year.

• Introduce redundancy to improve system reliability

• Although common boiler, turbine, water treatment, coal and ash plant defects are known, no diagnosis charts and failure mode analysis documentation is in place to assist in detecting causes of failures quickly. This is a major maintenance support shortcoming that has to be attended to if waiting times are to be reduced.

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