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Operation and Maintenance Schedule of a Steam Turbineplant (A Study of Calabar Power Plant)

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Abstract
Thermalelectricalgeneration power plant isoneofthemajor power generation plant methodsusedinNigeria to generate electricity both locally and internationally. But dueto inconsistency, failure and low power supply in Nigeria, there is a call for a proper operation and maintenancestrategyofthevariouskindsofpowerplantsaccessoriessoastofacilitatetheir efficiencies, sustainability andfunctionality.Calabarthermal powerstation,whichisoneofthemajorpowergeneratingstationsinNigeria was used as a case study. The station has an installed capacity of 561MW consisting of 12 units of 46.75 MW each. It is in the generating sector of the Calabar Electricity Distribution Company (CEDC) which is the state owned Electric Power company.The majorcomponentsofCalabra Power plantstationareboiler,steamturbine,condenserandthefeedpumps.Theoperationandmaintenanceof Calabar Power plantstationwasexaminedandtheconclusionwasthatit waschallengedwithinsufficientand low Gassupplyandrestrictions,poorwaterqualityandbreakdownof6 units due to boiler explosion and leads to poor power supply to the populace causing power generating plant to be shut down creating a 280.5 Mega Watts drop in power generation in the whole state. This occurrence has had a massive setback on the power plant, hence a proper maintenance strategy needs to be designed to curb the effectfor future occurrence anddevelopalonglastingsolutiontopreventfurtherpotentialdisaster.

Keywords: *PowersupplyinNigeria,steamturbine,thermalstation,operationandmaintenance of thermalstation.*

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I. Introduction

In Steamturbinesaredevicesusedtoconvertthepressureenergyofhighpressuresteamtokineticand hence electrical energy in power plants and certain types of engines. While steam turbines might be one of the more revolutionary inventions in the power generation and conversion industry. High performance steam turbines of today are specialized in their design and incorporate many efficiency increasingtechnologies (Kehinde & Okwuejunti, 2014).

Steam turbine maintenance is of high importance to keep the steam turbines efficiency high and to conformtosafetystandardstoavoidanyunforeseendangers.Thesteamturbineoperatesunderhigh steam pressures, and has a number of moving parts that move at extremely high velocities. The nozzlesandturbinebladesaredesignedviacarefulanalysisandthepartsaremanufacturedtoahigh degree of finish andaccuracy (Kehinde & Okwuejunti, 2014).

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A steam power plant continuously converts the energy stored in fossil fuels i.e. coal, oil, etc. or fossil fuels e.g. uranium, thorium into shaft work and ultimately into electricity. The working fluid is "water" which is sometimes in the liquid phase and sometimes in the vapor phase during its cycle of operations.

Afossilfuelledpowerplantisanexampleofbulkenergyconverterfromfueltoelectricityusing"water" astheworkingmedium.Theenergyreleasedbytheburningfuelistransferredtowaterintheboilerto generatesteamathightemperature,whichthenexpandsinthesteamathightemperature,whichthen expandsinthesteamturbinetoalowpressuretoproduceshaftwork (Harmond, 2008).Thesteamleavingtheturbineiscondensed into water in the "condenser" where cooling water from a river or sea circulates, carrying awaytheheatreleasedduringcondensation.Thewater(condensate)isthenfeedbacktotheboilerby the pump and the cycle goes on repeatingitself.

Steam turbine power plants operate on "Rankine cycle" for the production of electric power. If the steam from the waste heat boiler is used for process or space heating, the term "cogeneration" is the more correct terminology (simultaneous production of electric and heat energy).

Steam turbine plants generally have a history of achieving up to 95% availability and can operate for more than a year between shutdowns for maintenance and inspections. Their unplanned or forced outage rates are typically less than 2% or less than one week per year. Modern large steam turbine plants (over 500MW) have efficiencies of about 40-45% (Omokodhe, 2019).

The major components of a steam powerplant

Turbine (High, Intermediate and Lowpressure).

i. Boiler (Economizer, Evaporator, Drum and Superheater).
ii. Generator
iii. Condenser
iv. Feedpumps

Steamturbine

Steamturbinesaremachinesthatareusedtogeneratemechanical(rotationalmotion)powerfromthe pressureenergyofsteam.Steamturbinesarethemostpopularpowergeneratingdevicesusedinthe power plant industry primarily because of the high availability of water, moderate boiling point, cheap nature and mild reacting properties. The most widely used and powerful turbines of today are those thatrunonsteam (Emoyo, Adeyeri & Karee, 2009).Fromnuclearreactorstothermalpowerplants,theroleofthesteamturbineisboth pivotal and resultdetermining.

A steam turbine is basically an assemblage of nozzles and blades. Steam turbines are not only employedtooperateelectricgeneratorsinthermalandnuclearpowerplantstoproduceelectricity,but they are also used (a) to propel large ships, submarines and so on, and (b) to drive power absorbing machines like large compressors, blowers, fans andpumps.

Turbines can be condensing or non-condensing, depending on whether the back pressure is belowor equal to the atmospheric pressure. For small units without reheat, the steam turbine may consist of a single turbine when the steam expanding through the turbine exhausts to a condenser or a process line.Foralargeunitwithoutreheat,thesteammayexpandthroughaninitialsectionandthenexhaust toacondenserortoaprocess (Haywood, 2005).Theinitialturbineisdesignatedasthehigh-pressure(HP)turbineand the second turbine the low-pressure (LP)turbine.

For a single reheat cycle, the steam from the boiler flows to the HP turbine where it expands and is exhausted back to the boiler for reheating. The reheat steam coming from the boiler flows to the intermediate-pressure (IP) or reheat turbine where it expands and exhausts into a crossover line that supplies steam to double-flow LP turbine (O. I. Okoro, and T. C. Madueme, Renewable Energy, vol. 29, pp.1599-1610, 2004).

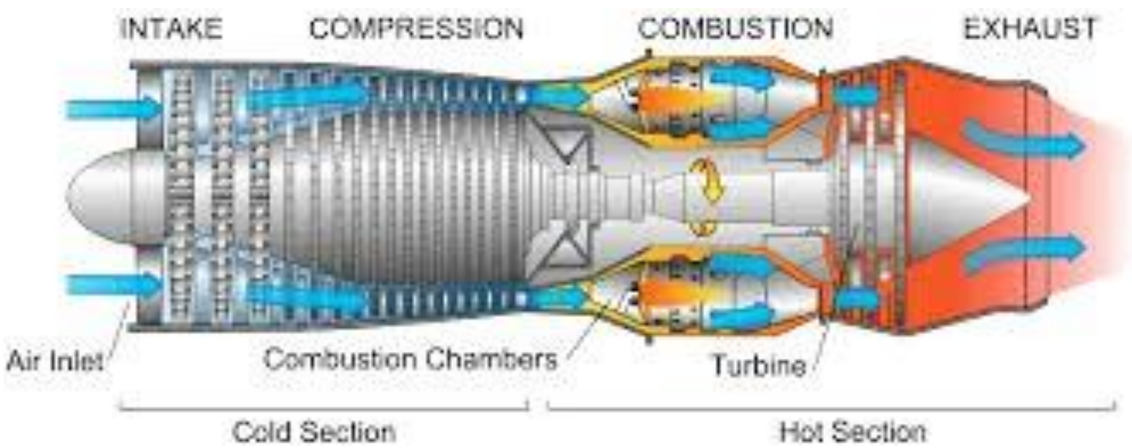


Figure 1a. Steam turbine

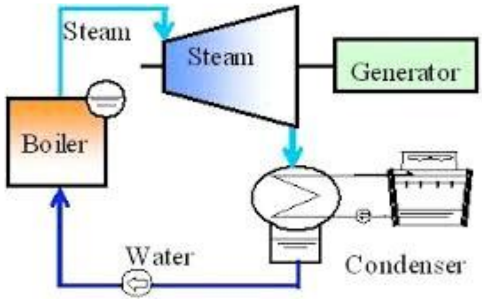
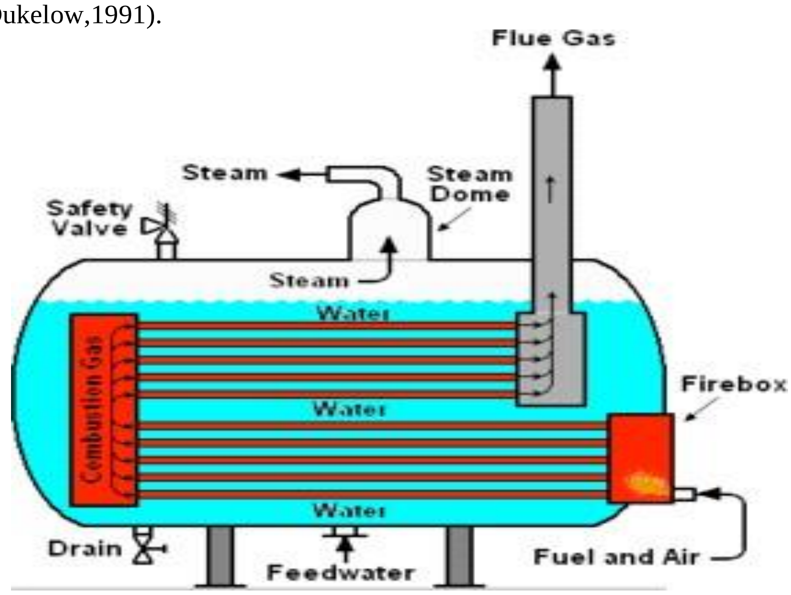


Figure 1b. Condensing steam turbine

Boiler

A boiler generates steam at the desired pressure and temperature by burning fuel in its furnace. Boilers are used in both fossil-fuel and nuclear-fuel electric generating power stations. A boiler is a complex integration of furnace, super heater, reheater, boiler or evaporator, economizer, and air preheater along with various auxiliaries such as pulverizers, burners, fans, stokes, dust collectorsand precipitators, ash-handling equipment, and chimney or stack. The boiler is where phase change (or evaporator) occurs from liquid (water) to vapour (steam), essentially at constant pressure and temperature (The Control of Boilers, 2nd Edition, Sam G. Dukelow,1991).



Figure

Boiler

The components of a boilerinclude

Economizer: An economizer is a heat exchanger which raises the temperature of the feed water leaving the highest pressure feed water heater to about the saturation temperature correspondingtotheboilerpressure.Thisisdonebyhotfluegasesexitingthelastsuperheater or reheater at a temperature varying from 370°C to540°C.

Evaporator:iswherephasechangeoccursfromliquid(water)tovapour(steam),essentiallyat constant pressure andtemperature.

Drum: Made from high carbon steel with high tensile strength and its working involves temperatures around 390ºC and pressures well above 350 psi (2.4MPa). The separatedsteam isdrawnoutfromthetopsectionofthedrumanddistributedforprocess.Furtherheatingofthe saturatedsteamwillmakesuperheatedsteamnormallyusedtodriveasteamturbine.

Super heater: The super heater is a heat exchanger in which heat is transferred to the saturated steam to increase its temperature. It raises the overall cycle efficiency(Emoyo, Adeyeri & Karee, 2009). In addition it reduces the moisture content in the last stages of the turbine and thus increases the turbine internal efficiency. In modern utility high pressure, more than 40% of the total heat absorbed in the generation of steam takes place in the super heaters. So large surface area is required for superheatingofsteam(Pearsons,SirCharlesA,“TheSteamTurbine”p.20-22).

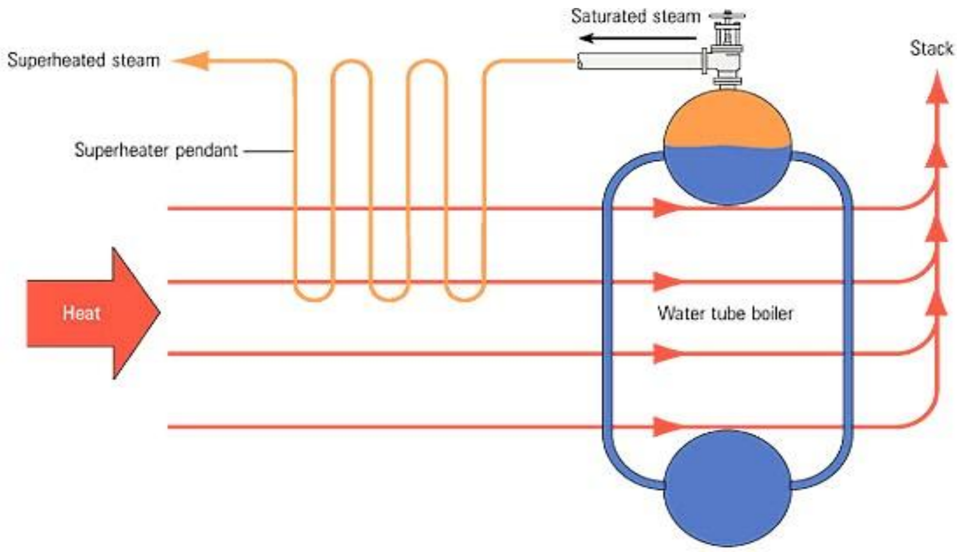


Figure 3. Superheater

Condenser

Condenser: The condenser condenses the steam from the exhaust of the turbine into liquid to allowittobepumped.Ifthecondensercanbemadecooler,thepressureoftheexhauststeam isreducedandefficiencyofthecycleincreases.Thesurfacecondenserisashellandtubeheat exchanger in which cooling water is circulated through the tubes. The exhaust steam from the lowpressureturbineenterstheshellwhereitiscooledandconvertedtocondensate(water)by flowing over the tubes. Such condensers use steam ejectors or rotary motor-drivenexhausters for continuous removal of air and gases from the steam side to maintain vacuum. For best efficiency,thetemperatureinthecondensermustbekeptaslowaspracticalinordertoachieve the lowest possible pressure in the condensing steam. Since the condenser temperature can almost always be kept significantly below 100 °C where the vapor pressure of water is much less than atmospheric pressure, the condenser generally works under vacuum (Aleksandr, 2009). Thus leaks of non-condensableairintotheclosedloopmustbeprevented.Typicallythecoolingwatercauses.

The steam to condense at a temperature of about 35 °C (95 °F) and that creates an absolute pressure in the condenser of about 2–7 kPa (0.59–2.1 in Hg), i.e. a vacuum of about -95 kPa (−28.1 inHg) relative to atmospheric pressure. The large decrease in volume that occurs when water vapor condenses to liquid creates the low vacuum that helps pull steam through and increasetheefficiencyoftheturbines

Feedpumps:Thesearepumpsthatconveystreatedfeedwaterunderpressuretotheboilerfor itsoperationofgeneratingsteam(Thomas, 2007).

Classification of powerplant

Conventional Steam Engines
Steam Turbines
Diesel
Gas Turbines
Hydro-Electric Nuclear

Non conventional
Thermoelectric Generator
Thermionic Generator
Fuel- cells

Photovoltaic Solar Cells Fusion Reactor
Biogas, Biomass Energy
Geothermal Energy Wind
Energy
Ocean Thermal Energy Conversion
Wave and Tidal Wave
Energy Plantation Scheme

All the above mentioned power plants are classified according to the ways in which steam is being generated. Some of the ways are explained below.
Nuclear Power Plant uses a nuclear reactor's heat to operate a steam turbine generator.

Geothermal Power Plant uses steam extracted from hot underground rocks.

Renewal Energy Plan may be fuelled by waste from sugarcane, municipal solid waste, land fill methane or other forms of biomass.
In Integrated Steel mills, a blast furnace exhaust gas is a low cost although low energy density fuel.

Waste heat from industrial processes is occasionally concentrated enough to use for power generation, usually in steam boiler and turbine.
Solar Thermal: electric plants use sunlight to boil water which turns the generator.

Fossil fuelled power plants may also use a steam turbine generator or in the case of natural gas fired plants many use a combine turbine.

Fossil fuel power plants are designed on a large scale for continuous operation. In many countries, such plants provide most of the electrical energy used.
A fossil power plant always has some kind of rotating machinery to convert the heat energy of combustionintomechanicalenergy,whichthenoperatesanelectricalgenerator.Themovermaybea steamturbine,agasturbineorinsmallisolatedplants,areciprocatingcombustionengine.
By- products of power plant operation need to be considered in both the design and operation.Waste heat due to the finite efficiency of the power cycle must be released to the atmosphere, often using a cooling tower, or river or lake water as a cooling medium. The flue gas from combustion of the fossil fuels is discharged to the air; this contains carbon dioxide and water vapour, as well as other substances such as nitrogen, nitrous oxides, sulphur oxides, and (in the case of coal-fired plants)fly ash and mercury. Solid waste ash from coal-fired boilers must also be removed, although some coal ash can be recycled for building materials. Gas burning is much simpler as the fuel is ready for combustion and requires no preparation. The other advantagesare:

i. Cleanliness
ii. Ease of control of furnacetemperature
iii. Abilitytoproducealongslowburningflamewithuniformandgradualheatliberation
iv. Ease of temperatureregulation

Natural gas is used for steam generation in gas producing areas or in areas served by gas transmission lines and where coal is costlier. The proportioning, mixing and burning of gas airmixturecan be achieved in many ways. Natural gas is often informally referred to as simply "gas", especially when compared to other energy sources such as electricity. Before it can be used as a fuel, it must undergo extensive processing to remove almost all materials other than methane (Mafana, 1998). The by-product of that processing include ethane, propane, butanes, pentanes, and higher molecular weight hydrocarbons, elemental sulphur, and sometimes helium and nitrogen.

Natural gas is the major source of electricity generation through the use of gas turbines and steam turbines. Particularly high efficiencies can be achieved through combining gas turbines with a steam turbineincombinedcyclemode.Naturalgasburnscleanerthanotherfossilfuelssuchasoilandcoal and produces less CO per unit energy released. For the equivalent amount of heat, burning natural gas produces about 30% less than carbon-dioxide than burning petroleum and about 45% less than burningcoal (Salibury, 2009).

II. Methodology

OPERATION AND MAINTENANCE OF A STEAM POWER PLANTCYCLE

Steam is the most common working fluid used in vapor power cycles because of its many desirable characteristics, such as low cost, availability, and enthalpy of vaporization. Other working fluids used include sodium, potassium, and mercury for high-temperature applications. Steam power plants are commonlyreferredtoascoalplants,nuclearplants,ornaturalgasplants,dependingonthetypeofthe fuelusedtosupplyheattothesteam.Butthesteamgoesthroughthesamebasiccycleinallofthem (Black, 1995). Therefore all can be analyzed in the samemanner.

The carnot vaporcycle

The Carnot cycle is the most efficient cycle operating between two specified temperature levels making use of steam as the working fluid. Thus it is natural to look at the Carnot cycle first as a prospective ideal cycle for vapor power plants. If we could, we would certainly adopt it as the ideal cycle. But as explained below, the Carnot cycle is not a suitable model for power cycles. The assumption is that steam is the working fluid used since it is the working fluid predominantly used in vapor power cycles.

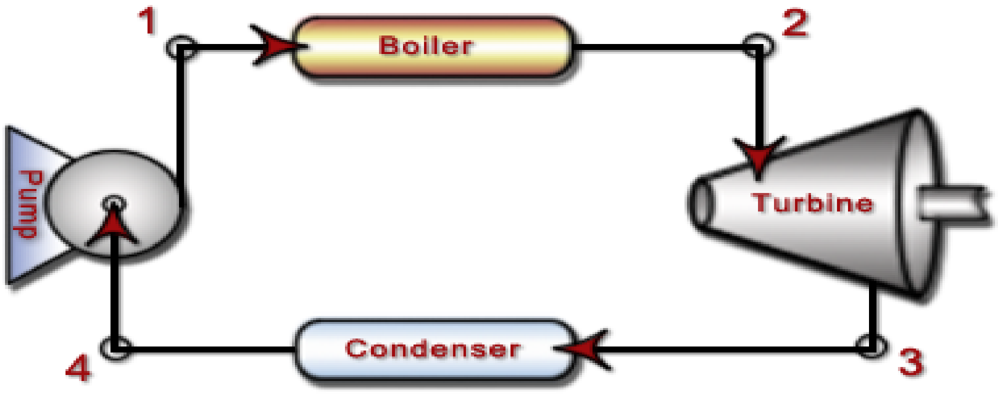


Figure 8. Carnot vapor cycle T-S diagram

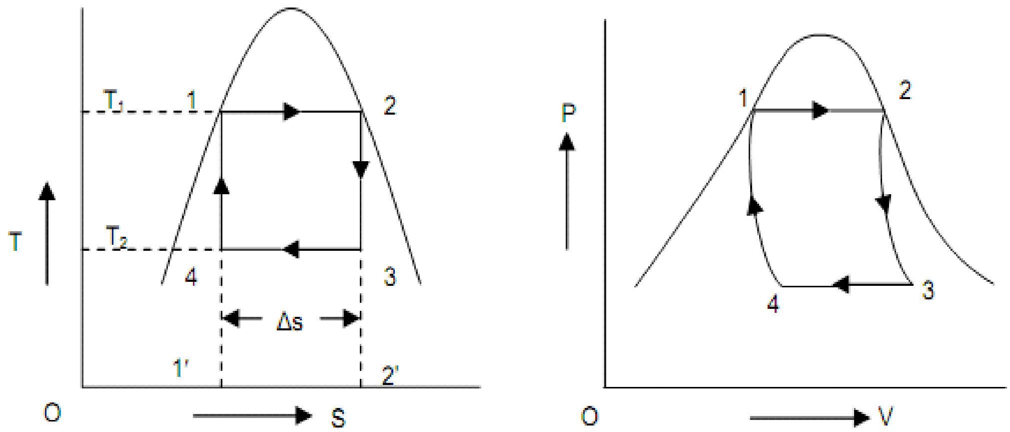


Figure 9. *Carnot Cycle on P-V and T-S Diagram*

Consider a steady-flow Carnot cycle executed within the saturation dome of a pure substance. The fluid is heated reversibly and isothermally in a boiler (process 1-2), expanded isentropically in the turbine (process 2-3), condensed reversibly and isothermally in the condenser (process 3-4), and compressed isentropically by the compressor to the initial state (process 4-1).Several impracticalities are associated with this cycle.

Isothermally heat transfer to or from a two-phase system is not difficult to achieve in practice since maintaining a constant pressure in the device will automatically fix the temperature atthe saturationvalue.Therefore,processes1-2and3-4canbeapproachedcloselyintheactual boilers and condensers. Limiting the heat transfer processes to the two-phase systems, however, severely limits the maximum temperature that can be used in the cycle (it has to remain under the critical-point value, which is 374ºC for water). Limiting the maximum temperature in the cycle also limits the thermal efficiency. Any attempt to raise the maximum temperatureinthecyclewillinvolveheattransfertotheworkingfluidinasinglephase,whichis not easy to accomplishisothermally.

The isentropic expansion process (process 2-3) can be approximated closely by a well-designedturbine.However,thequalityofthesteamdecreasesduringthisprocessasshownon T-s diagram. Thus the turbine will handle steam with low quality, that is, steam with high moisture content. The impingement of liquid droplets on the turbine blades causes erosion and is the major source of wear. Thus steam with qualities less than 90% cannot be tolerated inthe operationofpowerplants.Theproblemcouldbeeliminatedbyusingaworkingfluidwitha very steep saturated vaporline.

The isentropic compression process (process 4-1) involves the compression of a liquid-vapor mixturetoasaturatedliquid.Therearetwodifficultiesassociatedwiththeprocess.First,itisnot easy to control the condensation process so precisely as to end up with the desired quality at state4.Second,itisnotpracticaltodesignacompressthatwillhandletwophases.

OPERATIONS

Waterentersthepumpatstate1assaturatedliquidandiscompressedisentropicallytotheoperating pressureoftheboiler.Thewatertemperatureincreasessomewhatduringthisisentropiccompression process due to slight decrease in the specific volume of the water. The vertical distance between states 1 and 2 on T-s diagram is greatly exaggerated forclarity.

Water enters the boiler as a compressed liquid at state 2 and leaves as a superheated vapor atstate

3.Theboilerisbasicallyalargeheatexchangerconsistingofaneconomizer,anevaporator,and

superheater where heat originating from combustion gases, nuclear reactor or other sources is transferred to the water essentially at constant pressure. The boiler, together with the section where the steam is superheated (the superheater), is often called the steam generator.

The superheated vapor at state 3 enters the turbine, where it expands isentropically and produces workbyrotatingtheshaftconnectedtoanelectricgenerator.Thepressureandthetemperatureofthe steamentersthecondenser.Atthisstate,steamisusuallyasaturatedliquid-vapormixturewithahigh quality. Steam is condensed at constant pressure in the condenser, which is basically a large heat exchanger,byrejectingheattoacoolingmediumsuchaslakeorariveroratmosphere.Steamleaves the condenser as saturated liquid and enters the pump, completing the cycle. In areas where wateris precious,thepowerplantoperatesbyairinsteadofwater.Thismethodofcoolingwhichisalsousedin carenginesiscalleddrycooling.SeveralpowerplantsintheworldandafewintheUnitedStatesuse dry cooling to conservewater.

MAINTENANCEOFSTEAMPOWERPLANTACCESSORIES

The definition of maintenance often states that maintenance is an activity carried out for any equipment to ensure its reliability to perform its functions.

Maintenance to most people is any activity carried out on an asset in order to ensure that the asset continues to perform its intended functions, or to restore to its favorable operating condition. The purpose of maintenance is to extend equipment lifetime, or at least the mean time to the next failure the repair of which may be costly. Furthermore, it is expected that effective maintenance policies can reduce the frequency of service interruptions and the many undesirable consequences of such interruptions. Maintenance clearly impacts on component and reliability; if too little is done ,this may resultinanexcessivenumberofcostlyfailuresandpoorsystemperformanceandtherefore,reliability isdegraded,doneoften,reliabilitymayimprovebutthecostofmaintenancewillsharplyincrease.Ina cost effective scheme, the two expenditures must bebalanced.

Some of the common maintenance strategies are asfollows.

BreakdownMaintenance

This is one of the earliest maintenance programs being implemented in the industry. The approach to maintenance is totally reactive and acts only when equipment needs to be fixed. This strategy has no routinemaintenancetaskanditisalsodescribedasnoscheduledmaintenancestrategy.Torectifythe problem, corrective maintenance is performed onto the equipment. Thus, this activity may consist of repairing,restorationorreplacementofcomponents.Thestrategyistoapplyonlythecorrectivemaintenance activity, which is required to correct a failure that has occurred or is in the process of occurring.

PreventiveMaintenance

This is the time-based maintenance strategy where on a predetermined periodic basis, equipment is taken off-line, opened up and inspected. Based on visual inspection, repairs are made and the equipment is then put back on-line. Thus under this equipment maintenance strategy, replacing, overhaulingorremanufacturinganitemisdoneatfixedintervalsregardlessofitsconditionatthetime. Although this is a well-intended strategy, the process can be very expensive as typically 95% of the time everything was alright. Nevertheless, some preventive maintenance is necessary as some regulationsuchasDOSHregulationrequirethatannual/bi-annualboilerinspectiontobeconducted.

PredictiveMaintenance

Predictive maintenance is a more condition-based approach to maintenance. The approach is based onmeasuringoftheequipmentconditioninordertoassesswhetheranequipmentwillfailduringsome future period, and then taking action to avoid the consequences of those failures. This is where predictive maintenance technologies (i.e. vibration analysis, infrared thermographs, ultrasonic detection, etc.) are utilized to determine the condition of equipment, and to decide on any necessary repairs. Apart from the predictive technologies, statistical process control techniques, equipment performance monitoring or human senses are also adapted to monitor the equipment condition. This approach is a more economically feasible strategy as labors, materials and production schedules are used much moreefficiently.

ProactiveMaintenance

Unlike the three type of maintenance strategies which have been discussed earlier, proactive maintenance can be considered as another new approach to maintenance strategy. Dissimilar to preventive maintenance that biased on time intervals or predictive maintenance concentrate on the monitoring and correction of root causes to equipment failures. The proactive maintenance strategyis also designed to extend the useful age of the equipment to reach the wear-out stage by adaptationof a high mastery level of operatingprecision.

III. Results

PERFORMANCE ANALYSIS OF A STEAM POWERPLANT

The instrument being used to measure the performance of a steam power plant is the Key Performance Indicator (Kpi). Some of which are:

i. Energy generated(MWH)
ii. Percentage consumption(%)
iii. Station consumption(MWH)
iv. Number of trips/categorisation offaults
v. Make up water loss(Tons)
vi. Generation utilisation index(%)
vii. Capacity utilisation index(%)
viii. Fuel utilisation index(SCF/MWH)
ix. Routine maintenance index(%)
x. Plant reliability index(%)
xi. Generated thermal efficiency(%)

Formula

(Calculations and results from Calabar thermal station database)

- Generation - energygenerated
- %consumption
- Stationconsumption - what the stationconsumes
- Generation utilizationindex-
- Capacityutilizationindex -
- Fuelutilizationindex -
- Routinemaintenanceindex -
- Plantreliabilityindex - Where T_d = Down time, T_e = Expected RunningTime
- Generated thermal efficiency-
- Energysentout - total (1) –total(3)
- % energysentout
- Availabiltyfactor

- Averageavailability
- Averagegeneration
- Total generated efficiency-

The performance indicator of Calabar thermal Power station from January-December 2009 is calculated below.

Table 1: Shows the total Energy Generated and Consumed from the Month of January, 2020 – December,2021 at Calabar Thermal Power Plant

MONTH	ENERGY GENERATED	ENERGY CONSUMED
January	443950	19775.79
February	364163	27618.96
March	280664	24211.7
April	492846	32593.44
May	393975	29617.82
June	432687	29617.82
July	514994	32992.86
August	524984	33993.97
September	490846	42499.89
October	698241	33491.49
November	456571	33491.49
December	977892	35983.59

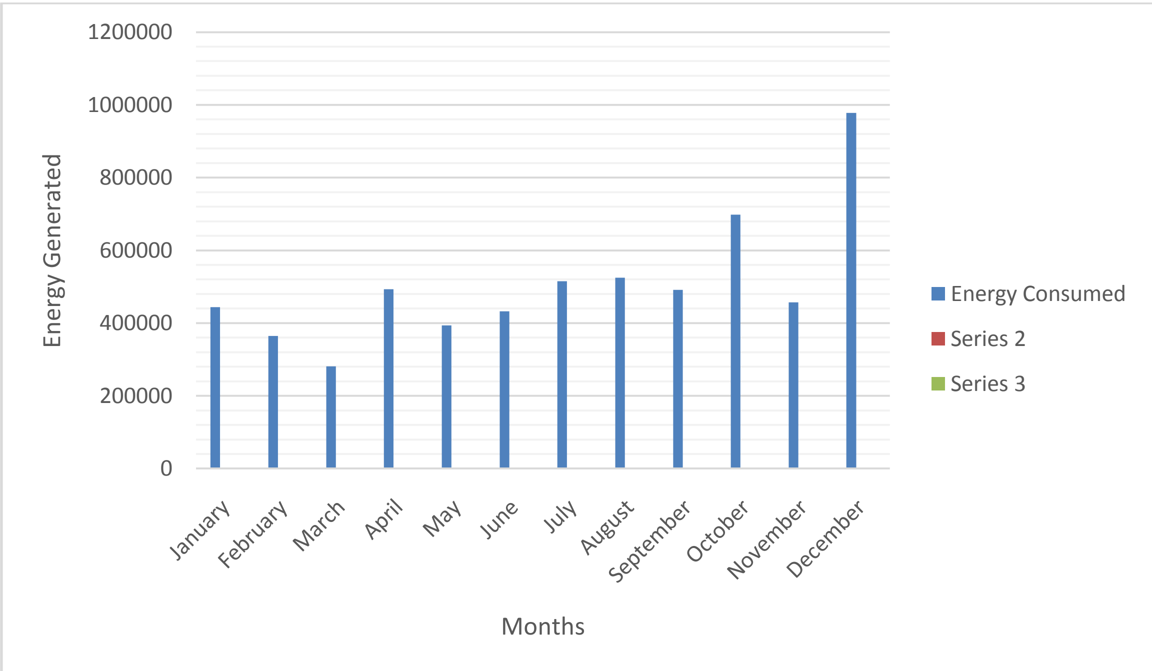


Figure 1: Graph of Energy Generated VS Months

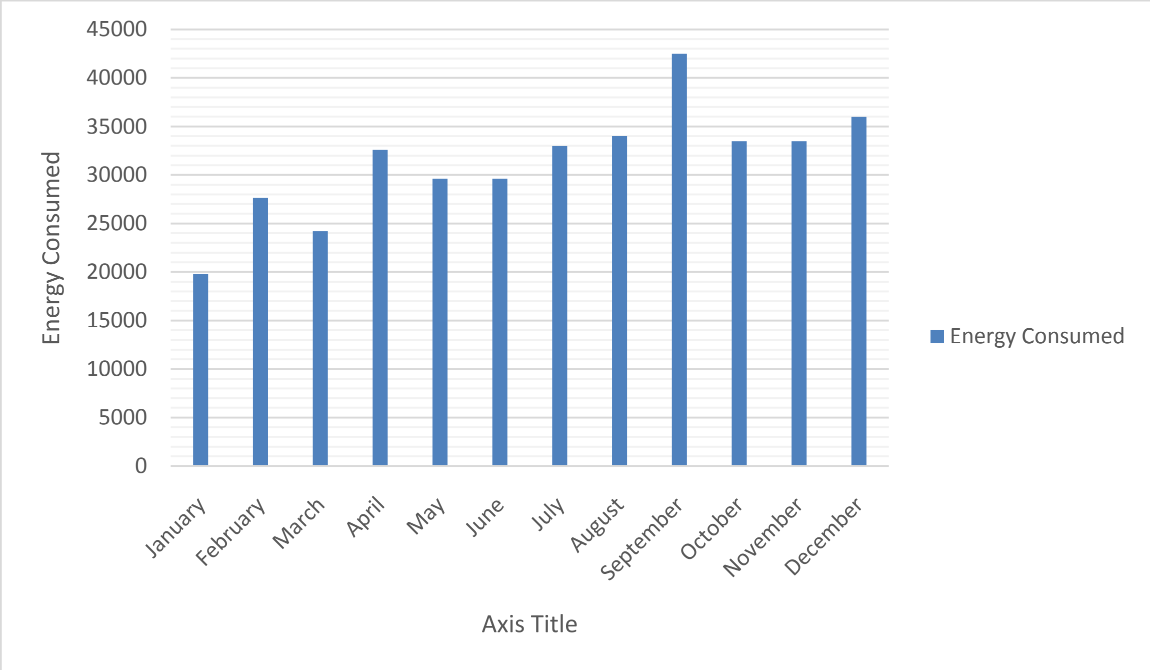


Figure 1: Graph of Energy Consumed VS Months

Itisobservedon fig. 1 thatthemonthofDecembergeneratedthehighestamongothermonthsintermsof power generation,meanwhile,themonthofMarchgeneratedtheleastamongothermonthsintermsofpower generation. The plant is being faced with the challenge of limited supply of gas from the gas station.

The month of October supplies the highest in all the months of the year 2020, this was due to plant shutdown in August so as to carry out all necessary maintenance work. This kind of shutdown is always carried out once in a year due to crevices or scales built up on the plantcomponent.

At a glance faults are being encountered at the plant and it is classified into 3 categories:

- Systemfault
- Plantfault
- Gasfault

Intotal,variousfaultsareidentified,96systemfaults,27plantfaults,and10gasfaults.Allthishinders the efficiency and reliability of the power plant to function properly. It is also observed that proper routine maintenance is being carriedout.

IV. Summary

The reliability of a power plant unit is one of the most important performance parameters whichreflectthequalityandstandards.Thegreatcareandeffortdevotedtoincreasingthereliabilityandqualityofelectricalpowerisanindicationoftheeconomicimplicationforthe power industry. This study has investigated the reliability and availability of Calabar power station units in relation to implementation of a preventive maintenance programme. The availability analysis shows different results for each unit indicating differences in their system installation, maintenance and operation. The availability and reliability of the turbinespresentedinthisstudyreflectonsitebehavior,includingtheeffectsofchangesin auxiliary systems maintenance policy. Identifying the effects of component failure on the system under analysis, based on the failure effects classification, a maintenance policy can be formulated to reduce their occurrenceprobabilities.

V. Conclusion

The reliability evaluation of Calabar thermal power station was calculated with the help of the key performance indicator (kpi). It can be seen from the analysis that the key performance indicator ofthe month of October is the highest among others in terms of percentage generation efficiency, percentage availability factor, average generation and energy generated, and this happened after a shutdown in August so that the annual maintenance routine can be carried out. It is also discovered that the plant is generating below its maximum capacity.

VI. Recommendations

The following were recommended for effective and efficient power plant in the state of study and other states in the nation.

- It is highly recommended that adequate maintenance of equipment is carried out so as tomeet the demands ofconsumers.
- It is also recommended that the Government should set up programs that will aid the effectiveness of the equipment at theplant.
- Supply of gas is also a major setback, so therefore availability of gas should be in abundance for the running of the plant foreffectiveness.
- There should be adequate personnel operating eachunit.

- It is also recommended that the two units that have been out of service since 2007 should be fully repaired and restored to normal workingcondition.
- It is also recommended that only demineralized water should be used as a working medium in the plant to avoid scaling or crevices to the boiler or turbineparts.
- It is recommended that the plant should be expanded by the addition of more units to boost powersupply.

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