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Assessment of Maintenance and Operation of a Steam Turbine Power Plant

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ABSTRACT

Thermal electrical power generation is one of the major methods used in Indian thermal station. Due to inconsistency and failure in the power supply in India, there is a need for a proper operation and maintenance schedule strategy of the various kinds of power plants accessories so as to facilitate their efficiencies and functionality. Indian thermal station, which is one of the major power generating stations in India was used as a case study. It is in the generating sector of the Power Holding Company of India (PHCI) which the state is owned Electric Power Company.

Keyword: - *steam turbine, thermal station, operation and maintenance Schedule of thermal station*

I. INTRODUCTION

A thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After which it passes through the turbine, the steam is condensed in a condenser; this is known as the Rankine cycle. Steam turbines are devices used to convert the pressure energy of high pressure steam to kinetic and 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 increasing technologies. Steam turbine maintenance is of high importance to keep the steam turbines efficiency high and to conform to safety standards to avoid any unforeseen dangers. The steam turbine operates under high steam pressures, and has a number of moving parts that move at extremely high velocities. The nozzles and turbine blades are designed via careful analysis and the parts are manufactured to a high degree of finish and accuracy. 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.

II. THE MAJOR COMPONENTS OF A STEAM POWER PLANT

- Turbine (High, Intermediate and Low pressure).
- Boiler (Economizer, Evaporator, Drum and Super heater).
- Generator
- Condenser
- Feed pumps

Steam turbine

Steam turbines are machines that are used to generate mechanical (rotational motion) power from the pressure energy of steam. Steam turbines are the most popular power generating devices used in the 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 that run on steam. From nuclear reactors to thermal power plants, the role of the steam turbine is both pivotal and result determining. A steam turbine is basically an assemblage of nozzles and blades. Steam turbines are not only employed to operate electric generators in thermal and nuclear power plants to produce electricity, 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 and pumps. Turbines can be condensing or non-condensing, depending on whether the back pressure is below or 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. For a large unit without reheat, the steam may expand through an initial section and then exhaust to a condenser or to a process. The initial turbine is designated as the high-pressure (HP) turbine and 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 [18].

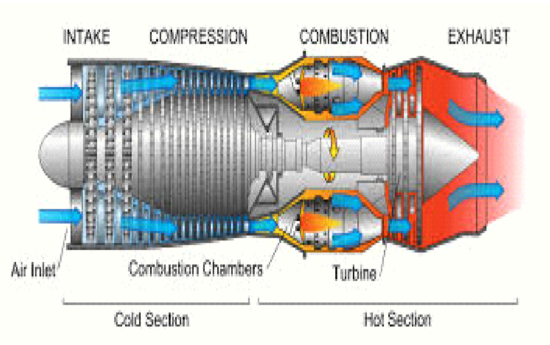


Figure 1. Steam turbine

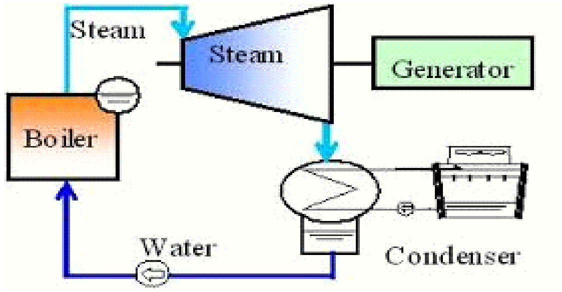


Figure 2. Condensing steam turbine

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, reheated, boiler or evaporator, economizer, and air preheater along with various auxiliaries such as pulverizes, burners, fans, stokes, dust collectors and 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 [11].

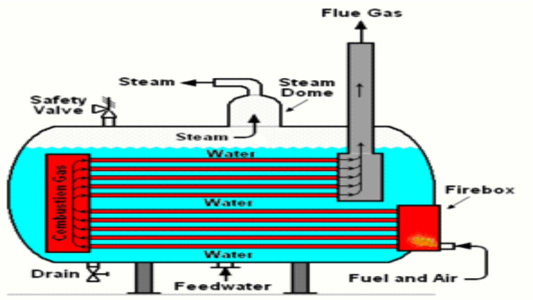


Figure 3. Boiler the components of a boiler include

III. 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 corresponding to the boiler pressure. This is done by hot flue gases exiting the last super heater or reheater at a temperature varying from 370 C to 540 C.

***Evaporator**:* is where phase change occurs from liquid (water) to vapour (steam), essentially at constant pressure and temperature.

***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 separated steam is drawn out from the top section of the drum and distributed for process. Further heating of the saturated steam will make superheated steam normally used to drive a steam turbine. Saturated steam is drawn off the top of the drum and re-enters the furnace in through a super heater. The steam and water mixture enters the steam drum through riser tubes; drum internals consisting of demister separate the water droplets from the steam producing dry steam. The saturated water at the bottom of the steam drum flows down through the down comer pipe, normally unheated, to headers and water drum. Its accessories include a safety valve, a water-level indicator and level controller. The feed-water of the boiler is also fed to the steam drum through a feed pipe extending inside the drum, along the length of the steam drum. A steam drum is used without or in the company of a mud-drum/feed water drum which is located at a lower level. A boiler with both steam drum and mud/water drum is called a bi-drum boiler and a boiler with only a steam drum is called a mono-drum boiler. The bi-drum boiler construction is normally intended for low pressure-rating boiler while the mono-drum is mostly designed for higher pressure -rating[8].

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. 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 superheating of steam[9].

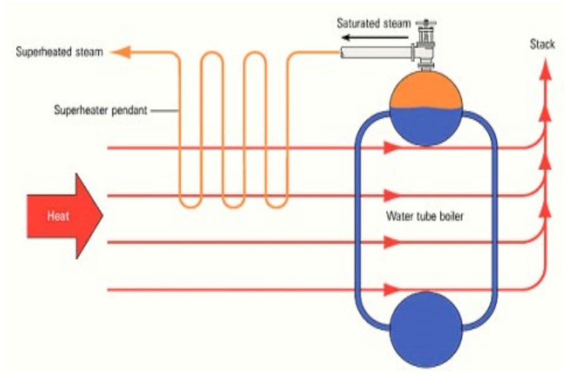


Figure 4. Super heater Condenser

***Condenser**:* The condenser condenses the steam from the exhaust of the turbine into liquid to allow it to be pumped. If the condenser can be made cooler, the pressure of the exhaust steam is reduced and efficiency of the cycle increases. The surface condenser is a shell and tube heat exchanger in which cooling water is circulated through the tubes. The exhaust steam from the low pressure turbine enters the shell where it is cooled and converted to condensate (water) by flowing over the tubes. Such condensers use steam ejectors or rotary motor-driven exhausters for continuous removal of air and gases from the steam side to maintain vacuum. For best efficiency, the temperature in the condenser must be kept as low as practical in order to achieve 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. Thus leaks of non-condensable air into the closed loop must be prevented. Typically the cooling water causes 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 increase the efficiency of the turbines. The limiting factor is the temperature of the cooling water and that, in turn, is limited by the prevailing average climatic conditions at the power plant's location (it may be possible to lower the temperature beyond the turbine limits during winter, causing excessive condensation in the turbine). Plants operating in hot climates may have to reduce output if their source of condenser cooling water becomes warmer; unfortunately this usually coincides with periods of high electrical demand for air conditioning [12]. Figure 4. Condenser The condenser generally uses either circulating cooling water from a cooling tower to reject waste heat to the atmosphere, or once-through water from a river, lake or ocean. The heat absorbed by the circulating cooling water in the condenser tubes must also be removed to maintain the ability of the water to cool as it circulates. This is done by pumping the warm water from the condenser through either natural draft, forced draft or induced draft cooling towers that reduce the temperature of the water by evaporation, by about 11°C to 17°C (20 to 30°F)— expelling waste heat to the atmosphere. The circulation flow rate of the cooling water in a 500 MW unit is about 14.2 m /s (225,000 US gal/min) at full load. The condenser tubes are made of brass or stainless steel to resist corrosion from either side. Nevertheless they may become internally fouled during operation by bacteria or algae in the cooling water or by mineral scaling, all of which inhibit heat transfer and reduce thermodynamic efficiency. Many plants include an automatic cleaning system that circulates sponge rubber balls through the tubes to scrub them clean without the need to take the system off-line. The cooling water used to condense the steam in the condenser returns to its source without having been changed other than having been warmed. If the water returns to a local water body (rather than a circulating cooling tower), it is tempered with cool 'raw' water to prevent thermal shock when discharged into that body of water. From the bottom of the condenser, powerful condensate pumps recycle the condensed steam (water) back to the water/steam cycle.

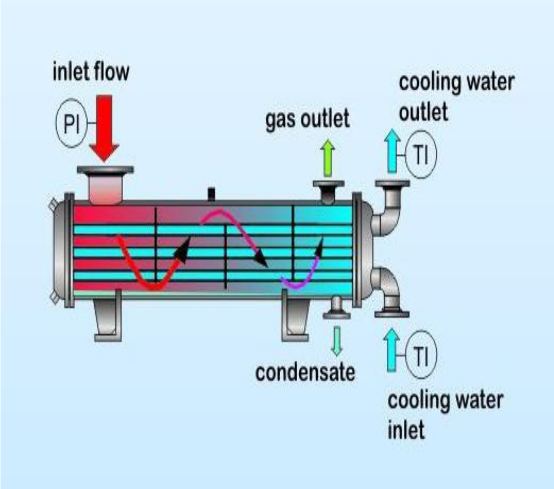


Figure 5. Condenser

Feed pumps: These are pumps that convey treated feed water under pressure to the boiler for its operation of generating steam [6].

III. OPERATIONS

Water enters the pump at state 1 as saturated liquid and is compressed isentropically to the operating pressure of the boiler. The water temperature increases somewhat during this isentropic compression 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 for clarity. Water enters the boiler as a compressed liquid at state 2 and leaves as a superheated vapor at state 3. The boiler is basically a large heat exchanger consisting of an economizer, an evaporator, 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 work by rotating the shaft connected to an electric generator. The pressure and the temperature of the steam enters the condenser. At this state, steam is usually a saturated liquid-vapor mixture with a high quality. Steam is condensed at constant pressure in the condenser, which is basically a large heat exchanger, by rejecting heat to a cooling medium such as lake or a river or atmosphere. Steam leaves the condenser as saturated liquid and enters the pump, completing the cycle. In areas where water is precious, the power plant operates by air instead of water. This method of cooling which is also used in car engines is called dry cooling. Several power plants in the world and a few in the United States use dry cooling to conserve water.

Remembering that the area under the process curve on the T-s diagram represents the heat transfer for internally reversible processes, it is seen that the area under the process curve 2-3 represents the heat transferred to the water in the boiler and the area under the process curve represents the heat rejected in the condenser. The difference between these two is the work produced during the cycle. .

IV. ENERGY ANALYSIS OF THE STEAM CYCLE

All four components associated with the Rankine cycle (pump, boiler, turbine and condenser) are steady-flow devices, and thus all four processes that make up Rankine cycle can be analyzed as steady-flow processes. The kinetic and potential energy changes of the steam are usually small relative to the work and heat transfer terms and are therefore usually neglected. Then the steady-flow energy equation per unit mass of steam reduces:

For 1 kg fluid, the SFEE for the pump as the control volume gives

$$\boldsymbol{h_1} + w_p = \boldsymbol{h_2}, \textbf{where h } = \textbf{enthalpy and wp} = \textbf{ work}$$

$$w_p = \boldsymbol{h_2} - \boldsymbol{h_1}$$

The SFEE for the boiler as the control volume gives

$$\boldsymbol{h_2} + Q_1 = \boldsymbol{h_3}, \textbf{where Q } = \textbf{ heat energy}$$

$$Q_1 = \boldsymbol{h_3} - \boldsymbol{h_2}$$

Similarly, the SFEE for the turbine

$$\boldsymbol{h_3} = W_T + \boldsymbol{h_4}, \textbf{where WT } = \textbf{workdone in turbine}$$

And the SFEE for the condenser gives

$$\boldsymbol{h_4} + Q_2 = \boldsymbol{h_1}$$

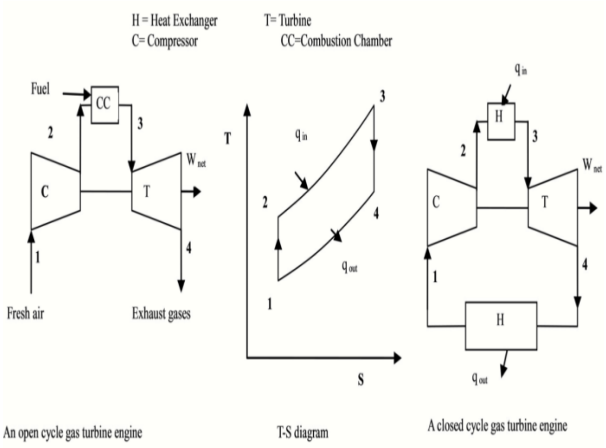
$$Q_2 = \boldsymbol{h_1} - \boldsymbol{h_4}$$

The efficiency of the Rankine cycle is then given by:

$$W_{net} = \frac{W_T - W_P}{Q_2 - Q_1} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2}$$

The thermal efficiency of Rankine cycle can be improved by:

- Increasing the inlet pressure and temperature conditions.
- Increasing the condenser vacuum, i.e. lowering the exhaust pressure.



An open cycle gas turbine engine

T-S diagram

A closed cycle gas turbine engine

Figure 6. Energy cycle analysis diagram

Now increasing the inlet steam pressure for the given inlet steam temperature and condenser pressure would result in increase in work, increase in thermal efficiency, and always an increase in initial steam temperature would always result in increase in work and thermal efficiency (since heat will be added in the cycle at a higher temperature) and decrease in moisture content of steam at turbine exhaust. So there is no upper limit for initial steam temperature. It is limited by the materials used in the boiler tubes and the turbine. Most modern steam turbines are limited to a maximum operating temperatures of 535ºC to 595ºC [6].

Thermal Power Station of Maharashtra State Power Generation Company Limited is located at Koradi in Nagpur district of Maharashtra. There are seven power generating units installed during years 1974 – 1983 in two stages. Units 1 to 4 (120 MW each capacity) were installed in the year

Table 1: Description on Total Number of Installed Units

Unit . No	Year of Install.	Capacity (MW)			Supplier	Present condition	Unit Generation (MU)	Hours runs till 2018
		Till Jan-1990	Jan 1990 to 2007	2007 to till date				
1.	6/3/1974	120	113	103	Boilers - ACC VICKERS, BABCOCK Dureapus Turbines - ELECTRIM ELBLAG POLAND	Under operation	19700.227	224844.38
2.	3/24/1975	120	115	105		Under operation	17827.661	209210.54
3.	3/3/1976	120	115	105		Under operation	17497.054	195718.19
4.	7/22/1976	120	115	105		Under operation	17166.745	197623.03
	Stage-1	480	460	420				
5.	7/15/1978	200	200	200	Boilers - BHEL Tiruchirapalli Turbines-BHEL India	Under operation	28782.785	178040.29
6.	3/30/1982	210	210	210		Under operation	26900.402	162103.00
7.	1/13/1983	210	210	210		Under operation	28688.692	153351.13
	Stags-II	620	620	620				
	Total	1100	1080	1040				

1974-76 by M/s Electrim, Poland. Unit 5 (200 MW), 6 (210 MW) & 7 (210 MW) were installed subsequently by BHEL. A brief description on total number of installed units is as indicated below in Table 1.

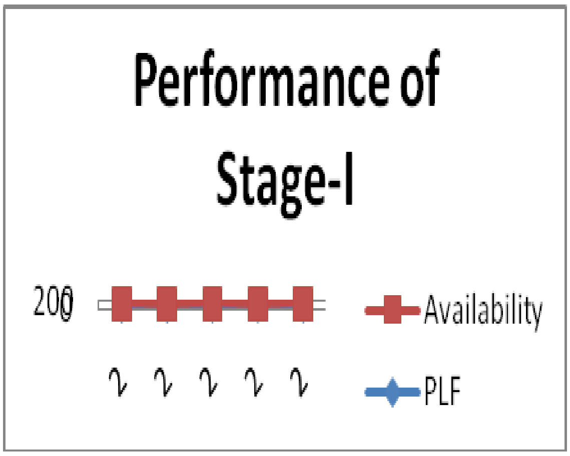


Figure: 7. Performance of Stage-I

V. RECOMMENDATION

As discussed in the foregoing chapters, as per the present conditions of Koradi Thermal power plant the achievable heat rate and auxiliary power consumption will be as follows:

Though the recommended heat rate is in no way justified in terms of national thrust on energy conservation, but given the condition constraints pertinent with Koradi power station, this should be treated as a benchmark value for this power plant unless a comprehensive R&M programme coupled with de-bottlenecking of operating problems causing reduced loadability of the units is carried out. It has also been noticed in respect of Units 1 to 4 that overloading of these units further may be detrimental to the safety of men and machines. However, in the overall interest of utilization of fossil fuels in an efficient manner, following broad recommendations are proposed for improvement of performance level of the power station:

1. The boilers of Units 1 to 4 have become uneconomical for operation on long term basis. Either comprehensive R&M or replacing the boiler with new should be thought of in right earnest to improve performance level of the power station.
2. Arrangements may be done to get washed coal /imported coal for the plant
3. Stage – 1 turbine are being operated under restricted load condition due to vibration, eccentricity, mechanical governors, IPH problems etc. A detailed study should be conducted for a long term solution of these problems.
4. Closed cycle cooling system should be provided for Unit # 5 to improve performance of this unit.
5. Proper storage facility for coal along with blending facility will improve the quality of coal being fed into the boilers
6. Improved control systems with state of the art facilities should be provided in order to achieve better performance levels and accuracy of measurements
7. Dry ash handling and storage facility should be provided to meet CPCB/ MoEF stipulations of 100% ash utilization.
8. For calculation of heat rate on annual basis, the stock measurement system gives almost believable values with some margin of errors. But considering strict stipulations from regulatory authorities, it would be in the overall interest of the organization to install gravimetric feeders for new units. Installation of gravimetric coal

feeders for existing units may incur considerable investment for which a convincing justification may be difficult.

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