ANALYSIS OF GENERATOR AND TURBINE OPERATIONS AT KTPS POWER PLANT

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Abstract: *This paper analyzes Generator and Turbine operations at Kothagudem Thermal Power Station (KTPS) in Telangana, India. It focuses on key aspects such as capacity, types of equipment, operational efficiency and maintenance practices. KTPS, with a total capacity of 1,800 MW, utilizes steam turbines coupled with synchronous generators to convert thermal energy into electrical energy. operational efficiency is evaluated through metrics like heat rate and plant load factor, while maintenance practices include predictive maintenance, scheduled outages and real time monitoring. Performance is measured by availability factor, capacity utilization and forced outage rate. The analysis underscores the importance of high efficiency, reliability and regulatory compliance in enhancing the operational effectiveness of KTPS.*

Keywords: *Primary Water Cooling, Hydrogen Cooling, Generator, Turbine, Brushless Exication, Permanent Magnet Generator.*

1. Introduction

In India, thermal power plants are a major source of electricity, contributing over 60% of the total power generation. These plants primarily use coal as fuel, although natural gas and oil are also utilized in some regions. India has some of the largest thermal power stations in the world, which play a critical role in meeting the country's growing energy demands. Thermal plants are essential for ensuring a stable and continuous power supply across India's diverse regions.

Kothagudem Thermal Power Station (KTPS) is a prominent thermal power plant located in the Bhadradri Kothagudem district of Telangana, India. It is one of the oldest and largest coal-based power plants in South India. KTPS is owned and operated by the Telangana State Power Generation Corporation Limited (TSGENCO). The power station has a total installed capacity of 1,800 megawatts (MW), consisting of various units: one unit of 500 MW, two units of 250 MW each, and one unit of 800 MW.

The power plant primarily uses coal as a fuel source to generate electricity, sourced from nearby coal mines such as the Singareni Collieries Company Limited (SCCL). KTPS has implemented various measures to minimize its environmental impact, including the use of electrostatic precipitators and other pollution control equipment to reduce particulate emissions. Additionally, efforts have been made to comply with environmental regulations and promote sustainable practices.

KTPS plays a crucial role in meeting the power demand of Telangana and the southern region of India. The electricity generated at KTPS is supplied to the state grid, helping to power industries, homes, and commercial establishments. The availability of a reliable power supply from KTPS also attracts industries and contributes to the overall development of the area.

The KTPS operates with a heat rate of around 2,400 to 2,600 kCal/kWh, indicating efficient fuel-to-electricity conversion. The plant typically achieves a Plant Load Factor (PLF) of 75% to 85%, demonstrating reliable and consistent power generation. In addition to maintaining optimal load factor, KTPS has implemented advanced control systems to minimize auxiliary power consumption and reduce losses. The plant has also made efforts to retrofit older units with modern technologies to enhance efficiency and reduce emissions. Regular maintenance practices and real-time monitoring further contribute to improving operational reliability and reducing downtime, ensuring steady electricity supply to the region.

Dipak Sarkar Published a book on Thermal Power Plant Design and Operation deals with various aspects of a thermal power plant starting from fundamentals leading in depth to technical treatment. The book is aimed at providing new dimension to the subject and thrust of the book is focused on technology and design aspect with special treatment on plant operating practices and troubleshooting. To Utility Operators and Design Engineers this book would be of immense help as reference book and to execute day-to-day activities [1].

Mohammed Elamin discusses the different aspects of thermal power generation including plant components engine types and the fundamental of thermodynamics with respect to power generation. The main components of thermal power plants and their role in the operation of the power plant are discussed. Understanding the main concepts of Rankine cycle, thermodynamics and heat transfer laws is vital in power generation engineering. The use of internal combustion engines such as diesel engine in power generation is further studied. The aim of this research is to provide a description of the thermal power generation methods in an easily digestible form and to conduct a comparison between them with a particular focus on the thermal efficiency, power range [2].

M. Dubey, Abhay Sharma proposed work, energy analysis of a coal-based thermal power plant is done using the design data from a 210 MW thermal power plant under operation in India. The entire plant cycle is split up into three zones for the analysis: (1) main steam system, (2) steam turbine, condenser, feed pumps and the HP and LP heaters, (3) the entire analysis with boiler, turbo-generator, condenser, feed pumps, regenerative heaters and the plant auxiliaries. It helps to find out the contributions of different parts of the plant towards energy destruction. The energy efficiency is calculated using the operating data from the plant at different conditions, viz. At different loads, different condenser pressures, with and without regenerative heaters and with different settings of the turbine governing [3].

2. Overview of KTPS

The KTPS in Telangana features the 5th and 6th stages as key expansions in its power generation capacity. The 5th stage, commissioned in the early 2000s, includes units with a capacity of approximately 250 MW each, utilizing conventional coal-fired technology with enhanced efficiency and reduced emissions. In contrast, the 6th stage, a more recent addition, consists of a larger unit of 500 MW, incorporating advanced technologies to meet stringent environmental standards and improve thermal efficiency. Together, these stages significantly contribute to the region's power supply and modernization efforts. The figure 1 presents an overview of the thermal plant unit, highlighting its main components such as the boiler, turbine and generator as well as their respective roles in the power generation process[4].

The steam flow is as shown below:

Boiler → Drum → Super Heater → HP Turbine → ReHeater → IP Turbine →

LP Turbine → Condenser

The feed water flow is show below:

Condenser → CEPs → LPH → Deaerator → BFPs → HP heaters→ Economiser →

Drum→ Boiler

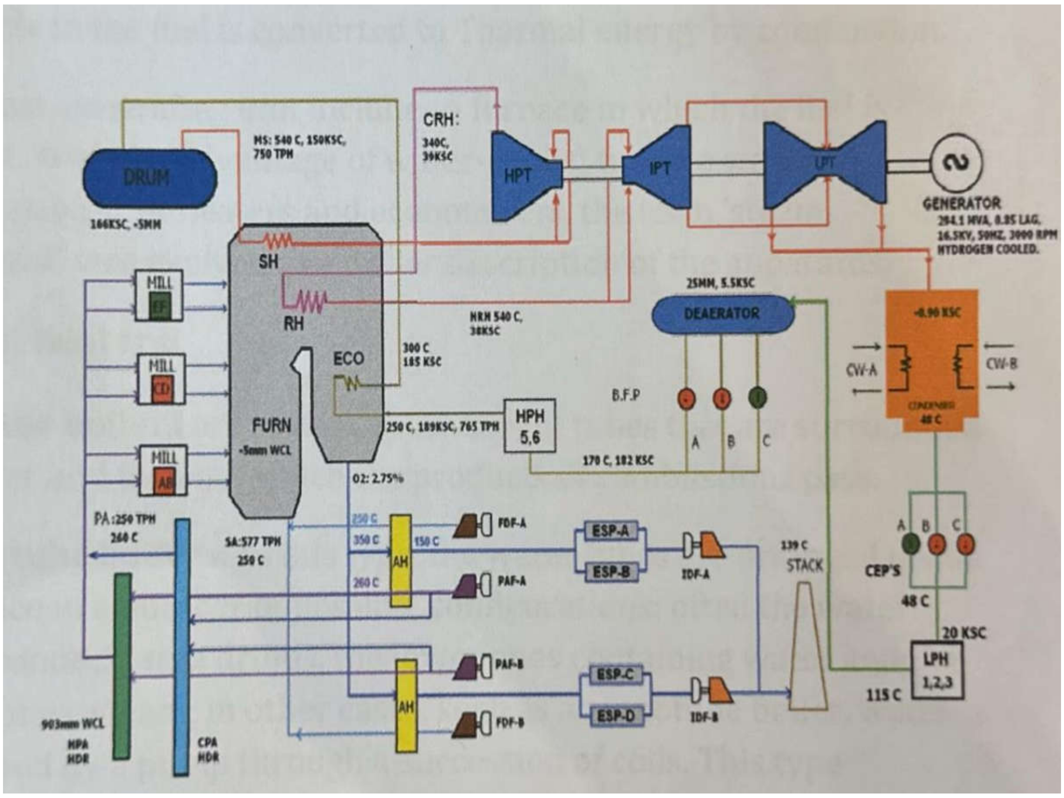

Figure 1. Unit Overview

Components of Thermal Power Plant: A thermal power plant primarily consists of several key components that work together to convert heat energy into electrical energy.

Boiler: The boilers used in KTPS are designed to generate steam for power generation by burning coal. These boilers have a high capacity, typically ranging from 250 MW to 800 MW, depending on the specific plant unit. The steam produced can reach temperatures of around 540°C. The key materials required for boiler operation include coal (as the primary fuel), water (to generate steam), and air for combustion. The inputs to the boiler include coal, water, and air, while the outputs are high-pressure steam, flue gases, and ash.

Boiler Drum: The boiler drum in the 6th stage of the KTPS is a designed for efficient steam generation and separation. It serves to separate steam from water within the boiler system, facilitating a continuous flow of steam to the turbines. The below figure 2 presents the boiler drum.

Figure 2. Boiler Drum

Figure 3. Super Heater

Super Heater: The above figure 3 presents the superheater, an essential component in thermal power plant. The superheater increases the temperature of the steam produced by the boiler to improve turbine efficiency. It typically operates with steam temperatures ranging from 500°C to 540°C for superheated steam, depending on the unit. The superheater is made from alloy steels to withstand high temperatures and pressures. Its input is saturated steam from the boiler, and its output is superheated steam, which is then fed into the turbine for power generation.

Economiser: The economiser is used to heat the feedwater by utilizing waste heat from the flue gases, thereby improving boiler efficiency. It typically operates with feedwater temperatures ranging from 100°C to 180°C, depending on the unit. The economizer is made from high-strength carbon steel and alloy steels to withstand the corrosive and high-temperature environment. Its input is cold feedwater from the condensate system, and its output is preheated feedwater, which is sent to the boiler for steam generation.

Turbine: The below figure 4 shows the turbine, an important part of thermal power plant. Turbines are essential for converting thermal energy from steam into mechanical energy. The steam entering the turbine typically has temperatures ranging from 500°C to 540°C, depending on the unit. Made from high-strength alloy steels and stainless steel, the turbine is designed to withstand the extreme conditions of high heat. As steam passes through the turbine blades, it causes the rotor to spin, producing mechanical energy. The input to the turbine is superheated steam from the boiler, while the output is mechanical energy that drives the generator to produce electricity.

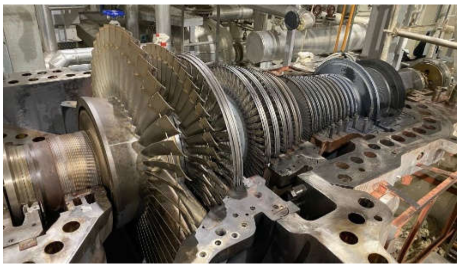

Figure 4. Turbine

Generator: The generator is responsible for converting mechanical energy from the turbine into electrical energy for supply to the grid. It operates with a capacity of up to 500 MW per unit, depending on the turbine-generator combination. The generator is constructed using high-quality copper for the windings and steel for structural components to withstand high mechanical and electrical stresses. The input to the generator is mechanical energy from the turbine, and the output is electricity, which is then fed into the power grid for distribution.

Condenser: The condenser is used to convert exhaust steam from the turbine back into water by cooling it, which improves the overall efficiency of the cycle. The condenser typically operates with cooling water temperatures ranging from 30°C to 40°C, depending on ambient conditions. It is made from copper and brass tubes for efficient heat exchange and corrosion resistance. Its input is exhaust steam from the turbine, and its output is condensed water, which is returned to the boiler as feedwater after being treated and preheated.

HP and LP Heaters: High pressure heaters are crucial components in the thermal cycle of KTPS. Their primary function is to preheat the feedwater before it enters the boiler. By increasing the temperature of the feedwater, high pressure heaters enhance the thermal efficiency of the steam generation process, allowing the plant to generate steam more effectively while reducing fuel consumption.

Low pressure heaters are important components in the thermal cycle of KTPS. Their primary function is to preheat the condensate (returning steam) before it enters the high pressure feedwater system. By raising the temperature of the condensate, low pressure heaters improve the overall efficiency of the steam cycle, ensuring that the power plant operates more effectively while minimizing energy losses.

Deaerator: The below figure 5 presents the deaerator, a key component in thermal power plants. It removes dissolved gases from the feedwater to prevent corrosion in the boiler and other equipment. The deaerator is used to remove dissolved gases, primarily oxygen and carbon dioxide, from the feedwater, preventing corrosion in the boiler and other components. It typically operates at temperatures between 100°C and 120°C, depending on the steam pressure. The deaerator is made of carbon steel to resist corrosion and handle high temperatures. Its input is feedwater and steam, and its output is deoxygenated water, which is sent to the boiler for steam generation.

Figure 5. Deaerator

Figure 6. Cooling Towers

Cooling Towers: The above figure 6 presents the cooling towers at KTPS, which are designed to dissipate heat from the plant's steam cycle. These are typically wet-type, forced draft cooling towers with a capacity to handle large volumes of water. The temperature of the cooling water before and after the cooling process usually ranges from 40°C to 30°C. The materials used in their construction include reinforced concrete and steel, which are designed for durability and corrosion resistance. The primary inputs are water and ambient air, and the main output is cooled water that returns to the plant's condenser system.

3. Generator

The below figure 7 presents the generator, which operates on the principle of electromagnetic induction, where mechanical energy is converted into electrical energy. By rotating a coil within a magnetic field, it induces an electric current within the wire.
In a thermal power plant, high pressure steam produced from burning coal is directed into a steam turbine, which rotates, transforming thermal energy into mechanical energy. This turbine is connected to a synchronous generator, where the rotating rotor induces an electric current in the stator windings, based on Faraday’s Law of induction. The generators at KTPS operate at a combined capacity of 1800 MW, including a 1x800 MW supercritical unit and 250 MW and 500 MW units. The power generation process follows the Rankine cycle: heating water to produce steam, expanding the steam in the turbine, condensing it back to water, and returning it to the boiler[5].

The generator at KTPS consists of several key components, each designed for specific functions and materials suited to high-capacity power generation. The stator is made of laminated silicon steel to minimize eddy current losses and operates within a temperature range of 40°C to 90°C. It receives induced current from the rotor and outputs AC power to the grid, handling loads typically between 30% and 100% of the rated capacity (e.g., 500 MW for Stage VI units). The stator windings, typically made of copper or aluminum for high conductivity, are designed to carry the rated current and operate at temperatures between 60°C and 120°C under full-load conditions.

The rotor, made of steel with copper or aluminum windings, converts mechanical energy from the steam turbine into a magnetic field, operating within a temperature range of 60°C to 100°C. The rotor windings, also composed of copper or aluminum, are responsible for carrying the DC excitation current and typically operate at temperatures of 60°C to 120°C, matching the generator's load fluctuations. The bearings, made of steel or special alloys, support the rotor's weight and ensure smooth rotation, typically operating at temperatures between 30°C and 80°C. Finally, the exciter, which uses permanent magnets or field windings, provides DC excitation to the rotor, typically operating between 40°C and 90°C. Its load varies based on the generator's voltage requirements. These components work in unison to ensure the efficient conversion of mechanical energy to electrical power, maintaining the stability and performance of the 1800 MW capacity at KTPS.

Figure 7. Generator

Brushless Excitation System: The brushless excitation system, as presented in the figure 8 below, is employed at KTPS to significantly enhance reliability and efficiency by eliminating the mechanical wear and maintenance associated with brush systems. The major components of brushless excitation are the Permanent Magnet Generator (PMG), Automatic Voltage Regulator (AVR), main exciter, and rotating rectifier, which work together to supply and regulate the excitation current for the generator. The brushless excitation system operates by using an AC exciter, mounted on the same shaft as the main generator, to produce AC electricity. This AC is then converted to DC by a rotating rectifier assembly located on the rotor, eliminating the need for brushes. The DC output is fed directly to the generator field windings, creating the necessary magnetic field for electricity generation. A voltage regulator continuously monitors the generator output voltage and adjusts the field current to maintain a stable voltage. Integrated cooling mechanisms, often employing hydrogen for its high thermal conductivity, ensure the components remain within safe operating temperatures. This brushless design enhances reliability, reduces maintenance needs, and ensures efficient operation, contributing to a stable power supply from the plant.

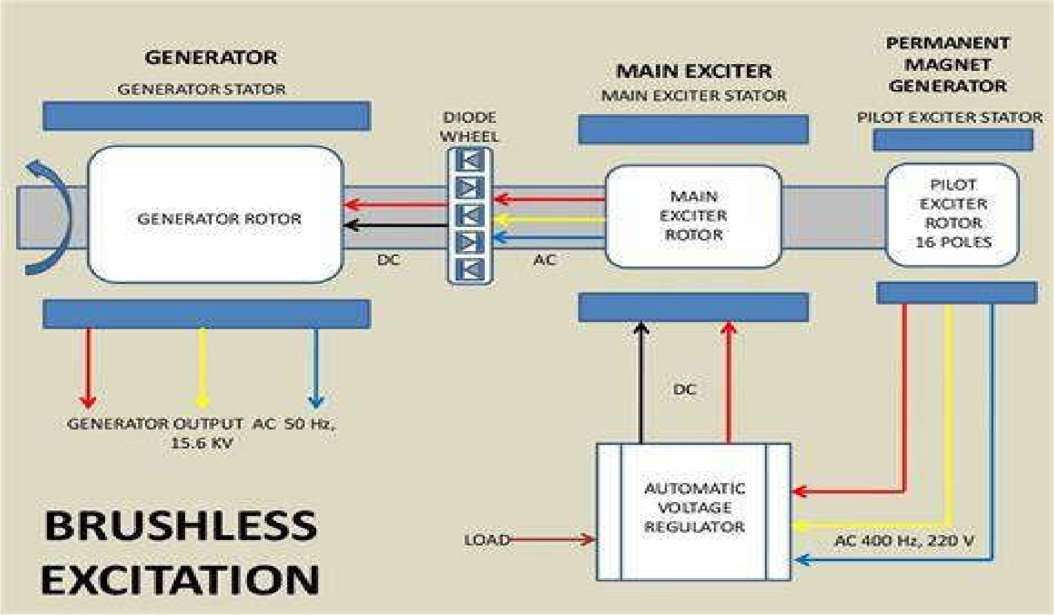

Figure 8. Brushless Excitation

Cooling Methods of Generator:

Generators use cooling methods to manage heat and maintain optimal operating temperatures.

Hydrogen Cooling: The KTPS employs a highly efficient hydrogen gas cooling method for its generators, leveraging the superior thermal properties of hydrogen to ensure optimal performance and reliability. The cooling process begins with hydrogen gas circulating within a closed loop system around the generator's rotor and stator components, where it absorbs the heat generated during operation. This heated hydrogen gas is then directed to gas to water heat exchangers located on the stator frame. These heat exchangers transfer the absorbed heat from the hydrogen gas to water, effectively cooling the gas down. The cooled hydrogen is then recirculated back into the generator, maintaining a continuous cooling cycle.

Daily, two bottles of hydrogen are inserted into the generator to replenish any lost hydrogen and maintain optimal pressure and cooling efficiency. Seal oil is essential in the hydrogen cooled generators at the KTPS, playing a crucial role in blocking the stator and rotor core. It acts as a barrier to prevent hydrogen gas from escaping the generator, which is vital for safety and maintaining the system's efficiency. The seal oil is continuously supplied to oil rings mounted on the rotor shaft. These rings rotate with the shaft, creating a seal that blocks hydrogen gas. This containment ensures the hydrogen cooling system operates effectively by keeping the gas within the generator, thereby facilitating optimal heat dissipation.

Primary Water Cooling: The primary water cooling system plays a critical role in maintaining the temperature of the generator's stator windings. The primary water cooling system works by circulating water through small diameter copper tubes, known as strands, which are intricately wound around the stator windings. These tubes are engineered to withstand high temperatures and pressures, ensuring that they can effectively transfer heat away from the windings. The water is continuously circulated through these tubes, absorbing the heat generated by the electrical currents in the stator windings. As the water flows through the strands, it absorbs the heat, reducing the temperature of the windings and preventing overheating.

Once the water has absorbed the heat from the stator windings, it becomes heated and is then directed to gas to water heat exchangers. In these heat exchangers, the hot water is cooled by transferring its heat to another medium, typically cooler water or air, which is then expelled. This process ensures that the primary water is continuously cooled before being recirculated back through the stator windings, maintaining an effective and efficient cooling cycle.

4. Turbine

A turbine converts thermal energy from steam into mechanical energy through blade rotation. The principle of a turbine involves converting the kinetic energy of a moving fluid such as water, steam, air, or gas into mechanical energy, typically rotational. When the fluid flows through the turbine, it strikes the blades or vanes, imparting force and causing them to rotate. This rotational motion is transferred to a shaft connected to a generator or other machinery, converting the fluid's energy into useful mechanical work. The process relies on the momentum and pressure differences of the fluid to efficiently transfer energy[6].

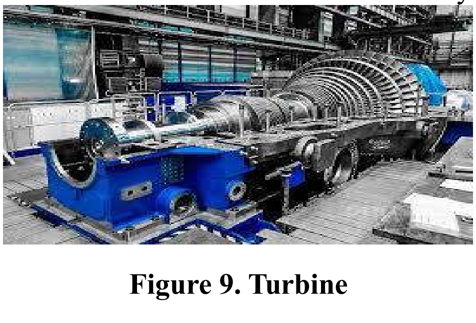

Figure 9. Turbine

Stages of Turbine: The above figure 9 presents the turbine, which consists of three stages: HP, IP, and LP. The turbine has a single-flow HP cylinder, a double-flow IP cylinder, and a double-flow LP cylinder. The HP, IP, and LP rotors are connected by rigid couplings. The lines leading from HP exhaust branches to the re-heater are provided with check valves, which prevent flow of hot steam from the reheater back to the HP turbine. The steam coming from the re-heater goes to the IP turbine through two combined stop and control valves and the exhaust from the IP turbine is taken to the LP turbine by two cross around pipes one either side of the turbine at the operating floor level. This reduces the requirements on the overall height of the turbine bay.

HP Turbine: The outer casing of the HP turbine is of barrel type construction. This avoids mass accumulation due to absence of flanges. As a result of the almost Complete rotation symmetry the wall thickness is kept moderate and of nearly equal strength at all section. The inner casing carries the guide blades and is axially split and Cinematically supported. The space between the inner and outer shells is sealed from the neighbouring spaces by sealing rings. As the inner casing is not subjected to large pressure drops the joint flange and bolts are designed for less stringent conditions. The inner casing is fixed in the horizontal and vertical planes in the outer casing so that it can freely expand radially in all direction and axially from a fixed point when heating up while maintaining eccentrically. The barrel construction permits rapid start up and higher rates of load changes due to absence of high thermal stresses. Barrel type casing are also easy to cast which means the castings can be of exceptionally good quality. The connections of the main steam piping with the HP turbine are by means of sleeve joint having buttress threads. These threads are located in the outer casing and connection with the piping is made through breech nuts. This arrangement provides ease of opening the joint during maintenance. The HP turbine operates under a pressure of approximately 100 to 150 bar[7].

IP Turbine: The IP casing is split horizontally and is of double shell and double flow construction, with the inner casing carrying the guide blades and kinematically supported within the outer casing. The construction provides flexibility for choosing the locations of bleed steam point to suit the best thermal efficiency. The reheated steam enters the inner casing through the top &bottom. The arrangement confines the high steam temperature to the admission branch of the casing while the joint of the outer casing is only subjected to lower pressure and temperature at the exhaust of the inner casing. Although the casings are of split design yet these do not impose restriction in start up timings and rapid load changes due to the provision of suitable stress relieving grooves built in the inner casing. The hydraulic turning gear blades are located on the coupling of the IP rotor. The steam entering the IP turbine typically operates at a pressure of 2.0 to 6.0 MPa (20 to 60 bar).

LP Turbine: KTPS utilizes LP turbines as integral components of its steam generation process. With a total installed capacity of approximately 1,720 MW, the plant comprises several coal-fired units where LP turbines effectively extract energy from steam after it has been processed through high pressure and intermediate pressure turbines. These turbines are specifically designed to handle steam at lower pressures, maximizing the efficiency of the energy conversion process by capturing the remaining energy in the steam, thereby enhancing the overall performance of the power generation cycle. In addition to their operational significance, the LP turbines at Kothagudem also contribute to the plant's efforts in reducing emissions and improving environmental sustainability. The plant has implemented various measures to comply with regulatory standards, focusing on minimizing the ecological impact of its operations. Regular maintenance and technological upgrades are vital for ensuring the optimal functioning of the LP turbines, thus extending their lifespan and boosting efficiency. The steam entering the LP turbine typically operates at a pressure of 0.3 to 2.0 MPa (3 to 20 bar).

5. Maintenance Practices

Preventive Maintenance Practices: Preventive maintenance in thermal power plants is a proactive approach aimed at maintaining equipment in optimal working condition to prevent unexpected failures and ensure uninterrupted operation. This strategy involves scheduled inspections, servicing, and replacements of components based on time intervals or usage metrics rather than waiting for equipment to fail. By systematically addressing wear and tear, preventive maintenance enhances the reliability and efficiency of power generation, reduces downtime, and minimizes costly emergency repairs. This approach not only extends the lifespan of equipment but also helps in compliance with regulatory standards and improves overall safety.

Predictive Maintenance Practices: Predictive maintenance (PDM) is a proactive maintenance strategy that leverages data analysis and advanced monitoring techniques to predict equipment failures before they occur. By continuously assessing the condition and performance of machinery, organizations can identify potential issues and schedule maintenance activities accordingly, minimizing unplanned downtime and reducing maintenance costs. Techniques often include vibration analysis, thermal imaging, oil analysis, and ultrasonic testing, allowing for timely interventions that enhance equipment reliability and extend its lifespan.

Corrective Maintenance Practices: Corrective maintenance in a thermal power plant refers to the actions taken to repair or restore equipment to its normal operating condition after a failure or malfunction has occurred. Unlike preventive maintenance, which aims to prevent issues before they happen, corrective maintenance is reactive and involves diagnosing the problem, repairing or replacing faulty components, and ensuring the system is back online as quickly as possible. This approach is essential in minimizing downtime and maintaining the overall efficiency of power generation, but it often requires careful planning and execution to avoid prolonged disruptions in service.

Upgrades and Retrofits Maintenance Practices: Upgrades and retrofits in thermal power plants refer to the process of enhancing or modifying existing equipment and systems to improve efficiency, performance, and reliability. These interventions can involve incorporating advanced technologies, replacing outdated components, or implementing new systems that comply with modern environmental and safety standards. Upgrades often focus on increasing energy efficiency, reducing emissions, and extending the operational lifespan of the plant, ultimately contributing to more sustainable energy production.

Training and Retrofits Maintenance Practices: Training in thermal power plants involves educating staff and operators on best practices for operating, maintaining, and managing plant equipment effectively. This includes familiarization with safety protocols, operational procedures, and the latest technologies. Ongoing training helps ensure that personnel are equipped to handle equipment, respond to emergencies, and implement maintenance strategies efficiently, ultimately enhancing the plant's overall performance and safety.

6. Conclusion

The study conducted at KTPS provided valuable insights into the intricate operations of power generation. The exploration of generator operations highlighted the critical role these systems play in energy production. Understanding the various stages of turbine operation underscored the importance of efficiency and reliability in generating electricity. The investigation into cooling methods, specifically hydrogen cooling and primary water cooling, revealed their significance in maintaining optimal performance and safety standards. These cooling techniques are essential for managing temperatures and ensuring the longevity of equipment. The assessment of maintenance practices emphasized the necessity of regular inspections and proactive measures to prevent operational failures. The operation of generators and turbines at the KTPS is a critical component of the plant's overall functionality and efficiency. The turbines convert thermal energy from steam into mechanical energy, which is then transformed into electrical energy by the generators. The advanced engineering, high-quality materials, and precise manufacturing processes ensure that both turbines and generators operate reliably under high stress and temperature conditions. The integration of sophisticated cooling systems, such as hydrogen gas cooling for the generators and water cooling for the turbines, ensures optimal performance and prevents overheating. Regular preventive maintenance further enhances the reliability and longevity of these components. Together, these systems enable the KTPS to generate electricity efficiently and sustainably, meeting the energy demands of the region.

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