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Full Length Article

A Detailed Study On KTPS-VII Stage 1*800 Mw Overview

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ABSTRACT

Thermal power generation remains a primary source of electricity worldwide, particularly in developing nations such as India. With technological advancements, power plants have evolved from subcritical to supercritical and ultra-supercritical systems, offering higher efficiency, lower emissions, and improved operational performance. Kothagudem Thermal Power Station (KTPS) Stage VII, located in Telangana, represents a modern 800 MW supercritical coal-based generating unit developed to meet the increasing energy demand of the region.

This study presents a detailed overview of the operational principles, system design, and protection mechanisms employed in the KTPS Stage VII unit. The plant integrates advanced boiler, turbine, and generator technologies to efficiently convert thermal energy into electrical energy. Additionally, automation and control systems play a crucial role in ensuring reliable and safe operation while minimizing human intervention.

The project highlights the significance of KTPS Stage VII in strengthening regional power infrastructure and supporting economic development. It also demonstrates how contemporary engineering practices can enhance power generation efficiency while addressing environmental considerations.

***Keywords**: Thermal Power Generation, Supercritical Power Plant, Kothagudem Thermal Power Station (KTPS), Boiler-Turbine-Generator System, Power Plant Automation, Energy Efficiency, Power System Protection, Coal-Based Power Plants*

INTRODUCTION

Energy has always been a fundamental driver of human civilization, and its importance continues to grow with technological progress and industrial expansion. Among various forms of energy, electrical energy holds a dominant position due to its versatility, ease of transmission, and wide range of applications in domestic, industrial, agricultural, and transportation sectors.

Electricity plays a vital role in improving living standards, supporting industrial productivity, and enhancing agricultural practices such as irrigation and mechanization. One of its major advantages is that it can be generated in centralized locations and transmitted efficiently over long distances with minimal losses. Furthermore, it is relatively clean at the point of consumption, making it highly suitable for modern applications The level of electrical energy consumption per capita is widely recognized as an indicator of a nation's economic development. Developed countries such as Japan, United Kingdom, and United States exhibit significantly higher electricity consumption compared to developing regions. Although India has shown steady growth in electricity consumption over the decades, the demand continues to rise due to rapid industrialization, urbanization, and population growth.To meet this increasing demand, it is essential to expand generation capacity and adopt advanced technologies such as supercritical thermal power plants, which provide improved efficiency and reduced environmental impact.

LITERATURE SURVEY

Several researchers and standard organizations have contributed extensively to the understanding of electrical machines and power system components relevant to thermal power plants.

V. K. Mehta and Rohit Mehta provide a comprehensive foundation in electrical machinery, covering DC machines, induction motors, and synchronous machines. Their work is widely appreciated for its clear explanations and practical problem-solving approach, making it useful for both academic and industrial applications.

P. S. Bimbhra offers an in-depth analysis of electrical machines with particular emphasis on transformers and electromechanical energy conversion. His work includes detailed discussions on magnetic circuits, phasor diagrams, and performance evaluation methods such as open-circuit and short-circuit tests. It is considered a valuable reference for advanced engineering studies and practical system design.

The Bureau of Indian Standards standard IS 2026 defines essential guidelines for the design, testing, and performance evaluation of power transformers in India. It specifies parameters such as insulation levels, temperature rise limits, and short-circuit withstand capacity, ensuring reliability and safety in power system operations. The standard is aligned with international IEC practices to maintain global compatibility.

OBJECTIVE

The primary objective of this study is to provide a comprehensive analysis of power generation at Kothagudem Thermal Power Station (KTPS) Stage VII, an 800 MW supercritical coal-fired unit. The study focuses on understanding the plant's operational framework, major components, efficiency aspects, and protection systems.

PRINCIPLE OF OPERATION

The Rankine cycle serves as the fundamental thermodynamic cycle in steam-based thermal power plants, describing the conversion of heat energy into mechanical and subsequently electrical energy. In this cycle, feedwater is first pressurized using a pump and then supplied to the boiler, where it absorbs heat produced by coal combustion and is converted into high-pressure steam. This steam expands through the turbine blades, transforming thermal energy into mechanical work and causing the turbine shaft to rotate. After expansion, the low-pressure steam is directed to a condenser, where it is cooled and converted back into liquid water by rejecting heat to the surroundings, typically through cooling towers or water-cooling systems. The condensed water is then pumped back into the boiler, completing the cycle. The efficiency of the Rankine cycle is primarily dependent on the temperature difference between the boiler and condenser, with conventional systems achieving efficiencies in the range of 30–40%. In supercritical power plants, the operating pressure exceeds the critical pressure of water, eliminating the distinct phase change between liquid and steam. Instead, water is directly converted into a supercritical fluid, resulting in improved thermal efficiency and reduced fuel consumption.

Reheat Cycle

To improve the efficiency and operational performance of the basic Rankine cycle, a reheat cycle is commonly employed in modern thermal power plants. In this configuration, steam initially expands in the high-pressure turbine and is then returned to the boiler for reheating before being sent to the intermediate- and low-pressure turbines for further expansion. This process increases the average temperature at which heat is added to the system, thereby enhancing thermal efficiency. Additionally, reheating significantly reduces the moisture content in the later stages of the turbine, which helps prevent blade erosion and extends the lifespan of turbine components. Typically, the incorporation of a reheat cycle results in an efficiency improvement of about 4–5% compared to a simple Rankine cycle.

Regenerative Cycle

The regenerative cycle is another modification designed to enhance the efficiency of thermal power plants by utilizing extracted steam from the turbine to preheat the feedwater before it enters the boiler. In this process, small quantities of steam are bled from different stages of the turbine and directed to feedwater heaters, where they transfer heat to the incoming water. This preheating reduces the amount of heat required in the boiler, thereby lowering fuel consumption and increasing overall efficiency. Multiple feedwater heaters, including both low-pressure and high-pressure types, are typically used to maximize heat recovery. By increasing the temperature of the feedwater entering the boiler, the regenerative cycle improves the thermodynamic performance of the plant and minimizes energy losses..

Layout and Block Diagram of KTPS

KTPS Unit Overview

The unit overview displayed in the control room represents the operational workflow of a coal-fired thermal power plant at Kothagudem Thermal Power Station (KTPS), managed by the Telangana State Power Generation Corporation (TSGENCO). The system operates based on the Rankine thermodynamic cycle, where thermal energy derived from coal combustion is transformed into electrical energy.

In this process, coal is first pulverized into fine particles and mixed with preheated air before being fed into the furnace. Combustion of this mixture generates high-temperature flue gases, which transfer heat to water flowing through boiler tubes, converting it into high-pressure steam. The generated steam is directed through multiple turbine stages—High Pressure Turbine (HPT), Intermediate Pressure Turbine (IPT), and Low Pressure Turbines (LPTs)—causing rotational motion.

Flue gases produced during combustion are treated in electrostatic precipitators to remove particulate matter before being released through the chimney. This integrated system ensures efficient and continuous power generation while maintaining environmental compliance.

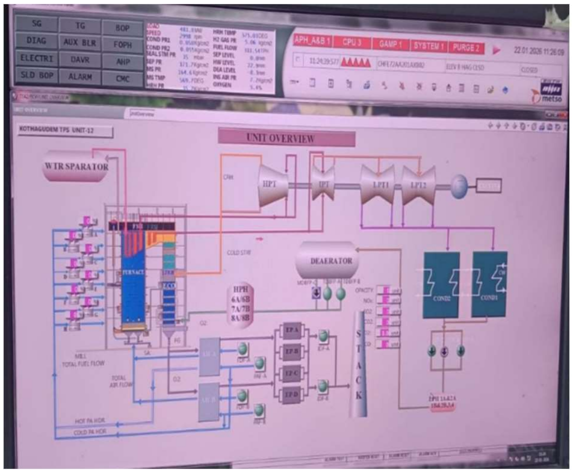

Fig 1 Unit Overview

Plant Layout

The plant layout corresponds to Stage-VII of the Kothagudem Thermal Power Station and illustrates the spatial arrangement of major subsystems involved in electricity generation.

Coal is transported from the coal handling plant to the boiler via conveyor systems. Inside the boiler, combustion of coal produces high-temperature steam. This steam is then supplied to the turbine-generator unit, where mechanical rotation is converted into electrical energy.

Post-expansion, the steam is condensed using a cooling system supported by cooling towers. Flue gases generated during combustion pass through electrostatic precipitators, which capture fly ash before emission into the atmosphere. The ash handling system collects and disposes of ash residues safely.

The generated electrical power is stepped up in the switchyard and transmitted to the grid. This layout highlights the logical and efficient arrangement of plant components to ensure smooth and reliable operation.

Block Diagram of Thermal Power Plant

The block diagram provides a simplified representation of the energy conversion process in a coal-based thermal power plant.

Coal stored in the storage yard is supplied to the boiler through the coal handling system. Within the boiler, combustion releases heat energy, converting treated water into high-pressure steam. This steam is directed toward the steam turbine, where it expands and produces rotational motion.

The turbine is mechanically coupled to a generator, which converts this mechanical energy into electrical power. After expansion, the steam is cooled in a condenser using circulating water from the cooling tower, transforming it back into liquid form.

The condensate is then pumped back to the boiler, completing the cycle. Ash produced during combustion is collected and handled separately. The entire process is continuously monitored through a centralized control system to maintain efficiency and safety.

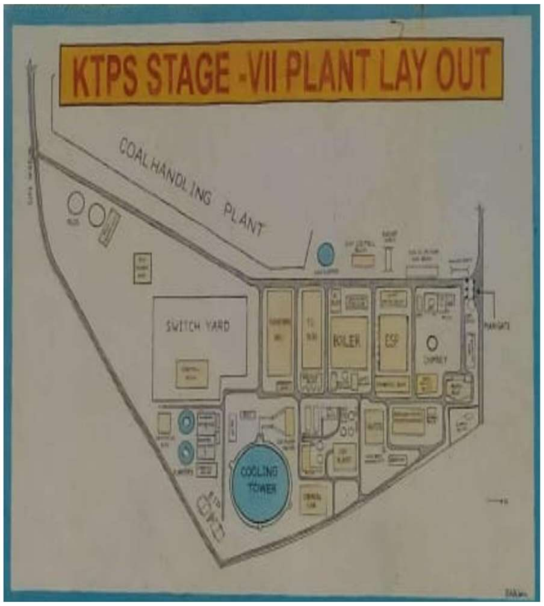

Fig 2 Plant Layout

Major Components of Thermal Power Plant

1. Coal Handling System

The coal handling system is responsible for receiving, storing, processing, and supplying coal to the boiler. It ensures uninterrupted fuel availability and improves combustion efficiency through proper preparation and feeding.

2. Superheater

A superheater increases the temperature of saturated steam beyond its boiling point without changing pressure. This process removes moisture content and produces dry steam, which enhances turbine efficiency and prevents blade erosion.

3. Cooling Tower

A cooling tower dissipates heat from hot water by exposing it to air, allowing partial evaporation. The cooled water is then recirculated within the system.

Fig: 3 cooling tower

4. Ash Handling Plant

This system collects, transports, and disposes of ash generated during coal combustion. It ensures safe handling of both fly ash and bottom ash.

Fig: 4 Ash handling plant

5. Switchyard

The switchyard is an electrical facility that regulates, protects, and distributes generated power. It connects the plant output to the transmission network.

Fig 5 switchyard

6. Boiler

A boiler is a closed vessel where water is heated using fuel combustion to generate steam required for power production.

Fig:6 Boiler

7. Economiser

An economiser improves plant efficiency by preheating feedwater using residual heat from flue gases. It reduces fuel consumption and enhances overall thermal performance.

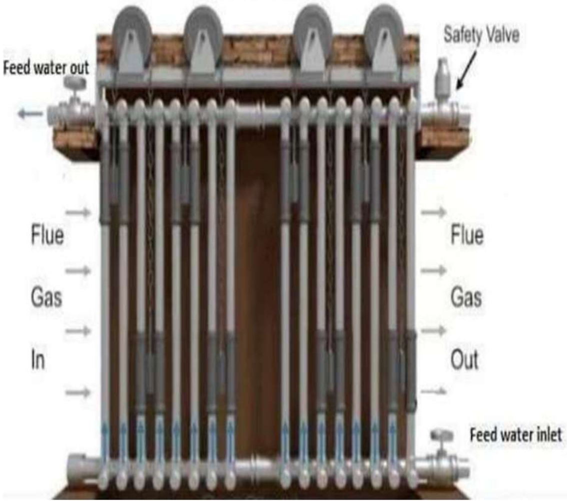

Fig:7 Economiser

8. Steam Turbine

The steam turbine converts thermal energy from high-pressure steam into mechanical energy by rotating blades connected to a shaft.

Fig:8 Steam Turbine

9. Condenser

The condenser converts exhaust steam from the turbine into water using cooling water. This process improves efficiency and allows reuse of water.

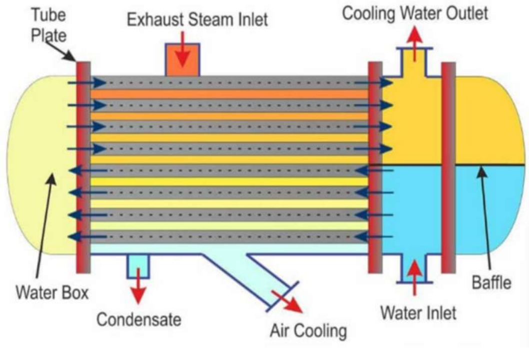

Fig:9 condenser

10. Chimney

The chimney discharges flue gases at high altitude, reducing environmental impact and maintaining proper draft in the boiler.

Fig 10 Chimney

Generator and Transformer

In Stage-VII of the Kothagudem Thermal Power Station (KTPS), advanced supercritical technology is employed to enhance efficiency and reduce fuel consumption. Supercritical operation occurs at pressures and temperatures exceeding the critical point of water (22.12 MPa and 374°C), allowing improved thermodynamic performance.

In this system, high-pressure and high-temperature steam produced in the boiler drives a steam turbine, which is mechanically coupled to a large-capacity synchronous generator. As the turbine rotates, it drives the generator rotor, creating a rotating magnetic field. This varying magnetic field induces a three-phase alternating current (AC) in the stator windings through electromagnetic induction.

The generated electrical output is then stepped up in voltage using a transformer before being transmitted to the power grid. The generator used in KTPS Stage-VII is designed for approximately 800 MW capacity and incorporates advanced cooling techniques such as hydrogen cooling for the rotor and air or water cooling for the stator to maintain thermal stability and operational reliability.

Synchronous generators are widely used in power plants due to their ability to operate at constant speed, which ensures stable frequency. They also provide voltage regulation and allow control over power factor through excitation adjustment, making them essential for grid stability and efficient power delivery.

Principle of Operation

The working principle of a generator is based on **Faraday's Law of Electromagnetic Induction**, which states that an electromotive force (EMF) is induced in a conductor whenever there is a change in magnetic flux linked with it.

This change in flux can be achieved either by moving a conductor through a magnetic field or by varying the magnetic field around a stationary conductor. As a result, free electrons in the conductor experience a force, causing current to flow when the circuit is closed.

The magnitude of induced EMF depends on:

- Magnetic field strength
- Length of the conductor
- Velocity of motion
- Angle between motion and magnetic field

The EMF is given by:

$E = B \times l \times V \times \sin\theta$

Where:

- E = Induced EMF (Volts)
- B = Magnetic flux density (Tesla)
- l = Length of conductor (m)
- V = Velocity (m/s)
- θ = Angle between field and motion

The direction of induced current is determined using **Fleming's Right-Hand Rule**, which relates the directions of magnetic field, motion, and induced current.

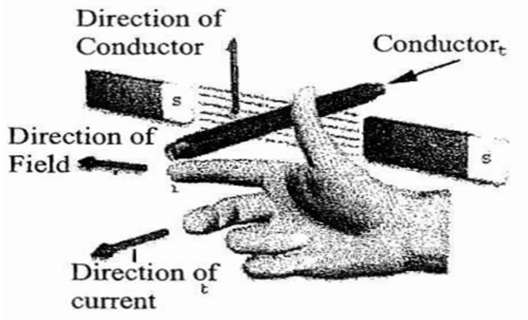

Fig 11 Flemings Right Hand Rule

Construction of Generator

A generator is an electromechanical device that converts mechanical energy into electrical energy. Its construction integrates electrical, magnetic, and mechanical components designed for efficient and reliable operation.

1. Field System

The field system generates the magnetic field required for energy conversion. It consists of electromagnets supplied with direct current to produce a controlled magnetic flux. In large generators, electromagnets are preferred over permanent magnets due to their flexibility and strength.

2. Armature System

The armature is the core region where voltage is induced. It consists of laminated silicon steel to minimize eddy current and hysteresis losses. Conductors placed in slots rotate within the magnetic field, producing EMF.

3. Slip Rings and Brushes

In AC generators, slip rings are used instead of commutators. These rings transfer electrical power from the rotating part to the stationary circuit. Carbon brushes maintain continuous electrical contact and ensure efficient current collection.

4. Shaft

The shaft connects the turbine to the generator rotor and transmits mechanical energy. It is designed for high strength and precise alignment to minimize vibration.

5. Frame (Yoke)

The frame provides mechanical support and acts as a path for magnetic flux. It is typically made of steel for durability and strength.

6. Bearings

Bearings support the rotating shaft and reduce friction. Proper lubrication ensures smooth operation and longer service life.

7. Cooling System

Modern generators use air, hydrogen, or water cooling systems to dissipate heat generated due to electrical and mechanical losses.

8. Control and Protection Systems

Voltage regulators, excitation systems, and monitoring devices are integrated to maintain stable operation and protect the generator from faults.

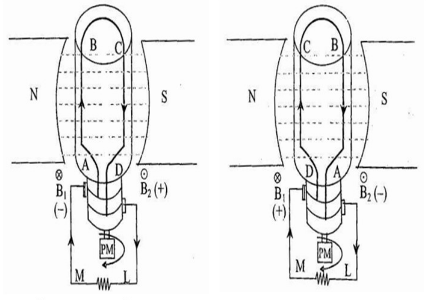

Fig 12: Generator Construction

SWITCHYARD AND ITS PROTECTION

The 400 kV switchyard at KTPS Stage VII plays a vital role in the transmission and control of electrical power generated by the plant. It is designed using a double busbar configuration with a one-and-a-half circuit breaker scheme, which provides high reliability and operational flexibility. In this arrangement, Bus-I is connected to key components such as the generator transformer, station transformer, bus reactor, and a provision for a future flue gas desulfurization transformer. Bus-II is connected to multiple outgoing feeders that facilitate the transmission of power to the grid. The single line diagram of the switchyard represents a simplified view of the electrical connections between major components, helping in understanding system operation, maintenance, and protection strategies.

The switchyard receives electrical energy from generating units and incoming transmission lines and delivers it to outgoing transmission lines for distribution. It consists of various electrical components such as busbars, circuit breakers, transformers, current transformers, voltage transformers, and lightning arresters. Busbars serve as common connection points for multiple circuits and are designed to carry large currents efficiently. Switching stations perform several important functions, including protection of the transmission system, control of power flow, maintenance of system frequency within acceptable limits, and fault analysis for improving system performance.

Circuit breakers are critical protective devices that interrupt the flow of current during abnormal conditions such as overloads or short circuits. Different types of circuit breakers are used in power systems depending on voltage levels and requirements. Minimum oil circuit breakers use a small quantity of oil for arc extinction and are suitable for medium voltage applications. Air blast circuit breakers utilize compressed air to extinguish arcs and are used in high-voltage systems due to their fast operation. In modern high-voltage switchyards, SF_6 circuit breakers are widely used because sulphur hexafluoride gas has excellent insulating and arc-quenching properties. This gas is non-flammable, chemically stable, and capable of withstanding high electrical stress, making it ideal for 400 kV systems.

Isolators and earthing switches are essential for safe maintenance of electrical equipment. Isolators are used to disconnect circuits under no-load conditions and are operated only after the circuit breaker has opened the circuit. Once the circuit is isolated, earthing switches are used to ground the equipment, discharging any residual charges and ensuring safety for maintenance personnel. Instrument transformers, including current transformers and voltage transformers, are used for measurement and protection purposes. Current transformers reduce high current levels to standardized values, while voltage transformers step down high voltages to safer levels for monitoring and control devices.

Lightning arresters protect substation equipment from overvoltages caused by lightning strikes or switching operations. They divert surge currents safely to the ground, preventing damage to insulation and equipment. These protective devices play a crucial role in maintaining the reliability and safety of the power system.

An electrical power system is broadly divided into generation, transmission, distribution, and utilization, with substations acting as key nodes that facilitate the flow of electrical energy between these stages. Substations consist of essential components such as transformers, switchgear, busbars, and auxiliary systems. Electrical power is generated and transmitted using a three-phase alternating current system operating at 50 Hz. Transmission at high voltages reduces line losses and improves efficiency. Typical voltage levels include generation voltages ranging from 11 kV to 27 kV, transmission voltages such as 220 kV, 400 kV, and 765 kV, and distribution voltages like 33 kV, 11 kV, and 415 V.

Fig 13 Switch Yard

Switchyard protection systems are designed to detect faults and isolate faulty sections quickly to prevent damage and ensure continuous power supply. Protective relays monitor system parameters and detect abnormalities such as overcurrent or voltage fluctuations. When a fault is detected, the relay sends a signal to the circuit breaker, which disconnects the affected section from the system. This coordinated operation helps maintain system stability and protects equipment from damage. The main objectives of a power supply system include ensuring uninterrupted power delivery, minimizing fault duration, maintaining voltage and frequency within specified limits, achieving high efficiency, and providing reliable service to consumers at economical cost.

EFFICIENCY OF POWER PLANT

Efficiency of KTPS

The Kothagudem Thermal Power Station (KTPS), located in Telangana, is a major power generation facility with a total installed capacity of approximately 1800 MW. The plant comprises multiple generating units, including a modern 800 MW supercritical unit along with earlier units of 250 MW and 500 MW capacities. The operational efficiency of the station plays a crucial role in meeting the growing electricity demand of the region. Continuous efforts are made to enhance performance by optimizing both turbine and generator operations.

The overall efficiency of the power plant has improved significantly over time due to technological upgrades and better operational strategies. Historically, the efficiency of the plant was around 25.7%, which increased to approximately 30.1% following renovation and modernization efforts, with further targets set around 32.5%. These improvements have been achieved through better maintenance practices, system optimization, and adoption of modern technologies. Preventive maintenance activities such as regular inspection, cleaning, lubrication, and timely replacement of components have helped in reducing downtime and sustaining performance.

Improvement of Efficiency

Enhancing the efficiency of a thermal power plant involves improving combustion processes, heat recovery, and equipment performance. In KTPS, boiler efficiency can be increased by ensuring proper combustion of coal through optimized air–fuel ratios and the use of improved burner designs. The use of better-quality coal and regular removal of ash deposits through soot blowing also contributes to efficient heat transfer. Heat losses can be minimized by maintaining proper insulation, while devices such as economizers and air preheaters help recover waste heat from flue gases, thereby improving thermal efficiency.

The performance of turbines and condensers also plays a vital role in overall plant efficiency. Maintaining appropriate steam pressure and temperature, reducing leakages, and upgrading turbine components can significantly enhance energy conversion efficiency. The condenser must operate under high vacuum conditions to ensure efficient condensation of exhaust steam. This requires proper circulation of cooling water and periodic cleaning of condenser tubes to prevent fouling. Improved condenser performance directly reduces energy losses and enhances system efficiency.

Modern control and monitoring systems such as distributed control systems (DCS) and supervisory control and data acquisition (SCADA) systems enable real-time monitoring and optimization of plant operations. These systems help operators maintain optimal parameters and respond quickly to deviations. Additionally, reducing auxiliary power consumption through the use of energy-efficient motors and variable frequency drives improves net plant efficiency. Renovation and modernization initiatives, including the adoption of supercritical technology and periodic energy audits, further enhance performance while reducing fuel consumption and environmental impact.

Conclusion

Thermal power plants primarily operate on the conversion of heat energy into mechanical work, which is subsequently transformed into electrical energy through generators. This process is fundamentally governed by the Rankine Cycle, a closed-loop system in which water is repeatedly used as the working fluid. In its basic form, the Rankine cycle provides moderate efficiency; however, modern thermal power plants incorporate several enhancements to improve performance.

Advanced modifications such as steam superheating, reheating, and regenerative feedwater heating significantly increase the efficiency of the cycle. Superheating reduces the moisture content of steam at the turbine exhaust, thereby improving turbine performance and preventing blade damage. Reheating of partially expanded steam enhances the average temperature of heat addition, leading to an efficiency gain of approximately 4–5%. Similarly, regenerative feedwater heating using low-pressure and high-pressure heaters improves efficiency by recovering heat from extracted steam, contributing an additional improvement of about 6–7%.

As a result of these combined advancements, modern thermal power plants—particularly supercritical units like KTPS Stage VII—achieve overall efficiencies in the range of approximately 40% to 42%. These improvements demonstrate the importance of integrating advanced thermodynamic techniques and optimized operational practices in large-scale power generation systems.

Future Plan

Despite significant technological progress, thermal power plants continue to face operational and environmental challenges. One of the major concerns is the use of high-ash coal, which typically contains 35% to 40% ash content, leading to reduced combustion efficiency and increased maintenance requirements. Additionally, water scarcity poses a challenge for cooling and steam generation processes.

To address these issues and improve sustainability, several future strategies are being considered. Biomass co-firing is one such approach, where a portion of coal is replaced with biomass fuel to reduce carbon emissions and environmental impact. The integration of artificial intelligence-based predictive maintenance systems is another promising development, enabling real-time monitoring of equipment health and reducing unexpected failures and downtime. Furthermore, hybrid power generation systems that combine thermal and solar energy are being explored to optimize fuel usage and enhance overall plant efficiency.

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