Chapter -7

TQM & TEM in Thermal Power Plants

7.1.0 Introduction:
This chapter deals with various aspects related to TQM & TEM in Thermal Power Plants.

Typical coal based thermal power plant consists of following main parts
1) Wagon Tippler:
   - It is the machine which is used to tip the coal from the wagon. The coal tipped is directly fed to conveyor belt.
2) Crusher:
   - It crushes the coal into small pieces.
3) Coal Mills:
   - In it small pieces of coal are converted into pulverized form.
4) Furnace:
   - It is the chamber in which fuel burns & fire blows.
5) Boiler Drum:
   - It contains water for boiling.
6) Electrostatic Precipitator:
   - In this we have electrodes which attract fly ash and extract it from flue gases so that it cannot enter atmosphere.
7) Chimney:
   - It is used to release flue gases into the atmosphere.
8) Turbine:
   - Turbine is the part which revolves due to steam pressure.
9) Turbo Generator:
   - It is the main machine which produces electricity.
10) Condenser:
    - It condenses steam coming from low pressure turbine (L.P.T.) to hot water. By removing air and other non-condensable gases from steam while passing through them.
11) Cooling Water (C.W.) Pump:
    - This pump sends water from cooling tower to condenser.
12) Cooling Tower:
    - It is used to cool the water. The hot water is led to the tower top and falls down through the tower and is broken into small particles while passing over the baffling devices. Air enters the tower from the bottom and flow upwards. The air vaporizes a small percentage of water, thereby cooling water falls down into tank below the tower from where it is pumped to the condenser and cycle is repeated.
13) Raw Water Pump House:
    - It supplies raw water to the boiler.
14) Clarifier Pump House:
    - The water from raw is clear at clarifier by putting alum in it & filtering it & then supplied to the condenser.
15) Condensate Extraction Pump:
    - C.E.P. pump is used to extract the condense water from the hot well and supply to the deaerator after passing through L.P. heater & Economizer, so that high pressure steam in the cylinder can be created.
16) Low Pressure Heater:
    - It is used to increase the temperature of water, in this way efficiency of system increases.
17) Deaerator:
    - It is used to remove air from water which is entrapped in the water molecules. It is very important part because the entrapped air affect air drum badly.
18) Boiler Feed Pum (B.F.P.):
    - It is the heaviest drive in the plant & supply water to boiler drum from deaerator.
19) High Pressure Heater (H.P.):
    - In this temperature of water increases. Thus efficiency further increases.
20) Economiser:
    - In this flue gases exchange heat to the water to increase system efficiency, causes saving in fuel consumption (5 to 10%). Economizer tubes are made up of steel either smooth or covered with fins to increase the heat transfer surface area.
Detailed study on thermal engineering aspects in power plant and implementation of TQM + TEM was carried out for the following plants:

1. Thermal Power Station, Sikka, Dist: Jamnagar
2. Saurashtra Cement Ltd, TPP, Ta: Ranavav, Dist. Porbandar
3. Ambuja Cement Ltd, TPP, Ambujanagar
4. Sanghi Industries Limited, Sanghipuram Captive Power Plant
5. Welspun Power & Steel Ltd., 43 MW TPP., Anjar, Dist: Kutch
6. Essar Power Ltd., TPP, Surat-Hazira Road, Hazira, Dist: Surat
7. Essar Steel Ltd., TPP, Hazira, Dist: Surat
8. Kutch Lignite Thermal Power Station, Panandhro, Ta: Lakhpat
9. Gujarat Electricity Board, Thermal Power Station, Ukai, Dist: Surat
10. Essar Power Corporation Ltd.(EPCL), Khabaliga
11. Power plant of Jindal Saw Ltd, Pragpar, Samaghoga
12. Power plant of Gujarat Heavy Chemicals Ltd., GHCL Sutrapada
13. Power plant of Jaypee Cement Ltd, Abdasa
14. Welspun Power & Steel Ltd., 95 MW TPP., Anjar, Dist: Kutch

7.1.1 Industrial Field/ Plant Visits:
To study thermal engineering aspects, field/plant visits were arranged to these sixteen plants with minimum one and in general two visits. The relevant required information w.r.t. the various components mentioned in section 7.1.0 was collected and analysed in a systematic manner.

7.2.0 Details of Power Plants Along With Their Flow Sheets:
The relevant details regarding these main parts along with process flow sheets are mentioned in this section

7.2.1 Thermal Power Station, Sikka:
Process Description
A thermal Power plant consists of three essential elements: - “heat Source”, ‘heat utiliser’, and the waste heat reservoir or ‘heat sink’. To generate power or produce useful work it is required that heat be supplied to a working fluid from the heat source. The utiliser is required to convert a portion of the heat supplied to the working fluid into useful power. By the second law of Thermodynamics all the heat cannot be, converted into useful work, therefore a heat sink is required to dispose off the remainder heat.

Fig 7.1 is a diagram of a modern steam power plant showing the essential elements. It may be divided into two main parts. The first part consists of boiler (or heat source) and its auxiliaries and the other part i.e. the ‘turbine cycle’ consist of turbine not only the heat utiliser but also the heat sink.

Considering first the boiler half of the cycle, feed water is supplied through an economizer to the boiler, drum. The economizer reclaims part of heat from, the flue gases and transfers it to the feed water, thus decreasing the heat to be supplied in the boiler while reducing the temperature of the stack gases. In the boiler drum, separation of steam and water takes place and the saturated steam enters the super heater where further heat is added. The major part of the steam leaving the super heater is taken to the steam turbine. In many plants, some of the steam is bled off for auxiliary purposes. Such as steam jet air ejector, fuel Oil heating etc. Steam passing through the steam turbine produces mechanical power, which drives the alternator where electrical energy is generated for distribution.

The steam) after doing work in the high pressure section of the turbine is taken back to the boiler ‘re-heater’ to a temperature equal to or close to the initial steam temperature and brought back to reheat section of the turbine, where steam is expanded through the intermediate anti ‘low pressure’ sections of the turbine. Reheating may be done at one or more stages during the expansion of steam in the turbine depending on the initial steam conditions.

In passing through the turbine in the modern regenerative cycle, some of the steam is bled from the turbine at various stages to heat the boiler feed water. Cooling water, which is circulated through the condenser, condenses the steam exhausted to the condenser. The requirements of cooling water for a steam plant are enormous. For, instance a 500 MW unit operating in the higher range of steam condition viz. of 167 bar, 540 deg. c. / 540 deg. c. re-heat needs about 66000m³/ hr of cooling water. The site therefore must be near a source from which the station can draw the required amount of cold and a sink into which it can discharge the same amount of warm water.

Where limited cooling water is available, the cooling water system consists of a closed system in which the hot water from condenser is cooled by passing it through cooling towers and the re-cooled water is circulated.
through the condenser and over and over again. To make up the evaporative losses in the cooling tower a plant equipped with cooling towers needs only 2.3% of the quantity needed by a similar station having a ‘once through’ system. Since a very large quantity of steam flows into the condenser steam space, it is unavoidable that the certain proportion of non-condensable gases accompanies it. In order that a very low pressure approximating a perfect vacuum may be maintained in the condenser, these non-condensable, must be removed from the steam space of the condenser. These are removed by means of steam jet air, ejector, consisting principally of a nozzle through which steam passes at high velocity and in which the non-condensable vapors are entrained. The steam passing through the nozzle (motive steam) and the non-condensable gases mechanically entrained in it are then taken to a heat exchanger known as after condenser where the steam is condensed at atmospheric pressure and the non-condensable vapors are vented to atmosphere. The steam jet air ejector, built in either one or more stages, is essentially a compressor for raising the pressure of the non-condensable vapors from an almost perfect vacuum to, Atmospheric pressure to dispose there off. Alternatively, mechanical vacuum pumps, can be used to remove the non-condensable vapors from the condenser. Mechanical vacuum pumps are finding more and more application in modern steam plants. The main steam having been the approximately saturation temperature. This water known as the condensate drains by gravity to the bottom of the condenser and collects in a storage compartment known as the Hot Well. From the hot well condensate is extracted by means of pumps known as condensate extraction pumps or condensate pumps. The condensate pump removes the condensate from the hot well and pumps it through the low pressure part of the feed water cycle. This consists of the steam jet air ejector condenser and low pressure feed water heaters in which condensate passing through a nest of tubes is heated by extraction steam on the shell side of a closed vessel. The lowest pressure heater is equipped with a drain pump the duty of which is to remove the drains (formed by the condensing steam.) from the heater and to pump them back into the main condensate line, beyond the heater. The type of heater is known as a pumped heater. From the low pressure heater the condensate passes to a deaerating heater. The deaerating heater is of the direct contact type wherein condensate is heated to its boiling point by intimate mixture with steam extracted from a turbine stage, in order to eliminate entrained oxygen. Removal of oxygen in the deaerating heater is based on the principle that solubility of non-condensable gases in water is greatly reduced as the temperature of the water approaches the boiling point. The non-condensable gases discharged from the surface of water must be removed. Normally the deaerator is operated at a pressure higher than atmospheric. So that these gases may be vented to atmosphere. A vent condenser is normally used in which the incoming condensate cools the non-condensable gases and simultaneously condenses the steam. As mentioned earlier the economizer is used to heater feed water by recovering heat from flue gases leaving the boiler. Heat recovery equipment used to recover the waste heat is the air heater. Power plants may use the economizer or, the air, heater or both. A large number of feed water heating stages with a high discharge temperature from the high pressure heater preclude the use of art extensive economizer in such installations it is necessary to an air pre heater to recover the lower, values in a stoker fired installation. Modern pulverized fuel installations have been designed to use very high air pre heater temperatures of the order of 260 to 315 deg. c. with higher values distinctly feasible. In steam generators provided with re-heaters, achieving a temperature match between turbine metal temperatures and boiler outlet steam temperature after a hot trip out is a known problem. When turbine is tripped there is no steam flow through re-heaters, which in turn restrains rate of firing causing low temperatures at super heater and re-heater outlet. In such situations: it is imperative to wait and allow turbine to cool in order to obtain steam temperature matching between turbine metal and steam temperatures. This restriction is overcome in modern power plants by providing bypass systems for, HP & HP turbines establishing steam flow through the re-heaters even when turbine is not service. HP by pass system consists of a pressure reducing and de-super-heating station which together control by pass steam conditions at re-heater, inlet. Similarly LP by pass system also consists of pressure reducing station and water injection spray station to cool the by passed steam before admitting to the condenser. The HP/LP by pass capacities is determined by taking into consideration the steam generator characteristics. Normally HP/LP bypass systems capable of bypassing 60% to 100% of steam generator, capacity are provided. In addition to reducing the start up time by overcoming restrictions on firing, HP/LP bypass system also offers the following benefits. HP bypass valves open out and control any pressure fluctuations in super heater thereby avoiding safety valve simmerring. LP bypass valves similarly control re-heater pressure during any pressure excursion in re-heater. During start ups HP/LP bypass system helps to keep turbine clean by diverting silica in steam to condenser. Since the deaerator uses extraction steam whose pressure varies with load on the turbine, It is found that at lighter loads the pressure becomes sub atmospheric. It is then essential that the non-condensable continues to be
removed from the deaerator and a steam jet air ejector is necessary for accomplishing this result. The expense and the complication in operation occasioned by such an installation make it undesirable. For this reason, it is common practice to provide for the Shifting of the extraction stages at high loads so that the next higher extraction point furnishes the deaerator steam supply. This operation is sometimes called pegging in all modern plants; the change over to pegging steam is automatically carried out.

The mixture of condensate and the condensed extraction steam in the deaerator is collected in a storage tank which is connected to the Suction of the boiler feed pumps. In many power plants a surge tank (or condensate storage tank) containing reserve stored water is connected in parallel with the deaerator. The function of the surge tank is to serve as an emergency supply of distilled water. In the event of failure of other sources or as a reservoir for excess water of the deaerator, this should be sufficient to operate the power plant for several minutes. However, most designers consider it wise to augment this storage capacity with a large deaerator storage tank.

The boiler feed pump is connected to the discharge of the deaerator storage tank. Since water in the deaerator is at saturation temperature it is essential that the boiler feed pump be located sufficiently below the deaerator, to avoid flashing of the water in the boiler feed pump suction.

Whether leaving the deaerator goes to the boiler feed pump suction and is pumped into the next higher pressure heater, this heater is shown as a drain cooler heater, that is a heater, the drains from which pass through a heat exchanger (drain cooler) giving up heat to the incoming condensate. After leaving this heater, the feed water goes to the top or high pressure heater in which feed water is heated to its final temperature. The top heater is shown as a flashed heater so called because it drains are permitted to pass through a controlling orifice, or trap to the next lower heater where part of the saturated water flashes into steam. This arrangement eliminates the use of drain pumps and drain coolers, but it causes a considerable thermo-dynamics loss. This final feed water, temperature leaving the top heater is of the order of 150 to 230 deg. C. in modern power plants and occasionally even higher.

The number of feed water heaters used in modern power plants varies from few as one in the smaller plants consuming inexpensive fuel to as many as 8 to 10 in large plants consuming expensive fuel.

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**Figure 7.1 Process Flow Diagram for Coal Based Power Plant**
7.2.2 Saurashtra Cement Ltd, Thermal Power Plant, Ta: Ranavav:

A typical flow diagram of the thermal power plant is as per figure 7.2. Flow sheets are practically identical with Sikka thermal power plant.

Figure 7.2 Process Flow Diagram for Coal Based Power Plant, Saurashtra Cement Ltd
7.2.3 Ambuja Cements Ltd., Thermal Power Plant, Ambujanagar:

**Process Description**
The schematic of process flow diagram is as per the figure 7.3

**CFBC Boiler:**
The boiler is based on circulating bed technology and is most advanced and clean technology available in the world. The Boiler designed by M/s Lurgi Lentjes and supplied, erected & commissioned by M/s Bharat Heavy Electricals Limited. The boiler confirms the strictest pollution norms and is suitable to run on any type of solid fuel at a thermal efficiency of 89%. The Boiler can also operate on Biomass as supplement fuel. The Boiler is designed to maintain SOx level of 100mg/NM3, which is achieved by dosing of crushed lime stone directly in to the combustor. As the combustor height is 40 mtrs, the residence time for reaction of sulphur in coal with lime stone is maximum. The system runs in interlock with the SOx level monitored continuously at stack.

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The ash generated from the boiler is having carbon content of 2%. This quality is maintained irrespective of type of fuel

**Steam Turbine:**
The 30 MW straight condensing single cylinder steam turbine is supplied, erected & commissioned by M/s. Bharat Heavy Electricals Limited. The turbine is based on Siemens technology and is one of the most efficient turbines. The power is generated at 11KV and is stepped down to 6.6KV before distribution to load centre

**Air Cooled Condenser:**
Cooling medium is required for cooling the exhaust steam for re-circulation in to Boiler. The cooling can be performed by air or water. Since water is precious and the continuous availability may be difficult in near future, we have selected air-cooled condenser, which is supplied by M/s GEA - Germany. The finned tube is elliptical and fins are galvanized to resist corrosion due to coastal environment. The total water requirement for all the three units of 30 MW shall be reduced by 90% (saving of 9000 KL of water per day in comparison with conventional condenser)

**Ash Handling System:**
The ash handling system is based on pneumatic conveying and is a closed loop system, which ensures clean environment. The ash is conveyed to two ash silos, each of 600 MT capacities. The silos are equipped with bag filters and automatic sprout system for unloading of ash.

**Electrostatic Precipitator:**
The four-filed ESP is supplied by M/s Thermax Limited and is designed to restrict dust emission to 50mg/NM3 in worst condition

**Water Treatment Plant (RO):**
The De-mineralized water is required for Boiler make up as salts present in water will damage the Boiler tubes by scaling / corrosion. The D. M. water plant is based on modern Reverse Osmosis technology combined with mix Bed ion exchanger as a polishing unit. The water hardness is maintained as zero. 100% sewage treated water is used as raw water and the RO reject is further used by blending with raw water and reused. High density RO is treated in separate RO system designed for seawater operation. The reject of this unit is sent to cement mills for spray purpose.

**Control System:**
The power plant is operated from the central control room equipped with Yokogawa Gentium 2000 twin monitor station. The complete process is controlled from DCS.

**Fuel Handling System:**
The fuel handling system is suitable for three units and has capacity of 250 TPH. The section comprises of unloading, stacking, reclaiming, primary & secondary crushing and screening of coal. Each transfer point and fuel bunker is equipped with bag filters.
7.2.4 Sanghi Industries Limited, Captive Power Plant, Sanghipuram:

**Brief Process Description of D. G. Power Plant**

To meet the Power requirements of our 3.5 MTPA cement plant, Sanghi Industries have established a 55.33 MW Captive Power plant based on 4 nos. of DG sets of 11.33 MW capacity each & 4 Nos of D.G.Sets of 2.5 MW Capacity each.

The DG sets are being supplied by MAN B & W Diesel, Mirrlees Blackstone, United Kingdom along with accessories. The Circuit Breakers, Motor Control Centre, Control and instrumentation for the plant with a few mechanical auxiliaries are being sourced from India.

The DG plant operates on Heavy fuel oil as fuel. The total plant contains the following systems.

i) **Intake Air System**

The Diesel Engine needs air for combustion of fuel that is injected into the Engine. The atmospheric air is drawn through a filter and then compressed in a turbo charging compressor and cooled in an inter stage cooler and then allowed to enter the Engine cylinder through an intake manifold, as per the firing order of the engine.

ii) **Exhaust System**

The exhaust gases generated within the Engine cylinder at higher temperature and pressure enters the turbine. The exhaust gases will transfer their energy to the turbine and afterward escapes to the chimney via a silencer. Thus a major part of the energy of exhaust gases is recovered by turbine of the turbocharger.

iii) **Light Fuel System**

Initially the Engine will be started by using HSD. After attaining proper operating temperatures, the Engine will be switched on to heavy fuel system.

The system consists of unloading / transfer pumps, unloading piping arrangement and storage tank. From the storage tank HSD will be taken to the booster pumps and pumped to the Engine Injectors.

iv) **Heavy Fuel System**

The Engine will run on Heavy fuel on continuous basis. The system comprises unloading pumps, unloading arrangement, storage tanks, precentrifuge tanks, centrifuges, centrifuged oil storage tanks, booster pumps, viscosimeters, electric heaters etc. The oil will be maintained at an appropriate viscosity so as to facilitate spontaneous and complete combustion of fuel in the engine by using electric tracing and electric heaters.

v) **Jacket Water and Secondary Water Systems**

Water will be circulated in the engine jacket, which will take away heat from the body of the engine. This water in turn will be getting cooled in a plate heat exchanger by a secondary water system. The same jacket water is used for cooling charge air and lube oil prior to entering the engine jacket. The systems consist of heat exchangers, pumps, thermostat valves, expansion tanks etc.

vi) **Lube Oil System**

Lube oil will be circulated through all the bearings, connecting rods, timing gear etc. by an engine driven lube oil pump through cooler and filters. There will be continuous checking of oil level and if any shortages occur, the oil will be added to make up the level. The system consists of pump, filter, heat exchangers etc.

vii) **Fuel Unloading and Storage System**

A storage yard comprising storage tanks, unloading pumps, transfer pumps, piping and other auxiliary equipment required for handling all the fuels as well as lube oil has been envisaged with appropriate approvals etc.

viii) **Compressed Air System**

The diesel engines will be started by using compressed air. The air from the air receiver enters cylinder through starting air valve and make the engine rotate. The engine once starting rotation generates enough temperature in the cylinders, which is sufficient to ignite fuel. The system comprises of air compressors, air receivers, piping and control valves.

ix) **Electric System**

The power is generated at 11 KV and fed to the 11 KV/220 KV switch yard for stepping up and for further transmission to the main plant and Grinding Unit. The system comprises circuit breakers, Motor Control Centre’s PCC’s cabling earthing, relays etc.

x) **Control and protection**

The alternators and other equipment will be protected from unexpected faults by appropriate control and protection system.

Process flow chart is as per fig 7.4
Figure 7.4 Process Flow Diagram for DG Power Plant, Sanghi Industries
7.2.5 Welspun Power & Steel Ltd., 43 MW Thermal Power Plant, Anjar:

Process Description
The process flow chart is as displayed in fig 7.5. There is modification in process for heat recovery. The hot waste gases that generated from kilns no. 1 to 4 are directly passes to the Waste Heat Recovery Boiler (WHRB) where the temperature of steam is upraised to 460-470 °C and the pressure is about 67 kg through the hot gases. This steam blown to the Turbine having 7,500 RPM and is reduced through Reduction Gear Box (RGB) to the generator for production of power. The gases after cleaning are passed through the ESP and releases in the atmosphere.

Figure 7.5  Process Flow Diagram for 43 MW TPP , Welspun Power and Steel
Figure 7.5 a) Plant Overview for TPP, Welspun Power and Steel
7.2.6 Essar Power Ltd., Thermal Power Plant, Surat-Hazira Road, Hazira:

Introduction:
ESSAR Power Limited has commissioned an independent power plant based on naphtha/NGL fuel. The total rated power generation capacity of the plant is 515 MW. The power plant configuration consists of three gas turbine generators having 110 MW capacity each, and three matching Heat Recovery Steam Generator (HRSG) to generate an additional power of 185 MW.

Working Cycle of Combined Cycle Power Plant (CCPP):
Naphtha / NGL fuel based combined cycle power plant mainly consists of two cycles. Primary cycle is Brayton cycle on which gas turbine operates. Secondary cycle is the Rankine cycle on which steam turbines operates. Air is first compressed in compressor for combustion in gas turbines which converts chemical energy and thereafter to electrical energy. This is open cycle operation which have lesser efficiency (approx. 35.5%). The enthalpy of exhaust combustion gases is used to generate steam in Waste Heat Recovery Generator, which is used to run steam turbine. This combine cycle operation of Bryton and rankine cycle not only increases the overall output of the power station but also improves its efficiently substantially (51 %). Plant can operate on both gas as well as liquid fuel both. CCPP is environmentally clean technology as there is no air pollution. Low NOX generating burners are installed to reduce NOX emission.

Process:
Natural gas and or naphtha are used as fuel for the ESSAR CCPP. NGL and or naphtha (based on the availability of fuel) is taken in combustion chamber and is expanded in the gas turbine. The gas turbine rotates at 3000 rpm and directly coupled to the generator through which electricity is generated.

The exhaust gas from the gas turbine can be released either in the atmosphere (during the open cycle mode) or its heat is recovered in HRSG to generate steam (combine cycle mode). The steam is fed to steam turbine which in turn generates electricity.

The steam expanded in the stages of the steam turbine goes to the condenser and gets condensed with the help of cooling tower. The condensate is the extracted and fed back to HRSG. Thus the cycle is repeated and process is continued.

The cooling tower is cooled to the atmosphere temperature with the help of forced draft cooling tower.

Relevant figures w.r.t. this CCPP are fig 7.6, 7.6a, 7.6b

Figure 7.6 Process Flow Diagram for Naphtha / NGL Fuel Based Combined Cycle Power Plant
Figure 7.6a Heat Balance Diagram for Naphtha / NGL Fuel Based CCPP, Essar Power Ltd.
Figure 7.6 b) Water Scheme and Material Balance Diagram, CCPP, Essar Power Ltd.
7.2.7 Essar Steel Ltd., Thermal Power Plant, Hazira:

Captive power plant

Natural gas is fired in the gas turbine unit generate 10 MW power from each unit (total two unit). The exhaust gas temperature at 540°C is being utilized to generate steam which is supplied to a condensing type, non-reheat steam turbine through steam piping to generate 10 MW output. Thus operating two gas turbines and a steam turbine generates a total of 30 MW power. The process does not involve direct use of water. Water is mainly used for cooling operation, which is recycled. The process flow diagram is given in figure 7.7.

Figure 7.7 Process Flow Diagram for Gas Based Power Plant
7.2.8 Gujarat Electricity Board, Kutch Lignite Thermal Power Station, Panandhro, Ta: Lakhpat:

Process Description:

Kutch Lignite Thermal Power station of capacity (2 × 70 MW + 1 × 75 MW) is located near Panandhro village in Taluka Lakhpat, District Kutch. KLTPS being a pit head Thermal Power Station as it is situated very near to lignite open mines.

The lignite is supplied from the Mines by the Gujarat Minerals Development Corporation through reclaimers and conveyor belts. Initially the lignite is fed to a crusher where in it is crushed to small pieces from where it is fed to the lignite bunkers via shuttle conveyors. The lignite mills further pulverizes the crushed lignite to powder form. The powdered lignite is then through in the lignite burners of the boilers air pressure developed by the lignite mills that are attached to the bunkers by feeders.

In the boiler, the pulverized lignite is fired with support of furnace oil and Light Diesel Oil. To achieve the complete combustion of the fuel the desired air fuel ratio is maintained by monitoring the oxygen and carbon oxide percentage in the flue gas. For the complete combustion, air is supplied by secondary air fan called the forced draft fan through air preheater for maintaining the necessary temperature of the ambient air.

The boiler is four corner, tangentially fired, non-reheater type, balanced draft, natural circulation type, wet bottom boiler. The furnace of the boiler is made up of water tubes, which are called water walls, which are connected with the boiler drum via downcomers and ring headers.

Water in the water wall is converted into steam when the boiler is fired. This steam is fed to the boiler drum via risers tubes which will again pass through the turbo separators where the separation of water particles from the steam takes place. Here the steam will be almost saturated, which will again go to the various stages of the super heaters headers. From the last stage of the super heater header steam will go to the high-pressure cylinders of the turbine via main steam line and main steam stop valve where the conversion of kinetic energy into mechanical energy takes place. The pressure and temperature of the steam is 94 kg/cm$^2$ and 515 deg C in unit I and 2 and 100 kg/cm$^2$ and 530 deg C in unit 3 respectively.

The steam leaving the low-pressure cylinders will go to the condenser, which is under vacuum. The steam is condensed in the condenser by circulating cooling water, which is cooled in cooling towers. The condensed steam is collected in the form of hot water (condensate) in hot well. This hot well water is extracted by condenser extraction pump and fed to the deaerator tank via low-pressure heater. In the deaerator, separation of gases & air will take place.

The output of the deaerator is connected to the suction of the boiler feed pump, which will feed water to the boiler drum through HP heaters and economizer. Thus the regenerative cycle will continue as a close loop system where only some make up of Demineralized water is required which is done in hotwell.

The rotor of turbine is connected with the generator rotor through coupling. The RPM is maintained to 3000 by controlling steam into turbine-by means of turbine governing system. The rotor of the generator is excited by the external D.C. static excitation system which will in turn create magnetic flux. The alternating energy is generated of the order of 11 kV, which is stepped up to 220 kV by generator transformer and fed to the common grid.

The burning of lignite will create flue gas and ash. Heat energy of flue gas is utilized by heating the air and water in the second pass of the boiler, by means of air preheater and economizer. ESP’s are employed for collection of fly ash from the flue gases.

Unburnt lignite is deposited at the bottom of the furnace, with heavy particles of ash in the form of clinker, which falls in the water. The water is drained and the ash is disposed to ash dykes.

The schematic of process flow diagram is as per fig 7.8.

![Figure 7.8 Process Flow Diagram for Lignite Based Power Plant](image-url)

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Figure 7.8 a) Process Flow Diagram for Lignite Based Power Plant
7.2.9 Gujarat Electricity Board, Thermal Power Station, Ukai:

Process Description:
Process description is identical with any coal based thermal power plant. The flow diagram is as per fig 7.9

Figure 7.9 Process Flow Diagram for Ukai Coal Based Thermal Power Plant
7.2.10 Essar Power Corporation Ltd. (EPCL), Khambaliya:

Process Description:

The thermal power plant is based on the Rankine cycle. Coal from the Stockyard is transported up to the raw coal bunkers with the help of belt conveyors. The coal is pulverized in the Bowl mill where it is grounded to a powder form. This crushed coal is taken away to the furnace through coal pipes with the help of hot and cold air mixture from PA fan. PA fan takes atmospheric air, a part of which is sent to Air pre heater for heating while a part goes directly to the mill for temperature control. Atmospheric air from FD fan is heated in the air heaters and sent to the furnace as combustion air.

Water from the boiler feed pump passes through economizer and reaches the boiler drum. Water from the drum passes through down comers and goes to the bottom ring header. Water from the bottom ring header is divided to all the four sides of the furnace. Water is partly converted to steam as it rises up in the furnace. This steam and water mixture is again taken to the boiler drum where the steam is separated from the water. The steam is sent to the super heaters for superheating. The super heaters are located inside the furnace and the superheated steam is finally sent to the Turbine.

Flue gases from the furnace are extracted by the Induced draft fan which maintains balance draft in the furnace. This flue gases emits their heat energy to the various super heaters in the boiler and finally passes through air pre heater and goes to the electrostatic precipitator where the Ash particles are extracted. This Ash is collected in silos and is used for various purposes.

The Superheated Steam enters the High pressure cylinder of the turbine, where it passes through a ring of stationary and moving blades until it reaches the end of the high pressure cylinder and in its passage some of its heat energy is changed into mechanical energy. The steam leaving the high pressure cylinder goes back to the boiler for reheating and returns by a further pipe to the intermediate pressure cylinder. Here it passes through another series of stationary and moving blades. Finally, the steam is taken to the low pressure cylinders. The steam expands in this LP cylinder and finally exhausts in the condenser. This condensate is taken back to the system by the condensate extractor pump and hence forms a closed loop cycle. The turbine is coupled to the generator. The turbine rotates the generator and the electricity is produced in the stator windings and the same is fed through terminal connections to the Generator transformer and then to the Grid. The switchyard is of 400KV having 4 double circuit outgoing lines. The process flow diagram is given in figure 7.10.

Figure 7.10 Process Flow Diagram for TPP, Essar Power Corporation Ltd.
7.2.11 Vadinar Power Corporation Ltd (VPCL), Vadinar:

Process Description:
VPCL is a cogeneration power plant of 125MWe; generates power and steam to meet out the demand of Essar Oil Refinery. Power is required to drive electrical equipment whereas steam in various unit of refinery to run turbo-drive equipment as well as in various chemical processes. The plant comprises of three 175 TPH boiler and two steam turbines of capacity 38.5MW each. All the three boilers generate steam at the rate of 175 TPH by firing Fuel oil; fuel gas or combination of both. The Gas turbine plant equipment consists of two gas turbine generators and two heat recovery steam generators with 110 MW each. To meet the incremental Process Steam, Power demand of the refinery complex, VPCL is expanding with a Coal/Oil based Thermal Plant ,PF Fired boiler each having a capacity of 750 TPH and 3 Siemens make Extraction Steam Turbines – 2×105 MW & 1×92.8 MW. Hence the current total power generating capacity is 600 MW which has been set up in three phases. (77 MW+220 MW+303 MW). The process flow diagram is given in figure 7.11.

Boiler/Steam generators:
For 77 MW:
Boilers generate steam at the rate of 175 TPH each by firing fuel oil and fuel gas to cater the refinery steam and power demand. It generates steam at 62kg/cm\(^2\) pressure and 455\(^\circ\)C temperatures. All the three boilers are connected to a common header from where it is distributed to all turbo driven equipment as well as major consumer steam turbine for power generation. Boilers are supplied by M/S Babcock ,Germany. These boilers are highly reliable efficient and can be operate even in cases of power failure.

Steam Turbine:
Steam turbines generate power at the rate of 38.5MW each (Total 77 MW) to cater the refinery power demand. These steam turbines are condensing type with one extraction at pressure 40 kg/cm\(^2\) and temperature 400 DegC. Sea cooling water is used for the purpose of cooling condensate. Steam extracted from the extraction is then supplied to the refinery and is referred as HP steam. Maximum extraction can be drawn in total 208TPH.

Balance of Plant:
Refinery generates LP steam at various units which returns to CPP; which is utilized in the purpose of de-aeration in de-aerator; and Boiler air preheating to improve thermal efficiency. Excess LP steam if any is dumped in to dump condenser. Total eight no of turbo drive equipments meet out the blackout operation of one boiler to meet out the refinery safe shut down in cases of power failure. These drives include fuel oil pump; boiler feed water pump; Force draft fan. Two de-aerator are used for the purpose of de-aerating boiler water with the help of low pressure steam (4kg/cm\(^2\);190 Deg C).

Fuel System:
VPCL has two Fuel oil storage tank of capacity 9000 m\(^3\) each which can cater the demand of 15 days at full plant capacity. This highly viscous fuel oil is kept at fluidic condition by keeping the tank temperature around 165 Degree C.

Figure 7.11 Process Flow Diagram for TPP, Vadinar Power Corporation Ltd
For 220 MW:
Refining capacity of Essar Oil Limited (EOL) has been expanded 14 MMTPA to 20 MMTPA. The power and steam requirement of the existing refinery is met by the existing 77MW captive cogeneration plant. The cogeneration plant has three steam boilers each of 175 TPH capacity and two steam turbines each of 38.5MW capacity.
Vadinar Power Company Limited has commissioned cogeneration plant consisting of two Bharat Heavy Electricals Limited Frame-9E gas turbine generators (GTG) and two matching capacity heat recovery steam generators (HRSG) by Thermax Babcock & Wilcox India, to meet the incremental power, steam and feed water demand of the refinery complex.
The new cogeneration plant would be located adjacent to the existing co-generation site at Vadinar in Jamnagar District of Gujarat State.
Description of Main Plant Equipment
The main plant equipment consists of two gas turbine generators and two heat recovery steam generators. The gas turbine and generator package PG9171E, with ISO rating of 126.10 MW capacity and a matching capacity HRSG.
The gas turbine is a common form of heat engine working with a series of processes consisting of Compression of air taken from atmosphere, increase of working medium temperature by constant pressure ignition of fuel in combustion chamber, expansion of SI and IC engines in working medium and combustion. The HRSG is designed to extract maximum recoverable heat from exhaust gas of the gas turbine. For this purpose the exhaust gas flow from the gas turbine is arranged in a direction counter to the water/steam circuit of HRSG. The exhaust gas from the turbine enters the secondary and primary super heaters. From the super heaters the exhaust gases travel through the evaporator and economizer modules and finally through the condensate preheater before getting exhausted to the atmosphere by the stack.
The diverter damper positioned at the GT exhaust controls the exhaust gas flow to the HRSG. At loads, the diverter damper remains in full open position towards HRGS to utilize all the available heat from exhaust gas. The gas turbine can be operated independent of the HRSG in open cycle mode by fully closing the diverter and bypassing the gas through bypass stack.
The HRSG is also designed for supplemental firing with Natural gas as primary fuel & distillate oil as secondary fuel through six duct burners installed at the exhaust gas transition duct before the superheater to enhance the steam generation.
However, operation of HRSG independent of the Gas Turbine, using only the duct Burners is not possible as the combustion air required for the burners is provided by the Gas Turbine exhaust gas.
Passivated DM water from refinery utility would be used for cooling the gas turbine auxiliaries like lube oil cooler, GT leg supports, Flame detectors, atomizing air pre-cooler. Gas Turbine auxiliary cooling water (ACW) is a closed loop system with overhead surge tank for make up. Chemical dosing in ACW system is done for protection against corrosion and biological growth. The passivated DM water is heated in HRSG condensate pre heater (CPH) and supplied to a constant pressure de-aerator. The high pressure boiler feed water pump (BFW) draws suction from the de-aerator and delivers to HRSG. The BFW is a multistage centrifugal pump with hydraulic scoop control for flow regulation.
The main fuel to be used in the cogeneration plant would be Natural gas. In case of non-availability of natural gas, liquid fuels like light cycle oil (LCO) or naphtha or HSD would be used as back up fuels. The fuels would be supplied from refinery complex.
Two storage tanks each are provided to store Naphtha and LCO/HSD. Each tank has a storage capacity of 3000 m³. The layout of the tanks meets the Oil and Industrial Safety Directorate (OISD) guidelines.
A separate gas conditioning skid (GCS) is provided for receipt and supply of Natural Gas to the GTG and HRSGs
Power generated from this cogeneration plant would be internally distributed to various utilities in the refinery complex. The gas turbine generator would be connected to the 220 kV switchyard through a generator circuit breaker and a generator transformer. The generator transformer would be rated 160 MVA stepping up voltage from 11 kV to 220 kV provided with on load tap changers on the high voltage side.
For power evacuation, the gas turbine generators would be connected to generator transformers through isolated phase bus ducts and the generator transformers secondary at 220kV would be connected to 220 kV switchyard bays. The new switchyard would be connected to existing switchyard. The existing switchyard is already connected with the grid.
The steam generated from this cogeneration plant would be distributed to various utilities in the refinery complex.
The gas turbine with associated auxiliaries would be located outdoor. The description of the GTG package given below is typical for each unit.
 Coal/Oil based Thermal Plant (Phase – 2) consisting of

To meet the incremental Process Steam, Power demand of the refinery complex, VPCL is expanding with a combustion of fuel (Coal / Oil) and gets converted into steam. This steam is then expanded in steam turbine, part boiler by the Boiler Feed Pumps which takes suction from Deaerator, and absorbs the heat generated from the air flow into the stage one rotor passages. Each guide vane has a shaft protruding through the casing, with a spur gear that meshes with a circumferential rack. The position of the rack is automatically set by the Gas Turbine Control System. The compressor is constructed with individual rotor discs (wheels) for each compressor stage. Each disk clamps the rotor discs between the forward and aft stub shafts.

The turbine section comprises of turbine rotor, turbine shell, exhaust frame, exhaust diffuser, nozzles and diaphragms, and stationary shrouds. The gas turbine unit has combustors suitable for firing natural gas/LCO/Naphtha/HSD. The combustion of air and fuel mixture takes place in the combustors and the hot pressurized combustion gas produced by the compressor and the combustors would be converted to mechanical energy, i.e., expanded in the gas turbine which would drive generator on one end and axial flow air compressor on the other end. The gas turbine would be having a rated speed of 3000 rpm.

The gas turbine generator is provided with lubrication oil system complete with lube oil pumps, lube oil reservoir, and lube oil coolers. The gas turbine generator would have its own starting system. A 3 phase, 6.6kV induction motor is provided as AC starting motor.

The new plant would be located adjacent to the existing co-generation site at Vadinar in Jamnagar.

The main plant equipment consists of two boilers and three steam turbines. The boilers are coal and oil fired PF with a 750 tph capacity and two steam turbines are having a capacity of 105 MW with HP and MP steam extractions and one steam turbine is having a capacity of 92.8 MW with HP and LP steam extractions.

The HRSG is of dual pressure (HHP/HP & LP), fired, horizontal gas flow type with a self-supporting stack. A condensate pre heater (CPH) to recover the thermal energy of the hot gas to the maximum extent is provided apart from the super heater, evaporator and economizer sections. HRSG is provided with internal thermal insulation, platforms and ladders as required. Feed water and steam sampling arrangements is provided. The height of the HRSG stack is 65m above the ground level to meet the environmental requirement.

For 303 MW:
The power and steam requirement of the existing refinery is met by Vadinar Power Company Limited (VPCL) from its 77MW (Base Plant) and 220 MW (Phase- 1) Captive Cogeneration plants which consists of

- **Base Plant**: 3 Oil Fired Boilers each of 175 TPH capacity & 2 Steam Turbines each of 38.5MW capacity,
- **Phase – 1**: 2 Gas Turbines each having site rating of 110 MW & 2 HRSG’s each having capacity of 315 TPH in fired mode.

To meet the incremental Process Steam, Power demand of the refinery complex, VPCL is expanding with a Coal/Oil based Thermal Plant (Phase – 2) consisting of

- 2 Thermax make PF Fired boiler each having a capacity of 750 TPH and
- 3 Siemens make Extraction Steam Turbines – 2 x 105 MW & 1 x 92.8 MW

The new plant would be located adjacent to the existing co-generation site at Vadinar in Jamnagar.

**Description of main plant equipment**
The main plant equipment consists of two boilers and three steam turbines. The boilers are coal and oil fired PF with a 750 tph capacity and two steam turbines are having a capacity of 105 MW with HP and MP steam extractions and one steam turbine is having a capacity of 92.8 MW with HP and LP steam extractions.

The thermal power plant is working on the rankine cycle where the high pressure DM water is supplied to the boiler by the Boiler Feed Pumps which takes suction from Deaerator, and absorbs the heat generated from combustion of fuel (Coal / Oil) and gets converted into steam. This steam is then expanded in steam turbine, part of which is extracted at different stages & sent as HP, MP & LP Steam for the processes in Refinery and the remaining Steam gets condensed in the Sea Water Cooled Condenser. Condensed steam is then again transferred to Deaerator from condenser hot well by Condensate Extraction Pumps. The Refinery compensates for the steam supplied by making up with DM Water which is fed at the Deaerator. Deaerator is used to remove non condensable gases & acts as a reservoir for boiler feed pump. This completes the entire cycle.

In boiler there are mainly three heat transfer zone exist called economizer, evaporator & super heater. Boiler feed water first enters the economizer travel where it is heated up to saturation temperature then it is enters to evaporator through drum where the latent heat transfer taking place, and at last saturation steam is converted in to superheated steam in super heater.

Heat generated due to firing in burner inside the furnace is transferred to super heater, evaporator & economizer and at last flue gases are exhaust through stack. Rate of firing in burners is depends on the load on boiler and is controlled by fuel & air master controller through DCS (Distributed Control System).
The superheated steam enters to the turbine through steam piping. Steam flow to the turbine is controlled through the governor; also there are two nos. of emergency shut off valves available at inlet of the turbine to completely close / Isolate the steam supply to turbine.

Depending on demand, to control the extraction steam, various control valves are available. Turbine controlling is through TURLOOP control system supplied by SIEMENS.

At the last stage of turbine, steam is condensed in condenser where sea water is used. Sea cooling water is in circulation from cooling tower to turbine condenser and back to Cooling Tower through Cooling Water pumps which are installed at CWPH (Cooling Water Pump House) & Underground piping. Sea Cooling Water which gains heat by Condensing the Steam from Turbine gets cooled in cooling tower through cooling fan in various shells. Chemical dosing in CW system is done for protection against corrosion and biological growth.

DM water from Refinery utility is used for the initial filling and make up of all DM Water Closed Circuits & make up at Deaerator for the Thermal Cycle. DM Water is also used for cooling of turbine lube oil, Boiler feed water pump lube oil, various fans lube oil etc. This DMCW is again cooled in Plate Heat Exchangers(PHE) with use of ACW (Auxiliary Cooling Water-Sea Water).ACW water taping is taken from SCW line going to STG condenser.

The passivated DM water is supplied to a constant pressure deaerator. The high pressure boiler feed water pump (BFW) draws suction from the deaerator and delivers to Boiler. The BFW is a multistage centrifugal pump with hydraulic scoop control for flow regulation.

The main fuel to be used in the boiler would be HFO/CSO and Coal. Also liquid fuel LDO would be used as start up fuel. The liquid fuels would be supplied from refinery complex and coal is supplied from jetty.

One storage tank of LDO having a capacity of 3000 m³ is available and two storage tank of HFO/CSO each having a capacity of 9238 m³ are available to store the fuel. Power generated from this plant would be internally distributed to various utilities in the refinery complex. The steam turbine generator would be connected to the 220 kV switchyard through IPBD and a generator transformer. The generator transformer would be rated 140 MVA stepping up voltage from 10.5 kV to 220 kV provided with on load tap changers on the high voltage side. For power evacuation, the steam turbine generators would be connected to generator transformers through isolated phase bus ducts and the generator transformers secondary at 220kV would be connected to 220 kV switchyard bays. The new switchyard would be connected to existing switchyard. The existing switchyard is already connected with the grid.

Figure 7.11 a) Process Flow Diagram for TPP, Vadinar Power Corporation Ltd
7.2.12 Gujarat Electricity Board, Thermal Power Station, Gandhinagar:
Process description is identical with any coal based thermal power plant. The flow diagram is as per figure 7.12

Figure 7.12 Process Flow Diagram for TPP, Gandhinagar
7.2.13 Power Plant of Jindal Saw ltd, Pragpar, Samaghoga Ta: Mundra:

Process Description:

Waste Heat Recovery Power Plant

Jindal saw Ltd.-Integrated Pipe Unit (JSL, Coke Oven plant has installed the power plant to utilize the waste heat from the gases being generated by its coke oven unit. JSL has installed two batteries of non recovery type of coke oven comprising 34 oven each. The capacity of each battery is 1.0 lacs coke per annum. The coal is being heated in oven in controlled atmosphere. During coke manufacturing, the carbonization 01 coal takes place. At high temperature, the volatile matters are burnt and release tremendous amount of heat. The un-burnt gases leaving the coke oven are burnt through secondary and tertiary air introduced at the outlet of oven and are discharged at a temperature of about 950 – 12000C. Two waste heat recovery boilers, one for each battery are installed. The high temperature gases will pass through different stages like superheaters, evaporators, economizers of the boiler and convert water into superheated steam at a high pressure and temperature. This superheated steam to be fed will be turbine to generate the power. The gases having lower temperature at the outlet of the boiler will be discharged into atmosphere through chimney.

Turbo Generator

In turbine the steam received from the boiler is expanded. The heat energy is converted into kinetic energy in the nozzles & glides over the turbine blade. Thus the kinetic energy is converted into the mechanical energy and turbine rotates at the designed RPM. The turbine is coupled with the generator which converts mechanical energy into electrical energy. The exhaust steam from the turbine is sent to surface condenser (air cooled condenser) which works under vacuum. The surface condenser is tube and shell type heat exchanger in which the steam remains in shell side and the cooling water is circulated in tubes. Thus the steam gets condensed. This condensate is sent back to dearator after passing through the LP heaters. The process is closed cycle, which ensures the minimal requirement of treated water and helps in water conservation also. In cooling tower, the hot water is being discharged in front of spray from the top basin of cooling tower through the target nozzles. This water is again split up into droplets while hitting on the tower fillings, which increases the exposure area of water. This small tiny particle comes in to the contact of flowing air, the sensible heat of the water is transferred to air and further cooling takes place through evaporation. The cold water is collected in the cold water basin and re cycled to the system. The water discharged from the small cooling tower as a blow down shall be utilized for coke quenching, hence the fresh water consumption will be reduced which enables to maintain zero discharge from power plant. In this way project will conserve lot of water.
Figure 7.13 Process Flow Diagram for TPP, Jindal Saw ltd, Pragpar, Samaghoga
7.2.14 Power Plant of Gujarat Heavy Chemicals Ltd, GHCL, Sutrapada:

Process description is identical with any coal based thermal power plant. The flow diagram is as per figure 7.14

Figure 7.14 Process Flow Diagram for Coal Based Thermal Power Plant of GHCL
7.2.15 Power Plant of Jaypee Cement Ltd, Abdasa:

A typical flow diagram of the thermal power plant is as per figure 7.15. Flow sheets are practically identical with typical thermal power plant as discussed earlier.

Figure 7.15 Process Flow Diagram for TPP, Jaypee Cement Ltd, Abdasa
7.2.16 Welspun Power & Steel Ltd., 95 MW Thermal Power Plant, Anjar:

A typical flow diagram of the thermal power plant is as per figure 7.16. Process description and flow sheets are practically identical with the Welspun Power & Steel Ltd., 43 MW Thermal Power Plant as discussed in 7.2.5.

Figure 7.16 Process Flow Diagram for 95 MW TPP, Welspun Power and Steel
7.3.0 Energy Conservation in Thermal Power Plant:

7.3.1 Barrier to Efficiency Improvement in Power Sector:
- Emphasis on plant load factor instead of ‘efficient generation’.
- Degradation of equipment resulting in loss of capacity.
- Delayed overhauls (Seasonal Constraints)
- Financial constraints lead to inadequate maintenance
- Lack of awareness on efficiency related issues:
  - Inadequate MIS systems (analysis of financial impact of various operating parameters)
  - Inadequate monitoring system for parameters
- Non availability of working performance measuring instruments at stations.
- Non dedicated group or task force to target efficiency improvement
- Maintenance management & Operation management systems.

7.3.2 Need of Improving Efficiency:
An Average increase of 1% in the Efficiency would result in:
- Coal savings of approx. 11 million tons per annum for nation(approx) worth Rs.44,000 Million-( coal price taken as Rs 4000/ ton as national average cost)
- 3% CO$_2$ reduction per annum (approx.13.5 million tons per annum)
- Higher productivity from the same resource is equivalent to capacity addition
- Lower generation cost per kWh

7.3.3 Good Practices for Maintenance and Energy Conservations:

i) Equipment Criticality Analysis
Identify the equipments, which are having major influence on the performance of the plant. These critical equipments are monitored rigorously to improve the maintenance as well as operation performance. Many techniques can be used to categorize the equipments. These include risk based inspection methodology to or some criteria like: generation loss, maintenance cost, availability, MTBF etc to carry out criticality analysis of equipments of a power-plant.
Equipment Criticality Analysis Criticality Score= (G+E+S+A) x RF
Where: G= Effect on Generation E= Effect on Environment and Safety S= Effect on Service Level A = Effect on Efficiency & Aux Power RF= Redundancy Factor
Priority Score= (FF x SPC) + (ADT x MPC)
Where, FF= Frequency of Failure SPC= Spare Part Cost ADT= Average Down Time MPC= Man Power Cost

ii) Equipment Reliability
It can be analysed by finding following:
MTBD –Maintenance Effectiveness
MTTR –Maintenance Efficiency
Reliability –a function of failure-Probability that equipment will not fail within a specified time

iii) Risk Assessment
Evaluation of Risk Level can be done as below:
Index Risk Level Index = L x S x P
Where L –Likelihood, S –Severity, P –Persistence or Restoration period

iv) Proactive Maintenance
- ABC Analysis,
- Root Cause Failure Analysis (RCFA)
- Failure Mode Effect Analysis (FMEA)

v) Renovate / Modernize
- PLC for CW System
- SCADA for Transmission & Distribution
- Microprocessor based ESP

vi) Retire/ Replace
- Controllers
• Flat belts to replace V belts
• Ventilation fans

vii) Replace / Design out
• modified design
• Dry Fly Ash Evacuation System

viii) Energy Awareness drive
• Display of posters and slogans in plant
• Ongoing sensitization campaign for all employees
• Create awareness among local school children about energy conservation
• Employees suggestion scheme
• Celebration of Energy Conservation week
• Competition of posters & slogans
• Film show
• Display of energy conservation projects
• Technical training sessions from internal & external faculty
• Energy conservation walk involving all employees

ix) Monitoring & Review
• Plant Level Review
• Plant performance, Maintenance; Condition monitoring, Generation cost, Heat rate losses and analysis reports.
• Shift basis / Daily / Weekly / Monthly / Half Yearly-Calendar year / Financial year-O & E and MTP - agencies for generation of MIS
• Corporate review
• Plant performance, Profitability, Environmental reports.

x) Electrical Aspects to Save Energy in Power Plant
• Energy efficient operation
• Optimum use of electrical drives
• Energy efficient motors
• Energy efficient illumination system
• Speed variation mechanism
• Energy efficient transformers at load centers
• Online transformer monitoring system
• Numerical relays
• Led indicating lamps
• Use of harmonic filters
• Cable selection and laying

xi) Optimum Use of Electrical Drives
• Use energy efficient motors operate near rated capacity
• Use optimum size of the motors
• Look for restoration of efficiency after rewinding
• Check on temp rise of motors
• Keep proper lubrication of motors
• Keep proper alignment of motors
• Use soft starter instead of star delta for bigger motors

xii) Energy Efficient Illumination System
• Use energy efficient luminaries, e.g. CFL instead of FL, HPSV instead of HPMV, LPSV instead of HPSV, MH instead of HPMV
• Use group lighting system in equipment rooms
• Use timer/photo cell for outdoor lighting
• Electronic ballasts
• Use daylights/sky lights as far as possible
• Better painting of wall to increase reflection factor
• Change exit signs from GLS to LED
• Use occupancy sensor

xiii) Speed Variation Mechanism
• Use VFD in place of Mechanical gear / belt
• VFD capable of speed change in range of Reduction –9:1 / increase –3:1
• Energy saving is much more in variable torque application
• Harmonic generated to be taken care of h. Filters
• Where gear is being used, use high efficiency gear sets
• Where belt is being used, use flat belts instead of v belts
• Check belt tension regularly
• Eliminate variable pitch pulley

xiv) Technological Aspects
• Preheating of combustion Air
• Maintaining the right stack Temperature
• Maintaining of right 3T’s
• Automatic/ optimization Blow down Control
• Maintenance of proper Boiler & Feed water quality
• Maintaining of optimum condenser vacuum
• Excess Air control
• Optimization of flue path using CFD software.

xv) Reduction of Auxiliary Power Consumption

a) Coal Handling System
• Increasing the plant utilization factor (PUF)
• Incorporating PLC controllers
• Avoiding idle running of conveyors & crushers
• Incorporating soft starter -energy savers etc

b) Ash Handling System
• Constant monitoring of ash to water ratio
• Reducing ash to water ratios directly results in pump power savings and also water savings. studies have shown savings to the tune of 0.2 MU/annum for every 1% reduction in ash water ratio
• Changing of worn out pump internals based on periodic pump efficiency assessment
• Replacement of inefficient pumps with high efficiency pumps
• Optimization of pump operations

c) Compressed Air System
• Reduction of air leaks
• Optimizing discharge pressure by using demand controller toning down as per needs.
• Regular assessment of inter cooler/after cooler performance and periodic cleaning of tubes
• Adoption of heat of compression (HOC) dryers for air drying units

d) Cooling Tower
• Shutting off fans during favorable weather conditions
• Replacing existing aluminum cast blades with FRP blades.
• Incorporation of efficient nozzles for efficient water spare/atomization,

e) Reduction of Flue Gas Volume
• Manufacturer specifies operation at 20 % excess air.
• Operating regime changed to 12 % excess air.
• Strategic decision to procure commission and maintain CO measuring instrumentation.
• Oxygen control by measuring CO in flue gas
• Control of Oxygen for maintaining less excess air
• Control of excess air –a part of operation objectives

f) Control of Dry Flue Gas Losses
• Flue Gas Temperature Control
• Scheduled Boiler soot blowing
• Water walls
• Long Range Blowers
• Scheduled Air Preheater soot blowing
• Air Preheater water washing
• Furnace cleaning
• Air Preheater basket cleaning & replacement
• Flue Gas Volume Control
• Air Preheater seal setting
7.4.0 Case Study – I Application of Six Sigma Methodology in Thermal Power Plant to Reduce the Consumption of DM Water:

7.4.1 Introduction:

In the past few years, successful cases of Six Sigma implementation have been reported in numerous manufacturing industries. This technique has also been implemented in some service industries and supply chain management (Knowles, 90) but the same cannot be said about its implementation in process industries. In this research an attempt is being made to apply Six Sigma methodology to a process industry taking a specific case of a thermal power plant. DM (de-mineralised) water in thermal power plants is an expensive input material. A DM water make-up cycle is required to compensate for the losses incurred in the water steam cycle due to evaporation, start-up and shut-down, venting, valve passing and blow downs. It has been found that a 0.1% increase in DM water consumption increases the generation cost by Rs. 80.46 Lakhs per annum, which includes the cost of heat loss, extra water and consumption of chemicals. Hence, the Critical to Quality (CTQ) aim, selected for this Six Sigma application, is to reduce the consumption of DM water in a thermal power plant. In the present case study, the process was studied and the implementation of the Six Sigma project recommendation and improvement action plans reduced the mean make-up of water from 0.90% to 0.54% of MCR (Maximum Continuous Rating), accruing with it a comprehensive energy saving of nearly Rs. 296.09 Lakhs per annum.

Six Sigma methodologies have recently gained wide popularity because they have proven to be successful not only at improving quality but also at producing large cost savings (Antony, J. & Banuelas, 10). Six Sigma focuses on improving quality (i.e. reducing waste) by helping an organisation to produce products and services better, faster and cheaper (Mahanti & Antony, 10). Consequently, an organisation needs to have smarter Six Sigma solution assessments that are linked to bottom-line benefits. Park, 125 has stated that Six Sigma is a scientific and statistical quality assessment for all processes through measurement of quality level, which provides the opportunity and discipline to eliminate mistakes, improve morale and save money. Mathew et al, 10 have stated that doing things right and keeping them consistent are the ideas behind Six Sigma. A fundamental objective of Six Sigma is to achieve customer satisfaction with continuous improvement in processes. Six Sigma, as a quality tool, has found a place primarily in manufacturing industries where there is a specific product with specified dimensions, which are measurable at every intermediate manufacturing stage in order to perform the necessary measurements and analysis (Rajamaharan, 10). In process industries like thermal plants, no such convenience is available. Steam/ water, the main working fluid in these industries may not be visible and its quality is measured by various instruments mounted on the process hardware in the form of pressure, temperature and flow measurement. Normally, in manufacturing industries, production is already operating at 1–2 sigma level and by applying Six Sigma methodology it can be raised to 5–6 sigma level, whereas in the process industries there are many sub-processes that operate even at negative sigma levels because they are secondary in nature. Therefore, in the process industries, a significant increase in the sigma value through the application of Six Sigma tools cannot be expected and it is found that the improvement potential is a maximum of up to 2–3 sigma level, but as the process industries are huge investment industries, e.g. thermal power plants, fertiliser units, chemical plants. The cost benefits of applying Six Sigma can be significant to these industries. The present work is an initiative to implement Six Sigma in a thermal power plant. In thermal power plants, the main process is generation of electricity from fuel, but there are many sub-processes that affect the economy of power generation. Six Sigma tools can be applied to such sub-processes where cost implications are substantial. Optimisation of cycle make-up water (DM water) consumption is one such process. Any saving in DM water consumption pattern is a substantial cost saving for the industry and a service to society. Keeping this in mind, optimisation of cycle make-up DM water has been chosen as an initiation project of applying Six Sigma techniques to the thermal power plant industry.

Mostly thermal plants operate one module of a combined-cycle power plant, which consists of two gas turbines, two heat recovery steam generators and a Steam turbine. DM water is used for steam generation through a gas-based combined cycle power plant. Within this DM water closed cycle, the DM water cycle make-up is required to compensate for the losses incurred in the water–steam cycle due to evaporation, start-up and shut-down venting, valve passing and blowdowns. DM water enters a condenser at 27°C, which is then heated up to 520°C to create steam. A flow metre is used to measure the day DM water as a percentage of feed water flow. It is calculated that each 0.1% increase in cycle make-up increases the generation cost by Rs. 80.46 Lakhs per annum, which includes the cost of heat loss, extra water and consumption of chemicals. Hence, the CTQ aim, selected for Six Sigma application, is to reduce the consumption of DM water in a thermal power plant.
7.4.2 Methodology Adopted:
To solve any problem, the methodology adopted must cover all possible causes of the problem. If the problem solving methodology is not comprehensive enough, the solution obtained at completion will not be correct and the problem will resurface sooner or later. A process flow chart is prepared to proceed in a sequential manner and to present a one-shot picture of the entire methodology, as shown in Figure 7.17.
A literature survey is chosen as the first step to discover the present status of research and application of Six Sigma in the process industry. From the literature survey, it was found that most Six Sigma work has so far been carried out in manufacturing industries only, and there is scope for improvement in process industries through the application of Six Sigma techniques (Wright12). For this reason, an initiative has been taken to apply Six Sigma to a process industry.
To study the problem of DM water in a power plant, the DM water data need to be investigated for such a time that all possible variations of water consumption are covered. To do this, six months’ data of DM water consumption have to be collected. Further, to make the data more meaningful for other power plants, the DM water consumption data have to be presented in a ‘unit’ that can be applicable and comparable to other power plants. For this reason, DM water consumption has to be converted in terms of percentage of MCR (Maximum Continuous Rating) of feed-water flow.
As it is not possible to reduce the DM water consumption to zero, it is not possible to fix the LSL (Lower Specification Limit) for water consumption. Hence, for the case study, only the USL (Upper Specification Limit) of 0.7% and target value of 0.5% are specified and selected, based on the water consumption pattern existing in the best power plants around.

![Flow Diagram of Methodology Adopted](image)

**Figure 7.17. Flow Diagram of Methodology Adopted.**

In the present work, a five-step improvement cycle using Six Sigma organisation, i.e. Define, Measure, Analyse, Improve and Control (or DMAIC), has been successfully implemented in a thermal power plant to reduce DM water reduction and the results have shown a significant saving in cost.

Implementation of Six Sigma DMAIC methodology
The implementation process carried out in the five steps of Six Sigma DMAIC methodology is explained below.

**i) Define**
Define the problem and define what the customer requires Henderson & Evans32. The defining of the problem is the first and the most important step of any Six Sigma project because better understanding of the problem makes the job much easier later on, during analysis. The definition of the problem forms the backbone of any Six Sigma project. In define phase, a High Level Process Map – a SIPOC (Supplier, Input, Process, Output, Customer) diagram – was drawn for DM water consumption as shown in Figure 7.18. It was used to define the customer requirements and identify the project goals.
ii) Measure
In the measure phase, a measurement system analysis (MSA) is conducted which includes the Gauge Repeatability and Reproducibility (Gauge R&R) Raisinghani et al\(^{138}\). The purpose of the Gauge R&R study is to ensure that the measurement system is statistically sound. Gauge repeatability and reproducibility studies determine how much of the observed process variation is due to the measurement system variation. For the Gauge R&R study, it is not always possible to check the instrument at all stages, and taking it to a laboratory is not always possible. Therefore, the measurement phase of a process industry presents a different scenario as compared with a manufacturing industry. The process industry, being a continuous process, does not have discrete outputs within the process that can be measured separately, i.e. the item measured is an event, which may not happen the same way twice. For such situations, another measuring device, of tested accuracy and characteristics, needs to be put in series in the original instrument before the Gauge R&R study. In the case of DM water consumption at the thermal plant, the DM water flow is measured using a flow metre. To perform a Gauge R&R study on this process, another flow metre of tested accuracy and characteristics needs to be placed in series with the installed flow metre. Two people were needed to perform this experiment, which in this case were the operators on the shift. The sample size was ten, and two readings were taken on each sample, thereby making a total of 40 readings.
From the results of the Gauge R&R study, the repeatability and reproducibility comes out to be 2.75% and 0.00%, which puts the percentage study variation at 2.75%, which is less than 10%, so it is concluded that the flow metre was correct.

iii) Analyse
In this phase, data are analysed and the causes of any problems are discovered Kapur & Feng\(^{84}\). The following are some of the tools used in analysing the data collected by the flow metre.
iv) Run chart
Plotting a run chart is the first step in data analysis as, without a run chart, other data analysis tools such as the process capability and histogram can lead to erroneous conclusions. The purpose of this chart is to measure and track a key input, process, or to measure output over time and help a team to look at whether there are patterns over time in the problem. ‘Common-cause’ variation is a natural part of a process. Another type of variation, called 'special causes', comes from outside the system and causes recognisable patterns, shifts or trends in the data. The run chart shows if special causes are influencing the process. A run chart or trend chart was drawn from the data collected for the day DM water from the thermal plant measured using the flow metre. Minitab was used for plotting the run chart; it plots the value of each data point in the order that the points were observed. From the run chart, as shown in Figure 7.19, it was found that there was no obvious pattern. From the results found using Minitab, the P-values for clustering (0.51045), trend (0.36191), oscillation (0.63809) and mixtures (0.48955) come out to be greater than the significance level of 0.05, so it was concluded that the data do not indicate any special cause of variation.
v) Histogram

A histogram helps to display the large data that are difficult to interpret, and also to identify the mean relative to the customer’s specific requirements. By providing a visual summary of data, a histogram reveals whether the process is centred on a target value or the data meet the specifications. Minitab was used to plot the histogram, as shown in Figure 7.20.

The histogram clearly shows that the data were not centred and the mean is far beyond the USL (0.7) and target (0.5) values, which shows the problem of centring. Six months of data, i.e. 182 sample size, were taken to draw the histogram.

vi) Process capability analysis

Process capability analysis was performed to find the actual state of the process. Minitab was used to draw the process capability analysis curve for DM water from the thermal power plant measured through the flowmetre, as shown in Figure 7.21.

From the process capability analysis curve, it was found out that the Z-bench sigma value of the process was –0.75 and the existing DPMO (Defects Per Million Opportunities) level of the process comes out to be 774,435.70, which was remarkably high, and this shows that there are a lot of opportunities for improvement in the process.
vii) Fish-bone diagram
Using process capability analysis, the DPMO level and sigma level of the DM water consumption were known. It was now time to find the causes of increased DM water consumption during the combined cycle. Then, by identifying the causes and effects of increased DM water consumption, using the expert experience and critical analysis of the actual combined cycle at the site, a fish-bone diagram was drawn, as shown in Figure 7.22.

Figure 7.22. Fish-Bone Diagram

viii) Bar chart
After making a fish-bone diagram showing the possible causes of the problem, a bar chart was drawn that shows the components of the problem that have the biggest impact. To make the bar chart, actual DM water wastage
from different points was measured (or approximated where measurement was not possible). Based upon the measurement results, the bar chart was drawn and the causes (shown in Figure 7.23), with their percentage contributions, were found to have the biggest impacts on DM water consumption.

ix) Improve
- The optimal solutions for reducing mean and variation are determined and confirmed in the improve phase. The gains from the improve phase are immediate and are corrective in nature. Specific problems identified during analysis are attended to in the improve phase. This stage involves:
  - Use of brainstorming and action workouts.
  - Process optimisation and confirmation experiments.
  - Extracting the vital few factors through screenings.
  - Understanding the co-relation of the vital few factors.

![Figure 7.23. Bar Chart to Show Causes Percentage Contribution](image)

In the SWAS (Steam Water Analysis System), the important issues of periodic awareness and training of lab analysts, the communication gap between operational and chemistry staff, and the casual approach of some of the staff, were identified and an action plan has been prepared to tackle all such problems (as shown in Table 7.1).

**Control**
The process needs to be controlled to ensure that defects do not recur (Mathew et al\textsuperscript{108}). It is the final stage of Six Sigma implementation to keep hold of the gains obtained from the improve stage. Hence, in this stage, the new process considerations are documented and implemented into systems so that the gains are permanent. The control phase is preventive in nature. All possible causes of specific identified problems from the analysis phase were tackled in the control phase as described in Table 7.1.

<table>
<thead>
<tr>
<th>Serial no</th>
<th>Recommendation proposed</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All lab analysts to be individually interacted to emphasise the importance of closure of SWAS valves after sample collection.</td>
<td>Implemented</td>
</tr>
<tr>
<td>2.</td>
<td>Six month periodic training cum awareness programme for lab analysts to be conducted to make them aware of the importance of DM water loss</td>
<td>First programme already conducted</td>
</tr>
<tr>
<td>3</td>
<td>Instructions to be pasted on SWAS panel for closure of sample valve’s each time after sample collection.</td>
<td>Implemented instructions pasted</td>
</tr>
<tr>
<td>4</td>
<td>Operation staff to be instructed to cross check from time to time the position of SWAS sampling valves in their routine rounds</td>
<td>Implemented instructions being followed</td>
</tr>
<tr>
<td>5</td>
<td>As an improvement measure the frequency of blow down opening to be changed from weekly to fortnightly</td>
<td>Implemented</td>
</tr>
<tr>
<td>6</td>
<td>To avoid the loss of DM water due to vacuum pump overflow solenoid make-up valves of both the seal water tanks to be adjusted properly for both low and high level settings.</td>
<td>Implemented</td>
</tr>
</tbody>
</table>
Quarterly checking of solenoid valves of both seal water tanks to be carried out.

To detect the problem of seal water tank overflow at the earliest in the log sheet of the operator the daily checking of seal water tanks to be included.

The leakages identified from HP/LP (high pressure/low pressure pipelines valve passing to be attended during next shutdown.

The glands of all the pumps with excessive leakages to be tightened optimally.

A schedule to be prepared to check/tighten (if required) the glands of all the pumps fortnightly.

For on line sealing of HP steam leakages annual maintenance contract to be awarded.

Table 7.1 Action Plans (Improve and Control Phase).

- The control phase mainly defines control plans specifying process monitoring and corrective action.
- The control phase provides systematic re-allocation of resources to ensure the process continues in a new path of optimisation.
- The control phase ensures that the new process conditions are documented and monitored.

7.4.3 Results after Improvement:
The DM water consumption was 0.9% MCR which is equivalent to Rs. 724.14 Lakhs (Rs. 80.46 * 0.9%) per annum. (The cost calculation of the loss on account of 0.1% DM water is as shown in Appendix A.) The application of the project recommendation increased the sigma level to 1.63 with DPMO level of 51,389.17 (an improvement of 723,046.53) and the mean of the process reduced to 0.54066% (an improvement of 0.368% mean), as shown in Figure 7.24, which is equivalent to a saving of Rs. 296.09 Lakhs per annum. The estimated saving from the project after the implementation of all recommendations is expected to be Rs. 321.84 Lakhs per annum with mean DM water expected to reduce below 0.5%, which is substantial for any organisation.

Figure 7.24. Process Capability Analysis of DM Water after Implementing DMAIC Methodology
7.4.4 Conclusions:
On the basis of the results, the following conclusions have been drawn.

- This study illustrates the successful implementation of Six Sigma in the process industry. Six Sigma has been considered as a revolutionary approach to continuously improve processes through the effective use of statistical tools and techniques. The study illustrates the successful implementation of a Gauge R&R study and it is found that the total Gauge R&R of the flow metre comes out to be 2.75%, which is less than 10%. Hence, the flow metre used to measure the flow of water is perfectly fine. The application of Six Sigma project recommendations increased the mean DM water to 0.573% (with a total improvement of 0.336% mean), which is equivalent to a monetary saving of Rs. 270.34 Lakhs per annum. The estimated saving from the project after the implementation of all the recommendations is expected to be Rs. 321.84 Lakhs per annum, with mean DM water expected to reduce below 0.5%, which is substantial for any organisation.

- This study has resulted in savings of DM water for the industry. The water is a natural resource and is a must for sustainable development. Savings of water of any kind is a service to mankind. Six Sigma should become the mindset of organisations. Even the performance level of different departments can be evaluated through the sigma levels of the processes under their control.

- Six Sigma’s implications on service organisations may be studied and a specific set of tools and techniques may be designed.

- By combining lean concepts with Six Sigma methodology, improvements can be achieved at a faster rate. An initiative can be taken to implement a lean Six Sigma concept in a process industry.

7.5.0 Case Study-II TEM Implementation in Thermal Power Plant for Energy Conservation:
Out of the mentioned sixteen thermal power plants, typical case study for the Thermal Power Station, Gandhinagar has been considered in this investigation.

Energy saving opportunities in Thermal Power Station, Gandhinagar, which comprises of two units of 120 MW each, three units of 210 MW each with total installed capacity of 870 MW has been discussed in detail consisting of following three equipments multiple in number.
Case-I Condensate Extraction Pumps (CEP)
Case-II ID Fans
Case-III Compressors

The total annual energy cost saving potential in case of ID Fans is expected to be highest being Rs. 137.0 lakhs per year with total investment of Rs. 450 lakhs thus having payback period of 3.3 years.
In case of the condensate extraction pumps, total saving expected is Rs 21.65 lakhs with justifiable investment of Rs. 21.65 lakhs, thus having payback period of 1 year.
In case of the compressors, the expected saving is Rs 12.75 lakhs per year against the investment of Rs 9.25 Lakhs thereby having payback period of less than one year.
Thus there exists a great potential for energy conservation in Thermal Power Station, Gandhinagar. Other thermal power plants can also be analyzed in a similar manner. Thus TEM is of utmost importance in such units TEM and TQM appear to be complimentary to each other. TQM implementation is already discussed earlier in this chapter.

7.5.1 About TPP Consisting of Five Units - General Survey

i) About Unit
It is a Coal Based Power Station (Unit X). The thermal power station comprises of two units of 120 MW each (Units no. 1 & 2), three units of 210 MW each (Unit no. 3,4 & 5) with a total installed capacity of 870 MW. So, for R & M of this two units is proposed and order is being placed to M/s. BHEL.

<table>
<thead>
<tr>
<th>Unit No.</th>
<th>Installed Capacity</th>
<th>Derated Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>3</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>4</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>5</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>Total</td>
<td>870</td>
<td>870</td>
</tr>
</tbody>
</table>

Table 7.2 : Unit Capacity Details
ii) Special Latest Technology Adopted in the Unit:
For providing uninterrupted power supply to the consumers and for doing so UNIT X has gone in for the latest technology available. In Unit No.3 & 4 the advance features like protection and inter locks systems for automatic sequential start up & shut down of important auxiliaries also,(automatic turbine run up system) have been incorporated.
Similarly, for 210 MW unit no.5 UNIT X has gone for some latest technology & have introduced first time DDS control with WSPOSE system (Distributed Digital Control with workstation base plan Operator Environment System) by this system UNIT X has embarked in complete plant automation of the world's latest technology. The automation system controls and monitors plant start up, operation as well as shutdown. This automation system is of particular importance when the plant behaves in an unpredictable way. This system will than automatically and immediately respond without time delay to bring the plant or process into a safe operating state with respect to environment process components and human beings. The fast response time also prevents and individual plant component trip causing a tripping chain reaction and unnecessarily shutting down the entire plant. This system provides operating personal with the necessary tool to increase overall plant availability and efficiency. Such system have been adopted at various power station in India.

iii) General Process Description:
The coal is bought from the mines of coal fields (indigenous coal) and from Australia/South Africa/China (imported coal) by rail and is unloaded at site by Wagon tippler and passed through the primary crusher and secondary crusher for crushing. The process flow diagram is shown in figure 7.25

![Process Flow Diagram for Thermal Power Plant](image-url)
The crushed coal is stored in the bunker and fed into coal mills for pulverization. The powdered coal is fed into the boiler for firing. For start up of boiler, RFO/LSHS and LDO are used in small quantities, which are unloaded and stored into the storage tanks from where they are fired directly into the boiler with pumps. The other raw material water is drawn from river and in case of emergency, from the bore-wells dug in our premises. The water after the demineralization is used as make-up water for the power cycle. The water is also required for the cooling process and other purpose in the plant. The steam from the boiler passes through turbine the turbine fitted with condenser for driving the generator for power generation. Power generated is evacuated / transmitted through the transmission lines to the power grid. The used steam from the turbine is taken into the condenser, where it is condensed with the help of recycled water from the cooling tower. The warm water from here is cooled in the cooling towers. The blow down from the cooling towers is used for ash handling.

7.5.2 Salient Feature of TPS - Unit-IV only
Out of five units, Unit-IV was selected for Energy Conservation Study

i) Boiler Data
The boiler is of radiant, reheat natural type circulation, Single grumdry bottom and semi-out door type Unit designed for firing coal as the principal fuel and the HFO/LSHS/HPS oil firing capacity to 45% and light oil system for MCR 7.5% boiler MCR
Furnace Width 13868 mm depth :10592 mm Height : 63000 mm Volume : 5140 m$^3$
Fuel heat input : $529.9 \times 10^6$ Kcal/hr

**Data on Mills**
Size & Type: BCP 2360/77
No of mills: 6 Nos. per unit
Make: M/s-Steam industries. France
Basic Capacity of Mill: 47.2 T/hr for 70% through 200 mesh with
Grindability
Mill motor: 452 KV, 6.6 KW, 1000 rpm, BHEL Make
Wt of mill: 98.6 T, ID 2360 mm

**Boiler Feed Pump**
Numbers: 3 Nos.
Capacity: 430 T/hr.
Head: 1950 MWC.
Motor Capacity: 3500 KW

ii) Steam Turbine:
210MW Conden compound with HP,IP & LP three cylinder reheat Condensing single flow HP turbine with 25 stage double flow IP turbine with 20 stage double flow L.P turbine with 8 stage per flow six extraction steam inlet pressure 147.1 kg/cm$^2$ with 535°C

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rated output of Turbine</td>
<td>21,000KW</td>
</tr>
<tr>
<td>2</td>
<td>Rated speed</td>
<td>3000 rpm</td>
</tr>
<tr>
<td>3</td>
<td>Rated pressure of steam at inlet of ESV</td>
<td>150kg/cm$^2$</td>
</tr>
<tr>
<td>4</td>
<td>Rated temp. of steam at inlet of ESV</td>
<td>535°C</td>
</tr>
<tr>
<td>5</td>
<td>No of extraction lines for regenerative</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Heading of feed water Qty of cooling</td>
<td>270000 m$^3$ hr</td>
</tr>
<tr>
<td>7</td>
<td>Water through condenser</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Max pressure of ESV</td>
<td>155kg/cm$^2$</td>
</tr>
<tr>
<td>9</td>
<td>Max temp of steam at ESV</td>
<td>535°C</td>
</tr>
<tr>
<td>10</td>
<td>Steam flow at MCR</td>
<td>Blr 652 TPH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tur 475 TPH</td>
</tr>
</tbody>
</table>

Overall length 16.975 meter & width 10.5 meter

iii) 210 MW Generator:
The generator is 2 pole cylindrical rotor type, driven by direct coupled steam turbine. It generates 3 phase AC current, 50 Hz frequency.
The generator is hydrogen cooled with further cooling of stator by water system. The hydrogen is circulated by cooling fans for generator. The gas is it turn cooled by DM water, passing through H$_2$ cooler.

The stator conductor is having hollow section & the same is cooled by DM water passing through each generator coil. The stator water in turn is cooled by DM water. The generator is having static excitation system. The generator is 210 MW capacity generating voltage at 50 Hz is 25.75 KV.

Max continuous KW rating 210KW  
Max continuous KVA rating 247 KV  
Rated terminal voltage 15750V  
Rated Stator current 9050 Amp  
Rated power factor 0.85 lag  
Excitation current at MCR condition 2600 Amp  
Sleeping ring voltage 310 V  
Rated speed 3000 rpm  
Rated Frequency 50 Hz  
Efficiency at MCR condition 98.4 %  
Rated hydrogen pressure 3.5 kg/cm$^2$ gauge  
Short circuit ratio 0.9

iv) Coal Handling Details:

**Wagon Tippler**  
Make: Elicon Engg.  
Angle of tilting 170°  
Capacity 20 boyes/hr  
Motor 60 HP at 1000 rpm  
Secondary reduction Gear type rack/pinion type of sensing electronics  
Type Rotary  
Automatic weight bridge 280 MT  
Common hopper capacity 300 MT  
Reduction ratio 22:4:4

**Crusher**  
Total no. 2 Nos.  
Capacity 1000 TPH  
Type ring type with no bypass arrangement  
Make Elicon engg co.  
Hammers 30 rings plain- 32 toothed  
Motor 1100 HP(800 KW)  
Voltage 6.6 KV  
Speed 1440 rpm  
Power transmission Thro/ fluid coupling  
Gear box ratio 2:5:1

v) **ESP**  
1. Design Condition  
a) Gas flow rate : 337.9 m$^3$/sec  
b) Temp : 136° C  
c) Dust concentration : 58.1 gms/Nm$^3$  
2. Type of precipitator : FAA-7x36-2x90125-2  
3. No. of precipitator offered per boiler : Two  
4. No. of gas path per boiler : 2  
5. No. of fielding series in each gas pass : 7  
6. Guaranted collection efficiency for design condition : 99.47  
7. Pressure drop across the precipitator for design conditions : 15 mmWc  
8. Velocity of gas at electrode zone on total area : 0.75 m/sec  
9. Treatment time : 33.6 sec  
10. Collecting Electrodes  
a) No. of rows collecting electrode per field : 61  
b) No. of collecting electrode plate* per field : 549
* Nine plates are arranged in each row.
c) Total no of collecting plates per boiler : 7686
d) Nominal height of collecting : 5.5 mt
e) Nominal length of collecting : 400 mm
f) Specific collecting area : 222.7 m²/m³/sec

11. Emitting Electrodes:
a) Type : Spiral with hooks
b) Size : 2.7 mm
c) No of electrodes in the frame forming one row : 54
d) No of electrodes in each field : 3248
e) No of electrodes in each boiler : 3240
f) Total length of electrode per field : 235418 mts

12. Rectifier Control Panel
a) Type of control : Thyristor
b) Number : 28
c) Location : In the control room at ground level.

13. Auxiliary Control panel:
a) Number : 2
b) Equipment controlled: Geared motors of rapping mechanisms of collecting & emitting electrodes, heating elements on hoppers insulator.
c) Location : In the control room at ground level

14. Motors
Rapping of emitting electrodes
a) Quantity : 16 Nos
b) Rating : Geared motor, 0.33 HP/2.5 rpm at 3 phase 415 volts, 50 Hz
c) Location : On top of ESP

15. Rapping of collecting electrodes
a) Quantity : 8 Nos
b) Rating : Geared motor, 0.5 HP/1.1 rpm at 3 phase 415 volts, 50 Hz
c) Location: On the side panels of the casing

16. Hoppers Heating Elements:
a) For 16 hoppers at the rate of 6 KW/hopper : 96 KW
b) For 16 insulators at the of 1 KW : 64 KW

17. Recommended Current Setting

<table>
<thead>
<tr>
<th>Fields</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current in mA</td>
<td>200</td>
<td>260</td>
<td>320</td>
<td>390</td>
<td>440</td>
<td>490</td>
<td>610</td>
</tr>
</tbody>
</table>

7.5.3 Energy Saving Opportunities in TPS, Gandhinagar

Energy Saving Opportunities in TPS, Gandhinagar has been discussed in detailed in the following cases:

Case Study-I:
Energy Saving Opportunities for the case of Condensate Extraction Pump (CEP)

Case Study-II:
Energy Saving Opportunities for case of ID Fans

Case Study-III:
Energy Saving Opportunities for the case of Compressors

i) Case Study-I: Condensate Extraction Pump (CEP)

The as-run performance trials were conducted on the CEP's and the observations on CEP's and averaged duty parameters, are presented in Table no. 7.3
### Table 7.3 Energy Saving Opportunities

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Item Ref</th>
<th>Units</th>
<th>Rated</th>
<th>CEP#4A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unit Load</td>
<td>MW</td>
<td>210</td>
<td>207.0</td>
</tr>
<tr>
<td>2</td>
<td>Grid Frequency</td>
<td>Hz</td>
<td>50</td>
<td>49.60</td>
</tr>
<tr>
<td>3</td>
<td>Condenser Vacuum</td>
<td>Kg/cm²</td>
<td>-0.89</td>
<td>-0.78</td>
</tr>
<tr>
<td>4</td>
<td>CEP flow</td>
<td>TPH</td>
<td>628</td>
<td>580.0</td>
</tr>
<tr>
<td>5</td>
<td>Suction Head (Condenser Vacuum)</td>
<td>Kg/cm²</td>
<td>-0.89</td>
<td>-0.78</td>
</tr>
<tr>
<td>6</td>
<td>Disch. Header Pressure</td>
<td>Kg/cm²</td>
<td>18.80</td>
<td>19.50</td>
</tr>
<tr>
<td>7</td>
<td>Total head</td>
<td>Kg/cm²</td>
<td>19.69</td>
<td>20.28</td>
</tr>
<tr>
<td>8</td>
<td>Suction Temp. (Condenser)</td>
<td>°C</td>
<td>48.5</td>
<td>62.0</td>
</tr>
<tr>
<td>9</td>
<td>CEP Amps</td>
<td>A</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>CEP power at motor input</td>
<td>kW</td>
<td>470.7</td>
<td>493.0</td>
</tr>
<tr>
<td>11</td>
<td>Liquid kW</td>
<td>kW</td>
<td>340.55</td>
<td>324.02</td>
</tr>
<tr>
<td>12</td>
<td>Combined Efficiency *</td>
<td>%</td>
<td>72.35</td>
<td>65.72</td>
</tr>
<tr>
<td>13</td>
<td>Pump Efficiency (calculated at design motor efficiency)</td>
<td>%</td>
<td>79.5</td>
<td>71.4</td>
</tr>
<tr>
<td>14</td>
<td>% Load on motor (based on motor rated power)</td>
<td>%</td>
<td>102.00</td>
<td>106.8</td>
</tr>
<tr>
<td>15</td>
<td>% Load on flow</td>
<td>%</td>
<td>Ref</td>
<td>92</td>
</tr>
<tr>
<td>16</td>
<td>% Load on Head</td>
<td>%</td>
<td>Ref</td>
<td>103</td>
</tr>
<tr>
<td>17</td>
<td>Specific Energy Consumption</td>
<td>kWh/T</td>
<td>0.75</td>
<td>0.85</td>
</tr>
</tbody>
</table>

### Design Pump Efficiency
- Motor Efficiency: 91.0%
- Motor Rating (kW): 420.0

### Specific Energy Consumption
- 0.85 kWh/T

### Table 7.4 Energy Saving Opportunities for CEP

<table>
<thead>
<tr>
<th>S No</th>
<th>Item Ref</th>
<th>Units</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CEP Power consumption</td>
<td>MW</td>
<td>0.493</td>
</tr>
<tr>
<td>2</td>
<td>Unit generation</td>
<td>MW</td>
<td>207</td>
</tr>
<tr>
<td>3</td>
<td>Load as % of unit generation</td>
<td>%</td>
<td>0.238</td>
</tr>
<tr>
<td>4</td>
<td>Specific Energy Consumption</td>
<td>KWH/MT</td>
<td>0.85</td>
</tr>
</tbody>
</table>

#### Energy Saving Opportunities

- The Specific Power Consumption (SEC) by individual CEP's is about 0.85 against design rating 0.74 kWh/T. The as-run SEC of CEP is higher by 13%. This is very likely due to deterioration in pump internal condition (impeller & casing, pitting & wear out).
- The de-aerator level Control Valve pressure drop, of about 7-8 kg/cm², is a key result area, for power savings in CEP's.
- Based on as-run trial observations, it is seen that the discharge pressure of CEP's is normally around 18-19 kg/cm² to gland steam condenser (GSC). The pressure after drain cooler is only 11.0 kg/cm². The pressure drip profile in CEP water circuit is as under, which shows that a drastic pressure drop across the de-aerator level control valve alone. It is informed that, the higher CEP discharge pressure is required during emergency requirement as well as to maintain the Deaerator level a de-aerator control valve is provided (between GSC & drawn cooler with re-circulation line feeding water back to hot well) and pressure drop across Valve is 7-8 kg/cm².
Table 7.5 CEP Pressure Details

- The estimated power loss across the control valve is about 110 kW/CEP. To avoid this pressure drop and realize power savings, it is recommended to install a hydraulic turbine, which acts as a control valve also, and recovers power.
- The annual power savings through this measure amounts to around 77 kW (assuming 70% hydraulic turbine efficiency) i.e. about 0.6 MU worth Rs 16.5 Lakh. The techno economics of hydraulic turbines for CEP's is presented below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge Pressure of CEP's (avg) Kg/cm²</td>
<td>19.5</td>
</tr>
<tr>
<td>Pressure after GSC Kg/cm²</td>
<td>12</td>
</tr>
<tr>
<td>Avg. Pressure drop across control valve Kg/cm²</td>
<td>7 to 8</td>
</tr>
<tr>
<td>Power Loss due to Pr. reduction kW/CEP</td>
<td>110.6</td>
</tr>
<tr>
<td>((580 TPH x 7 kg/cm² x 10 x 9.81)/(3.6x1000))</td>
<td></td>
</tr>
<tr>
<td>Possible Power Generation ( @ 70 % Tur. eff) kW/CEP</td>
<td>77.4</td>
</tr>
<tr>
<td>Annual Energy Savings (77 x 24 hrs x 365 days x 0.9 availability factor) mu</td>
<td>0.6</td>
</tr>
<tr>
<td>Annual Cost Savings (0.6 mu x 2.72 Rs./kWh) Rs. Lakh</td>
<td>16.5</td>
</tr>
<tr>
<td>Investment Rs. Lakh</td>
<td>20</td>
</tr>
<tr>
<td>Simple Payback period Years</td>
<td>1.21</td>
</tr>
</tbody>
</table>

Table 7.6 CEP Analysis

- An alternative to hydraulic turbine is to install a control valve for de-aerator level control with internal characteristics, which are more advantageous in terms of pressure drop than the existing one. Instead of the existing 10-kg/cm² drop through the control valve a 5-kg/cm² pressure drop characteristics valve may be identified and installed.
- The cost benefits of this alternate scheme with low pressure drop in De-aerator level control valve is presented below.

No. of CEP's normally in operation : 1
Flow through CEP (Average) (Range 520 - 580 TPH) : 550 TPH
Combined CEP pump motor efficiency : 65%
Existing pressure drop through existing control valve : 10 kg/cm²
Pressure drop with new efficient control valve : 5 kg/cm²
Reduction in pressure drop across control valve : 5 kg/cm²

Equivalent reduction in CEP power consumption [((550 x 1000/3600 x 50 x 9.81)/(1000 x 0.65))] : 115 kW
Annual energy conversion potential : 0.796 MU/year
(115 x 8760 x 0.79 average factor)
Annual energy cost savings potential : Rs.21.65 Lakhs/yr
(0.796 x 10 x 2.72)
Justifiable investment for 1 year simple payback period : Rs.21.65 Lakhs
ii) Case Study-II: Energy Saving Opportunities for the case of ID Fans

Induced draft fans, which perform the vital task of evacuating the boiler flue gases, constitute a key HT auxiliary, both from functional point of view as well in terms of energy intensity. The technical features of ID fans are as under.

<table>
<thead>
<tr>
<th>Design Rating</th>
<th>MCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>NDZV 31 S1DOR</td>
</tr>
<tr>
<td>No. of fans/unit</td>
<td>3</td>
</tr>
<tr>
<td>No. of operating fans</td>
<td>2</td>
</tr>
<tr>
<td>Capacity</td>
<td>230 M³/Sec</td>
</tr>
<tr>
<td>Density</td>
<td>0.81 kg/m³</td>
</tr>
<tr>
<td>Total head developed</td>
<td>370 mmWe</td>
</tr>
<tr>
<td>Efficiency of fan</td>
<td>77.7 %</td>
</tr>
<tr>
<td>Regulation</td>
<td>Variable Speed With hydraulic coupling</td>
</tr>
<tr>
<td>Fan speed</td>
<td>695 rpm</td>
</tr>
<tr>
<td>Speed</td>
<td>750 rpm</td>
</tr>
<tr>
<td>Motor rating</td>
<td>1300 kW</td>
</tr>
</tbody>
</table>

The as-run trial observations, on ID fans, are presented in table 7.7

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Item Reference</th>
<th>Units</th>
<th>Rated</th>
<th>MCR</th>
<th>As Run Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ID #4A</td>
<td>ID #4C</td>
</tr>
<tr>
<td>1</td>
<td>Unit Load</td>
<td>MW</td>
<td>210</td>
<td>210</td>
<td>205</td>
</tr>
<tr>
<td>2</td>
<td>Frequency</td>
<td>Hz</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>Inlet pressure</td>
<td>mmWc</td>
<td>-</td>
<td>---</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>Discharge pressure</td>
<td>mmWc</td>
<td>-</td>
<td>---</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>Diff. Head</td>
<td>mmWc</td>
<td>370</td>
<td>285</td>
<td>291</td>
</tr>
<tr>
<td>6</td>
<td>Flue gas temp. at ID fan inlet</td>
<td>°C</td>
<td>156</td>
<td>133</td>
<td>156</td>
</tr>
<tr>
<td>7</td>
<td>Flue gas density at prevailing temperature</td>
<td>Kg/m³</td>
<td>0.81</td>
<td>084</td>
<td>0.80</td>
</tr>
<tr>
<td>8</td>
<td>Flue gas flow at ID inlet (Calculated)</td>
<td>TPH</td>
<td>670.7</td>
<td>511.4</td>
<td>547.1</td>
</tr>
<tr>
<td>9</td>
<td>Flue gas flow at ID inlet (Measured with pitot tube)</td>
<td>TPH</td>
<td>---</td>
<td>---</td>
<td>568</td>
</tr>
<tr>
<td>10</td>
<td>ID fan motor input power (Measured)</td>
<td>KW</td>
<td>1144</td>
<td>612</td>
<td>1135</td>
</tr>
</tbody>
</table>

Table 7.7 ID Fan Details

In order to assess the ID Fan efficiency as well as air ingress in the flue gas path, (up to ID fan) flue gas flow measurement was under taken using pitot to be digital manometer at APH outlet and ID fan outlet.

Flue gas flow was measured, for both ID fans, while, in operation, using, pitot tube and a Digital Manometer as shown in table 7.8. Apart from flow measurement, a scan of oxygen (percent) content, in flue gas, across APH and ID fans, was under- taken, to establish the extent of air leakages.
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Item Reference</th>
<th>Units</th>
<th>Rated MCR</th>
<th>Fan Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Air kW</td>
<td>kW</td>
<td>834.83</td>
<td>472.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>566.23</td>
<td>466.42</td>
</tr>
<tr>
<td>2</td>
<td>ID fan Motor Input kW (w.r.t. fan duty points)</td>
<td>kW</td>
<td>1144.1</td>
<td>612.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1135</td>
<td>1134</td>
</tr>
<tr>
<td>3</td>
<td>Combined fan, motor efficiency</td>
<td>%</td>
<td>72.97</td>
<td>77.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>49.89</td>
<td>41.13</td>
</tr>
<tr>
<td>4</td>
<td>Fan efficiency from curve</td>
<td>%</td>
<td>77.7</td>
<td>82.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>74.8</td>
<td>71.0</td>
</tr>
<tr>
<td>5</td>
<td>Fan efficiency calculated from combined motor efficiency and motor efficiency</td>
<td>%</td>
<td>77.3</td>
<td>81.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>52.9</td>
<td>43.6</td>
</tr>
<tr>
<td>6</td>
<td>ID fan loading on flow</td>
<td>%</td>
<td>Ref.</td>
<td>76.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>84.6</td>
<td>82.5</td>
</tr>
<tr>
<td>7</td>
<td>ID fan loading on head</td>
<td>%</td>
<td>Ref.</td>
<td>77.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>78.6</td>
<td>66.1</td>
</tr>
<tr>
<td>8</td>
<td>ID fan motor loading w.r.t. rated kW of motor</td>
<td>%</td>
<td>88</td>
<td>47.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>87.3</td>
<td>87.2</td>
</tr>
<tr>
<td>9</td>
<td>Specific energy consumption in ID fans</td>
<td>KWh/ton</td>
<td>1.71</td>
<td>1.197</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
<td>2.05</td>
</tr>
<tr>
<td>10</td>
<td>Share of ID fan kW in unit Gen.</td>
<td>%</td>
<td>---</td>
<td>0.583</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.11</td>
<td></td>
</tr>
</tbody>
</table>

**Table 7.8 ID Fan Flow Estimation (With Pitot Tube)**

As observed, there is an air in-leakage of stray air through ducting between APH outlet & ID Fan Inlet. The as-run efficiency & energy performance indicators are presented in Table no.7.9

**Table 7.9 As-Run Efficiency**

- As seen from the performance features both the ID fans have margins in capacity (at 205 MW unit load) ID 4A has a 15% margin & ID 4C about 17% margin with respect to head margins ID 4A has 22 margins & ID 4C has 35% margin. Both the ID fan motors of ID 4A & ID 4C have 13% margins on power capability.
- The combined efficiency of the ID fans are lower than rated combined efficiency as well as design combined efficiency from curves in as-run-condition vary from 74 to 71% & fan efficiency calculated from combined efficiency i.e., actual condition shows a margin of 21-27% efficiency reduction. This is mainly due to the low hydraulic coupling efficiency.
- The SEC of both ID fans is higher than rated by about 18% but w.r.t. design SEC they are higher by 67%. Here the increase is SEC in as-run condition is due to air ingress between APH in & ID fan in as well as low hydraulic coupling efficiency.

**Energy Saving Opportunities**

Abatement Air in leaks: In leak of air between APH inlet & ID fan inlet is felt to be an area of concern, affecting the overall unit performance. The qualification of in leak air and impact on power consumption and loading of ID fans is presented in table 7.10.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Item Reference</th>
<th>Units</th>
<th>As Run Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>IDF 4A</td>
</tr>
<tr>
<td>1</td>
<td>FD fan air flow (calculated from coal flow, stochiometric air &amp; % O₂ at APH)</td>
<td>TPH</td>
<td>395.6</td>
</tr>
<tr>
<td>2</td>
<td>Coal flow (For unit 4)</td>
<td>TPH</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
<td>% Ash in coal (avg of last 16 months)</td>
<td>%</td>
<td>35.8</td>
</tr>
<tr>
<td>4</td>
<td>Fly ash qty @ 80 % of total ash</td>
<td>TPH</td>
<td>17.89</td>
</tr>
<tr>
<td>Sr. No</td>
<td>Item reference</td>
<td>Units</td>
<td>Average of 4A &amp; 4C</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------------</td>
<td>-------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>1</td>
<td>Existing excess air level at APH I/L</td>
<td>%</td>
<td>117.98 (3.2 % O₂)</td>
</tr>
<tr>
<td>2</td>
<td>Proposed excess air level target at APH I/L</td>
<td>%</td>
<td>117.98 (3.2 % O₂)</td>
</tr>
<tr>
<td>3</td>
<td>Existing excess air level at ID fan I/L</td>
<td>%</td>
<td>145.86 (6.6 % O₂)</td>
</tr>
<tr>
<td>4</td>
<td>Proposed excess air level target at ID fans I/L</td>
<td>%</td>
<td>132.91 (5.2 % O₂ i.e. 3.2% + 2% O₂)</td>
</tr>
<tr>
<td>5</td>
<td>Present ID fan duty (Average of 4A &amp; 4C) *</td>
<td>TPH</td>
<td>560.5 X 2 FANS i.e., (568 + 553)/2</td>
</tr>
<tr>
<td>6</td>
<td>ID fan duty with 5.2 O₂% at ID inlet</td>
<td>TPH</td>
<td>491.8 X 2 FANS</td>
</tr>
<tr>
<td>7</td>
<td>Potential reduction in ID fan duty w.r.t. capacity</td>
<td>TPH</td>
<td>68.7 X 2 FANS = 137.4</td>
</tr>
<tr>
<td>8</td>
<td>ID Fan power saving potential on pro-rata basis ( @)</td>
<td>KW</td>
<td>277.5</td>
</tr>
<tr>
<td>9</td>
<td>Annual savings potential at 79% availability factor</td>
<td>MU/yr.</td>
<td>1.92</td>
</tr>
<tr>
<td>10</td>
<td>Annual cost savings potential ( @ Rs.2.72/unit)</td>
<td>Rs.Lakh</td>
<td>52.291</td>
</tr>
<tr>
<td>11</td>
<td>Investment towards APH seals &amp;bellow scaffolding</td>
<td>Rs.Lakh</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Table 7.11 O₂ % and Power Savings Scope

Although the overall air ingress amounts to 114 TPH & 99 TPH (in ID 4A & ID 4C respectively) not all of this in-leak is preventable. In fact an in-lead across APH to the tune of 62 TPH is allowed by design itself. Any in-lead air cross APH above 62 TPH needs to be arrested. Also, in-lead air after APH should be reduced.
*ID fan duty = (excess air qty. at ID I/L/excess air qty. at PH I/L) x (total FD flow + (1-(% ash in coal/ 100)) x total coal flow) + (1-ESP eff./100) x total fly ash.

**Incorporation of Variable Speed Drives**

Comparison of ID fan efficiency w.r.t design, indicates a drop in ID fan efficiency by an average 24.65%, mainly on account of flow control through hydraulic coupling speed control device. The ID fan efficiency can be improved by using the state-of-the-art V/F variable speed drives, which not only has a higher efficiency w.r.t. hydraulic coupling but also gives greater flexibility for flow control, during part load operations, which results in substantial energy savings. The potential savings in energy consumption of both ID fans (combined) in a Unit # 5, by incorporating V/f VSD's and the associated cost-benefit are estimated as shown in Table no. 7.12

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Item Reference</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Present power consumption of ID fans</td>
<td>2269 kW</td>
</tr>
<tr>
<td>2</td>
<td>Efficiency of hydraulic variable speed (design) coupling</td>
<td>75 %</td>
</tr>
<tr>
<td>3</td>
<td>Efficiency of V/F Variable Speed drive</td>
<td>95 %</td>
</tr>
<tr>
<td>4</td>
<td>Efficiency improvement margin available</td>
<td>20 %</td>
</tr>
<tr>
<td>5</td>
<td>ID fan power consumption reduction with V/F VSD</td>
<td>453.8 kW</td>
</tr>
<tr>
<td>6</td>
<td>Annual energy savings at 79% availability factor</td>
<td>3.14 MU</td>
</tr>
<tr>
<td>7</td>
<td>Annual Monetary savings ( @ 2.72 Rs./kWh)</td>
<td>Rs.85.42 Lakhs</td>
</tr>
<tr>
<td>8</td>
<td>Investment for V/F drives ( 2 No's)</td>
<td>Rs.442.0 Lakhs</td>
</tr>
<tr>
<td>9</td>
<td>Annual total energy cost savings in ID fan system (85.42 + 52.29)</td>
<td>Rs.137.71 Lakhs</td>
</tr>
<tr>
<td>10</td>
<td>Total investment towards in-leak air ingress abatement and V/F, VSD</td>
<td>Rs.452.0 Lakhs</td>
</tr>
<tr>
<td>11</td>
<td>Simple payback period on overall investment</td>
<td>3.28 Years</td>
</tr>
</tbody>
</table>

Table 7.12 : Potential Energy Savings

**iii) Case Study-III: Energy Saving Opportunities for the case of Compressors**

- Compressor's Specifications: Make and Model of Air Compressors: K.G Khosla Model 2HA2QT
- Type of Air Compressors: Reciprocating - 2-Stage - Double Acting
- Total no. of Air Compressors Installed: 5
- Total no. of Air Compressors earmarked Instrument Air Compressors (IAC): 3
- Total no. of Air Compressors earmarked as Service Air Compressors (SAC): 2
- Total no. of IAC's normally in operation: 2
- Total no. of SAC's normally in operation: 1
- Rated Capacity of each compressor (All 5 compressor are of identical FAD's): 15.27 M³/min (at 15°C)
- Rated Discharge pressure: 8.1 Kg/cm² (g)
- No. of Air Receivers & Capacity: Total - 5 (One for each compressor), 4m³ capacity
- No. of Inter Coolers and Type: One each, Shell & Tube, Air in shell-water in tubes
- Heat transfer area of Intercoolers: 60 Tubes x 10 mm OD x 0.8 mm Thick
- No. of After Coolers and Type: One each, Shell & Tube, Air in shell-water in tubes
- Availability of water drain traps I/C's & A/C's: Nil - Only drain-cock provided
- Air receiver drain: 1” Float Traps-one per receiver- by-pass provided
- Drive Motor details: 93 Kw, 415V, 1485 rpm, 164 FLA, 0.85 Pf, 3-Phase
Energy Saving Opportunities

- Both IAC and SAC compressors run continuously without unloading, indicating higher demand than generation.
- All the IAC compressors are presently operating at capacities less than rated i.e between 10 to 11.5 NM³/min as against rated 14.5 NM³/min.
- The PAC compressors are better off in terms of actual capacities at 12.7 NM³/min respectively.
- The main reasons for drop in compressor capacities are on account of
  - Internal piston-cylinder out
  - Short circuit between discharge and suction valves
  - Bleed off at intercooler and after cooler water drains
- However the key equipment i.e intercooler's of all IAC's and SAC's excepting SAC 4A are performing well indicated by inlet air temperatures at HP cylinder's being very close to ambient conditions.
- A major finding has been the avoidable use of compressed air for drier silica gel re-generation.
- The end user's of compressed air comprise of control devices, air cylinders both small and power type, actuators, which are met by IAC's and cleaning applications which are met by SAC's
- Instruments and control devices require upto maximum of 4 bar pressure, small cylinders (to operate dampers and small gate valves etc.) require upto 4 bar and large power cylinder's upto 6 bar.
- Plant air end users generally don't require pressure above 2 bar.
- Reduction in IAC discharge pressure from existing 7 bar to 5.5 bar
  - Provision of small self lubricated automatic compressor for applications requiring 6 bar pressure at local site. (CAD damper floor, HAD damper floor)
- Reduction in compressed air leak off loss through intercoolers, after coolers and receivers by incorporation of trident electronic traps
- Capacity improvement of IAC 4A, 4B, 4C and SAC 4A by reduction in short circuiting in HP/LP cylinders, and overhauling of cylinder and piston.
- Reduction in compressed air usage through
  - Reinstating fan for air drier regeneration
  - Converting existing drier system to heat less driers
- Reduction in compressed air power consumption by extending suction to shaded out door location and frequent cleaning of suction filters (DP gauge to be installed)
- Reduction in use of IAC's air by replacing power cylinders with servo electric motors.
- General
  - Belt tensioning
  - Inter cooler tube de-scaling
  - After cooler tube de-scaling

<table>
<thead>
<tr>
<th></th>
<th>Annual Energy Savings (MU/Year)</th>
<th>Annual Monetary Savings (Rs. Lakhs/year)</th>
<th>Investment (Rs. Lakhs)</th>
<th>SPB (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAC Pressure Reduction</td>
<td>0.118</td>
<td>2.95</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CA Bleed off loss reduction through i/c, a/c and Revr</td>
<td>0.442</td>
<td>1.1</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>IAC capacity improvement by overhauling (From 10.75 to 14 NM³/min)</td>
<td>0.348</td>
<td>8.7</td>
<td>1.0</td>
<td>0.11</td>
</tr>
<tr>
<td>Avoidance of compressed air use in drier through incorporation of heat less drier</td>
<td>0.16</td>
<td>4.0</td>
<td>7.5</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Table 7.13 Annual Savings

The total annual energy cost saving potential in case of ID Fans is expected to be highest being Rs. 137.0 lakhs per year with total investment of Rs. 450 lakhs thus having payback period of 3.3 years. In case of the condensate extraction pumps, total saving expected is Rs 21.65 lakhs with justifiable investment of Rs. 21.65 lakhs, thus having payback period of 1 year.
In case of the compressors, the expected saving is Rs 12.75 lakhs per year against the investment of Rs 9.25 Lakhs thereby having payback period of less than one year. Thus there exists a great potential for energy conservation in Thermal Power Station, Gandhinagar. Other thermal power plants can also be analyzed in a similar manner. Thus TEM is of utmost importance in such units TEM and TQM appear to be complimentary to each other. TQM implementation is already discussed earlier in this chapter.

7.6.0 Conclusions

Detailed study on thermal engineering aspects in power plant and implementation of TQM + TEM in power plant reveal the following:

- Barrier to Efficiency Improvement in Power Sector
- Need of improving Efficiency
- Good Practices for Maintenance and Energy Conservations

Hence appropriate detailing for all the above aspects has been done.

Six Sigma methodologies have recently gained wide popularity because they have proven to be successful not only at improving quality but also at producing large cost savings Antony, J. & Banuelas1 In process industries like thermal plants, no such convenience is available. Steam/ water, the main working fluid in these industries may not be visible and its quality is measured by various instruments mounted on the process hardware in the form of pressure, temperature and flow measurement. Normally, in manufacturing industries, production is already operating at 1–2 sigma level and by applying Six Sigma methodology it can be raised to 5–6 sigma level, whereas in the process industries there are many sub-processes that operate even at negative sigma levels because they are secondary in nature. Therefore, in the process industries, a significant increase in the sigma value through the application of Six Sigma tools cannot be expected and it is found that the improvement potential is a maximum of up to 2–3 sigma level, but as the process industries are huge investment industries, e.g. thermal power plants, fertiliser units, chemical plants. The cost benefits of applying Six Sigma can be significant to these industries. Optimisation of cycle make-up water (DM water) consumption is one such process. Any saving in DM water consumption pattern is a substantial cost saving for the industry and a service to society. It is calculated that each 0.1% increase in cycle make-up increases the generation cost by Rs. 80.46 Lakhs per annum, which includes the cost of heat loss, extra water and consumption of chemicals. Keeping this in mind, optimisation of cycle make-up DM water was chosen as an initiation project of applying Six Sigma techniques to the thermal power plant industry.

The summary of important outcome of this case study is as under:

- The application of Six Sigma project recommendations increased the mean DM water to 0.573% (with a total improvement of 0.336% mean), which is equivalent to a monetary saving of Rs. 270.34 Lakhs per annum.
- The estimated saving from the project after the implementation of all the recommendations is expected to be Rs. 321.84 Lakhs per annum, with mean DM water expected to reduce below 0.5%, which is substantial for any organization.

The study also elaborates on the energy conservation steps to be taken in a thermal power plant. Case study undertaken on few equipments demonstrate substantial saving possibilities in thermal power plants as could be seen from following facts and figures:

- The total annual energy cost saving potential in case of ID Fans is expected to be highest being Rs. 137.0 lakhs per year with total investment of Rs. 450 lakhs thus having payback period of 3.3 years
- In case of the condensate extraction pumps, total saving expected is Rs 21.65 lakhs with justifiable investment of Rs. 21.65 lakhs, thus having payback period of 1 year.
- In case of the compressors, the expected saving is Rs 16.75 lakhs per year against the investment of Rs 9.25 Lakhs thereby having payback period of less than one year.