Flow Synthesis of a 600 MW Thermal Power Unit

Sharavan Tripathi

Abstract--- *The processes of electricity production from coal at 4x600MW, Jindal Super Thermal Power Plant in Tamnar, were analyzed in accordance to flow of fuel, water, air and flue gases. The objectives of the analysis were to synthesize the overall area of the power plant pinpoint the locations and quantities of exergy losses, wastes and suggest ways to address these losses and wastes. In the analysis, the power plant was simplified into sub-systems, each with distinct exergy inflows and outflows and approximated into steady-state flow. The theory and Flow diagram were written and drawn on the basis of 600MW JPL thermal plant.*

I. Introduction

IN order to achieve the design prescribed values of performance parameters. Input and operating condition are required to be maintained well within design prescribed ranges of all the operating parameters. The factual variation in input parameters beyond design prescribed operating condition, normally lead to an adverse effect on performance parameters. In spite of best possible technology management, variation in input parameters adversely affects the performance parameters, which can be minimized by suitably modifying the operating parameter. Research work is focused on evolving a flexible operation and efficiency management system to suitably modify the operating parameters in accordance with the verifications in input parameters to minimize its adverse effect on performance parameters. Effective human resource management is prerequisite of operation and efficiency management system which begins with measurable material and process parameters. Measurable input parameters are given top priority and divided into three groups as under.

- Controllable input parameters.
- Semi-controllable input parameters.
- Un-controllable input parameters.

Techno economic feasible efforts can be adopted to reduce the variation of controllable input parameters. Optimally changed value of the controllable parameters leads to lesser modification of operating parameters and lesser loss of performance. Some of the input parameters can be changed up to a particular limit. Decisions of the management to decide the quantum of efforts optimally nears such limit and accordingly operating parameters are suitably modify to accommodate the remaining variation. Uncontrollable input parameters are accepted as such and solution lies only in the modification of operating parameters to optimally minimize the loss of life and efficiency of associated system or equipment. Supermodel of operation and efficiency management system is subdivided into many dependently independent models. Integrated supermodel is visualized as profit making business black box, which is supplied with cost material and capital investment and produce revenue electricity desirably at higher price than that of the input cost supplied. The major difference between thermodynamics and economics is conflicting; the former states that energy input shall always be larger than the output energy where as latter deals with lesser input and larger output. Present work is a blend of both and hence we are trying to deal with thermal power plant performance from the point view of energy, exergy and economy. Supermodel of a coal based thermal power station is presented as business black box in Fig. 1.

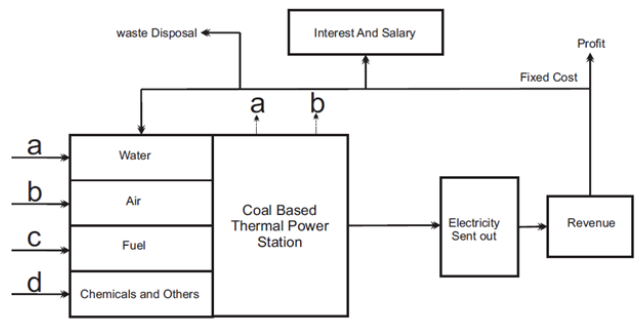

Fig. 1: Supermodel of a Coal Based Thermal Power Station

The profit making business black box concerns only with input cost and revenue realized. The input cost is broadly divided into two groups as fixed and variable cost. The cost incurred on salaries of thermal power plant personnel and on interest paid for initial capital investment is vital and play quite significant role in influencing the thermal power plant performance control parameters. The effective technology management system for properly regulating the activities of engineering, procurement and construction, commissioning, performance guarantee test and acceptance test specify the standards of connected activities. Commission management groups can do much more than acceptable standard of quality parameters particularly by evolving the procedure for poor but acceptable results on account of wide variation in input parameters. Costs need not be minimized at cost of quality but optimized by keeping operation and efficiency standards in consideration. International standards of human safety and equipment life parameters are also required to take care, during these activities. Component of fixed cost on salaries also need not be minimized but optimized and human resource management system always has the challenging task to get extra ordinary output from every seemingly ordinary person. Operation and efficiency management participate in optimizing the input cost on salary component but has no control on interest on capital invested and this component of fixed cost has to be acceptance as an uncontrolled input parameter.

Sharavan Tripathi, Asst. Training Officer, JIPT. E-mail: shravantripathi19@gmail.com

Variable cost increases on account of input material and waste disposable such as air, water, fuel, chemicals and spares. Material management system can reduce the cost of material by optimally controlling the associated activities of selection, procurement, transport handling etc. quantitatively and qualitatively. Quality and quantity standards of material management shall be analyzed in terms of monitored variable parameters in separate models which forms the supermodel on integration of all individual models. The significant variable cost is incurred on waste disposal. Coal combustion produce large amount of ash, flying with gases. Proper technology management of ash disposal can lead to reduction of cost on this account at the one hand and also met the mandatory standards of NO_x, SO_x and suspended particulate matter in exhaust gas. Cost waste water and other waste disposal also required to be minimized.

II. AIR FLOW MODEL

Through the atmospheric air is available at free of cost but generally has no engineering potential until it is made available at desired standards of quality and quantity by using the air handling equipment. Atmospheric air temperature, pressure, humidity or relative humidity and purity are important for the air handling equipment. On the basis of use and handling air in thermal power station is categorized as under.

- Compressed air system
- Air conditioning and ventilation system
- Combustion air system

- *Compressed Air System*

Relative humidity and purity of the input atmosphere air influence the selection layout operation maintenance etc of compressed air system. Service air compressors are meant for supplying, general service air for many purposes right from cleaning to atomizing the light diesel oil.

Instrument air compressors have self lubricated graphite piston rings to ensure supply of air, free of oil contamination. The air is further dehumidified to cater to the requirement of instruments which play vital role in operation and efficiency management system. Flow model of compressed air system is shown is Fig. 2.

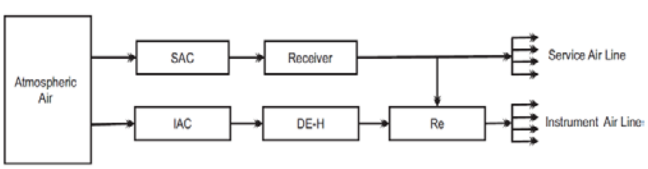

Fig. 2: Compressed Air (Service and Instrument) Flow Model

- *Air Conditioning and Ventilation System*

This system is meant for maintaining conducive environment for human being and control systems. Input air quality play vital role in deciding the cost of operation the air conditioning and ventilation system cost on refrigeration and heating very with environmental conditions.

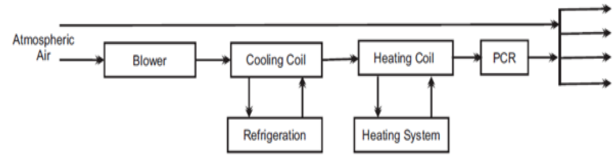

Fig. 3: Ventilation and Air Conditioning System

- *Combustion Air System*

The combustion air is supplied in two to three stages to maintain the desired standards of performance equipment life and environment. The first stage is known as primary air, supplied through the primary fan. Purpose of primary air is to dry the coal in the pulverizer and then transport it from pulverizer to the furnace. To fulfill these two requirement primary air pressure must be adequate and its temp should be high enough to dry the moisture content of the coal. The air temperature has to be controlled to avoid any possibility of coal firing in the pulverizer itself.

Wide variation in moisture can be accommodated by a similar variation in primary air temperature, which is not possible by any kind of air pre heating system. To solve this problem a portion of primary is not supplied through the air pre heater and stored in cold primer air duct, which helps in regulating the primary air temperature in accurate with variation in moisture content of the coal. Quantity of air from both hot and cold primary air duet is mixed before pulverize to maintain the design prescribed value of coal air mixture at the pulverizer discharge valves. Pressure in the hot primary air duet, differential pressure across the pulverizer coal-air mixture temperature and pulverized coal fineness are the operating meters which play vital role in maintaining the boiler performance in the design prescribed ranges.

The secondary air is supplied to ensure proper flow of products of combustion (i.e. flue gas) and to ensure complete combustion. Deferential pressure across the furnace is flow potential for flue gas flow, which is maintained by distinct portion of secondary, known as auxiliary air. The other portion of the secondary air supplied in the nearest surrounding of the coal air mixture, which is known as the fuel air. Tertiary air is supplied in some boilers to suppress the heat flux and potential for the purpose of reducing the formation of SOx and NO_x in the specific zone of high temperature under ideal oxidizing conditions. Both secondary and tertiary airs are supplied by forced draught fan through air pre heater.

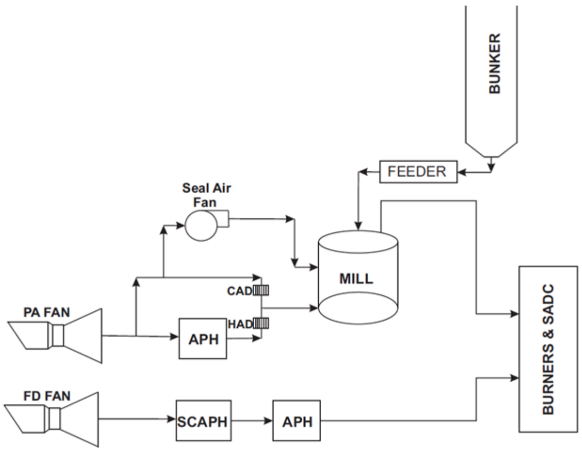

Fig. 4: Combustion Air Flow Systems

As shown in Fig. 4, primary air with coal and secondary and tertiary air are entering to system shown as secondary air damper control and burners. Secondary air damper control system and fuel supplying burners are provided with input controlling mechanism for controlling the boiler inputs. Quality, quantity and distribution of the combustion air control the boiler output parameters and hence treated to be very important point of the boiler operation and performance management system.

Theoretically determined combustion air cannot ensure complete combustion over the prescribed limitation/condition of time, temperature and turbulence even when pure combustibles are provided with, because of the combustion resistance offered by products of combustion. In actual situation the combustion resistance due to impurities in the coal (ash and moisture), Nitrogen in the air and products of combustion is much higher. On the basis of limitations of time temperature and turbulence, an additional amount of air, over and above the stoichiometric air has to be essentially supplied in order to ensure complete combustion of the coal. This additional amount is known as excess air.

Total of stoichiometric and excess air has to be equal to the total quantity of air supplied to the furnace in three stages as primary, secondary and tertiary. Combustion air management system has to maintain the safety and performance standard of boiler by incorporating the desired changes in operating combustion air parameters on the basis of variation in coal input parameters and environmental conditions.

III. WATER FLOW MODEL

Fig. 5 shows the block diagram of an integrated water flow model, which can be divided into the following.

- *General Purpose Water Flow Model*

In addition to water being the working substances for the energy conversion and heat rejection sink, it is also used for the following purposes in the thermal power plant;

- Hydrant and spray water flow model
- Ash handling water flow model
- Drinking water flow model
- ACW/CW water flow model
- *DM water flow model*

Though the above referred five models cannot be separated from each other but they can be analyzed separately on the basis of distinguishable functions. Input water to the first five systems is supplied by 10-20 control structure pumps in different power stations. Few of the pumps are required to supply water to the water treatment plant and having lowest discharge pressure. General Service water used from normal cleaning to the ash transportation has to be at the adequate pressure of the order of 4.0 Kg/cm^2 where as specific services such as fire fighting, clinker removal, ash removal jet formation etc require much higher pressure of the order of 8.0 Kg/cm^2. All these pressures are maintained by different control structure pumps. Water supplied to the water treatment plant is treated to the requirement of man material and machine at different qualities. Drinking water has to be treated to the requirement of power personnel of the plant.

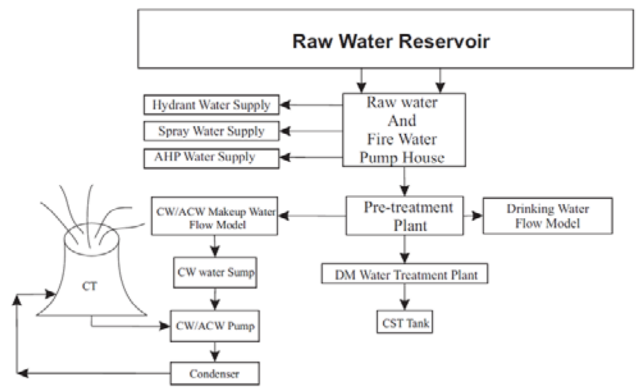

Fig. 5: Integrated Water Flow Model

Many rotating machine in the power plant have grease/force oil lubrication and cooling system, which in turn is cooled by bearing cooling water. In grease/self lubricated machines, water is essentially required for jacket cooling where as it is needed for oil cooling in the oil sump. This bearing cooling water system play vital role in up keeping the rotating machines. In some power station this water is required to be treated through clariflocuators and known as clarified water where as in others filtered raw water is used. De mineralized water is used in close working loop, which alternatively converts into steam and condensate water in boiler and condenser respectively. Condenser is a lowest heat sink from where water is pumped to boiler for converting into high pressure steam. High energy flow potential is utilized by the steam turbine and latent heat at a very low pressure is rejected to the condenser, leakage of steam from close working loop is compensated by supplying de mineralized make up water.

As the latent heat of steam has to be rejected in the condenser, the huge quantity of cooling water is needed to take away the latent heat. While good quality water is available in abundance, it is taken from the upstream of the river and supplied back to the downstream at 5^o to 10^o C higher temperature than that of original. In case of water shortage, circulating type of cooling water system is adopted for which cooling tower pumps; cooling towers and culvert (pond) etc are needed. A wet cooling tower consumes 2% to

4% water in evaporation. Some water is also consumed in first five flow system. This total consumption is compensated by the makeup water received from nearby river/canal.

- *Condenser Cooling Water Flow Model*

In order to condense the steam, it is either allowed to mix in same quantity water (as that of the steam itself) or exposed to the colder surface from which heat can be conducted to opposite surface exposed to the cooling water and are known as direct contract (jet type) condenser and indirect contact (surface type) condenser. Jet type of the condenser, even being highly efficient are normally not used due to the high requirement of cooling water of the same quality as that of steam which cannot be wasted in wet cooling tower. Jet condenser essentially needs very costly dry cooling tower at the one hand and can function only under the condition of very low ambient temperate at the other. In an indirect contact (surface type) condenser raw water is used for cooling the steam which may be thrown to the downstream of original source river/canal. In the event of inadequacy of cooling water quantity, the same is circulated again by cooling it through the wet cooling tower where 2 % to 4 % water is consumed in the process of evaporation. Two kind of cooling systems are distinctly known as once through cooling water system and circulating type of cooling water system. Cooling water quality for a circulating water system can be uniformly maintained where as in once through system quality of cooling water varies from one season to the other. In some of the once through cooling water system, cooling towers are erected and commissioned so that once through system can be converted into circulating type of cooling water system at any time when raw water quality of the source river/canal is high detrimental for the condenser tubes. Depth of condenser vacuum is decided by quantity and quality of the cooling water. Quantity of cooling water is controllable parameter and restricted by cross section area of the tubes and differentiated pressure across the water box. Cooling water temperature is uncontrollable parameter in a once through system and it is semi-controllable in case of circulating water. Cooling tower can reduce the temperature only up to the limits of wet bulb temperature. Cooling water inlet temperature cannot be achieved equal to its limiting value i.e. wet bulb temperature but tends to achieve in accordance with law of diminishing return. Cooling water management has to optimally decide the difference between the cooling water inlet temperature and wet bulb temperature so that it can be techno-economically sustainable.

- *De-Mineralized Water Flow Model*

Integrated de-mineralized water flow model is sub-divided into the following flow systems for the regulation of performance related parameters;

- De mineralized makeup water flow model.
- Condensate flow model.
- Feed water flow model.
- Boiler heat and mass flow model.
- Steam Expansion (Turbine flow) model.

- *De-Mineralized Make-Up Water Flow Model*

As the steam power is generated by close cycle where high parameter steam gives its energy to the turbine and converts into water again in condenser at lowest possible parameters for reuse. Mass of H_2O remains constant in the close loop either as water or as steam. Initial filling is essential and afterward water is supplied to compensate the leakage of steam/water out of the close circuit. Ideally water should be injected into the working loop at lowest heat sink i.e. condenser. After maintaining required water level in the condenser hot well, one should start the condensate extraction pump by putting hot well control valve on auto, so that the additional water supplied by de mineralized make up pump is automatically diverted to the deaerator. Thus, the DM make up system shall go on supplying water till required deaerator level is achieved. Last low pressure heater and deaerator are equipped with condensate preheating arrangement which initially heat up the water to avoid corrosion of the boiler tubes. When a minimum required value of water temperature in deaerator is achieved, one should start boiler feed pump and fill economizer, water walls and boiler drum to the minimum required level. This normal procedure of initial filling of water in condenser hot well, deaerator and boiler drum should not be bypassed until there is dire need for the same. Deaerator can be filled directly either by starting the emergency lift pump or boiler fill pump. In this procedure, the opportunity to heat water in last low pressure heater is bypassed which increase the startup time rather than seemingly reduction of the same by fast filling of deaerator. Falling economizer, evaporator and boiler drum by using the Boiler Fill Pump directly also suffer from not only initial heating in last low pressure heater & deaerator but also deprived the operators from chemical deaeration of feed water. In fact awareness has to be created for adopting the system's normal procedure and norms. The boiler fill pump is meant for filling all the components separately for any purpose (chemical, washing, pegging, etc.) other than the normal start up. The operation procedures are undisputedly appreciated, when no emergency equipment is used and hence using emergency lifts pump for filling the deaerator is not at all healthy sign of operation.

As regards, with the performance of Thermal Power Plant Performance, the consumption of makeup water is a one of the important performance parameter. Reduction of the makeup water consumption is concern of performance managers, the solution of which is not lying with makeup water flow equipments alone or on any other single equipment. Good water chemistry, intelligent and accurate boiler blow down management and better selection, erection, commissioning operation and maintenance of boiler, turbine and their auxiliaries can significantly reduce the flow of de mineralized make up water.

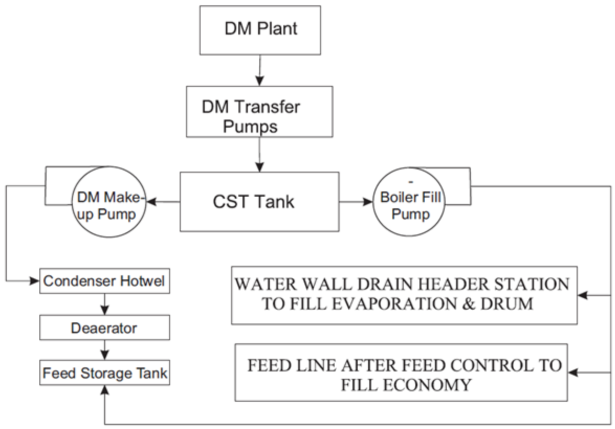

Fig. 6: De-Mineralized Make up Water Flow Model

- *Condensate Flow Model*

Fig. 7 shows the condensate flow system, which is consisted of condenser, condensate extraction pump, gland coolers, low pressure heaters and extraction lines. Steam is converted to water in condenser at saturation temperature corresponding to high vacuum, which is required to be extracted at a sufficient pressure to increase its sensible heat addition capacity. Thus condensate is heated by using waste heat available in steam utilized in main ejector for creating vacuum in the condenser. Steam from turbine glands is also utilized in heating the condensate at two distinct pressures separated by low pressure sealing steam. Low pressure gland leakage steam is utilized in gland cooler, provided with exhaust fan to remove dissolved air. Three low pressure heaters are meant for heating the condensate by utilizing the latent heat of extraction steam. Condensate produce from extraction steam is known as drip for all the feed water heaters. The condensate system is first stage of boiler water preheating which can be charged only when steam starts flowing through turbine. Condensate heating assist the deaerator, which has to fulfill the two major requirements of feed water namely of heating the water to the minimum requirement of boiler feed pump and also removing the oxygen from the feed water. Last low pressure heater is supplied with auxiliary steam so that the condensate can be heated before the deaerator even when the steam is not flowing through the turbine to improve the deaeration of the condensate.

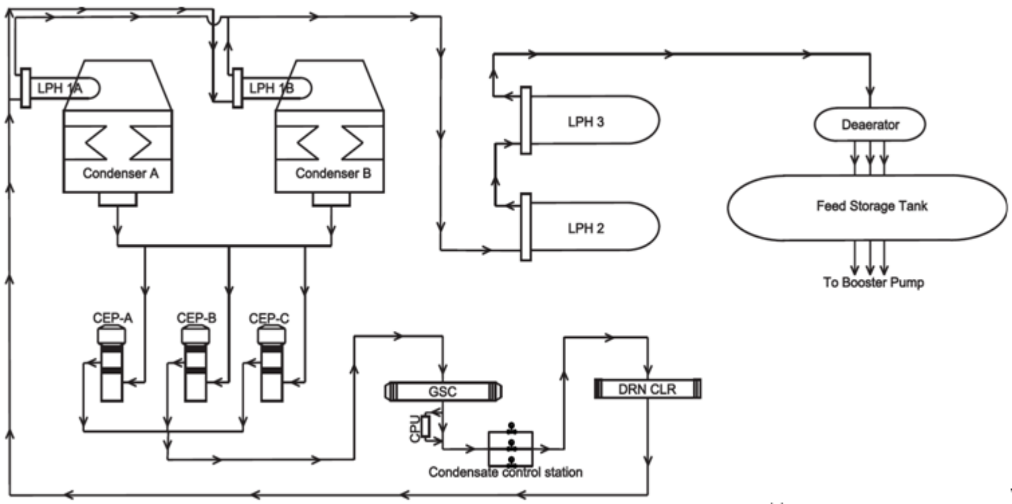

Fig. 7: Condensate Flow Model

- *Feed Water Flow Model*

Feed water system began with deaerator and ends at feed control station. Steam is supplied to deaerator for initial warming of the water and also for the deaeration. Initially, this steam is taken from auxiliary steam supply system, which is cascaded to extraction, meant for HPH 5 or 6 depending upon pressures in the extraction lines. Final output of both condensate and feed water system is feed water outlet temperature which appears in both the equations of cycle efficiency and boiler efficiency and hence treated to be very important efficiency control parameter. It has been observed that the availability for high pressure heaters in many thermal power stations has been very poor and lead to much lower feed water temperature. In addition to proper engineering, procurement, construction, commissioning, operation and maintenance of high pressure heaters, the stability of turbine parameters right from steam input to condense vacuum has to be taken care of for the purpose of maintaining the design specified value of the feed water temperature at economizer inlet.

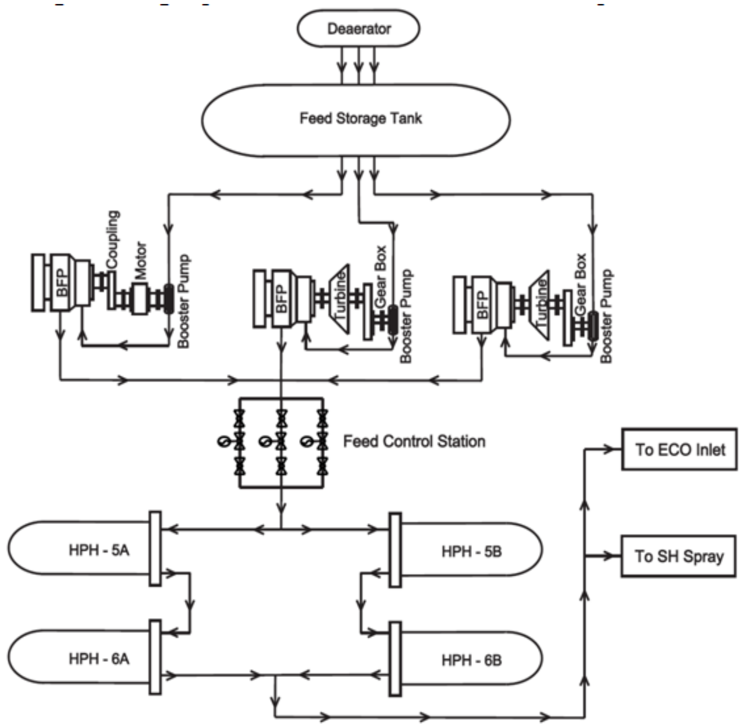

Fig. 8: Feed Water Flow Model

- *Boiler Heat and Mass (Water/Steam) Flow Model*

Feed water from regeneration feed heating system is supplied to the economizer. Its temperature and flow rate are very important and influence the boiler stability. Variation in actual feed water temperature at the outlet of last HP heater with the design prescribed value leads to many complicated changes in the process of steam formation and hence required to be accommodated by suitably modifying the operating and output parameters for the steam generators. Fig. 9 shows the flow of feed water from economizer inlet header to economizer coils and to the boiler drum.

Flow control is made from feed regulating station with help of three sets of isolating and control valves. Regulation of the feed control valve is done to maintain the normal water level in the boiler drum, and design prescribed differential pressure across the feed control station is maintained by the controlling device of the boiler feed pump. Design prescribed sensible heat requirement of water in the economizer, over the different values of temperatures, flow and pressure at inlet and outlet cannot be maintained in all operating situations. This essential variation is required to be followed by similar variation in changing heat flux available in the flue gas, which is indeed a difficult task. Actual heat given by flue gas to water in economizer cannot change in accordance with the heat demand because of variable quantity and quality of water and hence essentially lead to vary the parameters. Water temperature at the outlet of economizer is kept sufficiently lower than the saturation temperature. This gap between the saturation temperature and actual temperature, proportionately changes the heat loading of the boiler drum which not a heat exchanger and hence any such variation in heat load is passed over to the evaporator, meant for adding the latest heat and converting water into steam.

Requirement of latent heat decreases with the increasing pressure. Fluctuation of boiler working pressure leads to similar fluctuations of latent heat requirement. In addition to the pressure fluctuations, variable water temperature at the outlet of economizer also lead to the change in latent heat requirement passed to it via boiler drum. Variation in latent heat flux and potential of the flue gas, leads to similar kind of variation in circulation number.

Separated steam from boiler drum is supplied to the super heaters, where its temperature is increased to maximum value. Variation in superheat requirement and residual heat flux in flue gas leads to abnormal temperature, which results in to loss of efficiency and equipments life. Similar or more detrimental behavior of hot reheat temperature has also been observed. Temperature, pressure and purity of the super heated and reheated steam play vital role in the performance standard of the thermal power plant. In addition to the proper up keeping of the water/steam management, combustion management is also an equally important aspect of boiler efficiency control parameters which cannot be separated out from the steam generation boiler flow model.

After initial establishment of water flow in the entire circuit with required levels in condenser hot well, deaerator and boiler drum as described above, the additional make up is supplied against the loss of water from the circuit due to leakages through vents/drains/glands, taking auxiliary steam and using it for non-recoverable purposes, taking steam for soot blowing etc. Wastage of water is much more at time of startup due the open vents/drain, starting ejector, start up vent, etc. Safety valve popping off leads to sudden and huge loss of water from the circuit. In sub critical boilers steaming increase the silica concentration of evaporation circuit and decrease in the condenser. Hence, more removal of water from evaporator

ISBN 978-93-83459-12-4 © 2014 Bonfring

shall reduce the silica concentration in the entire circuit but it will increase if leakage of steam or condensate is more than the water removal from the evaporator. Leakage of steam/water from the various equipments of close thermal cycle, other than the evaporator, increases silica concentration in evaporator. To balance the silica concentration in evaporator, water blow down from evaporator is absolutely essential and leads to significant increase in makeup water consumption. Water blow downs such as continuous blow down, intermittent blow down and emergency blow down are very important and sensitive component of steam generation boiler flow model to maintain the performance standard in appropriate ranges.

Variation in design specified values of steam/water purity, pressure and temperature in various flow equipment leads to adverse effect on performance parameters until it is suitable taken care of by modifying the associated operating parameters.

- *Boiler Heat and Mass Flow Model-*

Fig. 9 shows the feed water flow model from economizer to boiler drum. In 600MW boiler economizer coil is divided into three sections of coil named as lower, middle and upper bank of coils.

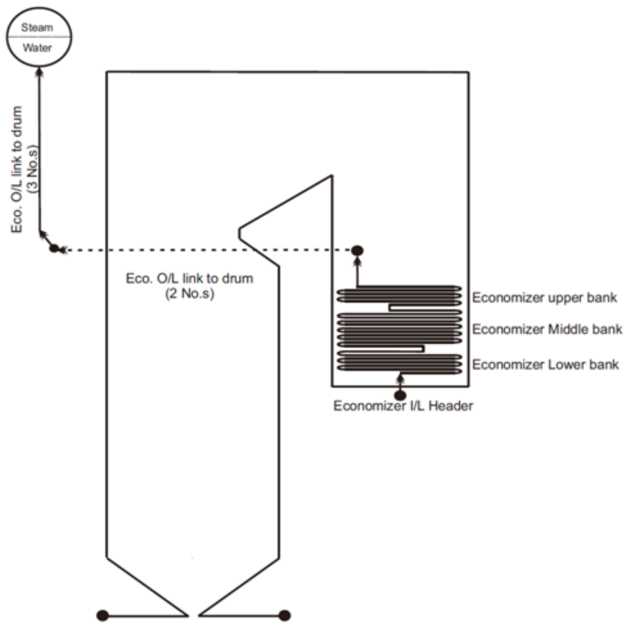

Fig. 9: Feed Water Flow Model in Economizer

Fig. 10 shows the feed water flow model from boiler drum to bottom ring-header. At 600MW boiler operating pressure, the density difference between water and steam is low; hence assisted circulation pump is required. From drum, 6 down comers are coming and connected to suction manifold header. 3 nos. of ACPsare provided for the boiler, which are single suction and double discharge pump. In this boiler all the 6 discharge pipes are connected to the front part of the ring-header.

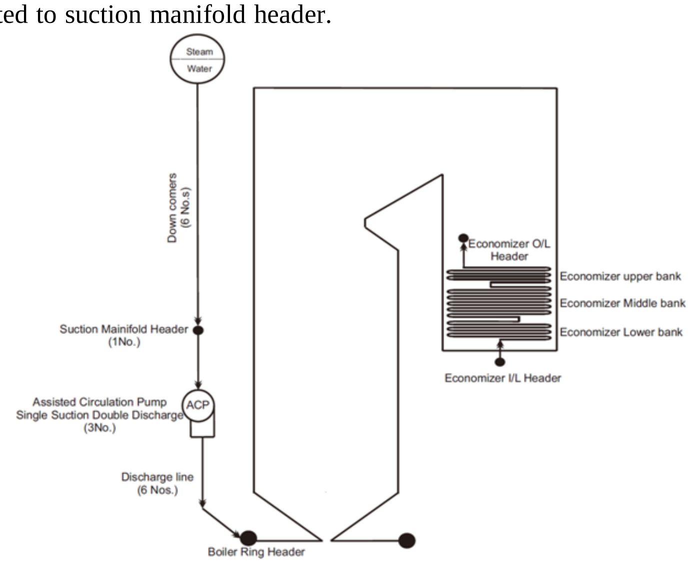

Fig. 10: Feed Water Flow Model Boiler Drum to Ring-header

ISBN 978-93-83459-12-4 © 2014 Bonfring

Fig. 11 shows the flow of feed water to ring header, which partly converts into stem in water walls and there after supplied to boiler drum through outlet headers& raiser for the separation of steam from water.

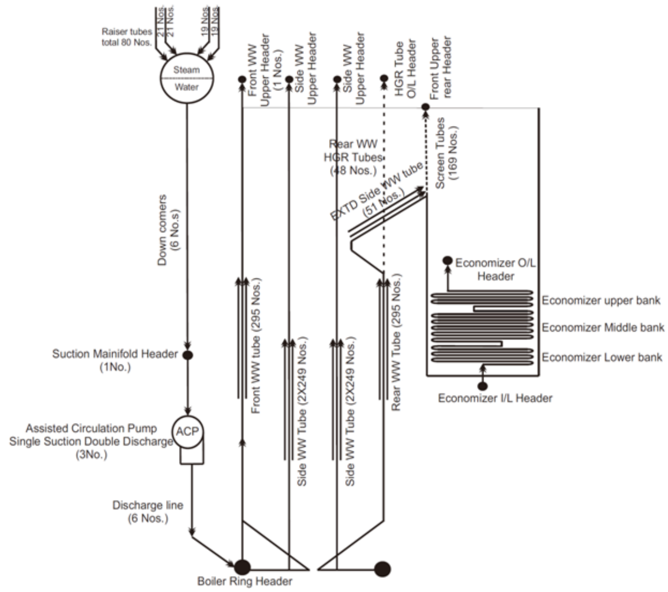

Fig. 11 Water and Steam Mixture Flow Mode

Fig. 12 shows the steam flow model in boiler. Separated steam flows through the complicated flow path constructed of nine headers (1, 2, 3R, 3L, 4R, 4L, 5, 6A, 6B, 6C, 6D, 7, 8 & 9), boiler roof in 2 stages and all the 4 walls of II pass of the boiler before it is supplied to Low Temperature Super Heater (LTSH).Fig. 13 shows the typical arrangement of hanger tubes for 600MW boiler. In this boiler economizer coils and LTSH coils are supported by steam cooled hanger tubes, connected in between SHH 5 & 7 and passing through 6A, 6B, 6C & 6D. Fig. 14 shows the steam flow through super heaters and re-heaters. In figure SHH-11 and SHH-12 are divisional super heater inlet and outlet headers respectively. SHH-13, 14 are final super heater inlet and outlet headers respectively. Re heater is placed above the goose neck and occupy the entire space in between I& II passes of the boiler. Cold re heat (CRH) steam is supplied to re heater through one inlet header but collected in two outlet headers from where it flows to the IP Turbine.

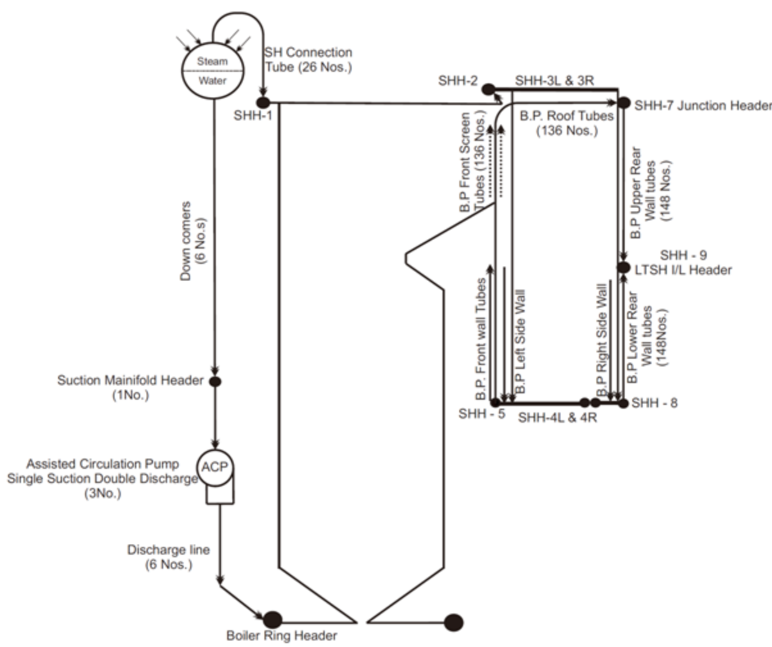

Fig. 12 Steam Flow Model in Boiler

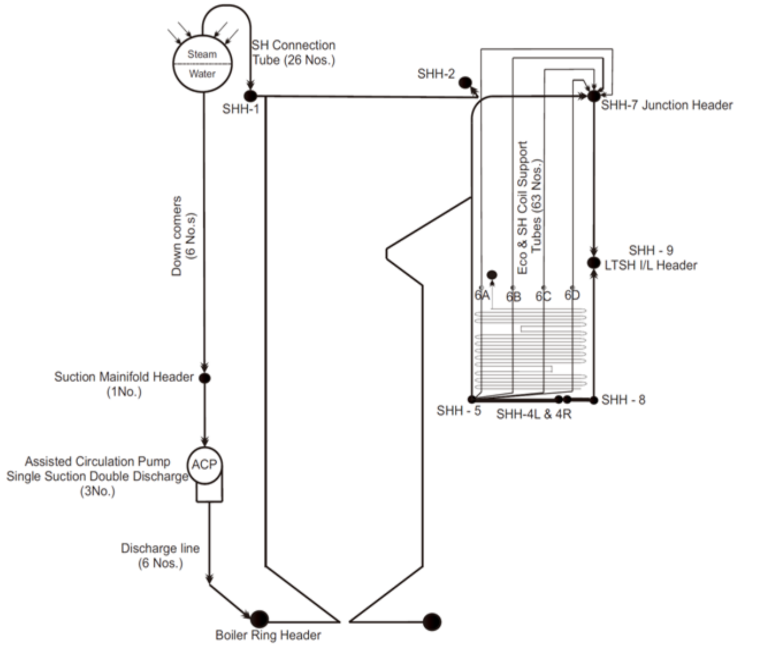

Fig. 13: Steam Flow Model in Support Tubes of Eco. and LTSH Coils

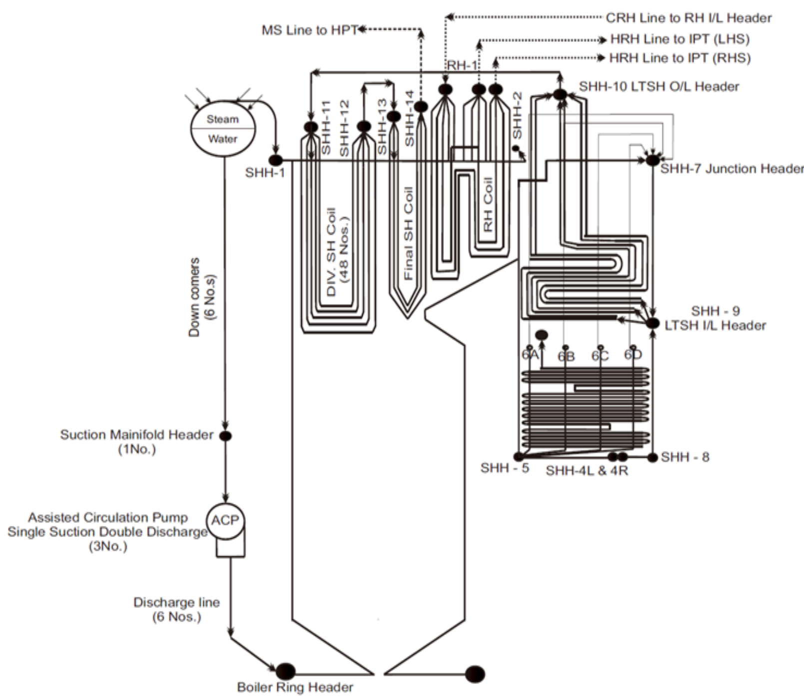

Fig. 14: Steam flow model in LTSH, DSH, SH and RH

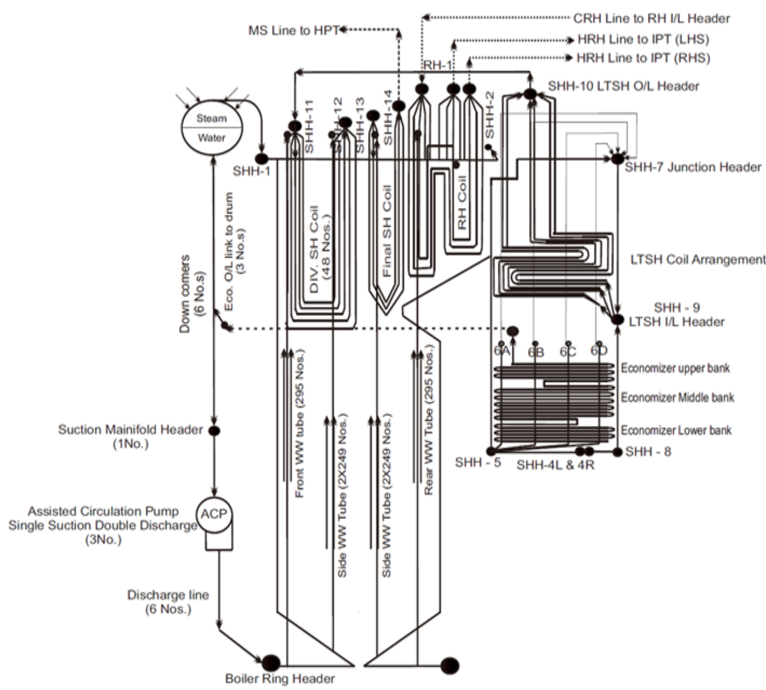

Fig. 15: Integrated water and steam flow model for 600MW boiler

- *Steam Expansion (Turbine Flow) Model*

Steam turbine is turbo machine, which supply kinetic energy to the alternator for producing electricity. This kinetic energy of steam turbine is received from steam produced by boiler. Quality and quantity of steam decides the performance and life of the steam turbine. Steam temperature, pressure, degree of superheat and purity variation leads to loss of life and efficiency, which can be controlled either by improving these quality parameters within the design specified ranges or by modifying the other operating parameters to accommodate the variation. In order to avoid condensation of steam in the last stages of a steam turbine, the temperature must dominate the pressure but has to be kept lower than sensitization temperature of steam handling equipments. Higher sensitization temperature steels are very costly and hence the compromise between the cost of boiler tubes and initial steam temperature is made by introducing the reheating after the expansion of steam in high pressure turbine in place of thinking for increasing the pressure dominated temperature in super heater itself. Parameters of steam may change even after the boiler outlet valves either because of throttling or because of nozzle action or because of partial admission losses. Energy profile of the steam under expansion through steam turbine blade channels, mainly depend upon the inlet/outlet blade angles, blade surfaces and blade positioning including the pitch. Impurities in steam also reflect adversely upon energy conversion in turbine blades. Pressure and temperature reduction in any manner, different from the design prescribed values indicate, either the poor quality of steam or permanent damage of the blade tips and surfaces.

In addition to the reduction of temperature and pressure of steam in the direction of steam flow, temperature gradient is developed in a radial direction due to high centrifugal force acting upon the steam stream flowing through the complicated blade channels. Heavier steam, being at lower temperature has the tendency to get separated towards the periphery of the circular cross section of turbine cylinder. After expansion of steam in intermediate pressure and low pressure turbines, its temperature reduces to saturation temperature which is followed by condensation. Wet steam being heavier, has the tendency to separate out at the peripheries. Colder steam and wet steam do not have much work potential and hence removed from the turbine cylinder at different points. This steam has sufficient heat and hence utilized in heating the condensate/feed water. The points from where steam is taken out are known as extraction points and steam is known as extraction steam. This process of pre-heating the boiler input water is known as regenerative feed heating system which is treated to be most effective method of improving the thermal cycle efficiency.

Steam expansion (turbine flow) models deals with input parameters of steam, steam energy losses in nozzles/throttle valves, inlet manifold, leakage through turbine main glands and glands of moving/stationary blades, flow through various extractions, pressure loss in re heater, carry over losses in between the stages, leaving velocity loss and condenser inefficiency. Exhaust low pressure steam posses lot of latent heat which has to be rejected to lowest heat sink. Air, being the substance of relatively low specific heat, rarely used for removing this latent heat from the condensation device in order to restrict the size of condenser. Water being the substance of highest specific heat is normally used to take latent of heat from the condenser. Temperature, pressure and water level in the condenser depend upon the temperature and flow of cooling water. Initial vacuum in the condenser is developed by a vacuum creating device at the time when there is no steam. After the entry of stream, condenser vacuum mainly depends upon the process of condensation and vacuum creating devices continue to function to remove the non condensable gases of the steam, which are inducted in the pre boiler system. Adequate quantity of cooling water and its temperature decide the vacuum at which condensation take place.

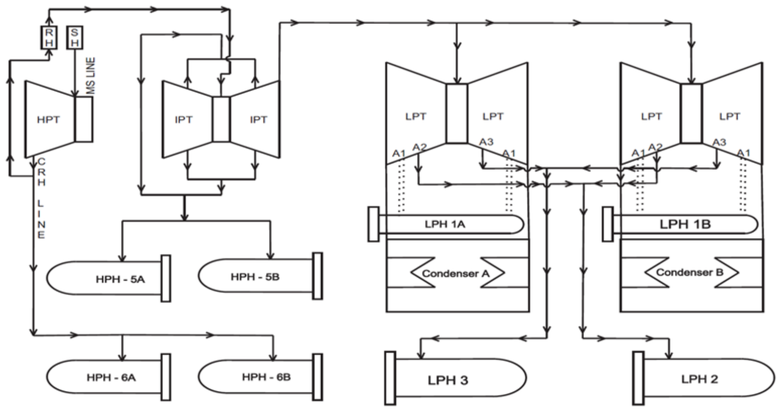

Fig.16: Steam Expansion (Turbine Flow) Model

IV. Fuel Flow Model

Steam generator of a conventional steam turbine power plant can be fueled with gas, oil and coal. In coal based steam power production, supplementary fuel oil is supplied for initial ignition energy and sometimes it is also used for combustion flame stabilization in case of very poor coal quality. Fig.11 shows the supply of input fuel along with combustion air. Base fuel is coal, which is received in the coal handling plant by any means of transport and after unloading, it is transferred with one point to the other through moving conveyor belts provided with magnetic separators. The coal crushers play vital role in reducing the coal size which can be further pulverized in unit pulverizer. Coal size of around 20-40mm is stored in the coal yard from where it can be supplied to the bunkers of any specific unit through two conveyor belts, one move on angle for supplying coal from ground to the bunker top from where it is filled in individual bunker by horizontally moving conveyor belt. Coal bunkers of every unit can store sufficient coal so that it can cater to the requirement of full load for a whole day.

Coal is supplied to the pulverizer through raw coal feed, which is equipped with coal quantity measuring system and pressured hot or cold air to prevent the choking of the raw coal feeder. After the first quantity regulation of coal, lot of qualitative measures are required to be adopted for better coal capacity and fineness management. Mill pulverization capacity is determined by the coal constituents and grindibility proximately ash and moisture content of the coal reduces the grindibility and hence taken care of by reducing the on line with capacity. Grindibility Index is also suitably taken care of by reducing the mill capacity for low hard groove index. In spite of the incorporation of the three important elements of proximal analysis (i.e. Ash, Moisture & Hard Groove Index), the desired fineness of pulverized coal is not achieved, the combustion manager have no option to further reduce down the mill capacity to achieve the desired standard of fineness. Combination of cold and hot primary air changes to incorporate the variable moisture content of the coal. Proximate and ultimate analysis of coal, roughly indicate towards the modification of the operating parameters for steam generator and its auxiliaries. In addition to the above, petrographic classification of the coal as organic maceral, inorganic mineral and moisture can enable the combustion manager to accurately modify the associated operating parameters on the basis petrographic analysis. Quality of pulverization, ignition energy and amount of excess air significantly changes for a different kind of macerals which exhibit distinct combustion character. In fact, it is combustion resistance offered by cool impurities (ash, moisture), nitrogen in combustion air and products of combustion, demand specified standards of excess air and workable combination of Time, Temperature and Turbulence. In addition to above the combustion resistance also varies for one maceral to the other. Both, oxygen dominated macerals, vitrinite and Hydrogen dominated maceral, exinite and their associations, exhibit good combustion ease and obviously often less combustion resistance. Contrarily, the carbon dominated maceral, inertinite does not exhibit the good combustion character and hence offers more combustion resistance. Thus on the basis distinct organic macerals in the same ranking coal need different quantity of excess air to ensure complete combustion of coal over the same conditions of time, temperature and turbulence. High speed diesel oil or light diesel oils are used in the beginning while there is no steam in the plant because of its fluidity at lowest atmospheric temperature existing in most of the TPS. This oil has alternatively higher calorific value and normally atomized with compressed air. This oil is used in all conventional igniters and one of the elevation oil guns.

After the establishment of sufficient heat flux, heavy oil/furnace oil is cut off from the service. Steam atomization is used for H.O. Attempts have been made to replace the by electrical system. All most all conventional igniters had already been replaced by high energy arc (HEA) ignition system. Efforts also had been made to replace igniters and oil guns by electrical system of sufficiently high initial ignition energy which ignites the coal directly, so developed system is known as DIPC i.e. direct ignition of pulverized coal.

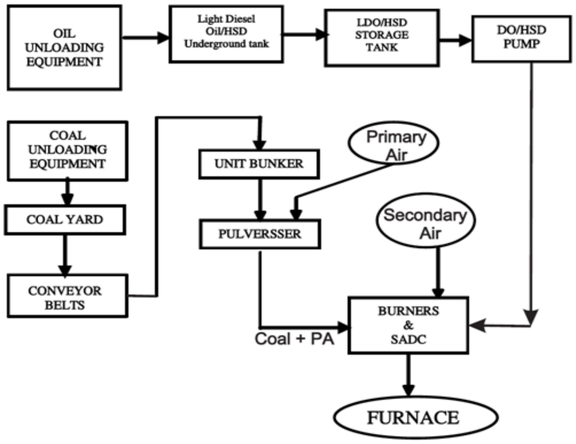

Fig. 17: Fuel Flow Supply Model

V. Flue Gas (Combustion Products) Flow Model

In pulverized fuel fired boiler, fuel air mixture and secondary air are supplied either from the front wall or from the rear wall or from the corners in the tangential direction of circle, which can be drawn at the center of furnace at each firing elevation. For the prescribed boiler width and length healthy combustion conditions are maintained to provide safe working and also to ensure complete combustion. Differentiate pressure across the furnace, platen super heater, re heater, final super heater, low temperature super heater, economizer, air pre heater and electro static precipitator has to be maintained by induced draught fan to ensure proper flow of products of combustion, CO_2 and O_2 percentages in flue gas is monitored and maintained to ensure complete combustion to ensure proper heat utilization across the various heat exchangers, differential temperature in flue gas is also monitored. Heat flux and potential of the products of combustion is controlled to avoid high temperature corrosion of the boiler tubes and also keeps the environmental standards of SO_x, NO_x, and suspended particulate matter under control. For the reference unit of 210MW, choosing four firing elevations out of six elevations is an important operating condition to shift the heat flux up and down. In addition to the burner selection, burner tilt also shifts the heat flux up and down. This highest concentration of heat flux is termed as fire ball, influence boiler life and efficiency. Unstable flame and fluctuating fire ball may lead to boiler output parameters, which in turn may further cause damage to steam turbine and pollution standards. The environmental standards can be maintained by pre-combustion treatment, combustion modification and post combustion treatment. Combustion control shall be covered in details with optimization techniques of flue gas exhaust temperature.

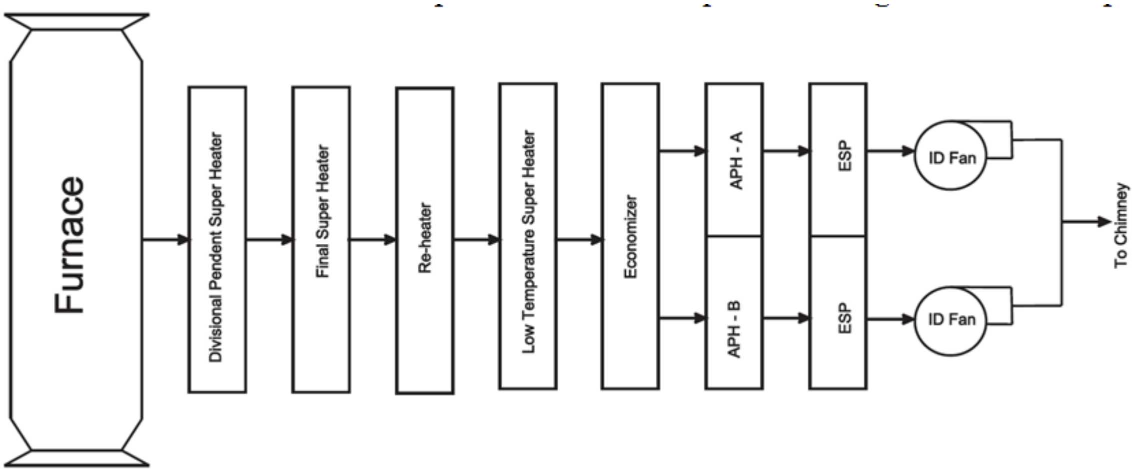

Fig. 18: Flue Gas Flow Model

On combustion, coal air mixture convert into ash, CO_2, steam, N_2, O_2 with traces of CO, NOx and SOx, this is termed as flue gas. Around 20% ash falls below the combustion zone in bottom part equipped with water sealed, water slurry ash collection system known as bottom ash hopper. Falling ash quality and quantity is an important combustion concern. Carbon percentage in bottom ash is a boiler efficiency control parameters which can be brought down to design specified value by managing the fuel and air parameters as described in previous sections. Clinker formation is also required to be controlled by properly controlling the heat flux and potential by introducing the tertiary air, which also controls SO_x and NO_x. Remaining 80% ash carried to the second pass along with moisture (steam) and dry gases and known as fly ash. A little portion of fly ash is also collected in the hoppers below the economizer and air pre-heaters. Air pre heater is last heat exchange in flue gas path and hence play very vital role in deciding the flue gas exhaust temperature. Pressure reduction of primary air, secondary air and flue gas across the air pre heater are operating parameters indicate its health. Differential temperature of primary air, secondary air and flue gas across the air pre heater affect the boiler efficiency. After air pre heater, flue gas passes through the electro static precipitator, where suspended particulate matter is removed to very low value (lesser then 150mg/Nm^3) and then it is exhausted to atmosphere through induced draught fan and chimney. Electro static precipitator consume lot of electricity in charging the solid suspended particulate matter of the flue gas and its ash removal efficiency is required to optimized in order to met the design prescribed standard and of suspended particulate matter in flue gas at exhaust of chimneyIn the event improper functioning of the electro static precipitator, induced draught fan blade erosion takes place which in turn adversely affects thedifferential and absolute pressure in various heat exchangers of the boiler and ultimate leads to the loss of boiler efficiency and life.

VI. Ash Flow Model

20% to 50% ash of the coal supplied to power plants (Indian coal contains 20% to 50% ash), which makes a significant amount to be handled with. In any coal based power plant, ash is the third highest (after water and coal) material mass, being handled safely and hygienically. Transport of ash from boiler hoppers to safe site is very important power plant business. In some power stations, very little amount of so produced high ash is utilized for manufacturing the brick. A small portion can also be utilized as soil conditioner and also mixing in the cement. But all together, major amount of it has been safely disposed of at place where its detrimental effect can be neutralized.

VII. Electricity Generating Model

Desired output of any power station is electricity, quantity of which is mentioned in the units of MW (KWHr - saleable domestic energy unit) with quality parameters such as power factor and frequency. While a turbo generator system is synchronized with huge grid, its frequency cannot be significantly changed by any single steam turbine input. In fact frequency control of the grid is complete management of entire power industry, including each and every endeavor of generation, transmission and distribution. Frequency is function of electricity generation and its consumption, mismatch of which is reflecting in frequency accordingly. Generation is contributed by many units with different quantities of active and reactive power, equal consumption (including system losses) of which by all the consumers will lead to the stable frequency. Demand forecasting efforts are based on assumptions and anticipations which vary from actual consumption due to diversified events, acts and habits of the consumers such as time of sunrise/sunset, season, performance of last monsoon, whether conditions (cloudy, stormy, rainy, temperature, humidity), festival or national holidays, special events, and government development policies etc. Large numbers of parameters pertaining to technical and commercial losses of the transmission and distribution system influence the grid frequency. Variation in electricity consumers' habit from an individual to stable factory or to a moving railway engine, influence the frequency in manner, which can be controlled by quick follow up action either by changing the generation or by controlling the consumption. Use of pumping power stations and planned shutdown of pre decided feeders can help in reducing and increasing the frequency respectively. Pumping power plants and huge water reservoir hydro units can quickly and largely help in frequency stabilization. This inaccurate behavior of electricity consumption leads to frequency fluctuations. Large transmission and distribution network connect the electricity producers and consumers, which are not only in remote localities but also subjected to national calamity, socio-political evils and techno-economic shortcomings. Electricity generating flow model of the present work did not cover the model of electrical reforms covering every aspect of generation transmission and distribution.

Kinetic energy of steam turbine and excitation electricity are major inputs, which regulate the quantity of active and reactive power and in turn the power factor. Prescribed standard of these major input and output parameters along with associated parameters are covered under the scope of this work. Quantity and quality of the electricity sent out and measured at terminal of generator transformer as per the power purchase agreement shall be analyzed along with electricity measured at generator terminal for performance guarantee and acceptance tests.

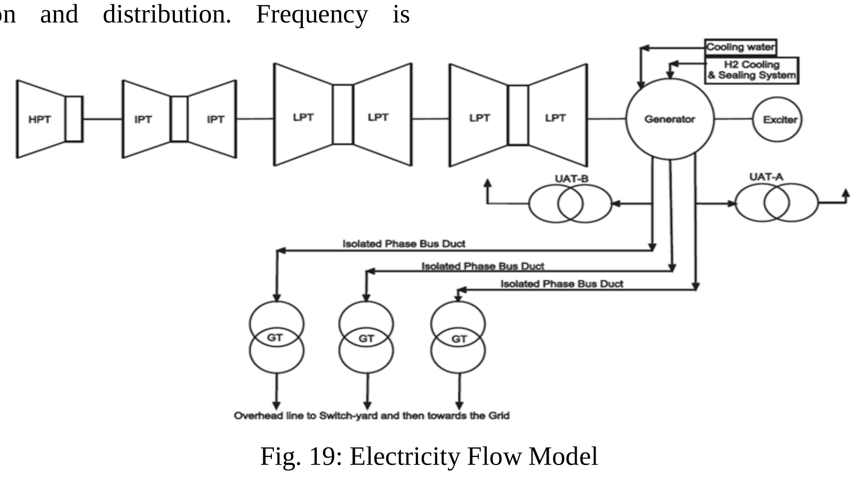

Fig. 19: Electricity Flow Model

ISBN 978-93-83459-12-4 © 2014 Bonfring

VIII. CONCLUDING REMARKS

Energy conversion process from chemical energy of the fuel to the electricity, in a thermal power plant is completed in various stages, namely from chemical energy of the fuel to the heat of flue gas, from heat of flue gas to the heat of steam, from heat of steam to the mechanical power of the turbine rotor, from mechanical power of the turbine rotor to the electricity at generator terminals. Energy conversion in all thermal power plant process equipments is governed by one or the other kind of fluid flow. Flow synthesis models provide ready references to the performance managers in controlling the quantity and quality of the fluids to minimize the adverse effects on life and efficiency of the equipments in the events of abnormally large variation of uncontrollable input parameters. Some of important parameters are explain below which will help to increase the thermal power plant efficiency-

- Feed water temperature at the outlet of the last high pressure heater is a very important efficiency control parameter, which should be optimally half of the main steam temperature

$$T_{fw} = T_{ms}/2$$

- Oxygen in flue gas represents the excess air over and above the theoretical air, which is proportionate to coal combustibles but Excess Air requirement increases with increasing coal impurities. Information of O_2 % at the outlet of boiler does not provide reliable guidance message to forced draught fan operator to supply accurate quantity of air due to time lag and slow combustion response. By using the coal parameters received from proximate (FC, VM, M & A) / ultimate (C, H, O, N, S, M & A) or from petrographic (Inertinite, Vitrinite, Exinite, M & A) analysis, following alternate method of excess air estimation should be used;

Excess Air = K_1*FC-K_2*VM+K_3*M+K_4*A**2+K_5

Excess Air = K_1*C-K_2*(5H+3*O/8+S+N)+K_3*M+K_4*A**2+K_5

Excess Air = k_1*I-k_2*V-k_3*E+k_4*M+k_5*A**2+k_6

- Flue gas exhaust temperature rise from 18 deg C to 20 deg C causes 1% loss of boiler efficiency for higher ash coal to the moderate ash coal respectively. Accurate assessment and correct distribution of combustion air solve many of the steam generator's problems.
- Role of supplementary fuel firing equipments, monitoring devices, soot blowers etc play equally important role combustion management as that of secondary air dampers, burners, burner tilting mechanism etc.

Secondary air flow regulation = Stoichiometric air + Excess air – Primary air

- Electro static precipitator reduces the suspended particulate matter up to the extent of 150 mg/NM^3, higher fly ash erode the induced draught fan impeller very severely and makes it quite difficult to maintain the differential pressure across the various heat exchangers of the steam generators.

REFERENCES

[1] A.B.Gill (1984) Site Efficiency Engineer, Drakelow Power Station, "*Power Plant Performance.*" Butterworths, London Boston Durban Singapore Sydney Toronto Wellington. Butterworth and Co (Publishers) Ltd.

[2] A.K. Sahay, K. Yagnanarayana, S.B. Sahay (1999), "*Petrological Characteristic of Coal with reference to Their Industrial Behaviour*", National Seminar on Coal & Coal Combustion in Utility Boilers organized by NTPC, CBIP, BHEL and CPRI of India on 6-8 April.

[3] Ashutosh Das, D.K. Sharma (1999), "*Relation of Petrographic Composition of coal with Combustion of Coals.*", National Seminar on "Coal & Coal Combustion in Utility Boilers" organized by NTPC, CBIP, BHEL & CPRI of India on 6-8 April Published in National Seminar on "Coal & Coal Combustion in Utility Boilers" organized by NTPC, CBIP, BHEL & CPRI of India on 6-8 April.

[4] B. Valentim, M.J. Lemos de Sousa, P. Abelha, D. Boavida, and I. Gulyurtlu (2004), "*Relation between the Petrographic Composition of Coal and the Morphology of Pyrolysis Char Produced in Fluidized Bed*", Energy & Fuels, 611-618.

[5] Bhatt, M. S., Rajkumar, Jotribasu (1999), "*Performance enhancement in coal fired thermal power plants. Part I: boilers &Part II: steam turbines*" J. Energy Res., 23. (6), 489-515.

[6] Earley D, Penterson C (1998), "*Accurate burner air flow measurement for low NO burners*", FACT (Am. Sot. Mech. Eng.), 22(1).67-71 R.A. Doyle and A. Ball (1991), Department of Material Engineering, University of Cape Town, Rondebosh 7700 (South Africa,), "*On thermo-mechanical effects during solid particle erosion*", published in Wear, 151 87-95.

[7] J. Graham, K. Tittle, N.J.Ray and D.G.Kingerley (1990), CEGB, UK, "*Modern Power Station Practice*" volume-E. March.

[8] K.C Yadav (2008), *Management of Thermal Power Plant Performance Parameter*", Ph.D. Thesis, Mechanical Engineering Department, Faculty of Engineering & Technology, Jamia Milia Islamia, Okhla, New Delhi -25, India.

[9] Operation and Maintenance Manual of 600 MW BHEL Unit.

[10] R. Kurose, M. Ikeda and H.Makino (2000),. "*Combustion Characteristics of High Ash Coal In a Pulverized Coal Combustion*", Fuel December.

[11] Ryoichi Kurosea, MichitakaIkedaa, Hisao Makinob, Masayoshi Kimotoa, Tetsuo Miyazakic (2004), "*Pulverized coal combustion characteristics of high-fuel-ratio coals*" Fuel 83 1777–1785.

[12] S. Su, J.H. Pohl, D. Holcombe, J.A. Hart (2001), "*A proposed maceral index to predict combustion behavior of coal*", Fuel 699-706.

ABOUT THE AUTHOR

Mr. SharavanTripathi, The author is graduated in Electrical and Electronics Engineering from Swami Vivekanand University. He has more than 3 years of experience in Thermal Power Plant Training. His main areas of interest are coal based thermal power plant process, process equipment and Boiler pressure parts. He is presently working in Jindal Institute of Power Technology, Tamnar as Asst. Training Officer.

ISBN 978-93-83459-12-4