# Changing Role of Coal-Fired Power Plants: From Base Load Operation to Flexible Operation

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**Abstract –** *Coal-fired power plants have been the mainstay of Indian power sector and they will continue to hold this pivotal position even in the foreseeable future. However in recent times, particularly in this decade, there has been a paradigm shift in the operating philosophy of these plants. In contrast to their earlier base load operation, the coal-fired plants are now entering the regime of flexible operation, owing to the changing landscape of power sector. Although many of the coal-fired plants have been able to meet the moderate requirements of flexibility in generation but there is a price to pay for that. The flexible operation has considerable bearing on the performance parameters of these plants; also the plant reliability and equipment life are in question. Further, even greater degrees of flexibility requirements from coal-fired power plants are on the cusp. This paper is an attempt to briefly discuss the impact of flexible operation on the performance and reliability of coal-fired power plants.*

***Key Words***: **Synchronism, Unit heat rate, enthalpy, APC, reliability.**

## 1. INTRODUCTION

Presently, Indian power sector is undergoing through a phase of radical change in its fuel mix. Although nobody knows the 'Optimum Fuel Mix' for the future, but it is for sure that renewable sources of energy will constitute a major chunk of installed capacity in India as well as around the world.

Even now thermal power plants are facing operational requirements, which have not been anticipated during their design, due to large scale capacity addition of conventional and non-conventional power plants & suppressed demand. Plants designed as base load plants are operating as peaking plants or as per grid demand and even some times forced to stop as per severity of the situation. All this results in performance deterioration of coal-fired power plant in terms of heat rate, auxiliary power consumption, secondary fuel oil consumption to support low load operation and carbon emission. The severity of the problem increases with frequently changing demand.

The situation is going to aggravate further with increasing penetration of renewable sources of energy in the grid because of the variable nature of these sources and uncertainties associated with them.

## 2. CHALLENGES FOR GRID RELIABILITY

Electric power grid is constituted of various types of generation resources and loads and the most important aspect of an electric power Grid is its reliability and maintaining the balance between Load and Generation is one important aspect of reliability. Power grid is a dynamic system which has a lot of uncertainties associated with it, e.g., step changes in load and generation, faults in the system etc. For successful operation, the power grid must ride through all these dynamics and must maintain a reliable supply at all times. These sudden changes in demand or generation in the power grid can initiate a steep fall or rise in the frequency of the power grid, can be detrimental to the power grid operation, if not contained immediately. So, power grids have to maintain their alternating current frequency within defined limits to keep the machines in synchronism with each other. The synchronous generators connected to the grid form an inertial mass which stores the kinetic energy. This inertia of the machines acts as a readily available pool of energy for the grid. Whenever there is a step change in load or generation this kinetic energy changes so as to accommodate that change and correspondingly the grid frequency also changes. Thus an electrical grid which consists of inertial masses inherently tries to maintain the grid frequency. However, the system also has to have active support to re-match supply to demand within seconds so that the system frequency can be quickly restored after it has begun to change. The immediate arrest of this fall or rise of the frequency of the power grid necessitates Real Power reserves in the grid which respond almost instantaneously with the frequency change, popularly referred to as 'Primary response from the generators'. In the absence of Primary Response, such disturbances will have to be handled by automatic load disconnection, which is not desirable. So Real Power Reserves are essential in the power grid to provide primary frequency control and to help the system to cope up with uncertainties. This primary frequency support function is provided by requiring some plants to be designed and operated in a manner to allow the supply of increased or reduced power on a very short-term reactive basis.

But this scenario is changing with the integration of renewable energy sources. The reason being, many renewable sources add to the generation capacity of the grid but they lack any synchronously rotating mass which can add to the grid inertia also at present they do not have the capability to provide primary frequency response. For example; one of the most popular renewable energy sources, solar PV, is a static system thus it inherently lack the ability to provide frequency support to the grid. Similarly the wind turbines, although they have a rotating mass, but they are non-synchronous sources of generation. To further aggravate the situation, these renewable sources of generation are variable sources of generation and they are also highly unreliable sources. Thus increasing penetration of renewable sources in the country, and considering the fact that their generation output can vary unexpectedly, it poses more challenges in the operation of Indian Power system and creation of system reserves becomes much more necessary.

## 3. NEED FOR FLEXIBLE OPERATION

Typically the supposed role of most of the coal-fired plants was to continuously provide a base load and to keep some margins always available through turbine governing system for providing the primary frequency control. Thus they already incorporate some degree of flexibility to cope up with power grid uncertainties.

But now, with greater penetration of renewable sources the requirement of flexible operation is becoming more and more stringent for the coal-fired plants. This is because, since the renewable sources usually lack the capability to provide primary frequency control so addition of any such plant in to the electric grid effectively reduces the percentage of the capacity available for the primary frequency control. This makes the grid weaker in terms of dealing with instability. In addition to that these renewable sources are variable sources of generation and their output usually varies considerably with the factors which are beyond human control. So these renewable sources infuse in the electric grid some potential uncertainties and instabilities and thus one need a greater margin of primary frequency control reserves. This greatly enhances the requirement of flexibility demanded from conventional coal-fired units.

In some countries already, high proportions of these intermittent-service renewable energy plants have resulted in a reduction of the inertia of these grids. As a result, an increasing proportion of decreasing body of fossil-fired units has to provide the balancing service.

This point can be further explained by referring to the report of technical committee on Large Scale Integration of Renewable energy in which they have made an extrapolation of current load-demand data with the addition of just 20GW of grid-connected solar power which, according to the assessment, will results in an All India Duck curve, showing two very sharp peaks in the morning and evening. Fig-1


Fig-1: Expected all India Duck curve [3]

The blue curve in Fig-1, which indicates the generation by non-renewable sources, clearly shows the backing down of these units during day time. Similarly it also points out the abnormally high ramp up and ramp down rates to be met by these units during evening peak.
All these factors generate the need for partial load operation, cyclic operation, and operation at greatly reduced loads and extreme flexibility in generation, from the coal-fired power plants.

## 4. IMPACT OF FLEXIBLE OPERATION ON THE PERFORMANCE OF THE PLANT

The implications of flexible operation on the performance of coal-fired plant are calculated with reference to a 210MW unit of NTPC ltd. and are presented in terms of two of the most vital indicators of plant performance- Unit Heat Rate and Auxiliary Power Consumption and Carbon emissions.

### 4.1 Unit Heat Rate

Unit is designed for base load operation at 210 MW but when unit is run at off design conditions the heat rate and thus the first law efficiency of the plant deviates from the design value. The unit heat rate of coal-fired power plant is defined in terms of Boiler efficiency and Gross Turbine Cycle Heat Rate (GTCHR) and is calculated as a ratio of GTCHR to Boiler Efficiency.

$$\text{Unit Heat rate} = \frac{\text{GTCHR}}{\text{Boiler Efficiency}} \times 100$$

### 4.1.1 Boiler efficiency

Performance of boiler is calculated as a ratio of steam enthalpy output of boiler and input heat value of the coal fired. According to the manufacturer provided data the boiler efficiency increases with the Turbine maximum continuous rating (TMCR); as shown in Fig-2 this variation is steep in the beginning and slows down near the full load.

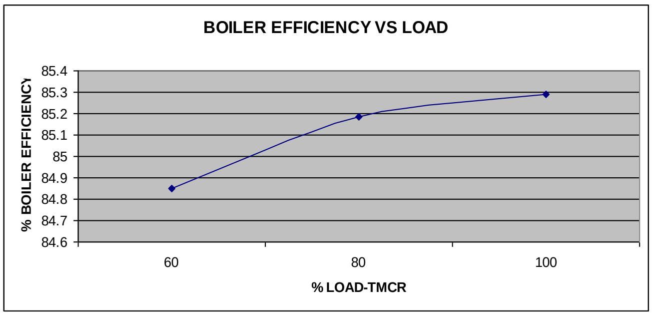


Fig-2 : Boiler efficiency v/s Load curve

### 4.1.2 Gross Turbine Cycle Heat Rate (GTCHR)

Turbine along with its auxiliaries working in closed cycle is called Turbine cycle and its performance is measured in terms of GTCHR. GTCHR is nothing but the heat input given to turbine in the form of steam enthalpy to generate one kWh of electrical energy at the generator output terminals. Fig-2 shows manufacturer provided curve of GTCHR and it clearly indicates that GTCHR increases considerably with reduction in load.

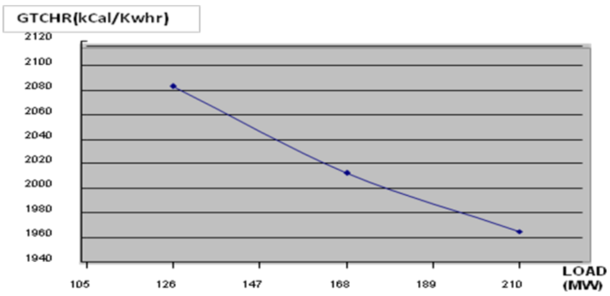


Fig-3 : GTCHR v/s Load curve

### 4.2 Auxiliary power consumption (APC)

To run the coal-fired plants various fans and pumps are to be required to be in service; the power consumed by these auxiliary equipments is called APC of the plant and is calculated as a percentage of the gross generation at the generator terminals. With reduction in plant load the power consumption of the auxiliaries also reduces but it is not proportional to reduction in load, in fact it is less than the percentage change in load, because of this APC of the coal-fired plant increases. Fig-3 shows the best fit curve for the APC data for the year 2016.

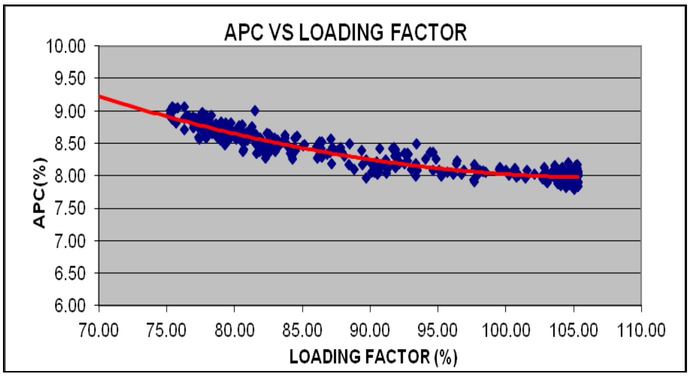


Fig-4 : APC v/s Loading factor curve

### 4.3 Carbon Emissions

This performance parameter is in fact a derived performance parameter as it is calculated only with the help of Unit heat rate and APC of the plant. The logic goes like this-with reduction in plant load the Unit heat rate increases and APC also increases. Increased vale of both these parameters calls for increase in coal consumption with same net energy export from the plant and the increased coal consumption leads to increased values of CO2 emission and other pollutants.

Thus flexible and partial load operation of coal-fired plants leads corresponding increase in the emission rates of these plants which partially offsets the environmental benefits associated with installing renewable energy sources.

## 5. IMPACT OF FLEXIBLE OPERATION ON THE RELIABILITY OF THE PLANT

Flexible and load following operation of coal-fired power plants involves rapid increase and decrease in process temperatures and pressure, which create significant thermal stress on pressure boundaries. When plant load change, the consequences are numerous: pulverizes go off and on, furnace temperatures and heat profiles are altered, and steam and flue gas velocities also vary. All these changes have a bearing on the life cycle of the component in question and build up of thermal stresses may also lead to faults in the components. This directly affects the reliability of the coal-fired power plants. Some of the dominant abnormal phenomena associated with load variation are-

### 5.1 Corrosion Related Issues

Cyclic operation challenges the ability of a plant to maintain water chemistry, which lead to increased corrosion and accelerated component failure. Increased levels of dissolved oxygen in feed water may result in condenser leakages. Other factors affecting chemistry include the increased need for makeup water and the interruption in operation of the condensate polishers and deaerators. Corrosion and fatigue can combine to accelerate damage to water walls.

### 5.2 Thermal fatigue

The effects of cycling on the steam generator usually materialize as stress cracking in the water wall tubing at attachments like the wind box, corner tubes, and wall box openings. Also affected are boiler super heater and Re heater headers, where ligament cracking is commonly seen between tube stubs. Header cracking is caused by frequent, large temperature swings associated with flexible and cyclic

### 5.3 Rotor Bore Cracking

When subjected to transients in the temperature of the admitted steam, the high-pressure and intermediate-pressure steam turbine rotors can suffer thermo-mechanical stress excursions, resulting in low-cycle fatigue damage.

## 6. MITIGATION STRATEGIES

To completely outcast these issues of performance deterioration and reliability loss certain design changes are required to be made in the process which will require big investments. But there are some low hanging fruits as well, like changing certain operation and maintenance strategies, which can be plucked very easily to improve the performance and reliability of the plants. One such front is that of APC. APC of the coal-fired plant can be reduced at partial load by switching off certain auxiliaries and shifting their load to running ones. Also installation of Variables frequency drives reduces throttling losses considerably in various HT drives.

Similarly condition monitoring of major drives and preventive maintenance can go a long way in improving the reliability of the plant. Since the aspects like long term degradation of equipment are more subtle and latent so to judge the condition of equipments in that perspective would require extensive data from the equipment and its analysis. Some of the condition monitoring systems which can be installed are- a stress monitoring system for boiler pressure part, turbine blade vibration monitoring system.

## 7. CONCLUSIONS

Large scale integration of Renewable energy sources with the electric power grid is inevitable and thermal power plants have to find their way in these troubled waters to maintain their economic viability and thus to sustain in the market. Further as the penetration of renewable sources in the electric power grid increases the requirements from the coal-fired plants will become even more stringent.

Due to the very fact that coal-fired power plants are highly reliable in comparison to renewable sources coal-fired power plants, in future, may be playing the role of load balancing plants only and the operators must prepare themselves for this. All these developments will pose a great threat for economic viability of these plants and to their long cherished high reliability.

To deal with the challenges of flexible and low load cyclic operation, coal-fired power plants need to adopt best operation practices, proactive and preventive maintenance practices. In addition to this the upcoming coal-fired power plants should be designed considering these specific objectives in the mind so that the plants can take on the challenge of flexible operation.

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