Chapter 2
Performance Parameters of Power Stations of Global/Indian Scenario

Electricity is the lifeline of modern civilization. While availability of electricity is a prime concern, conversion of fossil fuel to thermal power is not a very efficient process and generates pollution in the form of greenhouse gases and ash. Approximately 42 % of the total electricity produced globally is generated from coal. Burning of coal from these plants is responsible for almost 28 % of the global carbon dioxide (CO_2) emission. The greater the efficiency in heat utilization, the less pollutant is generated per unit of electricity generation.

Performance of a power station is normally judged by the availability factor, plant load factor, partial loading factor, forced outages, etc., and efficiency of heat conversion is judged by heat rate. Environment performance is judged by the level of nitrogen oxide (NO_x), SO_x, and suspended particulate matter (SPM) emission in the air. Definition of various traditional performance parameters are as follows (IEEE Std 762™-2006):

$$\text{Availability factor}\,(\%) = \frac{\text{Total time the generator operated on bar}}{\text{reference time}} \times 100$$

It describes the percentage availability of the respective generator in supplying power to the grid.

$$\text{Planned outage}\,(\%) = \frac{\text{Total time the generator out of operation for planned mantenance}}{\text{reference time}} \times 100$$

$$\text{Plant load factor}\,(\%) = \frac{\text{Sum total of different operating load} \times \text{time of operation}}{\text{Capacity} \times \text{total reference time}} \times 100$$

Plant load factor indicates the utilization of the available capacity.

Partial loading factor (%) = 100 − Plant Load Factor.

Forced outage (%) = 100 − planned outage (%) − availability (%)

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$$\text{Heat rate} = \frac{\text{Quantity of fuel (kg)} \times \text{Heat value of fuel (kcal/kg)}}{\text{Quantity of generation (kW)}}$$

Heat rate (kcal/kWh) indicates how much heat is used for generation of one unit of electricity.

$$\text{Efficiency} = \frac{860}{\text{Heat rate}} \times 100$$

Fossil fuel contains carbon which combines with oxygen in the air during combustion and produces carbon dioxide. The parameter is expressed as million ton.

Nitrogen oxide or NO_x is formed when combustion flame temperature reaches approximately 1400 °C. SO_x is generated as a result of the presence of sulphur in the fuel and its combination with oxygen during combustion. Both NO_x and SO_x are expressed as parts per billion (PPB) in the ambient air. SMP is the presence of fly ash particle in the air expressed in PPM.

Global Scenario

Since 1990, the electricity sector across the globe began changing its focus from a regulated environment to a market-driven approach. The environmental mandates has further driven the sector to technology adoption, change in usage pattern, and change in the classical concept of performance. This has presented a new challenge as to how the performance can be benchmarked against improving reliability, mitigating environmental requirements, while adding value in the service to the customer. The best practices for performance measurement across the different power generation assets globally has concentrated its focus on the value of the generation as a composite benefit delivered to the grid (regulated environment) or benefit delivered to the owners (de-regulated environment). In its 2010 report on 'Generating Plant Performance' the World Energy Council (WEC) had suggested a diverse matrix of performance indicator (World Energy Council Report 2010) as shown in Fig. 2.1.

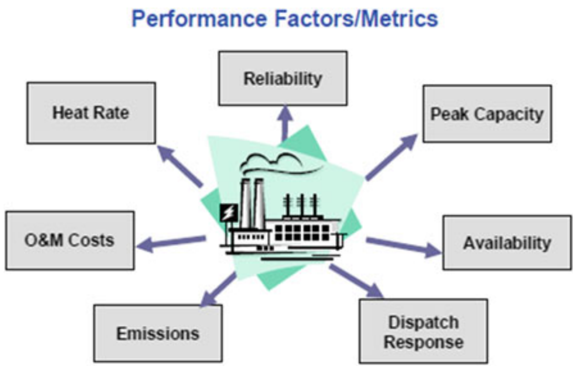


Fig. 2.1 Performance indicators as suggested by the world energy council

Electricity generating plant performance, which was until now primarily focused on effective heat energy utilization only, is replaced by a metrics consisting of availability, efficiency, emissions, cost, and others. This ensures that only the best possible performance can be attained with "perfect" operations and maintenance (O&M) management practices when equipment failure rate and repair time is minimized. In reality, the actual achieved performance for each generating plant around the world is far below its theoretically best achievable values. The Performance Generating Plant Committee report by the WEC estimated that 80 % of the gap in performance is due to "less than perfect" O&M management practices. Revisiting a plant's O&M management practices, along with replacement of inadequate or worn-out components to increase its availability and reliability to its theoretical best achievable limits, can substantially reduce its performance gap. The four core (primary) performance indicators according to the WEC's 2010 Generation Performance Report are

1. Energy availability factor (EAF)
2. Load factor (LF)
3. Planned capacity loss factor (PCLF)
4. Unplanned capability loss factor (UCLF)

As per Institute of Electrical and Electronics Engineers (IEEE) standard 762-2006, the aforesaid indices of performance definition is given below (IEEE Std 762™-2006).

EAF—The energy availability factor is the ratio of the potential amount of energy that could be produced by any utility after all planned and unplanned losses are considered to that of theoretical availability and is measured in percentage potential. It is a fact that not all available energy can be generated. However, EAF identifies what percentage of power during a given period could be generated. Factors beyond management control are included in the EAF. EAF is considered to be as given by the IEEE 762 weighted equivalent availability factor (WEAF) which includes outside management control outages or derating, if any. WEAF can be expressed as

$$\mathrm{WEAF} = \left[\frac{\sum_{i=1}^{n}\left[(\mathrm{AH}_i \times \mathrm{NMC}_i) - (\mathrm{EUNDH}_i + \mathrm{ESDH}_i) \times \mathrm{NMC}_i\right]}{\sum_{i=1}^{n}(\mathrm{PH}_i \times \mathrm{NMC}_i)}\right] \times 100$$

Where AH- Available Hours, NMC- Net Maximum Capacity, EUNDH- Equivalent Unit Derated Hours, ESDH- Equivalent Seasonal Derated Hours and PH- Period Hours. UCLF—The unplanned capability loss factor is the ratio of the maximum energy generation that a plant is not capable of supplying to the electrical grid because of unplanned energy losses to that of total capacity expressed in percentage. Unplanned losses include unplanned shutdowns, outage extensions, or load reductions due to unavailability. If an outage is not scheduled at least 4 weeks in advance, then it is considered to be an unplanned loss. A low value of unplanned capability loss indicates that important plant equipment is reliably operated and well maintained. UCLF is equal to IEEE 762 weighted equivalent unplanned outage factor (WEUOF) and is expressed as

$$\mathrm{WEUOF} = \left[\frac{\sum_{i=1}^{n}\left[(\mathrm{FOH}_i + \mathrm{EFDH}_i + \mathrm{MOH}_i + \mathrm{EMDH}_i) \times \mathrm{NMC}_i\right]}{\sum_{i=1}^{n}(\mathrm{PH}_i \times \mathrm{NMC}_i)}\right] \times 100$$

Where FOH- Forced Outage Hours, EFDH- Equivalent Forced Derated Hours, MOH- Maintenance Outage Hours and EMDH- Equivalent Maintenance Derated Hours. PCLF—The planned capability loss factor is the ratio of maximum energy generation that a plant is not capable of supplying to the electric grid because of planned energy losses to that of maximum energy available expressed in percentage. The planned capability loss includes annual maintenance shutdowns. An outage is considered to be planned if it is scheduled at least 4 weeks in advance. PCLF is equal to IEEE 762 weighted equivalent planned outage factor (WEPOF) and is expressed as

$$\mathrm{WEPOF} = \left[\frac{\sum_{i=1}^{n}\left[(\mathrm{POH}_i + \mathrm{EPDH}_i) \times \mathrm{NMC}_i\right]}{\sum_{i=1}^{n}(\mathrm{PH}_i \times \mathrm{NMC}_i)}\right] \times 100$$

Where POH- Forced Outage Hours and EPDH- Equivalent Planned Derated Hours. LF—The load factor is the ratio of the maximum energy the unit actually produced to that of EAF expressed in percentage. LF is equal to IEEE 762 net capacity factor (NCF) and is expressed as

$$\mathrm{NCF} = \left(\frac{\mathrm{NAAG}}{\mathrm{NMG}}\right) \times 100$$

Where NAAG- Net Actual Generation and NMG- Net Maximum Generation. With increase in population growth surpassing 7 billion, it has become a challenge to meet the necessary energy requirements. Installed capacity across the globe is given in Fig. 2.2 as of 2013.

The International Energy Statistics report of the International Energy Agency (IEA) shows the trend of energy generation growth from fossil fuel across the globe (Fig. 2.3).

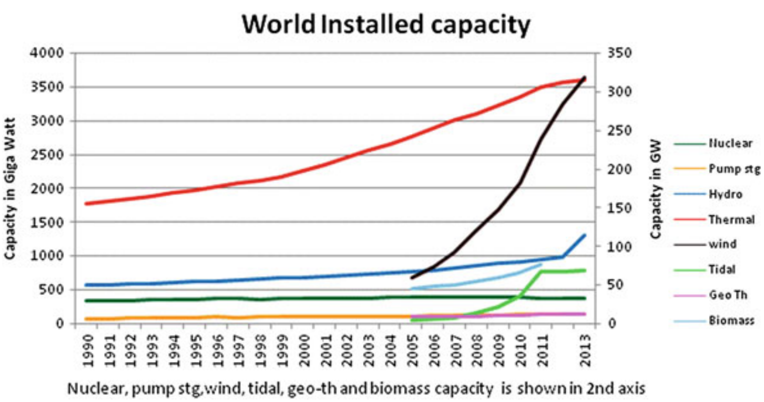


Fig. 2.2 World installed capacity source wise

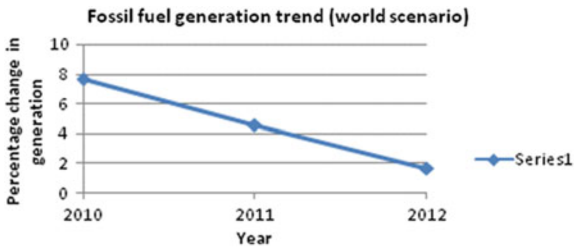


Fig. 2.3 Energy generation growth trend (world scenario)

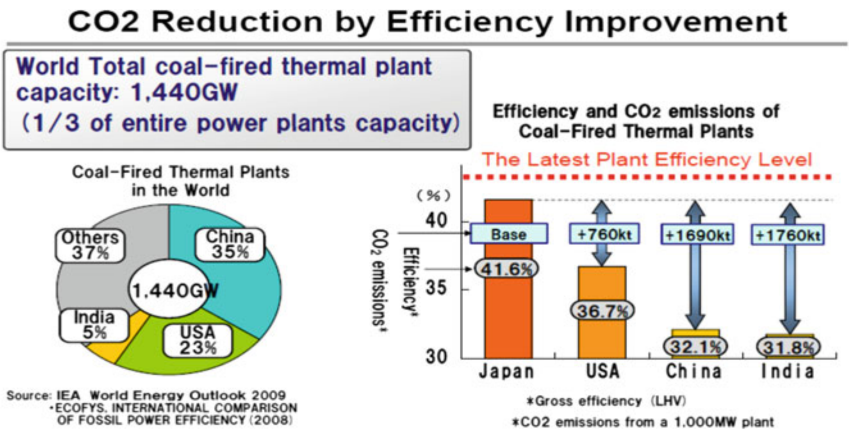


Fig. 2.4 Impact of efficiency on CO_2 reduction

The above trend shows that EAF is high but the generation growth is showing a negative trend indicating less demand from fossil fired plant for coal-fired units. This may be because many older units have been discarded and to reduce CO_2 emission, coal as a fuel has taken a back seat to make way for gas and renewable energy sources.

While the availability factor, and reliability enhances commercial compliance of a utility, the efficiency enhancement of generation reduces fossil fuel consumption and thereby reduces production of CO_2.

As per IEA World Energy Outlook 2009 (IEA 2010), efficiency of coal-fired utility across the globe is shown in Figs. 2.4 and 2.5.

As per the IEA report, there is enough scope of improvement in efficiency through adaptation of efficient technology and good operation practices. India needs to adopt high-efficiency supercritical units to enhance the gross efficiency.

Indian Scenario

India has enough coal reserve, and therefore the primary source of electricity is coal. The energy availability position of the country (CEA 2010–11) as per CEA report for the past decades is shown in Fig. 2.6.

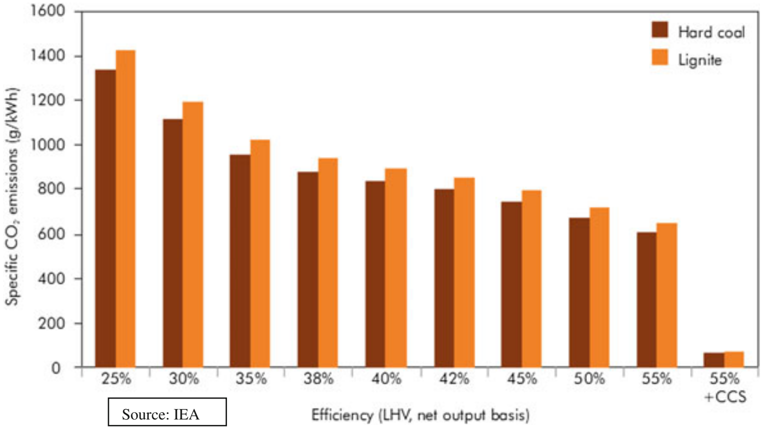


Fig. 2.5 Relation between net plant efficiency and specific CO_2 emission is shown

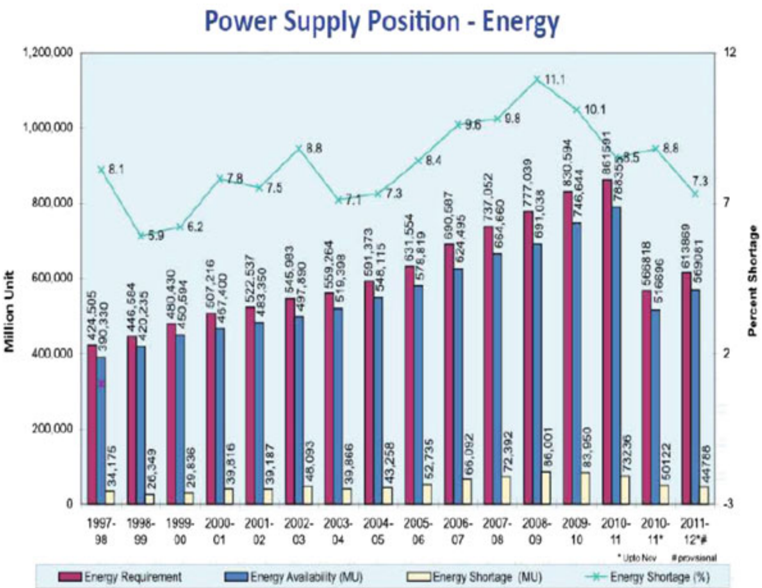


Fig. 2.6 Energy supply trend-Indian scenario

The energy shortage shows a negative trend over the past 5 years and indicates that the gap is reducing.

Although the demand is there, the loading factor for fossil-fired power as per CEA report is being reduced (CEA 2010–11) as shown in Fig. 2.7.

Scarcity of domestic fuel in conjunction with price volatility of international fuel is one of the major cause of such a downtrend.

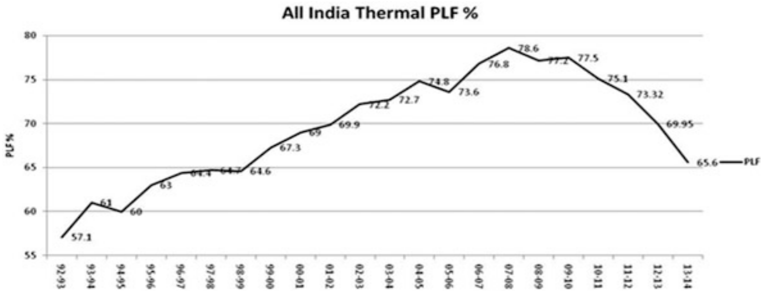


Fig. 2.7 Loading factor trend for fossil fuel generators in India

Nine supercritical units were synchronized to the grid during the 2011–2012 financial year. Planned maintenance accounted for was 5.93 %. This is an increase as compared with 5.83 % during the 2009–2010 financial year. Increase in unscheduled capital maintenance along with unscheduled R&M activity of some units were the main reason for the percentage increase in planned maintenance. Similarly, during the 2011–2012 financial year, the loss of generation due to forced outages of thermal units increased to 11.46 % as compared with 10.32 % during the 2009–2010 financial year. Increased forced shutdown of units due to a coal supply problem was one of the major reasons. Transmission constraints and equipment problems also added to the value.

Currently, India is going through adaptation of supercritical technology. The forced outage of supercritical units is high, indicating that the technology has not yet stabilized with Indian coal and atmospheric conditions. The O&M practices are being reviewed under Indian context.

Heat conversion at high temperature is always efficient, but the temperature limitation of turbine metal restricts high temperature conversion. With research for developing high temperature material for turbine ultra-supercritical units with steam temperature, approximately 700 °C is expected to substantially enhance the efficiency of a thermal unit (Fig. 2.8).

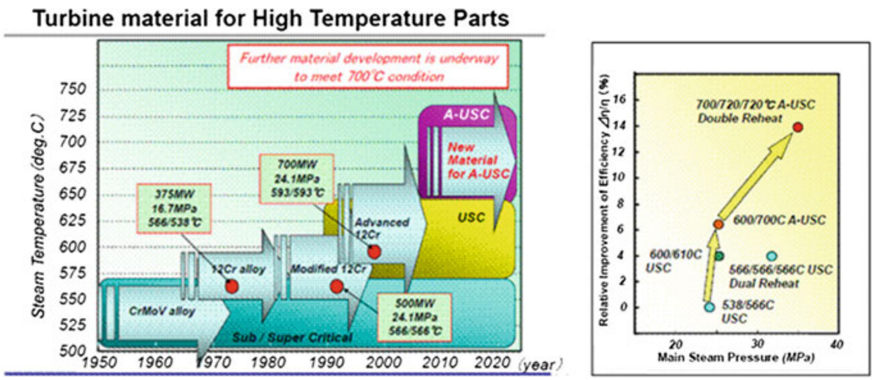


Fig. 2.8 Turbine metallurgy-development trend (courtsey Toshiba)

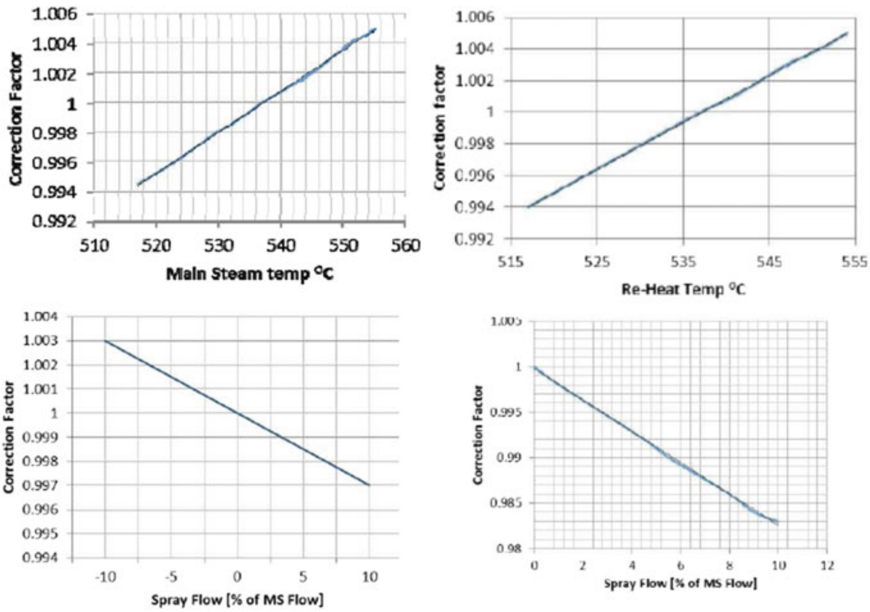
2.1 Impact of Performance Parameter on Economics of Generation

Performance parameter plays a major role in economics of generation. Better efficiency results in less consumption of resources such as coal, water, oil, auxiliary consumption, etc. The cost implication due to a rise in the heat rate, make-up water consumption, oil consumption, condenser back pressure, excess air, etc., indicate the urgent need to control these parameters within the designed ratings. A hard fact is that, with the passing of time, degradation sets in in various equipment and as a result, the plant's efficiency deteriorates. To understand the impact of degradation we must analyze the impact of different components of performance parameter. High-steam inlet temperature and spray.:

Energy from steam depends directly on pressure and temperature. At a lower temperature, energy in the steam is low and therefore work done by the turbine will be low, resulting in low turbine efficiency. Therefore, the steam consumption for the required output will be higher. How should the loss be calculated?

The designed MS temperature is T and the actual is $T1$, then variance is = $(T - T1)$.

Each manufacturer includes a turbine heat rate correction factor. Typical temperature correction factor curves for a 500 MW turbine is shown in Fig. 2.9.



Super heater spray flow Reheater spray flow

Fig. 2.9 Temperature correction factor for a typical 500 MW set. *Source* CIPECH14

Table 2.1 Effect of operating parameters on heat rate deviation

S. No.	Parameters	Deviation	Average HR loss (kcal/kWh)	Typical range of HR loss (kcal/kWh)
1	Main steam temperature (°C)	1	0.64	0.32–0.77
2	Reheat temperature (°C)	1	0.59	0.41–0.86
3	Super heater spray (Tones/h)	10	0.28	0.15–0.35
4	Reheat spray-4 (tones/h)	10	2.6	1.1–4.19
5	Exit gas temperature (°C)	1	1.2	0.95–1.91

Let *C* be the correction factor corresponding to *T*1 temperature, *H* is the design heat rate for the turbine and η is the efficiency of the boiler. Then deviation in heat rate can be calculated as $= \frac{H*(1-C)}{\eta/100}\,\%$. Loss due to heat rate deviation in different heads for a typical 500 MW unit is given in Table 2.1.

Heat rate deviation due to variation in condenser back pressure plays a major role. Condenser back pressure variation can occur as a result of many reasons such as variation in cooling water temperature, air leakage in the condenser, fouling of condenser tubes etc. The general impacts are given in Figs. 2.10 and 2.11.

Variation in turbine cylinder efficiency also changes the turbine heat rate. Typical parameters are

	TG HR (kW)	
	210 MW	500 MW
Change in HPT efficiency by 1 %	0.3 %	0.3 %
Change in IPT efficiency by 1 %	0.16 %	0.16 %
Change in LPT efficiency by 1 %	0.5 %	0.5 %

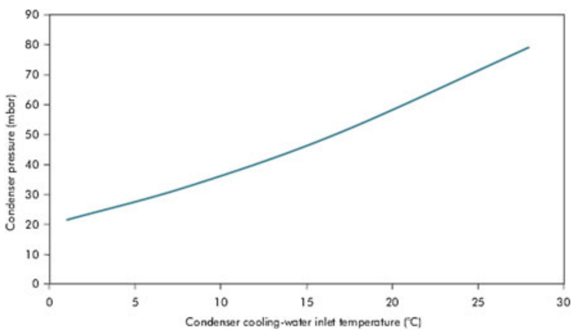


Fig. 2.10 Impact of cooling water temperature on back pressure. *Source* IEA (2010) Power generation from coal

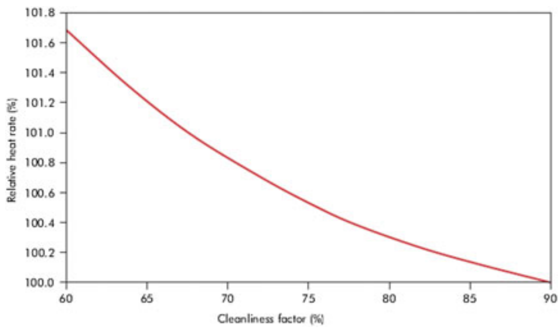


Fig. 2.11 Impact of condenser tube fouling on back pressure. *Source* IEA (2010) Power generation from coal

1% change in HP or IP turbine efficiency in a 500 MW unit leads to change in HR by about 4.5 kcal/kWh and having cost implications of about Rs. 57 lakhs per year (rail fed station)

If we consider coal price at Rs.-3500/ton, then it comes 1 kcal = 25 lakhs. So if we can save 50 kcal of any of the unit then it will impact 13 Cr in a year. This will reduce the cost of generation.

2.2 Impact of Performance Parameter on the Environment

Coal-based thermal power stations consume a high amount of resources such as coal, water, etc. Burning of coal produces fly ash particles in the atmosphere. Temperature of the water used for cooling in the condenser increases in the process. These create an immeasurable and everlasting impact on the environment and generate tremendous stress in the local ecosystem (Pokale 2012).

2.2.1 Environment Impact on Water

The specific requirement of water for a coal-based power plant is approximately 0.005–0.18 m^3/kWh. A large portion of the water is utilized for cooling purposes. Cooling water after exchange of heat in the condenser is allowed to cool through surface evaporation before returning it to the source water. Most aquatic organisms have developed enzyme systems that operate in only narrow ranges of temperature. High temperature of cooling water at the place of return adversely affects the marine life of fish and other living organisms. These stenothermic organisms can be killed by sudden temperature changes.

Ash pond discharge contains harmful heavy metals such as B, As, Hg which can leach out over a period of time. As a result, the ground water may become polluted and be unsuitable for domestic use.

2.2.2 Impact on Air Quality

1 kg of Indian coal produces on average 0.4 kg of ash. Out of that, 0.38 kg goes to air with flue gas. Coal burning at thermal power plants produces mainly CO_2, SO_x, NO_x, CFCs, and other trace gases. It also produces airborne inorganic particulates such as fly ash and suspended particulate matter (SPM). CO_2, NO_x, and CFCs are greenhouse gases (GHGs) (Shamshad et al. 2012).

2.2.3 Impact on Land

A large amount of land for the main plant and ash pond is required for a coal-based thermal power plant. The specific land requirement (per MW of installed capacity) for coal, gas, and hydroelectric power plants is 0.1–4.7, 0.26, and 6.6 ha, respectively. Plant-generated effluents create change in natural soil properties, causing it to become more alkaline due to the alkaline nature of fly ash. The quantity of effluent production from coal burning for 1 kWh of electricity production is given below:

- 0.65 kg coal is burnt
- 990 gm CO_2 is produced
- 7.6 gm SO_x is produced
- 3.5 gm NO_x is produced
- 0.061 gm soot is produced
- 2.3 gm SPM is produced.

In addition to mitigating the environment impact through technology, heat rate improvement reduces coal consumption and thus reduces the adverse impact on weather.

1 % improvement in efficiency (annual) in India will result in:

- Reduction of 4 million tons of CO_2
- Reduction of 0.03 million tons of SO_x
- Reduction of 4000 tons of NO_x
- Reduction of 500 tons of soot
- Reduction of 10,000 tons of SPM
- Saving of 2 million tons of coal
- Saving of 220 Crore Rs.

Therefore, performance improvement in coal-fired thermal power stations helps in long-term sustenance.

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