Chapter 2
Adoption and Introduction of Supercritical Technology in the Power Sector and Consequential Effects in Operation, Efficiency and Carbon Dioxide Emission in the Present Context

V.S. Verma

Abstract The paper highlights and traces the history of development of the power sector in India with special reference to the unit sizes of thermal turbo-generators which gradually increase from about 30 MW in 1947 to 660 and 800 MW at present. The initial focus has been on capacity addition to meet the demand increase. However, in the last two decades the greater stress was laid on the efficiency aspects of power generation to reduce the specific fuel consumption and consequently the CO_2 reduction. Reference has been made for adoption of CCS technology in our power stations and the pros and cons of the same have been discussed. Recommendations have been made towards the best practices for operation of the supercritical units in most optimal manner. Constructive criticism of the existing philosophical policies of the load dispatch centres has been made. Suggestions are also made to improve the situation. The action plan for climate change is referred to in connection with the strategy to adopt the supercritical technology in the overall improvement of the sector.

Keywords Indian power sector · Super critical technology · Operation · CO_2 reduction

Abbreviations

TPP	Thermal power plant
MS	Main steam
RH	Reheat
PLF	Plant load factor

Former Member, Central Electricity Regulatory Commission, New Delhi. Member (Planning), Central Electricity Authority, DG Bureau of Energy Efficiency

V.S. Verma (✉)
Central Power Research Institute, Bangalore, India
e-mail: vermavs@engineer.com; vermavs2@gmail.com

Malti Goel and M. Sudhakar (eds.), *Carbon Utilization*,
Green Energy and Technology, DOI 10.1007/978-981-10-3352-0_2

CEA	Central Electricity Authority
GHG	Green house gas
NTPC	National Thermal Power Corporation
PGCIL	Power Grid Corporation of India Limited
IPPs	Independent power producers
RPO	Renewable purchase obligation
CERC	Central Electricity Regulatory Commission
UDAY	Ujjwal DISCOM Assurance Yojana
T & D	Transmission & distribution

1 Background

The history of power development in India started since Independence when installed capacity of power generation was only 1367 MW, consisting of mainly the Hydroelectric Units of small capacity and few very small capacity coal fired units and diesel sets as well. The demand of electricity continuously increased and installed capacity also grew with installation of the thermal units in ratings of 30, 60, 82.5, 100, 110, 120, 140, 200/210 MW units. The units in ratings of 82.5, 110, 120, 140 and 200 MW were reheat units. The rest were non-reheat units. This scenario continued till the mid-seventies. The demand of electricity was still growing and the planner's attention was drawn to setting up of large capacity units commensurate with the increase of grid size 500 MW units were then conceived. The first 500 MW units were commissioned at Trombay Thermal Power Plant (TPP) of TATA Electric Co in the year 1984.

The increase in unit size was associated with corresponding increase in steam parameters (pressure and temperature) as well as efficiency of generation. Enhanced efficiency implies lesser green house gas (GHG) emissions.

The design efficiency and steam parameters associated with various unit sizes starting from 30 MW till 500 MW are indicated in Table 1.

It is pertinent to mention that most of the supercritical units which are in operation in various countries are operating either with natural gas as the fuel or

Table 1 Various unit sizes and main parameters

Unit size (MW)	Main stream pressure (kg/cm^2)	Main stream/reheat temperature (°C)	Gross design efficiency (%)
30–50	60	482	28.20
60–100	90	535	31.30
210 LMZ	130	535/535	35.63
210 KWU	150	535/535	37.04
250	150	535/535	38.3
500	169	538/538	38.6[a]

[a]The supercritical units will have heat rates better by about 2% over those of the subcritical units

Table 2 Parameters of supercritical units in operation

Power station	Size (MW)	Steam parameters	Fuel used	Year of commissioning	Efficiency (%)
Matsuura2	1000	255 bar/598 °C/596 °C	PC	1997	
Skaerbaek3	400	290 bar/580 °C/ 580 °C/580 °C	NG	1997	49
Haramachi2	1000	259 bar/604 °C/602 °C	PC	1998	
Nordjylland3	400	290 bar/580 °C/ 580 °C/580 °C	PC	1998	47
Nanaoota2	700	255 bar/597 °C/595 °C	PC	1998	
Misumi1	1000	259 bar/604 °C/602 °C	PC	1998	
Lippendorf	934	267 bar/554 °C/583 °C	Lignite	1999	42.3
Boxberg	915	267 bar/555 °C/578 °C	Lignite	2000	41.7
Tsuruga 2	700	255 bar/597 °C/595 °C	PC	2000	
Tachibanawan 2	1050	264 bar/605 °C/613 °C	PC	2001	
Avedore 2	400	300 bar/580 °C/600 °C	NG	2001	49.7
Niederaussen	975	265 bar/565 °C/600 °C	Lignite	2002	>43
Isogo 1	600	280 bar/605 °C/613 °C	PC	2002	

PC pulverised coal, *NG* natural gas

better quality of coal (Higher Calorific Value of the order of 6000/7000 kcal/kg). Very few numbers are in operation with coal of calorific value of around 3500 kcal/kg as available in India.

The supercritical technology has been adopted worldwide. These are in operation since 1950s specially in the countries like USSR, USA, Japan and others. The development of supercritical technology leads to better efficiency as well as consequential higher unit sizes of 800/1000 MW due to techno economic considerations.

The steam parameters and efficiency of some supercritical power plants in operation around the world is shown in Table 2.

The Central Electricity Authority (CEA) of India (Technical Standards for construction of Electrical Plants and Electrical lines) Regulations, 2010 published in the Gazette of INDIA dated 20 August 2010 prescribe the following guidelines for heat rate:-

1. Heat rate * (kcal/kWh) at 100% MCR with motor driven BFP	2. Heat rate * (kcal/kWh) at 100% MCR with turbine driven BFP
1810	1850

It may be noted that until the commissioning of 500 MW size units, the technology and other related aspects of operation and maintenance of TPPs with bigger unit sizes were under learning stage. Water chemistry is also one of the important subjects which was not very well understood with reference to the corrosion in the water tubes and in the flue gas ducting due to high temperature corrosion as well as sulphur contents in the coal and also maintaining the quality of steam and feed water in terms of dissolved silica, pH and oxygen. As a matter of fact, the grid size has been continuously increasing due to increasing demand for power, but the power plants were still operating at Plant Load Factors (PLFs) around 66% till eighties. This was mainly attributable to the teething problems in the newly adopted technology and increased unit sizes. The reasons were mainly boiler tube failures and other unit drippings on various protections, genuine and others.

The idea of installing large size units with supercritical parameters has been appreciated in the policy planning circles. However, the level of confidence in operation and maintenance of Subcritical units did not allow the planners to take a firm decision of going ahead with the Supercritical units in the country. In fact, way back in 1984, TATA Electric Co. was prevented to install a 500 MW unit with supercritical parameters at Trombay TPS. Higher reheat steam temperature of 568 °C was, however, adopted by them to gain advantage in turbine cycle efficiency.

The CEA set up a Committee under the Chairmanship of Member (Thermal), with the participation from National Thermal Power Corporation (NTPC), Bharat Heavy Electricals Limited (BHEL) and CEA in the year 1987 to go into the question of suitability of installing a larger unit's size with supercritical parameters and also to study the suitability of the supercritical technology adopted by Soviet Union (USSR) in their 200 MW units. A visit to USSR was also organised. The Committee in its report submitted that the grid size was adequate to sustain an outage of a 700–800 MW unit. It was also concluded that 700–800 MW boiler furnace size with Indian coal will be almost equivalent to a 1000 MW size boiler with better quality coal. The Committee, however, was of the firm view that the time was not ripe to adopt supercritical parameters in thermal units in India due to requirement of maintenance of a very high standard of water chemistry in supercritical units. The Committee recommended that one or two experimental units of 500 MW subcritical once through boiler designs must be installed to gain experience through designs of the boiler on the units. This will help in increasing the confidence level in O&M of the once through boilers. Accordingly, two units of 500 MW subcritical once through boilers were installed at Talchar Super Thermal Power Station of NTPC. The experience and feedback of operation of these units was also good.

Subsequently Govt set up another Committee under the chairmanship of Member (Thermal), CEA in 1989 to review the subject of next higher size of thermal unit to be adopted in the country with supercritical steam parameters. The cost aspects were also to be studied. This Committee concluded that a unit size varying from 660 to 800 MW could be adopted with supercritical parameters to gain advantage of efficiency with better steam parameters in these units. The statistics of availability of supercritical units vis a vis that of subcritical units around the world was also collected so as to arrive at the right conclusion in regard to availability of these units. From the data it was evident that the availability of some of the better operated units with supercritical parameters was by and large at par with subcritical units. This led to the conclusion that perhaps the time was right to adopt larger size units in the country with larger units to gain momentum in the capacity addition in the country. CEA consequently gave techno economic clearance to NTPC to install two supercritical units at their Sipat Power Station with 660 MW in the first stage. This power station was however delayed and the first unit of 660 MW with supercritical parameters was commissioned with commercial operations only recently in 2013 by Adani Power at their Mundra Power Station who became the first private developer in the country, to have installed and commissioned the 660 MW units in the country at the shortest gestation period of 36 months.

The above sequence of events was followed by many other developers and a large number of supercritical units in the country are now operating with 660 MW unit sizes. Four 800 MW units with imported coal have also been commissioned by M/s TATA Electric Company at Mundra. 800 MW unit size are the largest size operating today in the country.

The deployment of carbon capture and storage technology was however not agreed due to the following considerations:

a. Cost aspect (cost of generation may almost double)
b. The efficiency aspect (efficiency of generation would come down by 30% (12% points)
c. The plant footprint area would increase tremendously.
d. The disaster management plan was not known and addressed.

The country has however chalked out a plan of reducing the carbon dioxide emission from the thermal power sector as follows:

I. About 15,000 MW capacity consisting of 30, 60, 100, 110, 120, 140, 82.5, some of 200/210 MW units to be retired in a phased manner. These units are mainly non-reheat units (except 82.5, 110, 120, 140, 200/210 MW) with low efficiency and have already run for more than 25 years. The average efficiency of power generation would then appear to be better.
II. Renovate and modernise 200/210 and 500 MW units to upgrade their operating efficiency to near to design value.
III. Introduce supercritical/ultra-supercritical units of large size in future capacity additions, 13th plan and beyond.
IV. More penetration of renewable sources of energy (solar and wind).

All the above measures have been spelt out with a view to reducing carbon dioxide footprint from the power sector as a whole. All the above programmes are under way of implementation and are in different stages. Government of India has also taken a policy view point that in future all units in 13th plan and beyond, in the utility sector shall be with supercritical parameters. Supercritical units are about 2% better efficiency as compared to units with sub-critical parameters.

2 Efficiency Related Aspects

The average efficiency of operation of thermal power stations in the country is around 36%. The new units of supercritical designs are operating at around 40% efficiency whereas 500 and 600 MW subcritical units operate at around 38%

efficiency. The merit order dispatch in the grid is decided by the minimum variable price that is the cost of fuel. The system does not capture the efficiency of operation of the units meaning thereby the GHG emission aspects are not taken into account. The merit is decided based on the variable cost which has an element of cost of coal including transportation costs which can be more or less depending on the source and distance of transportation. To save fuel and consequently the carbon dioxide the merit order ought to be decided based on the operating heat rates of the machines.

The renovation and modernisation attempt was made by the government in the past and financial assistance was also provided to the states to affect the renovation and modernisation of various units with the help of CEA and Bureau of Energy Efficiency. Participation of the central public sector units such as National Thermal Power Corporation (NTPC), Power Grid Corporation of India Limited (PGCIL) were also sought.

Over the period of years of operation and the distribution business being a state subject, the tariffs of electricity not being commensurate with the cost, the distribution companies have accumulated huge losses. These losses had touched a figure of about 4 lac crores. A scheme called Ujjawal DISCOM Assurance Yojana (UDAY) has now been launched by the Govt of India for taking over existing debts of the state level power distribution companies with conditions of improving their efficiency, and reduction of T&D losses (both technical as well as commercial). There is a hope that the sector would generally improve and would become revenue surplus. After successful I supplementation of such a programme. The introduction of renewable sources of energy would drastically bring down the carbon dioxide emission since when these sources are contributing in the electricity generation; the coal consumption in the conventional thermal units is expected to come down.

3 Load Dispatch Philosophies

It may also be mentioned that distribution being a state subject, the dispatch from various generation units is controlled by the state load dispatch centres, and are thus susceptible to inefficient operation not really based on the best operation practices. Subcritical units are operated at a constant steam pressure and temperature down to a load called the control load, which is around 60%.

The effort was made to obtain the minimum heat rates on the turbine cycle side due to the maintenance of rated steam pressure and temperature even up to 60% loading on the unit. However, the turbine generally operated at lower efficiencies because of reduced steam flow rate at lower loads. This was not optimal to regain these lost efficiencies to the turbine, the sliding pressure mode of operation was evolved so that the steam turbines at lower pressure at reduced load increases the specific volume of steam enabling the turbine to operate at better efficiencies even at lower loads.

In case of machines operating at supercritical parameters, while operating on the sliding pressure mode, if the load comes down below 85% the unit comes down on subcritical parameters and the gain of efficiency for which the supercritical units were installed is completely lost. Therefore the large size supercritical units ought not to be operated on lower loads generally. The variations in the loads when required by load dispatch centres must be applied to the units other than supercritical ones. It is, however, observed that most of the state load dispatch centres are giving schedules of operation much lower than the 85%, to the supercritical units and these units thus operate at subcritical parameters. To avoid such erroneous operations, there is a need for training of manpower of the state generating and load dispatch centres and Independent Power Producers (IPPs) to operate the units in the correct operation mode. To improve upon the efficiencies, it may require modification in the legislations such as Electricity Act 2003 and subsequent regulations by the concerned regulators.

4 Grid Connectivity and Other Related Issues

The government has announced the target of solar installation of 100,000 MW and wind 60,000 MW by year 2022. To meet these optimistic targets, financing and technology issues are being addressed. The renewable purchase obligation (RPO) is now proposed to be made mandatory to be complied with by all the concerned entities including the distribution companies. The various thermal generators are also proposed to be mandated to install certain percentage of their installed capacity as solar power based through the amendments in the policy as well as Electricity Act 2003. This policy gives a good feeling that a large part of the energy should be drawn from the renewable sources of energy and minimum carbon dioxide emission will be let out as the coal quantity burned shall be reduced substantially due to increased generation by renewable sources.

The problem of introduction of greater proportion of renewable sources of generation however relates to the variable nature of solar and wind power. At a time when sun shines and the wind is blowing there is no necessity for the conventional generator to generate electricity and they will have to be backed down beyond the allowable limits. The conventional generators however are actually not designed for such variable generating mode and these machines are likely to be damaged during such operations. It has been the experience in the developed countries mainly in Europe that a large number of 800/900 MW conventional coal fired generators have suffered severe damages on generator insulations and the generator rotors have also suffered cracks. In India also some generating machines in some states have suffered such damages. Further at the time of peak load requirements generally the solar power is not available because typically the peak hours are morning and evening times when sun is not available in the right intensities. Supercritical units are therefore worst sufferers under such circumstances.

In view of the foregoing, following issues emerge:

1. To make the renewable power more acceptable from the grid operation point of view, some kind of storage system is necessary which will trigger in whenever the output of the machines comes down. The storage solutions however, are very expensive since it involves batteries of reliable nature and the cost of power generation increases three folds of the cost of generation without the storage. The question of affordability of renewable power will need to be addressed afresh. An alternative solution is that the renewable power developers have tie ups with hydro power plants which are on line and would trigger filling up the gaps. The availability of hydro power in the country is, however, becoming scarce. Since the exploitation of hydro potential itself is fraught with multiple difficulties involving difficult geological sites and, the approachability issues. In the past a few reservoir-based hydro stations have been converted to run-of-the-river projects by the states. This has resulted into a great loss to the development of appropriate type of hydro power in the country.
2. In accordance with the regulations in force, all generators including wind and solar plants are required to submit the schedule of generation for every 15 min time interval, i.e. 96 time intervals in a day in advance and also 24 h ahead, to the load dispatch centre to operate the grid efficiently. The wind generators, especially, so far have not come to terms with this requirement of the Central Electricity Regulatory Commission (CERC) regulations. CERC regulations had allowed plus minus 30% variations from the scheduled energy to be socialised and other violations beyond plus minus 30% will get penalised. Several institutions have come up in assisting the wind generators to predict every 15 min, the amount of generation. The generators should take advantage of such institutions.
3. There are other commercial issues to be settled relating to cross subsidies, regulatory assets and issues relating to separation of wire and content in the distribution sector.
4. It is seen that as the supercritical and subcritical units are being treated at par when it comes to merit order operation, and the supercritical units are required to be backed down also. The supercritical units are very delicate and sophisticated power generating units which are very sensitive to load fluctuations. These deteriorate very fast on efficiency and operate on subcritical parameters if asked to run at reduced loads. Accordingly, regulations must be in place to direct that the supercritical units will not normally be asked to back down and the backing down share shall be taken by inefficient and smaller units.
5. From considerations of efficiency, even the captive power plants also needs to be encouraged to build in larger unit sizes or else group captive plants to be encouraged to adopt larger and efficient units.
6. The merit order criterion should be based on efficiency not on the fuel price.

All the above factors will affect the efficiency of operation of the total system.

5 Conclusions

For the growth of power sector in India, installation of supercritical TPPs is recommended. The deployment of carbon capture and storage has not been encouraged in view of heavy cost and energy penalties. The following are the recommendations made for reductions of GHG emissions with adoption of supercritical technology.

a. In view of the fact that the demand of the power is fast growing, the installation of large size supercritical units is a must.
b. The captive generation needs to be encouraged only if they come in group captive with large size units in the range of 500–660 MW to maintain higher efficiency of power generation.
c. At the time of backing down of generation the supercritical units shall not be backed down below 80–85% generation to maintain high efficiencies.
d. Mass awareness programmes would need to be taken up and the components of the cost of generation need to be explained to the consumers.
e. Efforts shall be made to increase the temperature ratings of the supercritical units to around 700 °C from the present level of 600 °C. To attain still better efficiency.
f. The unit size also must be increased from 500/600 to 660/700/800 MW.

Bibliography

INDIAN Power Sector to India July 2011 International Seminar-Base paper for International Seminar on supercritical technology. 28th January 2011, New Delhi.

Keynote Address—V S Verma, Member CERC in the International Seminar on Supercritical Technology INDIA. Habitat Centre, Lodhi Road, New Delhi Jan, 2011.

Supercritical Technology for efficient Power Generation and lower carbon dioxide emissions, International Seminar by Steag Energy Services, GiZ and CEA, Min of Power, India July 2011.