Advance Power Plant Technologies and Steam Cycle for Super Critical Application

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Abstract:

Considering the high capital cost involved in new generation "clean technologies" developing countries like India having an abundance of cheap fossil fuel reserves have to give a major thrust to improvement in fossil-fired power technologies. Steam turbine based generating plants form the backbone of power generation in many countries in our country too, Base load is presently largely generated by fossil fuel based power plants. Most of these plants employ sub-critical coal fired boilers driving steam turbines to generate power. The adoption of "Supercritical cycles" for thermal plants on a wide scale has the ability to improve overall system efficiency, as well as provide benefits of lower emissions both on land & in air. Steam cycles for supercritical application operate at very high pressure & temperatures; these are thus characterized by features that take full advantage of the advanced parameters like higher expansion in turbines, more stages of feed heating & higher input levels to boilers, contributing to higher system efficiency. All the components of the cycle are optimally designed to take advantages of these elevated parameters. Additionally, these cycles are built considering large size machines to take full advantage of economies of scale, thus reducing "Footprint" per MW generated. All of these contribute to lower land & water use, less consumption of coal & reduced wastes & emissions. The paper deals with the design of these cycles in detail in addition to comparing them to the existing sub critical cycles, highlighting areas of improvement.

1. Introduction

Power generation technologies have also kept pace. Through old technologies like steam, hydro and Nuclear Turbine have progressed to dizzying levels, newer "clean technologies'' like wind & solar have also gained a major share of the grid in many countries, like India. There is now an ongoing debate both in favor of and against these clean technologies like. These are characterized by higher capital investment & longer pay back periods. Also these are site specific &always cannot be set up near consumption centers. The paper dwells on these advanced Technologies so alternatives to the conventional one. Considering the high capital cost involved in new generation "clean Technologies"[1] developing countries like India having an abundance of cheap fossil fuel reserves have to give a major thrust to improvement in fossil-fired power technologies. Hydro power (Renewable energy where power is created by the movement of large quantities of water) generation in India started in 1897 when 200KW hydro-station was first commissioned at Darjeeling. [6] The Sidrapong Hydel power station located at the foot-hills of Arya tea Estate at an altitude of 3,600 ft (1,100 m) and 12 Km from Darjeeling town. The first plant consisted of two 65Kw Crompton-Brunton single-Phase, 2300 volts and 83.3hertz alternators coupled with two Gunther's turbine. India's first Hydo-Electrinic power station with 2x65KW capacity was commissioned on 10th November 1897 by C.C Stevens. It is a noteworthy fact that the first power utility run on commercial basis for use of general public in India was developed in public sector under state patronage. This was followed by the 4.5 Mega watt hydroelectric power station near sivasamudram falls In Mandya District of the Cauvery River in Karnataka, in south India was the first major power station in India owned by few British companies. The Hydro Electric power station of the sivasamudram is the first of its kind in Asia and was established in 1902 by Mysore dewan sir K.Seshadri Iyer. And from here power was supplied to Bangalore the first city to get power in India and also Kolar gold field mines, including Mysore, In India the Annual hydroelectric production is 115.6 (T W h).

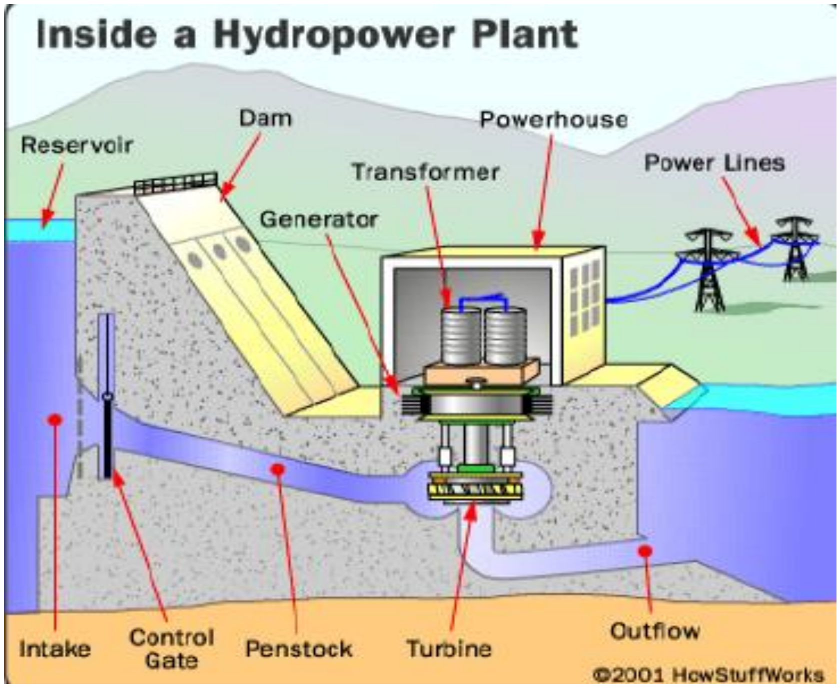

Fig1: Hydro electric power plant [6]

Due to the abundant availability of coal, a large number of thermal sets were set up by the British for meeting power demand in India's emerging cities. Due to the limited manufacturing capabilities of equipment in India all these plants were set up using imported equipment .The power equipment industry was established in India with the setting up of the first plant of BHEL at Bhopal in November 1956, under Heavy Electrical India limited (HEIL). Heavy Electricl plant in Bhopal is the mother plant of BHEL,The largest engineering &Manufacturing enterprise in India in the Energy-related and infrastructure sector, It was was dedicated to the nation on 6th of November 1960 by first prime minister of India Pt. Jawaharlal Nehru. BHEL spread of Operations with 180 products groups caters to the core sectors of Indian economy, power, industry, transportation, Transmission, oil & GAS, Renewable energy etc.In service of the nation BHEl sets generates 73% of the total power in the country while accounting for 65% of India's total installed generating capacity 1, 23,668 MW.From the above we see that India was a pioneer in the introduction of clean Technologies like Hydropower. There have been subsequent in power plant Technologies the world over, mainly in the Thermal &Nuclear Segments. Due to the abundant availability of coal in India, the Technology base for manufacture of large size steam turbines utilizing these coal. The first steam station was set up in Calcutta in 1899. We have a share of around 59% in India's total installed generating capacity contributing 69% (approx.) to the total power generated from utility sets (excluding non-conventional capacity) as of March 31, 2012.Through these technologies suited India's interests, they are one being categorized as technologies that harm the envirnment.this coupled with the system of earning Carbon credits for reduction of green house Gas emissions has led to a resurgence for the use of clean Technologies. For the past few years the India has made great strides in these newer clean Technologies like Wind, Tidal & the latest being Solar.

2. Wind, Tidal and Solar Power Plants

Wind power[5] generation was not taken up on a wide scale owing to lack of suitable large size generation plants, lack of suitable micro Grid to connect these plants & proper support from the government & power buyers. However this has now seen a vast change with the government mapping the wind potential areas of the country mainly in coastal regions & in hill areas of Karnataka, Maharashtra, etc. The indigenous availability of large size WEG's up to 2MW, Govt support for buying the higher priced Wind power coupled with ability to encash CER's of these plants have made Wind power an attractive investment source for many Govt. as well as private firms. In the process, the contribution of Wind power has grown to almost 15000MW as on date & is expected to rise further. Although a relative newcomer to the wind industry compared with Denmark or the US, a combination of domestic policy support for wind power and the rise of Suzlon (A leading global wind turbine manufacturer) have led India to become the country with the fifth largest installed wind power capacity in the world. Though Wind power seems attractive, it is best by a major problem of continued availability & dependability. In spite of great developments in technologies, it is still expensive compared to conventional technologies, thus limiting its reach beyond a point.

Fig 2: Wind turbine

Solar power [4] is another one clean technologies emerging in a strong way across the world, notably in countries USA & Southern Europe like Spain, Italy &also Egypt. In the past use of solar energy was limited to direct use of solar heat for heating purposes or for power generation using photo-Voltaic method. In this method the efficiencies were quite low with high capital costs, thus limiting its use to far flung areas where no other technology could be built. However the newer technologies developed over the years have bluunte the drawback to a great extent. In most parts of India, clear sunny weather is experienced 250 t0 300 days a year. The annual global radiation varies from 1600 to 2200 kwh/m^2 which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6,000 million Gwh of energy per year.

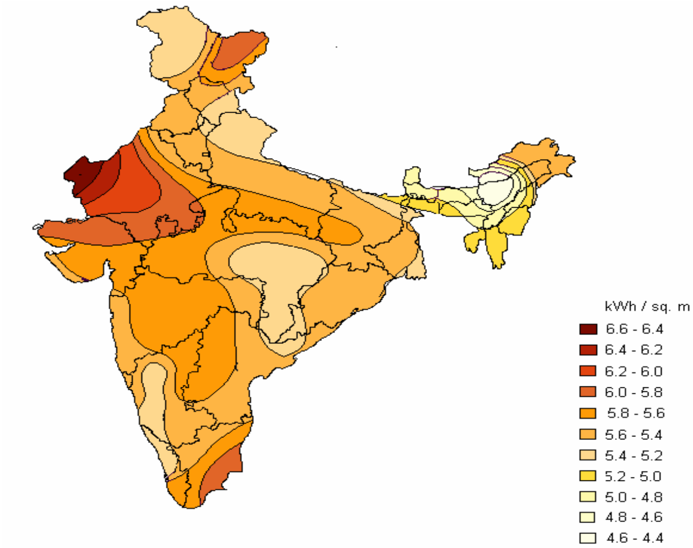

Figure 3: Map of India with Solar radiation levels in different parts of the country [3] Source: TERI

Some of the Technologies [2] are (I) Parabolic trough technology and (ii) Linear Fresnel reflector. Parabolic trough system is a type of solar Thermal energy collector. At the receiver can reach 400^0C and produce steam for generating electricity. Power tower systems the reflected rays of the sun are always aimed at the receiver where temperatures well above 1000^0C can be reached. Solar tower technology: All of the illustrated technologies use different proven methods to capture the solar heat in large collectors & transfer this heat to fluids or water to generate steam, which is then used to power a conventional steam power plant.

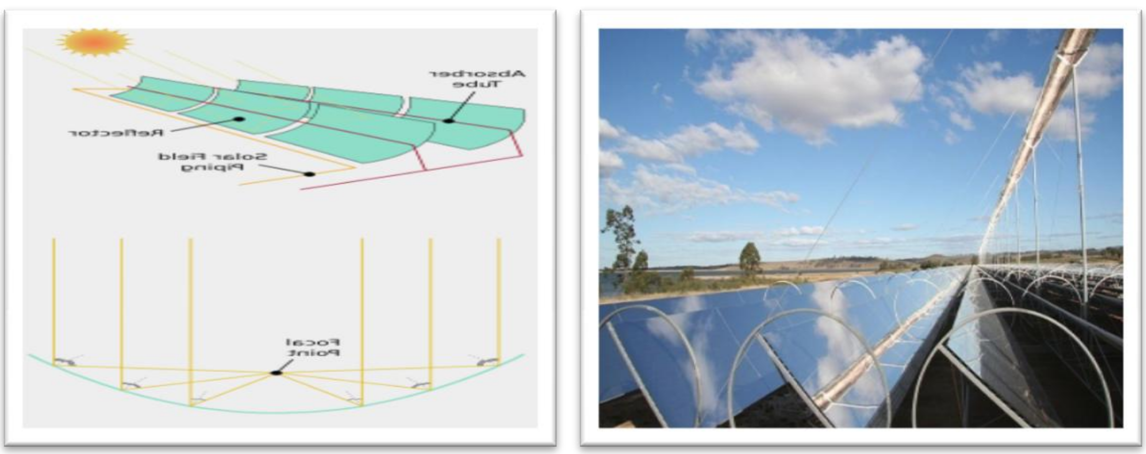

Fig 4: Solar trough along with liner Fresnel reflector

The important issues related to solar power stations are require high direct normal irradiation (DNI)> 5.5 kwh/sq meter, these are available in the geographical areas between latitude 35^0 south – cape town, Buenos Aires, 35^0 North –Memphis, Tehran. Global installed capacity: 867 MW, Mainly in USA and Spain. Under construction: Likely commissioning this year 624MW, Mainly in USA, Spain, Italy, Morocco, Iran and Egypt , likely commissioning next year 550MW in USA. Under JNNSM (JAWAHARLAL NEHRU NATIONAL SOLAR MISSION) BHEL Shall develop &supply suitable steam turbine based power plants to work in conjunction with the heat collection source to generate clean solar derived electrical power to the grid.

Fig 5: Solar tower technology [4]

Tidal potential in our country is huge, as we are blessed with a large coastlines of almost 5000km.The identified economic tidal power potential in India is of the order of 8000-9000MW. The other clean technology is the field of Nuclear Technology. The 320MW Tarapur Atomic power station (TAPS) was the first nuclear power plant in India. A 500MW plant went operational in 1969.

Fig 6: prototype fast Breeder reactor (PFER) at KALPAKKAM

BHEL has further upgraded its facilities to supply steam turbines for Nuclear Power stations up to 700 MW capacities being set up by Govt. of India. From the above we can conclude that there are many technologies in the world which can be collectively called ``Clean technologies''. These are characterized by low to Zero Emissions & pollutions & therefore environment friendly. Because of their clean nature these newer technologies like Wind, Tidal, and Solar & Nuclear have also gained major share of the grid in many countries However, there is now a ongoing debate both in favor of & against these Clean technologies. These technologies are characterized by higher capital investment & longer pay back periods. Also, these are site specific & always cannot be set up near consumption centers. Hence their use till date has been limited to those countries which have a good financial position or those wherein the demand for clean technologies has surpassed the negative aspects of these technologies. One clear common factor that emerges from the above technologies is the Steam Turbine, which is an important part of most of the above. Therefore the world focus has again shifted to further development of Steam turbines based power plants as these are not very capital expensive, are relatively efficient & have a long & reliable service life

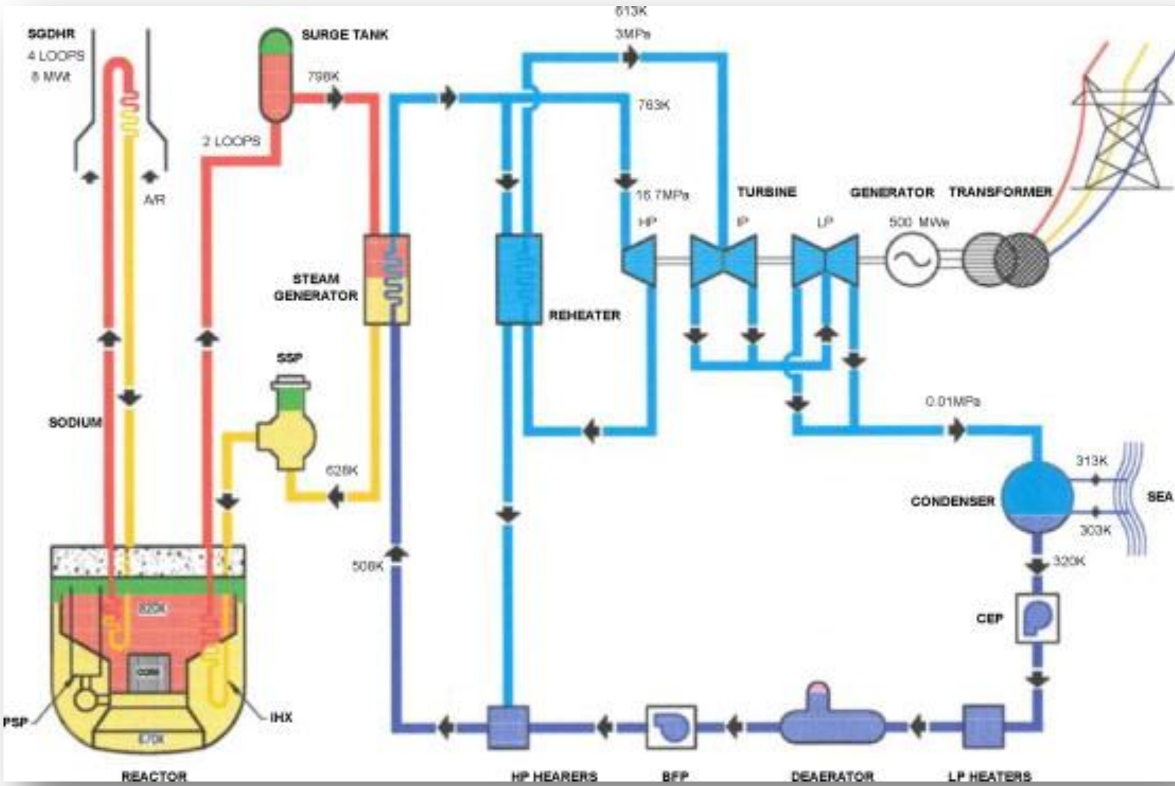

Fig 7: Energy flow scheme: PFBR

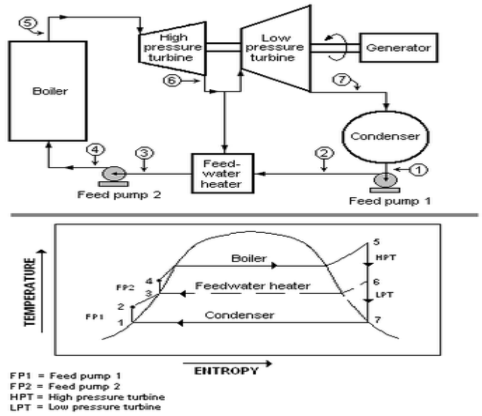

Fig 8: Steam turbine with supercritical parameters

The adoption of “supercritical cycles” for thermal plants on a wide scale has the ability to improve overall system efficiency. Steam cycles for supercritical application operate at very high pressures & temperatures. These are thus characterized by features that take full advantage of the advanced steam parameters, contributing to higher system efficiency. The factors that contribute to the higher cycle efficiencies are higher expansion in turbines, more stages of feed heating &higher input levels to boilers. To take full advantage of these features, all the components of the steam turbine cycle are optimally designed to take advantage of these elevated parameters. Additionally, these cycles are built considering large size machines, typically above 500MW to take full advantage of economies of scale, thus reducing “Footprint” per megawatt generated. Super critical steam parameters [12].

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Parameters more than critical state
Parameter steam temperature >374.15^{0}C

Parameters steam pressure > 221.2 BAR
Ultra supercritical pressure (≥ 300BAR)

3. Improvement in Efficiency with increasing inlet Parameters for Steam Turbines

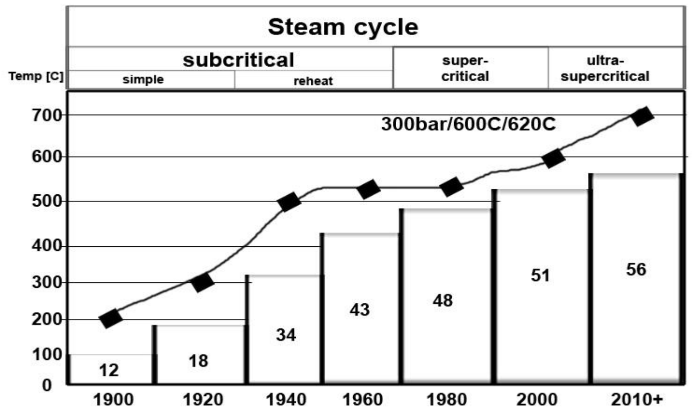

Fig 9: Steam cycle [11]

All of these measures contribute to lower land & water use, less consumption of fossil fuels like coal & correspondingly reduced wastes & emissions. Having seen the power stations from a wider perspective, it is necessary to see those components of the plant in details, which contribute to this wonderful improvement in efficiency. Most Sub-Critical Power stations are characterized a regenerative cycle having 6 heaters, with Three operating in the low pressure cycle & two at higher pressure. These are sufficient to Heat Feed water to the levels requires for Sub-critical boilers operating up to pressures of 170 g/cm^2.

Table 1. Steam cycle parameters (subcritical v/s supercritical) [10]

Parameters	Subcritical	Supercritical	
	500 / 600 MW	660 MW	800 MW
MS Pressure, ata	170	247	247
MS Temperature, ^{0}C	537	565	565
Reheat Pressure, ata	40.5	50	56.7
RH Temperature, ^{0}C	537 / 565	593	593
Final Feed Water Temp., ^{0}C	253	290	290

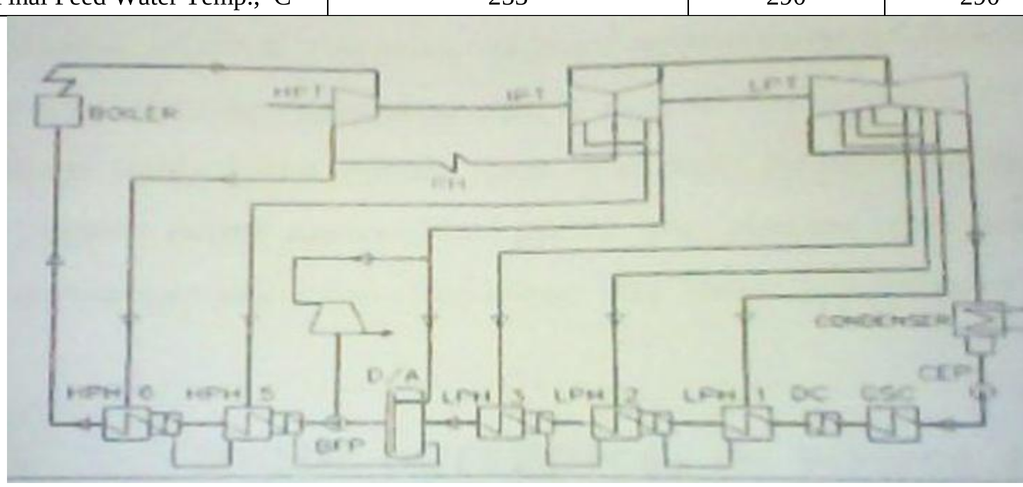

Fig 10: With 2 HP heaters, 3 LP heaters

However, with the advent of super- critical cycle, there exists a possibility of Using more stages of feed water heating, thus improving cycle efficiency & loading on individual heaters. We see that such cycles typically have EIGHT Heaters, with Three HP Heaters & Four LP Heaters.

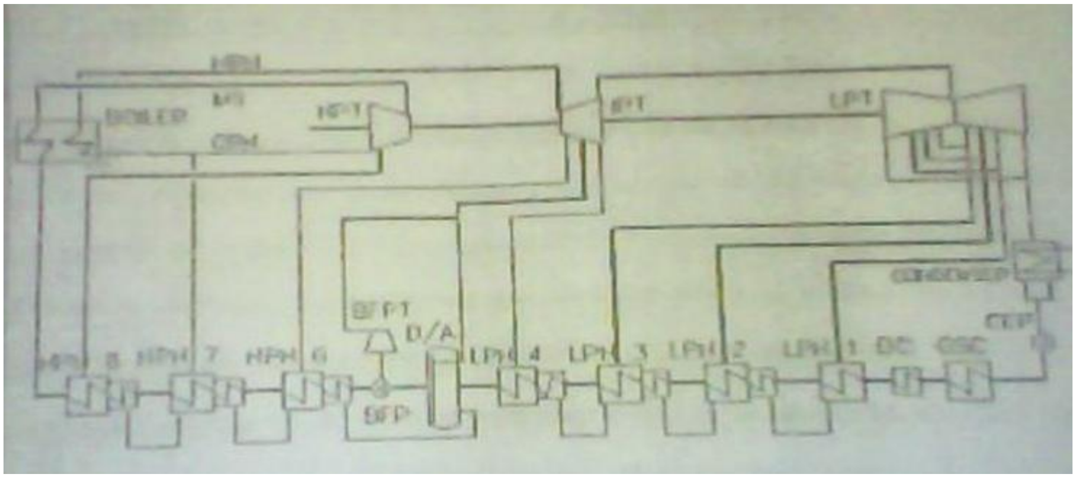

Fig 11. With 3 HP heaters, 4 LP Heaters

The feed water Temperature is raised to level of 290^0C, & possibility exists to increase it even further, considering the steam pressures adopted in the Steam Cycle. Supercritical plants are being adopted foe improved efficiency, low CO2 emission and reduced NOx, Sox, and particulate emission. In a supercritical plant, at critical pressure water transforms to steam spontaneously. The critical pressure and temperature is 22.1 bars and 374.15 deg C. Effect of steam parameters on turbine heat rate is such that for every 1 bar improvement of main steam pressure turbine heat rate could be reduced by approx. 0.015 %. For every 10^0C improvement of main steam temperature turbine heat rate could be reduced by 0.25 % to 0.30 %. For every 10 deg C improvement of reheat steam temperature, turbine heat rate could be reduced by 0.15 % to 0.20 %. Drivers for higher rated supercritical plants are demand for power, lower cost of generation, environmentally clean technology and lower requirement for fuel, land and water.

Table 2: Major differences of power cycle equipment [10]

Equipment	**Subcritical**	**Supercritical**
	500/600 MW	**660MW**
Boiler	Drum Type	Once Through Type
Turbine	1HP+1IP+1LP	1HP+1IP+1LP
LP heaters	3	4
HP heaters	2	3
Deaerator	1	1
Condensate extn. pumps	3X50%	3X50%
Boiler feed pumps	2X50%(TD)/ 1X50%(MD)	2X50%(TD)/ 1X50%(MD)
Vacuum pumps	2X100%	2X100%
HP bypass valves	2 NOS	2NOS
LP bypass valves	2 NOS	2 NOS

The Major differences in cycle equipment are outlined above in a tabular form. We see that the type of boiler has also changed from Drum type to a Drum Less or once through type, mainly to cater to the supercritical state of steam, thought it also gives tremendous benefits in load control & regulation over the whole load range. From the above descriptions we see that supercritical applications operating at very high pressures & temperatures have the inherent ability to contribute a great range of improvement in turbine cycle efficiencies. Realizing this advantage, the government of India has taken a decision to promote the use of such technology in our country by advocating a gradual shift to supercritical technology in the 12th plan period. By the 13th plan the Government envisages the total switchover to supercritical technology for utilities, thus contributing a great extent to a drastic reduction in Carbon Footprint & Global Warming. The major objective of the supercritical drive can then be characterized as to bring down equipment cost per MW and have more Efficient & Reliable product. Utilize available steam turbine modules for higher efficiencies of scale to provide higher competitiveness and to develop new & higher rating to cater to emerging market

4. Conclusions

Though older technologies like steam, hydro & nuclear turbines have progressed to dizzying levels, newer clean technologies like wind, tidal & solar have also gained major share of the grid in many countries. Though there exists an ongoing debate both in favour of & against these clean technologies as these are characterized by higher capital investment and longer pay back periods. Presently, base load in our country is generated by fossil fuel based power plants. Considering the high capital cost involved in new generation `` Clean Technologies``, developing countries like India having an abundance of cheap fossil fuel reserves have to give a major thrust to improvement in fossil-fired power technologies. We have also seen how the Steam Turbine based power station is prevalent in both the new as well as old technologies, in both the polluting as well as ``Clean Technologies”, thus emerging the leader of choice for power generation. Lastly the paper highlights how the power plant technologies including supercritical steam turbines to meet & exceed emerging requirements of society.

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