The Journal of CPRI,
Vol. 12, No. 2, June 2016 pp. 317-324

Energy environment implication in thermal power plant by using supercritical technology – Indian scenario

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In India, emissions of Green House Gases (GHGs) are increasing due to rise in energy demands to sustain economic growth. Coal is used as a dominant fuel in Indian thermal power plants but the efficiency of these is low in comparison with prevailing international standards. As such emissions of GHGs are much higher and feasible to achieve. The adoption of Clean Coal Technologies (CCTs) – like the Supercritical (SC) steam cycle – for new capacity addition in Indian thermal power plants will increase the efficiency of the Indian grid. These technologies are more environmentally and would help to meet increased energy demands. India has taken initiatives for the adoption of the technology as explained in the 11th plan of the Planning Commission. Finally, it is concluded from the study that SC and USC technology penetration would be helpful for reducing GHGs emission. The hypothetical scenarios analysis shows that up to 50% technology penetration for new capacity addition until 2027 would be helpful for reducing GHGs emission.

Keywords : *Green House Gases (GHGs), Clean Development Mechanism (CDM), Clean Coal Technology (CCT), LHV (Lower Heating Value)*

1.0 INTRODUCTION

India has a tremendous potential for CDM (Clean Development Mechanism) projects i.e. power generation based on a) High efficiency technologies (super critical technology). b) R&M (Renovation & Modernisation) of old scheme. c) Co-generation along with renewable energy sources as these also results in energy saving and displace associated CO_2 emission which otherwise would be produced by grid connected power stations[1-5].In India Green House Gases (GHGs) emissions from coal fired thermal power plants increase with increasing energy demands for the economic growth. If the country is to eradicate poverty and to meet human development needs 8% -10% economic growth over next 25 years. In order to sustain 8% -10% economic growth the demand for the energy must increase[1]. So one of the biggest challenges India is facing in terms of the quality of conversion system for energy production and how energy produced could be provided to the users in a most sustainable way at reasonable cost [2]. China and India Insights is another report which reveals that the economic growth target of India between 2007-2012 is 9% in the 11th five year plan[11]. For sustaining 8% -9% economic growth the corresponding growth of energy use is required and coal is the key source of commercial energy.

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2.0 OBJECTIVE OF THE STUDY

This study articulates that how adoption of supercritical technology would be helpful in meeting the energy needs for economic growth as well as for reduction of Green House Gases (GHGs) emission for improving the environmental profile of Indian power sector. Another objective of this study is to analyze how CCTs with reference to Supercritical (SC) and Ultra-Supercritical (USC) technologies would be helpful for thermal power plants in Indian power sector for fulfilling the goal of sustainability in this sector[6].

2.1 Super Critical Technology for Enhanced Energy Efficiency

Increasing efficiency of existing power plants using clean technologies and switching to fuels other than coal.

Adoption of ultra super critical boiler when their commercial viability under Indian conditions is established.

Supercritical units have higher plant efficiency than that of subcritical units because of higher steam parameters.

The Gross plant efficiency is around 40% -41% for supercritical units.

The advanced ultra supercritical units have reached an overall plant efficiency of 47% to 49% in the world [7].

2.2 Advantages of Supercritical Technology

Techno-economic benefits along with its environment - friendly cleaner technology; more and new power plants are coming-up with this state-of-the-art technology.

As environment legislations are becoming more stringent, adopting this cleaner technology have benefited immensely in all respect.

By raising the temperature from 580°C to 760° C thermal efficiency improves by about 4%. LHV (Lower Heating Value) is improved (from 40% to more than 45%), One percent (1%) increase in efficiency reduces by two percent (2%), specific emissions such as CO_2, NO_x, SO_x and particulate matters [7].

3.0 METHODOLOGY

3.1 Plant Load Factor

Plant Load Factor (PLF) is an important measure of the operational efficiency of thermal power plant[3]. It can be seen from Table 1 that Plant Load Factor (PLF) improves from 2002 to 2007 and also from 2007 to 2009 [2]. With the increase in the installed capacity and operational experience Plant Load Factor (PLF) has reached 78% in 2007. It is expected to increase further with the increase in the capacity addition for the future growth.

TABLE 1

PLANT LOAD FACTOR IMPROVEMENT FROM YEAR 2002 TO 2009

Year	Target (%)	Actual (%)
2002-03	70	72
2003-04	72	73
2004-05	73	74
2005-06	74	74
2006-07	76	77
2007-08	77	78
2008-09	79	77

The projected growth taken for this study is given in Table 2.

TABLE 2

PLANT LOAD FACTOR (PLF) GROWTH (%) TILL 2027

As on 31-03-2012	79
12^{th} Plan (2012-2017)	80
13^{th} Plan (2017-2022)	81
14^{th} plan (2022-2027)	82

3.2 Supercritical Technology Penetration Scenarios

According to working group report for 11th five year plan 18% of the total coal based capacity addition units based on Supercritical Technology. It is envisaged by the working group that capacity addition for 12th plan would increase to 50% -60% based on Supercritical Technology.

So, it was assumed for this study that there would be increase in the capacity addition in next five year plan as the number of design and manufacturing facilities are being set up in India.

This is a simple calculation exercise for calculating that how much Green House Gases (GHGs) emissions reduction are possible through penetration of advanced clean coal technologies (CCTs) such as Supercritical (SC) and Ultra Supercritical Technologies (USC) for coal based thermal power plants for each hypothetical scenario. Table 3 Emission Comparison Sub-Bituminous Coal [9].

TABLE 3
EMISSION COMPARISON SUB-BITUMINOUS COAL

Emission	Ultra Super Critical	Supercritical	Subcritical
SO_2 gm/MWh	413.14	440.38	454.99
Nox gm/MWh	290.56	308.72	317.8
CO2 Tones/ MWh	0.97	1.03	1.06

3.3 Method Used for Calculating Emissions Reduction

The steps involved for the calculations are as follows[8]:

1. Calculation of emission factors for Subcritical, Supercritical and Ultra Super critical Technology.
2. Calculation of weighted average emission factors for each period.
3. Calculation of total emissions for each period and scenario based on weighted average emission factor and the total generation of electricity.
4. Calculation of Emission reduction by the difference of emissions between a particular scenario and the scenario without Supercritical and Ultra Supercritical Technology Penetration (with sub critical technology only).

4. COMPARISON OF DIFFERENT SCENARIO

- Scenario – A (Absence of Supercritical and Ultra Supercritical Technology)
- Scenario – B (Low level of Supercritical and Ultra Supercritical Technology Penetration)
- Scenario–C(Moderate level of Supercritical and Ultra Supercritical Technology Penetration)
- Scenario – D (High level of Supercritical and Ultra Supercritical Technology Penetration)

4.1 Scenario –A

This scenario incorporates the existing government plans and policies. In this scenario the installed capacity is based on sub-critical technology. However, it is expected that all future capacity additions would be based on plants having efficiency equal to that for present 500 MW plants. In India the standard coal based plant is 500 MW with Sub-Critical Technology. In this scenario the total coal based power generation capacity is 124025 MW as on 31-03-2012. The projected total capacity addition for coal based thermal power plants during 12^{th} plan would be 83640 MW. Same capacity addition as for 12^{th} plan is recommended for 13^{th} plan and 14^{th} plan. Table 4 shows the Total Installed Capacity in Scenario-A [2].

TABLE 4		
TOTAL INSTALLED CAPACITIES (MW) IN SCENARIO - A		
Plan	**Capacity addition in each five year**	**Total installed capacity**
As on 31/03/2012	Subcritical 124025 Supercritical Nil Ultra Super critical Nil	124025
Beginning of 12th plan (2012-2017	Subcritical 207665 Supercritical Nil UltraSupercritical Nil	207665
Beginning of 13th plan (2017-2022)	Subcritical 291305 Supercritical Nil Ultra supercritical Nil	291305
Beginning of 14th plan (2022-2027)	Subcritical 374945 Supercritical Nil Ultra Supercritical Nil	374945

4.2 Scenario - B

This scenario assumes that 70% of the capacity addition would be subcritical where as for supercritical technology the capacity addition would be 20% and 10% for ultra-supercritical technology for each five year plan till 14th plan (2022-2027) respectively. Table 5 presents the level of technology penetration in each five year plan.

TABLE 5		
TECHNOLOGY PENETRATION IN EACH FIVE YEAR PLAN IN SCENARIO - B		
	Capacity addition in each five year	**Total installed capacity**
As on 31/03/2012	Subcritical 124025 Supercritical Nil Ultra supercritical Nil	124025
Beginning of 12th plan (2012-2017)	Subcritical 58548 Supercritical 16728 Ultra Supercritical 8364	207665
Beginning of 13th plan (2017-2022)	Subcritical 291305 Supercritical 16728 Ultra Supercritical 8364	291305
Beginning of 14th plan (2022-2027)	Subcritical 58548 Super critical 16728 UltraSupercritical 8364	374945

4.3 Scenario – C

In this scenario 60% of the technology would be sub-critical in each five year plan. On the other hand for supercritical and ultra supercritical for each five year plan the technology penetration is 25% and 15% respectively. The technology penetration level in this scenario in each five year plan till 14th plan is shown in Table 6

TABLE 6		
TECHNOLOGY PENETRATION IN EACH FIVE YEAR PLAN IN SCENARIO -C		
	Capacity addition in each five year	**Total installed capacity**
As on 31/03/2012	Subcritical 124025 Nil Supercritical Nil Ultra Supercritical Nil	124025
Beginning of 12th plan (2012-2017)	Sub critical 50184 Supercritical 20910 Ultra Supercritical 12546	207 665

Beginning of 13th plan (2017-2022)	Sub critical 50184 Supercritical 20910 Ultra supercritical 12564	291305
Beginning of 14th plan (2022-2027)	Sub critical- 50184 Supercritical 20910 Ultra supercritical 12564	374945

4.4 Scenario- D

In this scenario supercritical technology penetration is 30% and ultra-supercritical technology penetration is 20%.The sub critical technology assumed in this scenario is 50%. The technology penetration in each five year plans for scenario - D is given in Table 7.

TABLE 7

TECHNOLOGY PENETRATION LEVEL (MW) IN EACH FIVE YEAR PLAN IN SCENARIO - D

	Capacity addition in each five year	**Total installed capacity**
As on 31/03/2012	Subcritical 124025 Supercritical Nil Ultra Super critical Nil	124 025
Beginning of 12th plan (2012 - 2017)	Subcritical 41820 Supercritical 25092 Ultra Supercritical 16728	207665
Beginning of 13th plan	Sub critical 41820 Supercritical 25092 Ultra Supercritical 16728	291305
Beginning of 14th plan (2022-2027) 2027	Subcritical 41820 Supercritical 25092 Ultrasuper critical 16728	374 945

5.0 CALCULATION OF TOTAL EMISSION AND EMISSION REDUCTION UNDER DIFFERENT SCENARIOS TILL 2027

Table 8 presents net generation and absolute emission for 500 MW units and less than 500 MW units for year 2006-2007.

Emission Factor = Absolute Emissions

Net Generation

= 58721169.5/61372000

= 0.956 t CO_2/MWh

For Sub - Critical 500 MW units for 2006- 2007 net

TABLE 8

NET GENERATION (MWH) AND ABSOLUTE EMISSIONS (T CO_2) FOR 500MW UNITS (2006-2007)

Sr. No	**Plant Name**	**Net Generation (MWh)**	**Absolute Emission (tCO_2)**
1	Talcher	22356000	21238394
2	Rihand	15055000	14343401
3	Vindh Chal	9289000	9044126
4	Trombay	3828000	3788003
5	R-Gundem	3224000	3102701
6	Simhadri	7620000	7204544
	Total	**61372000**	**58721170**

For all power station in India from available reference [2] Emission tCO_2 is 377290081 and net generation is 340628000 MWh.

Emission Factor = Emissions

(Sub-critical) Net Generation

= 377,290,081

340,628,000

=1.1076(tCO_2)/ MWh

Table 9 represents Emission factor for Sub-Critical, Super-Critical and Ultra Super Critical technology based units of 500 MW and above for year 2006-2007.

TABLE 9

EMISSION FACTOR FOR SUB-CRITICAL, SUPER-CRITICAL AND ULTRA SUPER CRITICAL TECHNOLOGY BASED UNITS OF 500 MW AND ABOVE FOR YEAR 2006-2007

Sr. No	Unit rating (MW)	Percentage Generation efficiency	Emission factor (ef) (tCO_2/ MWh)
1	Subcritical (all as on March, 2007)	-	1.1076
2	Subcritical (500 MW)	34. 5	0.9568
3	Super-critical (660 MW)	35.5	0.9317
4	Ultra super critical (800 MW)	36.5	0.8978

Table 10 Presents the weighted average emission factor for four scenarios.

TABLE 10

WEIGHTED AVERAGE EMISSION FACTOR FOR FOUR SCENARIOS

Scenario	As on march 2012	Mar 2017	Mar 2022	Mar 2027
A	1.10	1.04	1.02	1.00
B	1.10	1.04	1.01	0.99
C	1.10	1.04	1.01	0.99
D	1.10	1.00	0.95	0.93

Table 11 Represents the total emission of Green House Gases in each five year plan.

TABLE 11

TOTAL EMISSIONS OF GREEN HOUSE GASES (GHGS) ($MTCO_2$)

Scenario	A	B	C	D
At the end of 11th plan (March-2012)	951	951	951	951
At beginning of 12th plan (March- 2017)	1612	1517	1511	1460
At beginning of 13th plan (March -2022)	2289	2095	2092	1981
At beginning of 14th plan (March -2027)	283	2689	2684	22515

Table 11 shows total emissions in four scenarios with the increase in installed capacity of coal based thermal power plant in each five year plan starting from 12th plan till 14th plan. It can be seen that there is increase in the CO2 emission with increase in the installed capacity in each five year within each scenario. There is reduction in emissions as the percentage of technology penetration increases from Scenario - A to technology penetration scenario B. There is very less total emissions reduction from Scenario - A to technology penetration scenario - B (30%).

It can be seen from Figure 1 the total installed capacity till 2027 in India during five year plans.

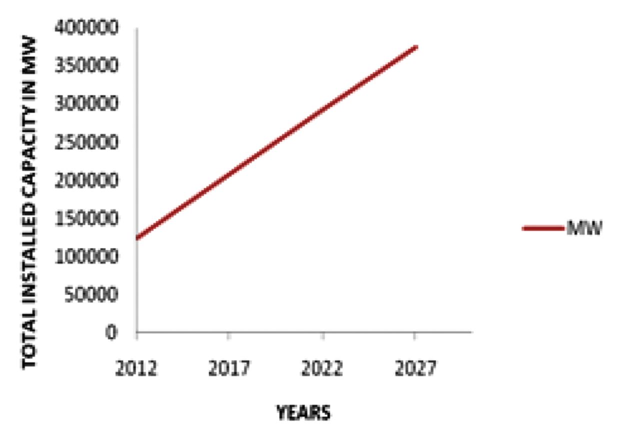

FIG. 1 TOTAL INSTALLED CAPACITY TILL 2027

The emissions reduction with the increase in the technology penetration in each five year plan till March 2027 can be seen in Table 12 and 13.

Table 12 Emission Reduction of Green House Gases (GHGs) ($MTCO_2$)

TABLE 12				
EMISSION REDUCTION OF GREEN HOUSE GASES (GHGS) ($MTCO_2$)				
Scena rio	**Mar. 12**	**Mar. 17**	**Mar.22**	**Mar 27**
A	0	949	1947	2944
B	0	974	197	3086
C	0	1524	3086	4686

Table 13 represents Percentage Emissions Reduction of Green House Gases (GHGs).

TABLE 13				
PERCENTAGE EMISSIONS REDUCTION OF GREEN HOUSE GASES (GHGS)				
Scena rio	Mar	Mar	Mar	Mar
	12	17	22	27
A	0	5.9	8.5	9.9
B	0	6	8.6	10.3
C	0	9.4	13.5	15.7

Table 14 represents Techno Economic Comparison Capacity of 500 V/s – 600 MW fuel Indian coal with 42% ash, Fuel-GCV-3200 Kcal/Kg[12].

TABLE 14				
TECHNO ECONOMIC COMPARISON CAPACITY OF 500 V/S – 600 MW				
Descrip-tion	**Unit**	**Sub-critic al**	**Supe-rcriti cal**	**Percent-age Re-duction**
Turbine Heat rate	KCal /kWh	1945	1850	95 (4.88)
Boiler Effici-ency	%	87	87	0
Plant Heat rate	kCal/ kWh	2236	2126	119 (4.89)
Coal consum-ption	MMT/ Annum	4.43	4.2	0.23(5.1)
Ash Generation	MMT/ Annum	1.86	1.77	0.1 (5.10)
Co_2	MMT/ Annum	5.55	5.27	0.28 (5.1)
$S0_2$	MMT/ Annum	0.04	0.04	0.0023 (5.1)

6.0 DISCUSSION

From the above literature it is predicted that coal will remain a dominant fuel for producing electricity in India till 2031. The environmental impacts associated with the coal based thermal power plants are emissions of CO_2, NO_x particulates and SO_x. Conventional Subcritical technology is presently used for coal based electricity generation. Adoption of the CCTs could be helpful for the reduction of the environmental impacts of the thermal power plants in Indian [10]. There is range of CCTs available such as Supercritical (SC) Technology, Ultra Supercritical (USC) Technology,Pressurised Fluidized Bed Combustion (PFBC) and Integrated Gasification Pressurised Combustion Cycle (IGCC). But India cannot afford to have expensive clean coal technologies,India needs technologies which are mature. Supercritical technology is one of the clean coal technologies which are mature and commercialized. Ultra-Supercritical Technology penetration would also be helpful in reducing Green House Gases (GHGs) Emissions. From the results of the technology penetration scenarios, it can be seen that there is increase in the reduction in Green House Gases (GHGs) emission in each five year plan. Although, there is very less difference for the percentage of reduction of emissions of Green House Gases (GHGs) from Scenario-A to Scenario - B there is huge difference between Scenario - C and Scenario – D as the percentage of the technology penetration increases from 40% to 50%.

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