MINIMIZATION OF GHG'S IN COAL BASED THERMAL POWER PLANTS

Kishor B. PORATE
Priyadarshini College of Engineering, Nagpur, India, +919881713585, kporate@yahoo.com

Krishna L.THAKRE
Viswesariya National Institute of Technology, Nagpur, India, +919890132808, k_thakre@yahoo.com

Ghanashyam L. BODHE
National Environmental Engineering Research Institute, Nagpur, India, +919823805550, gl_bodhe@neeri.res.in

Abstract: *Increased population and industrial development reflects on more demand of electricity. Around 65% electricity generation in India is due to coal based thermal power plants. Burning of coal result in generation of suspended particulate matter (SPM) and emission of flue gases like carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxides (NO_x). CO_2 is the main greenhouse gas responsible for global warming. SO_2 and NO_x when comes in contact with atmospheric humidity and aerosols, forms the mist which comes down as an acid rain. Global warming and acid rain detoriate quality of soil, water, plant growth and health of human being.*

This study and analysis based on comparison of Generation scheduling (GS) and optimal generation scheduling (OGS) programmed in MATLAB environment by Newton-Raphson method. Proposed scheme for the simulation and analysis comprises of five bus system with three coal based thermal generators and the load at four buses. This paper also deals with analysis of CO2, SO_2 and NO_x from various grades of raw, washed and mixed coal considering standard requirement of coal and emissions for generation of one unit electricity. . Comparisons of GHG's emissions have been made between without and with emission reduction control mechanisms. Modifications in the existing fuel firing system are suggested to improve the plant efficiency for CO_2 reduction. Combined active carbon adsorption and electron beam process method are suggested for the reductions of SO_2 and NO_x. Analysis have been made considering constant daily load cycle throughout the year.

Key words: *Coal based thermal power plant, Emission reduction controls, Global warming, Green house gases, Optimal Generation scheduling.*

1. Introduction

In India around 65% electricity is generated by coal based thermal power plant. Coal based power plants are the main producer of flue gases like CO_2, SO_2, NO_x etc. and suspended particulate matter. Quantity of these emissions are dependent on quality and quantity of coal. CO_2 is main greenhouse gas and mainly responsible for global warming due to its large emission and higher concentrations. Nearly 21.3% of GHG's are emitted by coal based thermal power plants [1-2]. SO_2 and NO_x are treated as acidifying emissions and generate acid rains when contact with the water and humid in the environment [3-4]. These emissions are harmful for environment and human being. To control CO_2 emissions, around thirty eight developed countries signed the Kyoto Protocol in December 1997 to reduce CO_2 emissions by 5% between 2008 and 2012 in relation to the levels registered in 1990 [5].

Several methodologies and techniques are suggested for the reduction of major flue gases and to improve the plant efficiency. Modification in the existing system, Clean coal technology, switching of fuels, washing of flue gases and Flue Gas Desulphurization (FGD), etc. are some of the options. Modifications in the burners, fuel balancing, and coal combustion with excess air, etc. may be suggested to reduce CO_2 up to 15%. To make modifications in the existing is comparatively simple and cheap but very less flue gases are minimized whereas about 90 % flue gases are reduced with chemical processes which are complicated and costly [6-7].

CO_2 can be reduced by using good quality coal and washed coal which further improves the calorific value and reduces the ash. CO_2 reduction is also achieved by absorption into liquid solvents, adsorption on solids chemical conversion, use of Integrated Gasification Combined Cycle (IGCC), hybrid oxy-fuel combustion thermodynamic cycle, increasing steam pressure, temperature and controlling the excess air [8-9].

SO_2 due to burning of coal can be reduces with the Emission Reduction Controls (ERC) like FGD process. In FGD process, mixture of limestone and water is sprayed over the flue gas and this mixture reacts with the SO_2 to form gypsum as a by-product [10-11]. In this chemical process of FGD, reduction of SO_2 occurs up to 90% but the process generates CO_2 emissions which enhance the impact of greenhouse effect which further increases global warming. [12-13-14].

Technologies to reduce NO_x emissions are combustion modifications and flue gas treatment. Combustion modifications include the use of low NO_x burners, optimal boiler designs, plant operating conditions, overfier technology, reburn of fuel, etc.

Flue gas treatment technologies are as; Selective catalytic reduction (SCR) is a post-combustion control technology which reduces NOx up to 90% with the injection of ammonia during process (NH_3) [15].

Selective non-catalytic reduction (SNCR) technology is also suggested for NO_x reduction to N_2 by injecting ammonia in the combustion gases at high temperature [16-17]. The injection of an intense pulsed relativistic electron beam (IREB) into a flue gas and magnetic pulse compression (MPC) modulator are also suggested for flue gas treatment to reduce SO_2 and NO_x [18-19].

Circulating Fluidized Bed combustion technology (CFB) is suggested in comparison with conventional pulverized-coal (PC) type of boilers to reduce SO_2 and $NO_{x..}$ CFB has its advantages like, high-efficiency combustion of low-calorific fuels, high-efficiency sulphur oxide capture through limestone addition to the furnace and low nitrogen oxide emissions without additional high-cost methods [20].

Combined methods like active carbon adsorption method and Electron beam process are suggested for simultaneous reduction of SO_2 and NO_x. These methods remove SO_2 and NO_x up to 98% and 80% respectively. The electron beam process involves an electron beam to irradiate SO_2/NO_x in exhaust gas and injected NH_3 to cause a reaction for their recovery as ammonium sulfate and ammonium nitrate as by-products which are used as fertilizers [21-22-23].

2. Problem formulation

Chemical composition of the coal is defined in terms of its proximate and ultimate analysis. The parameters of proximate analysis are moisture, volatile matter, ash, and fixed carbon. Ultimate analysis deals with quantitative determination of carbon (*C*), hydrogen (*H*), nitrogen, sulfur, and oxygen (*O*). The calorific value Q (Kcal/kg) of coal is the heat liberated by its complete combustion with oxygen. Gross Calorific value (GCV) Q is determined by Dulong formula which is expressed as,

$$Q = (144.4\%[C]) + (610.2\%[H]) - (65.9\%[O]) + (0.39\%[O^2] \quad [1]$$

Indian coal is classified by its grades defined on the basis of Useful Heat Value (*UHV*). *UHV* is an expression derived from ash in percentage (*A*) and moisture contents in percentage (*M*). *GCV* and net calorific value (*NCV*) are derived from *UHV*.

$$UHV = 8900 - 138(A + M) \quad [2]$$

$$GCV = (UHV + 3645 - 75.4M)/1.466 \quad [3]$$

$$NCV = GCV - 10.02M \quad [4]$$

Equations [1] to [4] indicates that calorific values of coal are depend on and related with percentage of carbon, hydrogen, oxygen, ash and moisture contents in a given grade of coal.

Data deals with UHV, GCV and NCV for various grades of coal, washed coal and quantity of coal (Indian) required to generate one unit of electricity is obtained from central fuel research Laboratory (CFRI), Jharkhand, India, and reported in Table 1.

Due to shortages of quality coal, F- grade raw coal is widely used for electricity generation in Indian thermal power plants. In some power plants combination of raw and washed coal is used in the mixed mode. Chemical contents of the F-Grade coal with their ash and moisture contents are shown in Table 2.

Table 1. Coal grades with their calorific values and coal required for generation unit electricity

Coal Grade	UHV Kcal/Kg	NCV Kcal/Kg	GCV Kcal/Kg	Coal required Kg/kWh
D	4511	5207	5266	0.55
E	3670	4529	4604	0.67
F	2927	3985	4066	0.79
Washed coal F	3327	4385	4466	0.72
F+50% Washed	3127	4185	4266	0.745

Table 2. Chemical contents of F-Grade coal

Coal	C%	H%	S%	N_2%	O_2%	A%	M%
F	37.69	2.66	0.8	1.07	5.78	47	5

In coal based thermal power plants coal burns with 10-30% excess air and with the chemical process carbon is converted to CO_2, hydrogen and sulfur are converted to moisture H_2O and SO_2. Nitrogen converted to NO_x and it is increases with excess air. Oxides of nitrogen are nitrous oxide (N_2O), nitric oxide (NO), and nitrogen dioxide (NO_2). NO_2 is mostly formed by oxidation of the NO, which is discharged in combustion products. About 90% of the NO_x is in the form of NO. NO_x emissions are generally functions of flame temperature, excess air, boiler conditions, nitrogen content in the coal and rate of gas cooling. In pulverized coal flames, about 30 - 35% of nitrogen in coal gets converted into NO and remaining nitrogen in the coal gets converted into molecular nitrogen.
The concentration of nitric oxide (NO) is given by

$$X_{NO} = K_{10.1} (X_{N2})^{0.5} (X_{O2})^{0.5} \quad [5]$$

Where X is the species concentration and $K_{10.1}$ is a equilibrium constant and depends upon the temperature of the gas. As per chemical process NO concentration increases whereas CO_2, SO_2 concentration decreases with the increase in excess air [24].

Average values of CO_2, SO_2, and NO_x emissions per unit of electricity for different coals are mentioned in Table 3.

Table 3. Average emissions of flue gases per unit of electricity for different coals

Pollutants Gm/Kwh	Raw coal	Washed coal	50% (Raw + Washed coal)
CO_2	991	791	891
SO2	6.96	6	6.48
NO_x	7.2	2.28	4.74

3. Proposed Methodology

In the proposed method, Newton –Raphson method programmed in MATLAB environment is suggested for GS and OGS. With OGS generator contributions are precise and generation is comparatively less for same load which reduces the losses, coal consumption and emissions. Emissions for various grades of coal are carried out by considering standard emissions and coal required for generation of one unit electricity. Modifications are suggested in the existing system for reduction of CO_2. Active carbon adsorption and electron beam process method jointly suggested for simultaneous reduction of SO_2 and NO_x. These methods remove SO_2 and NO_x up to 98% and 80% respectively.

4. System Simulation

Proposed scheme considered for the analysis and simulation shown in figure 1, comprises of three coals based thermal power plants, five bus system with four loads L2, L3, L4 and L5 connected at buses B2, B3, B4 and B5 respectively. Line impedances and capacitive susceptances of proposed scheme are shown in Table 4. All coal based thermal power plants are of 100 MVA and their maximum and minimum power generation limits are 10 and 85 MW.

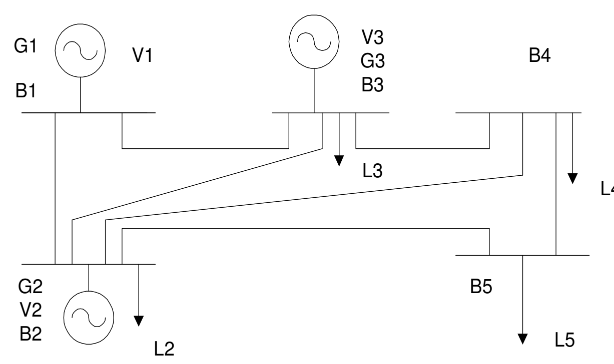


Fig.1. Proposed five bus scheme

Table 4.Line Impedances and capacitive susceptance of system

Line	Impedances	capacitive susceptance 1/2B
1-2	0.02 + j0.06	0.030
1-3	0.08 + j0.24	0.025
2-3	0.06 + j0.18	0.020
2-4	0.06 + j0.18	0.020
2-5	0.04 + j0.12	0.015
3-4	0.01 + j0.03	0.010
4-5	0.08 + j0.24	0.025

GS and OGS are carried out by proposed method for a constant load of 150 MW. Total generation in GS and OGS are 153.051 MW and 152.16 MW respectively. With OGS power losses are saved by 0.891 MW for a same which reflects on saving of coal and emissions [25-26-27]. Individual generator contributions are reported in Table 5.

Table 5. Generation scheduling and optimal Generation Scheduling

G1 - MW		G2-MW		G3-MW	
OGS	GS	OGS	GS	OGS	GS
23.65	83.051	69.52	40.00	59.00	30.00

Analysis also deals with GHG's emissions from F-Grade raw, washed and mixed coal considering with and without ERC. Comparative analysis has been made for each GHG's emission from raw and washed coal assuming constant daily load cycle throughout the year for 300 days . Generation by the plant as per the daily Load cycle is as shown in Figure 2.

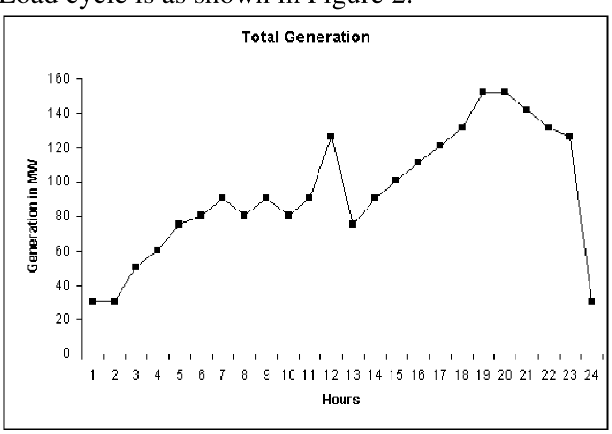


Fig. 2. Generation by plant as per Load cycle

OGS of each generator for every variation of load and total generation is reported in Table 6. Total electricity generated during the day is 2338.57 MWh.

Table 6. Optimal Generator contribution for variable loads

Load MW	G1 – MW	G2-MW	G2-MW	Total - MW
30	10.00	10.27	10.00	30.27
50	10.00	29.08	11.49	50.57
60	10.00	37.50	12.90	60.40
75	10.00	42.08	23.38	75.46
80	10.00	44.25	26.25	80.50
90	10.03	48.58	32.03	90.63
100	15.64	51.38	33.84	100.86
110	17.38	55.38	38.20	110.95
120	20.86	58.23	42.06	121.15
125	22.61	59.66	44.11	126.38
130	21.96	64.55	45.13	131.63
140	22.36	67.03	52.28	141.67
150	23.65	69.52	59.00	152.16
	Total energy during 24 Hours			2338.57

CO_2, SO_2 and NO_x emissions in Tons are calculated without and with ERC for raw, washed and mixed coal. These emissions are calculated for every variation in load, considering ERC and without ERC. With ERC, and making modifications in system emissions are reduced. Comparative emissions for different coal with and without ERC for CO_2, SO_2 and NO_x are shown in figures 3, 4 and 5 respectively.

4.1 Analysis yearly basis

Analysis has been made for emissions considering 300 working days. Generation is considered as reported in figure 2.

Calculations for Raw coal,

Total units of electricity generated for 300 days are,

Units generated/day * 300 = 300 *2338.57

= 701570 MWh = 701570000 kWh.

Raw coal required/year = 701570000 * 0.79

= 554240 Ton

CO_2 emissions/year without ERC = 695256 Ton

CO_2 emissions/year with ERC = 590968 Ton

SO_2 emissions/year without ERC = 4883 Ton

SO_2 emissions/year with ERC = 98 Ton

NO_x emissions/year without ERC = 5051 Ton

NO_x emissions/year with ERC = 505 Ton

Total emissions/year without ERC = 705190 Ton

Total emissions/year without ERC = 591571 Ton

Analysis of emissions also have been made for washed and mixed coal and reported in Table 7. Comparative analysis on yearly basis of each emission for variety of coal is shown in figure 6.

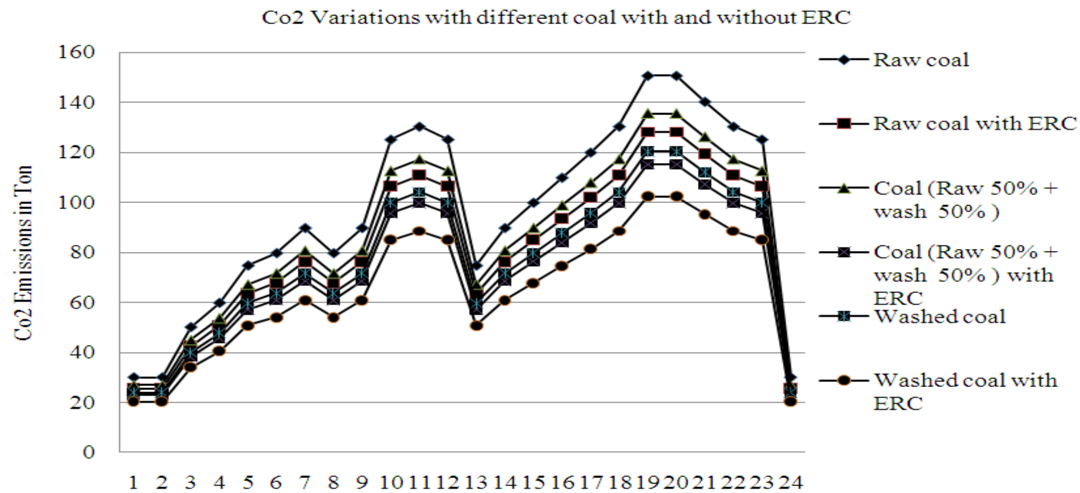


Fig.3. Variations of CO_2 for different coals with and without ERC

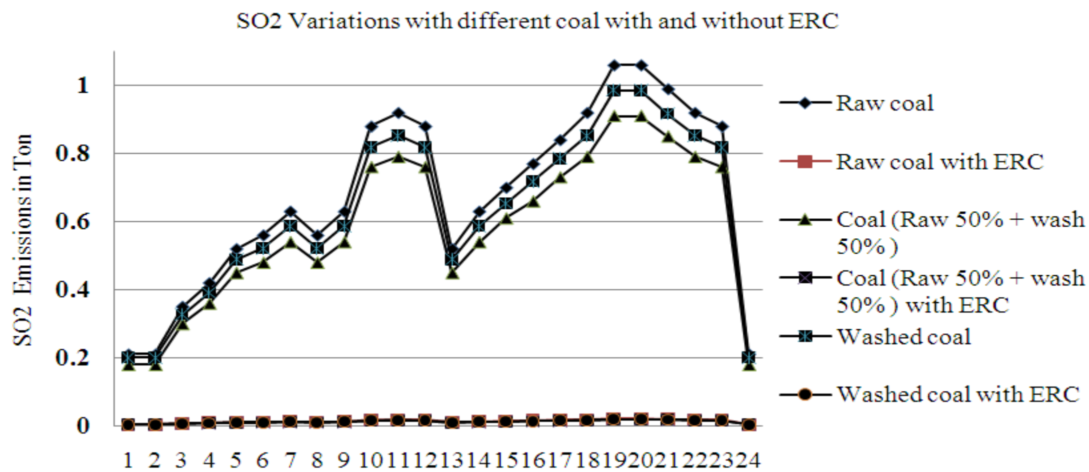


Fig.4. Variations of SO_2 for different coals with and without ERC

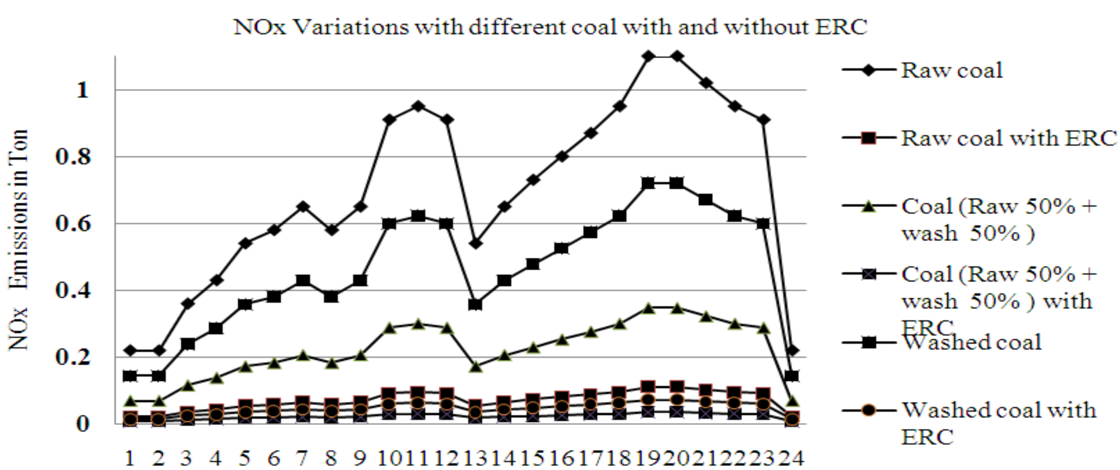
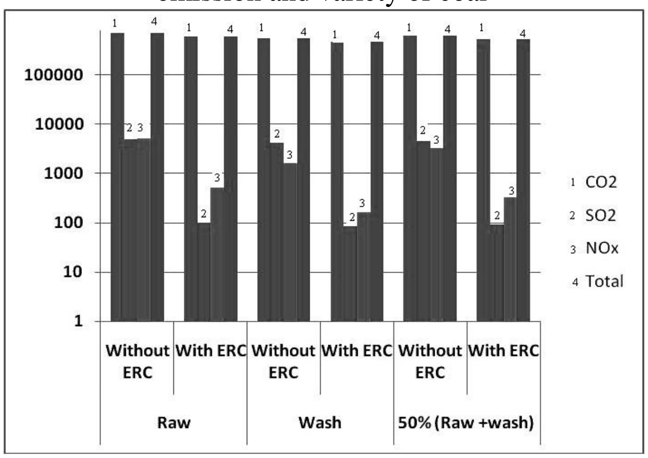


Fig.5. Variations of NO_X for different coals with and without ERC

Table 7. Comparative analysis on yearly basis for each emission and variety of coal

Emissions Ton	Raw coal		Wash Coal		50% (Raw + wash)	
	Without ERC	With ERC	Without ERC	With ERC	Without ERC	With ERC
CO_2	695256	590968	554942	471700	625099	531334
SO_2	4883	98	4209	84	4546	91
NO_x	5051	505	1600	160	3325	333
Total	705190	591571	560751	471944	632970	531758

Figure 6. Comparative analysis on yearly basis for each emission and variety of coal



5. RESULTS

Electrical power system with three coal based thermal power plants, transmission line and loads are considered for study and simulation. Generation scheduling and optimal generation scheduling is carried out through MATLAB programming. With OGS for a same load of 150 MW, generation is saved by 0.891 MW which reflects on saving of coal consumption and GHG's.

With the modifications in the existing system CO_2 emissions are reduced up to 15%. Implementation of active carbon adsorption and electron beam process method simultaneously reduces SO_2 and NO_x emissions by 90% and 98% respectively. Variations in the GHG's emissions are observed as per the grades of coal considering ERC and without ERC. These variations are reported in figures 3, 4, 5 and 6 respectively. Maximum environmental emissions are observed in case of raw coal without ERC and minimum in wash coal with ERC.

In raw coal with the application of ERC CO_2, SO_2 and NO_x emissions are reduced by 104288, 4785 and 4546 Ton /Year. Further with the use of mix coal and ERC these emissions are reduced by 59634, 7 and 172 Ton /Year. With the suggestion of wash coal and ERC, total reductions in CO_2, SO_2 and NO_x emissions are possible up to 223556, 4799 and 4891 Ton/year.

6. CONCLUSION

In this study Newton-Raphson method is suggested to determine GS and OGS of the coal based thermal generators. In OGS generation saving is observed, which saves large amount of coal and GHG's in long term. As per modification suggested in the fuel firing and injecting system, plant efficiency improves and CO_2 can be reduced up to 15%. Utilization of wash coal further reduces CO_2 by 17.15%. With the modification in system and utilization of washed coal CO_2 reduces up to 32.15%. With the suggestion of active carbon adsorption and Electron beam process simultaneous methods, removal of SO_2 and NO_x are possible up to 98 % and 90% respectively. Emissions are found minimum in wash coal with ERC and maximum in raw coal. Saving of total emissions in long term reduces green house effect which reflects on global warming and minimizes the problems of acid rains.

References

1. Barnali Nag.: *Estimation of carbon base lines for power generation in India; the supply side approach*, Elsevier journal on energy policy, Vol.34, pp.1399-1410, 2006.
2. Marion, J., Nsakala, N., Bozzuto, C., Liljedahl, G., Palkes, M., Vogel, D., Gupta, J.C., Guha, M., Johnson, H., and Plasynski, S., : *Engineering Feasibility of CO2 Capture on an Existing US Coal-*

Fired Power Plant, 26th International Conference on Coal Utilization & Fuel Systems, Clearwater, FL, pp.1-15, March 5-8, 2001.

3. Jason Dinsdale,: *The Environment Agency-Privacy Policy*, 14 Nov.2006.
4. Farshid Zabihian, Alan Fung,: *Fuel and GHG Emission Reduction Potentials by Fuel Switching and Technology Improvement in the Iranian Electricity Generation Sector,* International Journal of Engineering (IJE), Volume (3): Issue (2), pp.159-164.
5. Electo Eduardo Silva Lora, Karina Ribeiro Salomon,: *Estimate of ecological efficiency for thermal power plants in Brazil,* Elsevier journal of Energy Conversion and Management, vol. 46, pp. 1293–1303, 2005.
6. El-keib, A.A., Ma, H., Hart, J.L.,: *Economic dispatch in view of the clean air act of 1990* ,IEEE Transaction on power system, vol.9, pp.972-978, May 1994.
7. Helsin, J.S., Hobbs, B.F., *A muti objective production costing model for analyzing emission dispatch and fuel switching*, IEEE Transaction on power system, vol. 4, pp. 836- 842, Aug.1989.
8. Ba-Shammakh, M. , Elkamel*, A. , Douglas, P., Croiset, E.: *Optimal Air Pollution Control Strategies with Application to the Power Generation Sector*, Proceedings American Meteorological Society 12th Conference on Cloud Physics, Madison, WI.PP.1-15, 10 – 14 July 2006.
9. Chenhua Gou, Ruixian cai and Guoqiang Zhang,: *An advanced zero emission power cycle with integrated low temperature thermal energy*,Elsevier journal on applied thermal engineering,vol. 26, pp. 2228-2235, 2006.
10. Orfanoudakis, N.,Vakalis, A., Krallis, K., Hatziapostolou, A., Vlachakis, N.,: *Emission Reduction Techniques & Economics in Coal-Fired Power Plants,* pp. 1-14.
11. Prasad, D.S.N. , Rashmi Sharma, Shveta Acharya, Meenakshi Saxena, Arun Kumar Sharma,: *Removal of Sulphur Dioxide from Flue Gases in Thermal Plants*, Vol.3, No.2, pp.328-334, 2010.
12. Sulfur Oxides: *Pollution Prevention and Control, Pollution Prevention and Abatement*, Handbook, WORLD BANK GROUP, July 1998.
13. Paul S. Nolan,: *Flue Gas Desulfurization Technologies for Coal-Fired Power Plants,* Coal-Tech 2000 International Conference, Jakarta, Indonesia, November 13-14, 2000.
14. Chaaban, F.B., Mezher, T., Ouwayjan, M.,: *Options for emissions reduction from power plants:an economic evaluation,* Elseviers journal of Electrical Power and Energy Systems, vol. 26,pp. 57–63, 2004.
15. Foerter, D. , Jozewicz, W.,: *Cost of Selective Catalytic Reduction (SCR) Application for NOX Control on Coal-fired Boilers,* EPA/600/R-01/087, October 2001.
16. Xudong Gao, Baomin Sun, Shuie Yin, Yun Liu, Peishuo Bai and Lei Wang,: *Effect of NO Concentration on Effectiveness of Barrier Discharge Treatment Flue Gas Pollutants,* IEEE explorer conference at Beijing, China, pp. 5-10, 2010.
17. Shunsuke Tsukamoto, Takao Namihira, Douyan Wang, Sunao Katsuki, Reuben Hackam, Hidenori Akiyama, Akihiro Sato, Yoshitaka Uchida, and Masami Koike, : *Effects of Fly Ash on NOx Removal by Pulsed Streamers,* IEEE Transaction on Plasma Science, Vol. 29, No. 1, pp.29-37, February 2001.
18. Go Imada, Weihua Jiang and Kiyoshi Yatsui,: *Flue Gas Treatment of Nitrogen Oxides by Pulsed Relativistic Electron Beam, fitreme Energv-Density*, Research Institute, Nagaoka University of Technology, Japan, IEEE, pp. 1150-1154.2002.
19. Young-Wook Choi, In-Wha Jeong, Geun-Hie Rim,, Evgeny Pavlovitch Pavlov, Chang-Sik Choi, Hong- Ki Chang, Mee-Hye Woo, and Seong-Poong Lee,: *Development of a Magnetic Pulse Compression Modulator for Flue Gas Treatment,* IEEE Transaction on Plasma Science, Vol. 30, No. 5, Pp.1632-1637, October 2002.
20. Russkikh, E.E., Novosibirsk,: *Influence of Coal Grade on the Technical and Economical Efficiency of CFB-Units,* IEEE explorer, pp.386-390, 2007.
21. Hanada et al.,: *Dry Desulfurization-Denitration-Technology Dry Active Carbon-Method Sulfur Recovery Formula at Coal Thermal Power Plant,* Thermal/Electronic Power Generation, Vol. 40, No. 3, 1989.
22. *Renewing Isogo Thermal Power Plant" pamphlet, J-POWER. Research and development*: J-POWER; Sumitomo Heavy Industries, Ltd.;

Mitsui Mining Co., Ltd.Project type: Voluntary support project for coal utilization promotion Research and development: Ebara Corporation; Chubu Electric Power Co., Inc.; Japan Atomic Energy Research Institute, clean coal technology, japan

23. Aoki,: *Electronic Beam Flue Gas Treatment Technology*, Fuel Association Journal, Vol. 69, No. 3, 1990.
24. Moti L. Mittal, Sharm C.,:*OSC Research, Anthropogenic Emissions from energy activities in india, Generation and source characterization, Emissions from thermal power plants in India*, 2006.
25. Hadi Saadat, : *Power System Analysis, Tata McGraw-Hill Edition,* New Delhi, 2010.
26. Dhillion, J.S., Kothari, D.P.: *Economic emission load dispatch using binary successive approximation– based evolutionary search*, Transac.IET, Generation, Transmission and Distribution, vol 3, no 01, pp. 1-16, 2009.
27. Varadarajan, M., Swamp, K.S.: *solving multi-objective optimal power flow using differential evolution,* Transac. IET, Generation, Transmission and Distribution, vol. 02, no. 5, pp. 720-730, 2008.