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Performance Evaluation of Coal Based Thermal Power Plants in India

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Abstract

Prior to Independence Power Sector in India was mainly controlled by Britishers and governed by Electricity Act, 1910 which regulated the operations of licenses of electricity companies. With the advent of independence, leaders and planners of India had the consensus of reorganizing the structure of Indian economy. Uninterrupted supply of power is the precondition for rapid growth of industrialization. Enthusiasm of private investment in such industries was not very encouraging. The Indian Government, therefore, initiated the steps of nationalization of the electricity sector. However, post Electricity Act of 2003, again the role of private sector in generation and distribution of electricity has greatly increased. The sources of data and information for the study are Annual Reviews of Performance of Thermal Power Stations, General Reviews (Annual), Annual Reports published by Central Electricity Authority (CEA), Ministry of Coal, Power, Government of India and Websites of Thermal Power Stations located in different states. The study will include input and output variables such as Capacity, Generation, Maintenance, Outage, Operating Availability, Plant Load Factor, Fuel Consumption etc. on which data would be readily available.

Keywords: Thermal, PLF, FO, MU, Kwh.

1. Introduction

Prior to Independence Power Sector in India was mainly controlled by Britishers (Kale, 2004) and governed by Electricity Act, 1910 which regulated the operations of licenses of electricity companies. With the advent of independence, leaders and planners of India had the consensus of reorganizing the structure of Indian economy. Overwhelmed by the historic success of perspective planning with greater role of State in erstwhile USSR, leaders were enthusiased for setting up the big and heavy industries under the public sector enterprises with commanding heights because such industries require huge investment, have long gestation period and are natural monopolies with their product falls in the realm of merit goods. Enthusiasm of private investment in such industries was not very encouraging. However, uninterrupted supply of power is the pre condition for rapid growth of industrialization. The Indian Government, therefore, initiated the steps of nationalization of the electricity sector. The Electricity Act, 1948 led to the establishment of State Electricity Boards (SEBs) which were entrusted with triple role of electricity generation, transmission and distribution (Choukroun, 2001). The Act also paved the way for the creation of Central Electricity Authority (CEA) for developing sound adequate National Power Policy and co-ordinate the activities of concerned Planning Agencies. For realizing the objective of establishment of big and heavy industries including power generation industry, Government of India enunciated the economic planning in 1951 and period of First Five Year Plans was 1951-56. However, big thrust for achieving the

above objective got impetus with the onset of Second Five Year plan (1956-61) that continued for the next four decades.

The Constitution of India has made clear division of jurisdiction over infrastructure sector exclusively for Central Government (Centre List), some sectors exclusively for State Government (State List), and some sector in which both State and Central Government can legislate (Concurrent list). Electricity is placed in concurrent list, hence this sector is co-ordinated by Five Union Ministries viz. Ministry of Power, Ministry of Coal, Ministry of Renewable Energy, Ministry of Petroleum and Gas, Department of Atomic Energy, Ministry of Power and related departments of individual states. In terms of resource allocation highest priority was given to power sector in India during different Five Year Plans upto Eleventh Five Year Plan period i.e. 1951 to 2012, both Plan outlay and Actual Expenditure ranged between 9% to more than 20%. As a result, there was rapid expansion of Power Sector in India. During 1970s and 1980s, the regional political parties emerged which followed the appeasement policy of subsidized or free power and State Electricity Boards became victim of this rat race and many other unviable decisions (Fatima, S. & Barik, K. 2012). Political interference further aggravated the efficiency of SEBs which became instruments of populist politics. (Kale,2004).

New Economic reforms initiated in1991 further necessitated the amendment in electricity act to involve the private efforts and its involvement in the generation of electricity sector. The Electricity Regulatory Commission Act, 1998 provides for setting up of Central/State Electricity Regulatory Commission with the power to determine tariffs and distancing of Government from tariff determination. Electricity Act, 2003 further restructured the power sector in India including delicensing and participation of private sector. SEBs took the new role of corporations rather than Government Departments, and encouraged unbundling of SEBs.

2. Profile of Indian Power Sector

There are several sources of electricity generation in India such as Thermal, Hydel, Nuclear and Renewable sources but Thermal and Hydel are the main sources of electricity generation. During Post Independence period, Public Sector Undertakings took the commanding height in power generation in India and both Central Government as well as State Government played a dominant role. Fifth Five Year Plan (1974-79) onwards, Central Government got involved in a big way to supplement the efforts of State Government in power generation and transmission. The National Thermal Power Corporation (NTPC) and National Hydro Electric Power Corporation (NHPC) were set up in 1975. During 1960s, India began utilizing grid management to form 5 regional grids viz. Northern, Western, Eastern, North Eastern and Southern region. For constructing, operating and maintaining the inter-state and Inter regional transmission systems, National Power Transmission Corporation (NPTC) was set up which was renamed as Power Grid in 1992.

As a result of efforts made by Central Government, State Government and Private sector, India is third largest producer and fourth largest consumer of electricity. The electricity consumption in agriculture was recorded highest (17.89%) in 2015-16, among all countries. As per the statement of Central Electricity Authority (CEA) on March 29, 2017, India became net exporter of electricity and exported 5798 gwh to neighbouring countries against a total import of 5585 gwh. The total installed capacity on Dec. 31, 1947 was 1362 mw of which 854 mw was thermal power and 508 mw was hydropower and this has increased to 3,29, 231 mw of which 2,20,576 mw (67.0%) was thermal power, 44614 mw (13.6%) was hydro, 6,780 mw(2.1%) was nuclear power and 57, 260 mw (17.4%) was from renewable sources that includes small

hydro projects, biomas gasifies, biomas power, urban and industrial waste power, solar and wind energy (Monthly Report of CEA on 30.06.2017). The share of Central Government, State Government and Private sector in total installed capacity was 25%, 32% and 43% respectively as per the report of CEA on 30.06.2017. Thermal Power can be generated from Coal, Gas and Oil. As per the monthly report of CEA on 30.06.2017, Coal fired thermal power generation constitutes 88.2% (i.e. 1,94,533 mw of total of 2,20,576 mw), gas based thermal power constitutes 11.41% (i.e. 25,85 mw of total of 2,20,576 mw) and oil based thermal power constitutes 0.37% (i.e. 838 mw of total of 2,20,576 mw).

For the year 2017-18, electricity generation target from conventional sources was fixed at 1229.400 billion units (BU) comprising of 1042.028 BU thermal, 141.400 BU Hydro, 40.972 BU Nuclear and 5.000 BU import from Bhutan. This shows a growth of 5.97% over actual generation of 1160.141BU during 2016-17. As against the target for 2017-18, upto June, 2017 energy generation from conventional source was 307.663 BU which shows a growth of 3.74%. Sector wise plant load factor for coal and lignite based thermal power plants for 2016-17 was 71.98% (Central), 54.35% (State), 55.73% (Private) as against National average of 59.88% while for 2017-18 upto June 2017, PLF was 73.75% (Central), 59.17% (State), 57.20% (Private) against the national average of 64.49%.

The availability of power supply position during 2016-17 was 11,35,334 million units (MU) against the requirements of 11,42,929 MU with a deficit of 7595MU while for 2017-18 upto June, 2017, availability of Power Supply portion was 3,07,755 MU against requirement of 3,09,680 MU with a deficit of 1925 MU.

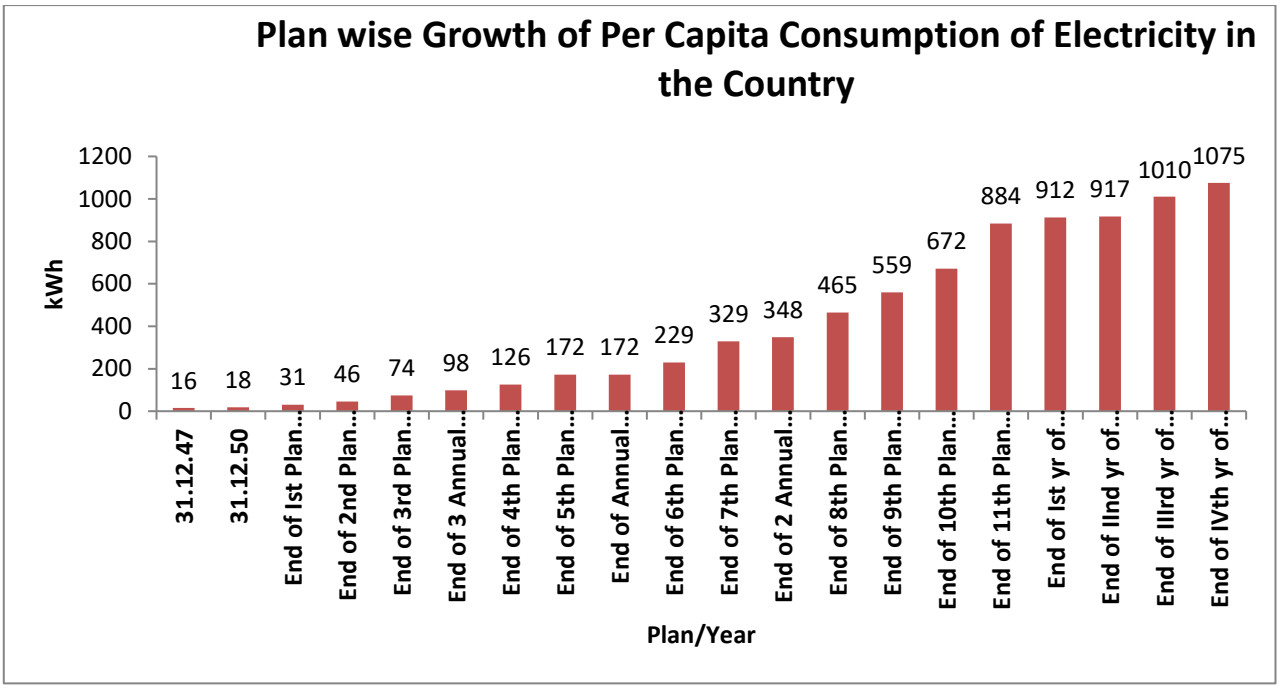
Over 1.4 billion people in the world have no access to electricity and India accounts for over 300 million of this number. As per the estimates of International Energy Agency, India needs to add between 600gw to 1200gw of additional new power generating capacity before 2050. Total capacity addition in thermal power in India during XIIth plan was 72339.6mw comprising 14877 mw (Central), 13922mw (State) and 43540mw (Private).

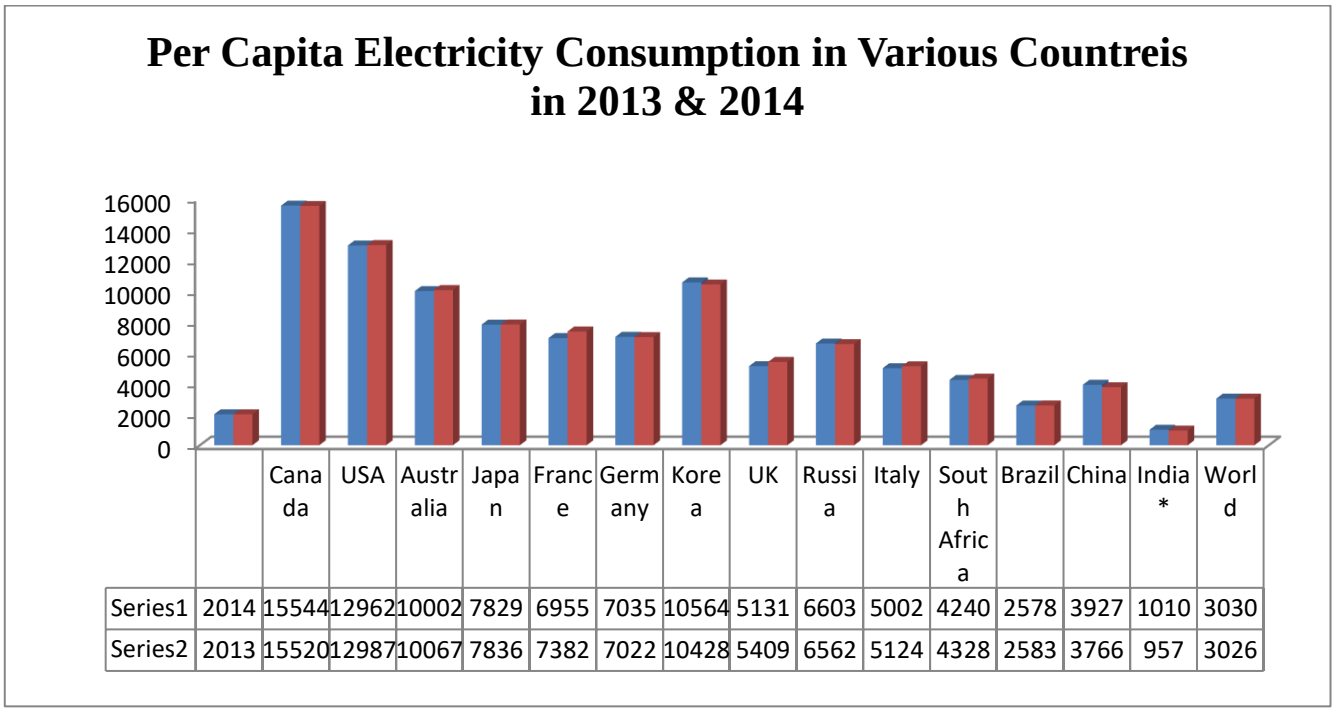
There has been continuous increase in the per capital consumption of electricity measured in kwh from 16.3 on December 31, 1947 to 1122 on March 31, 2017. For the distribution of electricity various groups of consumers such as Domestic, Commercial, Industrial, Traction, Agriculture and miscellaneous have been formed. The growth of electricity consumption in India as percentage of total shows that as on March 31, 2017 industrial group consumed the highest percentage of electricity (40.01%) followed by domestic (24.32%), agriculture (18.33%), commercial (9.22%), miscellaneous (6.50%) and traction (1.61%).

As on May 31, 2017 about 99% of villages in India were electrified and electrification rate was 100% in 13 states and 7 Union Territories. Upto Dec. 31, 2016, only 74% of total rural households were provided with electricity. Ministry of Power, Government of India launched Deen Dayal Upadhyaya Gram Jyoti Yojna (DDUGJY) in July, 2015 with the objective of providing round the clock power to rural areas.

3. Per Capita Electricity Consumption

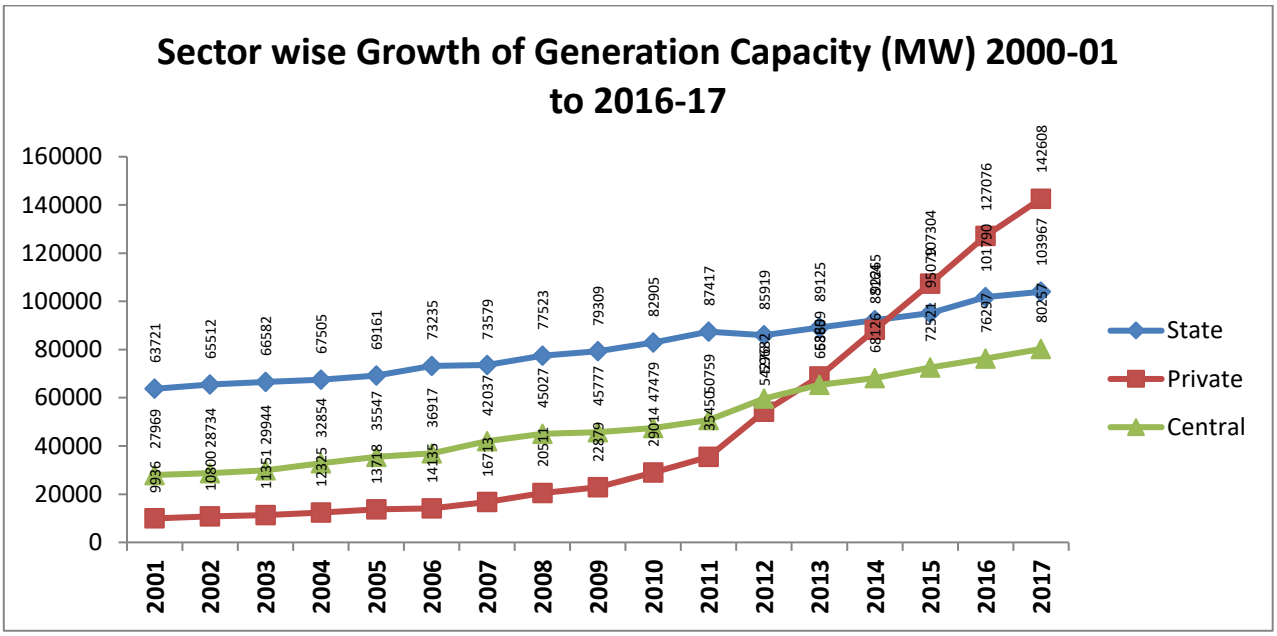
As a result of efforts made by different sectors of electricity generation (Central govt. , State govt. and Private sector) India has become third largest producer and fourth largest consumer of electricity. There has been continuous increase in the per capita consumption of electricity measured in KWH from 16.3 on December 31,1947 to 1122 on March 31,2017. However, per capita consumption of electricity is far below as compared to developed countries. As shown in graph, in the year 2014, per capita consumption of electricity measured in KWH was 12962, 15544, 7829, 10564 in USA, Canada, Japan, Korea where as it was only 1010 in India. This requires more and more capacity addition in all the sectors.





		Canada	USA	Australia	Japan	France	Germany	Korea	UK	Russia	Italy	South Africa	Brazil	China	India*	World
Series1	2014	15544	12962	10002	7829	6955	7035	10564	5131	6603	5002	4240	2578	3927	1010	3030
Series2	2013	15520	12987	10067	7836	7382	7022	10428	5409	6562	5124	4328	2583	3766	957	3026

4. Growth of Electricity Generation Capacity



Charts shows the sector-wise growth of generating capacity from 2000-01 to 2016-17. In 2000-01, generating capacity of Central govt. was 27969 MW (27.52%), state govt. was 63721 MW (62.70%) and private sector 9936 MW (9.77%). However, after the enactment of electricity Act,2003 contibution of the private sector has increased substantially. As a result the share of Central govt., State govt., and private sector in 2017 was 80257 MW (24.55%), 103967 MW (31.8%) and 142608 MW (43.63%) respectively.

5. Needs for the Performance Analysis in Coal Fired Power Plants

The contribution of the coal-based power generation is substantially greater than the other sources of power generation. Coal-based generation is likely to remain the key player of the Indian power sector at least for the next few decades (Chikkatur et al., 2009). The conventional sources of energy are major sources of generation of electricity in India. Conventional sources of energy are valuable, because their formations take millions of years whether it is oil or coal. Energy prices may rise in the long run to reflect the relative scarcity and high cost of exploration and extraction. To minimize the gap of supply and demand of electricity, the government incorporates more and more coal based power plants in their plans. However, an official document manifests that none of the targeted plans is achieved due to inadequate equipment supply, shortage of fuel supply, manpower crisis and huge investment. The present coal production in the country is not sufficient to meet the coal demand and supply. Additional coal supply can be met either through the expansion of existing operations or by importing the coal. Total power generation loss of 8,382.7 MU is reported due to a coal shortage by the power utilities (CEA, 2011). The available energy (coal and auxiliary power) is not enough to generate the required amount of electricity from the CFPPs.

At the same time, the increasing environment crisis is globally recognized as an important issue for India. It is reiterated for ready reference that CFPPs are a major source of carbon dioxide emissions. Indian coal has high ash content and low gross calorific value against the international average. Consequently, CO_2 emissions from Indian CFPPs are so high that it is leading towards global threat. In absolute terms, India is the world‟s sixth largest emitter of CO_2, contributing 3.3% of the world CO_2 emissions (Nag, 2006). Coal plays an essential role in our global energy mix, particularly for power generation but we need to use

it efficiently and reduce its environmental footprint.

Coal based power is generated by central, state and private generating companies. As far as ownership of the Installed Capacity (IC) is concerned, state sector emerges as the leading sector followed by central sector and private sector respectively. Based on the evidences resulted from the empirical study of Chitkara (1999), Behera et al. (2011), Shrivastava et al. (2012) and CEA reports reveal that the performance of state owned plant is poor in comparison to central and private owned power plant in the entire categories. The structure of state owned power plant is different in the sense of unit size, age and operating practices in comparison to central and private ones. According to CEA report, Plant Load Factor (PLF) of state owned plants is lower than central and private ones.

With ongoing government efforts to boost power generation in the country it is very important to monitor and assess the performance of operating generation companies in the country whether they are making use of their resources efficiently and effectively in generating electricity. Though consistent measurement of CFPPs performance is particularly important at the national level, yet significant regional differences exist. Similarly, at the state level, the performance of individual generating units and power plants can only be compared if it is measured consistently. Keeping in view the afore- mentioned points, the documentation is urgently required for performance evaluation of state owned CFPPs that is under short supply of coal and high environmental pressure.

6. Performance Evaluation Approaches and Issues

Performance evaluation is very critical to guide appropriate managerial interventions for performance improvement. Operational performance of power plants is measured through a number of ratios like Operational Availability Factor (OAF), Forced Outage (FO), Planned Maintenance (PM), Plant Load Factor (PLF), Heat Rate (HR), Specific Coal Consumption (SCC), Auxiliary Power Consumption (APC).

6.1. Thermal Performance Review (TPR)

The Central Electricity Authority (CEA) is the advisor to the Central government for proper of electricity planning in the country. CEA collect & record data concerning generation, distribution and utilization of power in the country. CEA is also responsible for carrying out studies related to cost, efficiency, loss, benefits of such utilization and also make public aware form time to time information secured under this act through the publication of reports and investigation. As a part of this obligation, every year CEA collects the operational performance data of the thermal power plants and publishes the findings in the form of Review of Performance of Thermal Power Stations known as Thermal Performance Review (TPR). Since the interest of the current study is about the performance of coal fired power plants, the review is restricted to review of performance of coal fired thermal power stations only.

6.2. Generation Performance Analysis

While making generation performance assessment, no single performance index is considered as the sole indication of overall performance. FO, PM, OAF, Partial unavailability or partial loss (PU) and PLF are taken as the main performance indices for the purpose of analysis (TPR, 2008). Generation performance analysis details electricity generation based on geographical location, sector and covers unit level generation also.

Electricity generation from assets located in different geographical regions (Northern, Western, Southern, Eastern and North Eastern); being managed under different ownership structure (State, Central and Private sector) during different months by different capacity groups are analysed against targets. Unit level performance analysis of different power generating units in respect of electricity generation, PM, FO,

OAF, reserve shut down (RSD), low system demand (LSD), Partial Unavailability (PU), and PLF.

6.3. Outage Analysis

Outage analysis of the generating assets is carried out to understand the trend of PM, FO and OAF. PM is further divided in to annual maintenance (AM) and capital maintenance (CM) and analysed with respect to the programmed schedule. Actual number of units under maintenance and average duration of maintenance activities in different geographical regions/ by different sectors are analysed for different capacity groups of units against the programmed schedule. Maintenance durations, outage hours, MU lost and generation loss as % of possible generation is analysed for individual units based on their geographical regions and purpose of maintenance.

Annual generation loss because of FO of different equipments is analysed and compared for previous four years.

6.4. Fuel Supply, Consumption and Station Heat Rate

Coal fired power plants are primarily designed to use coal as primary fuel. Power plants consume about 75% of domestic coal produced in the country. Long term coal linkage to the power plants is provided by a Standing Linkage Committee – Long Term (SLC-LT) comprising members from planning commission and ministries of coal, railway and power. In the event of initial start up, low load scenarios etc. fuel oil is used as a secondary fuel. Compared to coal, oil is costlier and avoided to the extent technically permissible. The review analyses coal supply to power plants against linkages, coal and oil consumption by individual plants. The section on coal supply to various power plants analyses the status of supply of different fuels like coal, gas and oil to thermal power plants. Region wise yearly trends in SCC and secondary fuel oil consumption (SFOC), coal quality issues and coal washery, gas supply to various gas based power stations are also analysed.

6.5. Auxiliary Power consumption in Thermal Power Stations

Power generating units consume a portion of electricity generated by them to power the auxiliary equipments. This section details APC of individual plants and average consumption level across different capacities, manufacturers and geographical regions. The study also identifies plants consuming below national average and classifies in different APC bands.

The review also includes other aspects of performance of thermal power plants like environmental, energy conservation and Renovation and Modernisation (R&M) of thermal power plants.

7. Findings of Thermal Performance Review

The review makes use of average approach in which performance of plants is compared against the national average and placed in above average and below average bands. Current practice of performance evaluation of thermal power plants in India is based on ratio analysis involving a number of outputs to input (PLF) and input to output (SCC, APC, and SFOC) ratios. Because of the complexities of power generation process, it has not been possible to adopt a single numerical measure of overall performance as no single operating index can represent the entire spectrum of performance of thermal power stations (TPR, 1980; TPR, 1993) and adequately provide a measuring unit for overall performance of the power generating units (TPR, 1995). The review does not provide any guidance to the less efficient power plants as to how much performance improvement is possible and the possible sources of best practices for benchmarking.

Year	Capacity (MW)	Generation (MW)	PLF(%)	PM(%)	FO(%)	Op. Av. (%)	Aux. Cons (%)	Sp. Coal Cons. (kg/kwh)	Sp. Fuel oil Cons. (ml/kwh)	Partial Loss (%) due to	
										Equipment etc.	LSD/RSD (%)
02-03	61152	383379	72.34	8.30	9.87	81.83	9.55	0.71	0.68	9.55	1.57
03-04	62727	398412	72.96	8.59	9.48	91.93	9.91	0.70	2.30	9.09	1.98
04-05	64646	415484	74.82	8.23	8.84	82.93	8.57	0.71	1.37	8.35	0.92
05-06	66449	426138	73.71	9.48	8.74	8178	8.44	0.70	1.77	7.08	2.10
06-07	67596.5	451480	77.03	8.43	8.14	83.72	8.29	0.72	1.89	6.15	1.02
07-08	70659.5	475552	78.75	7.50	7.71	84.76	8.17	0.73	1.40	6.30	0.52
08-09	74914.5	498019	77.22	5.66	9.29	85.05	8.33	0.74	1.93	8.21	0.27
09-10	80439.5	535433	77.53	6.05	8.85	85.10	8.34	0.72	1.51	7.57	0.46
10-11	86137	553696	75.08	5.83	10.32	83.85	8.49	0.72	1.85	9.88	1.43
11-12	97768	606684	73.32	5.93	11.46	82.61	8.44	0.72	1.83	8.34	1.09
12-13	118024.5	689036	70.13	5.71	13.59	80.69	8.15	0.70		9.8	0.88
13-14	132624.5	792477	65.56	5.02	17.64	77.35	8.16	0.69		8.96	3.16
14-15	147297	878320	64.29	4.66	19.05	76.29	8.02	0.68		9.41	2.22

Table 1 PERFORMANCE OF COAL/LIGNITE BASED THERMAL POWER STATIONSDURING 2002-03 TO 2014-15

Table 1 shows the Annual Performance review of thermal Power stations published by Central electricity review (2014-2015) for the years 2002-03 to 2014-15. Highlight of the review are as under

- It covers performance analysis of 570 Coal/ Lignite based thermal power stations aggregating 147297 MW and electricity generation is 278320MU.
- Operating Availability of 76.29% was achieved during the year 2014-2015 as against 77.34% achieved during 2013.2014.
- Plant load factor (PLF) of thermal power stations at the national level, during 2014-15, reduced to 64.29% from 65.57% achieved during pervious year, The Lower PLF was due to poor quality coal,

grid/transmission constraints and Reserve Shut down/Low system demand.

- Energy loss of account of planned maintenance was 4.66% as compared to 5.01% during 2013.14. The % decrease in planned maintenance was due to decrease in unscheduled Capital maintenance and unscheduled R&M activity of some units.
- The loss of generation due to non-availability of thermal units due to forced outages during 2014-15 increased to 19.05% as compared to 17.38% during 2013-14. The increased forced outages were due to increased forced shutdown of units due to coal supply problem and transmission constraints and equipment problems of some new units.
- Energy loss due to partial unavailability of the thermal generating units operating in the country during 2014-15 had decreased to 11.62% of the maximum possible generation during the year in comparison to the 12.13% in 2013.14.

The all-India average auxiliary power consumption by the thermal stations during 2014-15 decreased to 8.02% from 8.16% during 2013.14.

REFERENCES

1. Azadeh, Ali & Ghaderi, F & Anvari, Mehran & Izadbakhsh, Hamidreza & Dehghan, S. (2007). Performance assessment and optimization of thermal power plants by DEA BCC and multivariate analysis. *Journal of Scientific and Industrial Research*. 66, 860-872. Retrieved from: https://www.researchgate.net/publication/254202216_Performance_assessment_and_optimization_of_thermal_power_plants_by_DEA_BCC_and_multivariate_analysis Accessed on 01.08.2017.
i. Bajpai, K. Vijay, Singh, K. Sudhir (2014). Measurement of Operational and Environmental Performance of the Coal-Fired Power Plants in India by Using Data Envelopment Analysis. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering* 8(12), 3964-3973. Retrieved from: http://waset.org/publications/10000332/measurement-of-operational-and-environmental-performance-of-the-coal-fired-power-plants-in-india-by-using-data-envelopment-analysis Accessed on 14.08.2017.
2. Banker R.D. (1984). "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis". *Management Science*. 30: 1078–1092. doi:10.1287/mnsc.30.9.1078 Retrieved from: https://en.wikipedia.org/wiki/Data_envelopment_analysis Accessed on 21.08.2017.
3. Berg, S. (2010). "Water Utility Benchmarking: Measurement, Methodology, and Performance Incentives." International Water Association. Retrieved from: https://en.wikipedia.org/wiki/Data_envelopment_analysis Accessed on 21.08.2017.
4. Charnes A. (1978). "Measuring the efficiency of decision-making units" (PDF). *European Journal of Operational Research*. 2: 429–444. doi:10.1016/0377-2217(78)90138-8. Retrieved from: https://en.wikipedia.org/wiki/Data_envelopment_analysis Accessed on 21.08.2017.
5. Chen, Tser & Yeh, Tsai-Lien & Lee, Yi-Ting. (2013). Comparison of Power Plants Efficiency among 73 Countries. Journal of Energy. *Journal of Energy*, Vo. 2013, 1-8 Retrieved from: https://www.hindawi.com/journals/jen/2013/916413/cta/ Accessed on 11.08.2017.
6. Choukroun, S. (2001). Enron in Maharashtra: Power Sector Development and National Identity in Modern India. Philadelphia, University of Pennsylvani.

7. Färe, R., Grosskopf, S., Lindgren, B. & Roos, R. (2003). Productivity Changes in Swedish Pharamacies 1980–1989: A Non-Parametric Malmquist Approach The Journal of Productivity Analysis, 3, 85-101 Retrieved from: https://link.springer.com/chapter/10.1007/978-94-017-1923-0_6 Accessed on 21.08.2017.
8. Fatima, Sahba & Barik, Kaustuva. (2012). Technical Efficiency of Thermal Power Generation in India: Post-Restructuring Experience. International Journal of Energy Economics and Policy retrieved fromhttps://www.researchgate.net/publication/266460084_Technical_Efficiency_of_ThermalPower_Generation_in_India_Post-Restructuring_Experience accessed on 18.09.2017.
9. Fatima, Sahba & Barik, Kaustuva. (2012). Technical Efficiency of Thermal Power Generation in India: Post-Restructuring Experience. *International Journal of Energy Economics and Policy*. 2(4), 210-224. Retrieved from: https://www.researchgate.net/publication/266460084_Technical_Efficiency_of_Thermal_Power_Generation_in_India_Post-Restructuring_Experience Accessed on 13.08.2017.
10. Fatima, Sahba (2016). Performance Evaluation of Thermal Power Generation: Non-Parametric Frontier Approach. *Bulletin of Energy Economics*, 4(1), 81-92. Retrieved from: http://tesdo.org/JournalDetail.aspz?id-4 Accessed on 14.08.2017.
11. Hosseini Hassan, Mirza. & Hasanpour Javad (2011). Evaluating the efficiency changes of the Thermal Power Plants in Iran and Examining its Relation with Reform using DEA Model & Malmquist Index. 3rd International Conference on Information and Financial Engineering IPEDR vol.12, IACSIT Press, Singapore Retrieved from: http://www.ipedr.com/vol12/50-C123.pdf Accessed on 25.07.2017.
12. Jain Shafali, Thakur Tripta & Shandilya Arun (2010). Cost Benchmarking of Generation Utilities Using DEA: A Case Study of India. *Technology and Investment*, 1, 229-234, Retrieved from: https://file.scirp.org/pdf/TI20100400001_43637859.pdf Accessed on 03.08.2017.
13. Javaheri Sadraei Ahmad, & Ostadzad Hussein Ali (2014). Estimating Efficiency of Thermal and Hydroelectric Power Plants in Iranian Provinces. *Iranian Journal of Economic Studies*, 3(2), 19-42. Retrieved from: http://ijes.shirazu.ac.ir/article_3668_4b2f7d790befccb158b905ef7ea27abc.pdf Accessed on 01.08.2017.
14. K Behera, Santosh & P Dash, Ambika & Jamal Farooquie, A. (2010). Performance Analysis of Coal Fired Power Plants in India. *Proceedings of the International Conference on Industrial Engineering and Operations Management Dhaka, Bangladesh, January 9-10, 2010.* Retrieved from: http://iieom.org/paper/Final%20Paper%20for%20PDF/308%20Behera.pdf Accessed on 13.08.2017.
15. K Behera, Santosh & P Dash, Ambika & Jamal, Farooquie, A. (2010). Performance Evaluation and Efficiency Analysis of Coal Fired Thermal Power Plants in India. Retrieved from: https://astro.temple.edu/~banker/dea2009/paper/Behera.pdf Accessed on 13.08.2017.
16. Kale, S.S. (2004), Current Reforms: The Politics of Policy Change In India's Electricity Sector, Pacific Affairs, 77(3), 467-491.
17. Khalid Riaz, Khan Iram, Qayyum Abdul & Khan Arooj (20123). Technical Efficiency of Asian Energy Firms: A Bootstrapped DEA Approach. *Journal of Basic and Applied Scientific Research*, 3(5), 844-852. Retrieved from: http://www.textroad.com/pdf/JBASR/J.%20Basic.%20Appl.%20Sci.%20Res.,%203(5)844-852,%202013.pdf Accessed on 03.08.2017.

18. Li Jinchao, Geng, Xian & Li Jinying (2016). A Comparison of Electricity Generation System Sustainability among G20 Countries. *Sustainability*. Retrieved from: https://pdfs.semanticscholar.org/5354/290d15ae1fd5aba4d928bc152aece094e592.pdf Accessed on 03.08.2017
19. Meenakumari, R. & Kamaraj, N. (2008) Measurement of Relative Efficiency of State Owned Electric Utilities in INDIA Using Data Envelopment Analysis, *Modern Applied Science*, 2(5), 61-71. Retrieved from: www.ccsenet.org/journal/index.php/mas/article/download/2205/2059 Accessed on 11.08.2017.
20. Monthly Report on Board Status of Thermal Power projects in the Country, May-2017 by Government of India, Ministry of Power .
21. Murty, M.N., Kumar Surender & Dhavala, K.K. (2005). Measuring Technical and Environmental Efficiency of Thermal Power Generation in India: An Application of Directional Distance Function, Report of National Resource Accounting, Institute of Economic Growth, Delhi (India) accessed on 13.08.2017.
22. Power Sector at a Glance ALL INDIA, Retrieved from http://powermin.nic.in/en/content/power-sector-glance-all-india accessed on 25.07.2017
23. Ramanathan, R. (2003), " An Introduction to Data Envelopment Analysis –A ool for performance measuremen". Saga Publication Private Limited. Retrieved from http://ms.liau.ac.ir/files/books/DEA/R%20Ramanathan-An%20Introduction%20to%20Data%20Envelopment%20Analysis%20-%20A%20Tool%20for%20Performance%20Measurement%20%282003%29.pdf Accessed on 21.08.2017.
24. Shanmugam, K & Kulshreshtha, Praveen. (2002). Efficiency of Thermal Power Plants in India. *Vikalpa: The Journal for Decision Makers*. 27(4). 57-68. 10.1177/0256090920020405. Retrieved from:https://www.researchgate.net/publication/259373292_Efficiency_of_Thermal_Power_Plants_in_India Accessed on 13.08.2017.
25. Shanmugam, K & Kulshreshtha, Praveen. (2005). Efficiency analysis of coal-based thermal power generation in India during post-reform era. *International Journal of Global Energy Issues*. 23(1). 15-28. Retrieved from: https://www.researchgate.net/publication/5171972_Efficiency_analysis_of_coal-based_thermal_power_generation_in_India_during_post-reform_era Accessed on 11.08.2017.
26. Sherman H.D.; Zhu J. (2013). *"Analyzing performance in service organizations". Sloan Management Review. 54 (4): 37–42.* Retrieved from: https://en.wikipedia.org/wiki/Data_envelopment_analysis Accessed on 21.08.2017/ Singh, Joga (1991), Plant Size and Technical Efficiency in the Indian Power Industry, *Indian Economic Review, New Series*, 26(2), 239-252. Retrieved from: http//www.jstor.org./stable/29793560 Accessed on 14.08.2017.
27. Tone K. A slack-based measure ofsuper-efficiency in data envelopment analysis. European Journal of Operational Research 2002;143(1):32–41. http://www.deafrontier.net/papers/OMEGASlackCDEA.pdf Accessed on 21.08.2017.
28. Uwe Remme; et al. (February 2011). "Technology Development Prospects for the Indian Power Sector". International Energy Agency France; OECD retrieved from https://en.wikipedia.org/wiki/Electricity_sector_in_India accessed on 31.07.2017.
29. Vaninsky, Alexander. (2009). Environmental Efficiency of Electric Power Industry of the United States: A Data Envelopment Analysis Approach. *World Academy of Science, Engineering and Technology*.2(4), 509-515 Retrieved from:

https://www.researchgate.net/publication/242593455_Environmental_Efficiency_of_Electric_Power_Industry_of_the_United_States_A_Data_Envelopment_Analysis_Approach Accessed on 03.08.2017.

30. Yishi Zhang; Anrong Yang; Chan Xiong; Teng Wang; Zigang Zhang (2014). "Feature selection using data envelopment analysis". *Knowledge-Based Systems* (PDF). ELSEVIER. 64: 70–80. Retrieved from: https://en.wikipedia.org/wiki/Data_envelopment_analysis Accessed on 21.08.2017.
31. "BP Statistical Review of world energy, 2016" *retrieved from https://en.wikipedia.org/wiki/Electricity_sector_in_India* accessed on 25.07.2017
32. "Growth of Electricity Sector in India from 1947-2017" . CEA. *retrieved from* https://en.wikipedia.org/wiki/Electricity_sector_in_India accessed on 25.07.2017
33. "IBEF Power". *IBEF*. *retrieved from https://en.wikipedia.org/wiki/Electricity_sector_in_India* accessed on 25.07.2017
34. "Progress report of village electrification as on 31-05-2017" ,*CEA.* retrieved from https://en.wikipedia.org/wiki/Electricity_sector_in_India accessed on 31.07.2017
35. "Rural households electrification in India". *Government of India.* retrieved from https://en.wikipedia.org/wiki/Electricity_sector_in_India accessed on 31.07.2017