Chapter - 5

DATA ANALYSIS AND INTERPRETATION - I: PERFORMANCE TREND ANALYSIS

As discussed earlier, the performance of power plants have several dimensions like Reliability, Safety, Operational Performance, Costs, Financial Health, Innovation etc. and each dimension having several indicators. Operational performance of a power plant is described through a set of parameters like Operational Availability Factor (OAF), Plant Load Factor (PLF), Planned Maintenance (PM), Forced Outage (FO), Auxiliary Power Consumption (APC), Specific Coal Consumption (SCC), Heat Rate (HR) are being considered as the key performance indicators (TPR, 1980; TPR, 2008; Shumilkina, 2010; PGP, 2010). In this chapter trends of key performance parameters at national level during FY80 to FY08, on monthly basis during FY99 to FY08, at plant and unit level during FY04 to FY08 are analysed. Monthly trends of OAF, PM and FO during FY99 to FY08 is examined to gain further insights. The trend of APC, HR and fuel supply scenario are also analysed.

5.1 Operational Availability

In the availability based tariff (ABT) regime, OAF determines the extent of fixed cost recovery for power plants, gets echoed in policy documents (NEP, 2005) and several studies (CIIGBC, 2005; PGP, 2010). During FY08, 385 coal/lignite fired power generating units aggregating to a total capacity of 70.5 GW recorded availability of 84.76% and generated 475.5BUs of electricity at a PLF of 78.75%. 1% increase in OAF leads to 5.6 BUs of electricity generation potential and corresponds to about 840 MW of additional capacity utilisation, which could be more with growing installed capacity. CIIGBC (2005) had estimated that 10% improvement of OAF could reduce capacity addition by about 12 GW freeing capital investment of ` 48,000 Crores.

5.1.1 Availability Trends

Unit outage of 3.65 days during a year pulls down the availability by 1%. Availability and unavailability trends of coal/lignite fired power plants at all India level during FY80 to FY08 is shown in Figure 7.

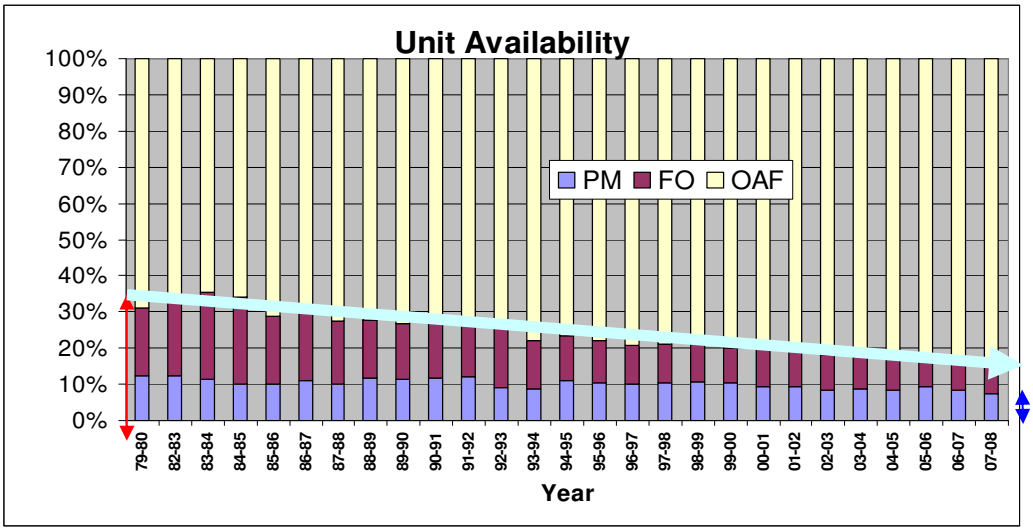

Figure 7 : Trends in Outages and Unit Availability during FY80 to FY08

From Figure 7 it is observed that over the years there is significant improvement in the availability of power generating units due to reduced PM and FO. There have been several attempts to cut down equipment outage due to PM, which resulted below 10% PM figures of 9.94, 9.87, 8.83 and 7.50 during FY85, FY88, FY94 and FY08 respectively. However lower PM levels could not be sustained for long time. All India PM level which was above 10% till FY01, has been capped under 10% and attained 7.50% during FY08. There has been a significant improvement in the FO front also, which varied from 24.19% to 7.71%. Over the years improved operation and maintenance practices resulted in reduced PM and FO levels leading to increased OAF of plants from 68.93% during FY80 to 84.76% during FY08 an increase of 22.96%.

Analysis of unit level availability reveals that during FY04 and FY08, the availability varied between 0% and 99.98%. Budge Budge Unit # 2 during FY08 and Dahanu Unit #1 during FY05 has recorded highest availability of 99.98%. On the contrary, several units remain unavailable round the year thus having lowest availability of 0%. It is observed that about 2 GW of installed capacities have availability below 5% i.e. less than 18.25 days a year. On the other hand about 10 GW of installed capacity remain available for more than 95% of time.

5.1.2 Month wise OAF

To explore the seasonal trends in the plant availability, month wise OAF during FY99 to FY08 are analysed. Monthly OAF figures computed by CEA in its thermal performance reviews for different years are shown in Table 11.

Table 11 : Month wise OAF at All India level

	FY99	**FY00**	**FY01**	**FY02**	**FY03**	**FY04**	**FY05**	**FY06**	**FY07**	**FY08**
April	80.96	82.29	80.03	80.78	83.42	83.10	87.21	85.49	84.02	87.08
May	80.67	81.96	81.44	81.13	81.37	82.45	83.56	83.43	85.24	89.30
June	80.04	80.37	80.04	79.18	80.71	80.72	81.22	83.49	84.02	86.29
July	74.60	76.94	75.16	75.51	79.48	76.80	82.20	76.80	80.02	78.20
August	75.80	77.45	73.99	74.71	79.69	77.40	76.34	74.91	78.90	79.21
September	75.16	78.20	75.50	77.55	76.97	79.14	80.75	74.45	79.68	80.15
October	76.01	76.29	79.60	78.43	81.18	81.69	79.85	81.97	82.98	83.01
November	78.79	75.69	81.55	80.20	83.01	80.76	81.65	80.61	82.73	85.14
December	79.01	80.55	82.88	82.18	83.73	83.42	84.68	82.37	84.33	85.94
January	81.34	82.69	82.94	82.32	85.74	85.68	85.49	85.38	87.19	87.05
February	80.56	82.81	81.54	83.66	83.36	85.04	86.48	86.45	87.49	87.49
March	83.64	83.56	83.55	83.52	83.22	86.89	85.96	86.38	88.08	88.15

From Table 11, it is observed that the average OAF fluctuated from 73.99% (August, FY01) to 89.30% (May, FY08). To understand the statistical significance of the variation of month wise average OAF figures, the null hypothesis $\mathbf{H_{1\_1}}$ that "Operational availability of coal fired power plants in India are uniform round the year" is tested using one-way ANOVA. For this purpose the SPSS input considered, is of the form shown in Table 12 and ANOVA results in Table 13. .

Table 12 : Sample Input Data for ANOVA of month wise OAF, PM and FO

Year	**Month**	**Month Code**	**PM**	**FO**	**OAF**
FY99	January	1.00	7.56	9.75	82.7
FY99	February	2.00	8.49	8.7	82.8
FY99	March	3.00	7.81	8.64	83.6
FY99	April	4.00	7.09	10.62	82.3
FY99	May	5.00	7.22	10.82	82
FY99	June	6.00	8.89	10.74	80.4
FY99	July	7.00	12.1	10.97	76.9
FY99	August	8.00	12.9	9.69	77.5
FY99	September	9.00	12.1	9.73	78.2
FY99	October	10.00	13.5	10.18	76.3
FY99	November	11.00	14.9	9.44	75.7
FY99	December	12.00	9.91	9.54	80.6
Contd ..					
FY08	December	12.00	6.4	7.66	85.9

Table 13 : One-way ANOVA Results of Month wise OAF

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	943.360	11	85.760	15.951	.000
Within Groups	580.652	108	5.376		
Total	1524.012	119			

It is observed that there is significant difference in the month wise OAF levels during FY99 to FY08, $F(11, 108) = 15.951$, $p < 0.01$. The null hypothesis is thus rejected at significance level of 1% indicating operational availability of coal fired power plants in India are not uniform round the year i.e. different during different months.

Significant differences in the month wise OAF levels evaluated using Post hoc Games-Howell test are detailed in Table 14. The results indicate that the mean OAF during January is significantly higher than that during July, August, September and October by 6.81%, 7.95%, 6.94% and 4.44% respectively.

Table 14: Significant Differences in Month wise OAF

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
January							6.81	7.95	6.94	4.44		
February							6.87	8.01	7.00			
March							7.26	**8.40**	7.40	4.89		
April							5.75	6.89	5.88			
May							5.39	6.53	5.52			
June								5.02				
July												5.29
August												6.43
September												5.43
October												
November							5.29	6.43	5.43			

Maximum difference in OAF levels (8.40%) is observed between March and August. Higher OAF registered during March may be due to achieving the year-end targets.

5.2 Planned Maintenance

Trend of PM at all India level is shown in Figure 7. PM includes Annual Maintenance (AM) of boiler, Capital Maintenance (CM) of turbo generator, Preventive Maintenances and other short duration maintenances (TPR, 2008). Generation loss on this account has come down from 12.52% during FY83 to 7.50% during FY08. During FY04 and FY08, plant level PM varied between 0 to 82.77%. Plants with PM of 2.13% lie in 1st decile, and with PM of 17.63% occupy the 9th decile, indicating any plant to remain in the top 10% have to bring down the PM below 2.13%.

Equipment wise analysis of PM durations during FY04 to FY08 reveal, about 35% to 50% of PM is due to AM of boiler, 15% to 20% accounted for by CM of turbine and the remaining due to Preventive Maintenance and other short duration maintenance activities. Plant level analysis of operational performance during FY04 to FY08 reveal many plants (Paras, FY06; Bakreswar, FY07; Ramagundam B, FY05 and FY08; Dahanu, FY06 and SouthGen, FY05) in different sectors have clocked 0 PM levels without deteriorating corresponding FO levels (5%). On the contrary many plants like Barauni, Harduaganj, Patratu and Tenughat have reported PM levels exceeding 50%. During the year FY07, Barauni reported PM of 82.77%. Unit level analysis depicts more disturbing pictures of maintenance activities. Unit level PM goes to as high as 100% and as many as 107 power generating units aggregating to 7 GW remained unavailable round the year for undertaking planned maintenance activities during the period FY04 to FY08.

Capacity group wise analysis of PM between FY00 and FY07 indicate that lowest PM of 3.09% was recorded by the 250 MW group of units during FY03 and FY04 while highest PM of 49.46% was recorded by 50/57.5 MW group of units during FY06.

5.2.1 Month wise PM Durations

Month wise variation of PM during FY99 and FY08 shown in Table 15 indicates the average PM durations varied from 3.88% (March, FY08) to 15.85% (August, FY01).

Table 15 : Month wise PM

	FY99	**FY00**	**FY01**	**FY02**	**FY03**	**FY04**	**FY05**	**FY06**	**FY07**	**FY08**
April	9.68	7.09	9.78	9.42	6.93	8.69	4.56	7.56	6.22	5.33
May	8.80	7.22	8.16	7.53	6.60	8.62	6.75	7.93	6.93	4.00
June	8.68	8.89	9.22	7.94	7.25	8.59	9.43	7.18	8.38	6.03
July	13.43	12.09	13.16	11.33	9.48	10.80	10.03	14.56	10.79	13.82
August	14.48	12.86	15.85	13.91	10.71	11.47	14.31	15.15	12.57	13.42
September	14.18	12.07	13.62	12.38	13.21	11.42	10.85	14.61	12.71	12.61
October	13.60	13.53	10.45	11.38	9.93	8.53	10.12	10.64	8.87	8.02
November	9.85	14.87	8.02	10.12	8.29	9.31	8.77	10.03	9.54	7.66
December	11.95	9.91	7.89	9.00	6.38	8.09	7.23	8.00	7.61	6.40
January	9.15	7.56	6.79	7.77	6.35	5.87	5.71	7.11	7.22	4.95
February	7.31	8.49	7.35	7.20	6.56	6.13	6.26	5.51	5.25	4.48
March	7.23	7.81	6.00	6.20	7.89	5.60	4.64	5.12	4.98	3.88

To test the statistical significance of the variation of month wise PM durations, the null hypothesis $\mathbf{H_{1\_2}}$ that "The planned maintenance activities are planned uniformly round the year" is tested using one-way ANOVA. The results are shown in Table 16.

Table 16 : One-way ANOVA Results of Month wise PM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	725.314	11	65.938	27.623	.000
Within Groups	257.805	108			
Total	983.119	119			

The results indicate significant difference in the month wise PM levels during FY99 to FY08, F (11, 108) =27.623, $p < 0.01$. The null hypothesis is thus rejected at significance level of 1% indicating planned maintenance activities are not uniform round the year. Post hoc Games-Howell test is carried out to find out the significant differences in PM durations and the results are listed in Table 17. Post hoc results indicate lower PM during July, August, September and October. Row-1 of Table 17 indicates that the PM durations during January is significantly lower compared to that during July, August, September and October by 5.23%, 6.92%, 6.08% and 3.69% respectively.

Table 17: Significant Differences in Month wise PM Durations

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
January							-5.23	-6.92	-6.08	-3.69		
February							-5.52	-7.21	-6.37	-3.98		
March							-6.09	-7.78	-6.94	-4.55	-3.85	
April							-4.8	-6.49	-5.65			
May							-5.02	-6.71	-5.87	-3.48		
June							-3.87	-5.56	-4.72			
July												
August												
September												
October								-3.23				
November								-3.94				
December							-4.11	-5.8	-4.96			

5.2.2 Operator wise PM Durations

To further understand the variation of PM durations across operators, the null hypothesis $\mathbf{H_{1\_3}}$ that "Planned maintenance duration does not depend on the operator" is tested using one-way ANOVA. For this purpose the PM durations of the 74 plants being operated by 23 different operators during the five year period FY04 to FY08 is considered as input. The input data format is shown in Table 18.

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Table 18: PM Durations of Different Plants and Operators

Plant	Operator	Period	PM	Operator Code
Amarkantak	MPGPCL	FY04	1.90	17
Amarkantak Ext.	MPGPCL	FY04	13.92	17
Anpara	UPRVUNL	FY04	2.89	28
Badarpur	NTPC	FY04	3.92	19
Contd ..				
Vindhyachal	NTPC	FY08	5.45	19
Wanakbori	GSECL	FY08	5.72	10

The results of one-way ANOVA are presented in Table 19 and indicate significant variation of PM across operators, $F(22,347) = 18.969$, $p < 0.001$.

Table 19 : ANOVA Results of PM across Operators

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	22798.840	22	1036.311	18.969	.000
Within Groups	18957.522	347	54.633		
Total	41756.362	369			

Post hoc Games-Howell test is carried out to identify significant operators and the results are shown in Table 20. Post hoc analysis reveals that of the 23 operators, the PM durations of as many as 13 operators (CESC, DPL, GSECL, HPGCL, KPCL, MahaGenco, MPGPCL, NTPC, REL, RRVUNL, TNEB, Torr Power and UPRVUNL) differ significantly. The results indicate the PM duration of operator-4 (CESC) is lower compared to operators 10, 16, 17, 19, 25 and 28 by 4.86%, 5.08%, 4.11%, 3.78%, 6.15% and 15.31% respectively. Maximum significant difference in PM levels is observed between operator-22 (REL) and operator-28 (UPRVUNL). PM levels of other operators like BSEB (M=51.67, SD=11.13), JSEB (M=48.89, SD=18.05) and TVNL (M=21.53, SD=22.88) even though higher from that of UPRVUNL, yet the difference with other operators is not significant.

Table 20 : Significant Differences in PM Durations among Operators

Operator Code	Operator	10	11	16	17	19	23	25	28
4	**CESC**	-4.86		-5.08	-4.11	-3.78		-6.15	-15.31
6	**DPL**								-13.88
10	**GSECL**								
11	**HPGCL**								
15	**KPCL**								-12.74
16	**MAHAGENCO**								
17	**MPGPCL**								
19	**NTPC**								
22	**REL**	-5.49	-4.17	-5.72	-4.75	-4.42	-3.65	-6.79	-15.95
23	**RRVUNL**								-12.3
25	**TNEB**								
26	**TORR POWER**								-13.1
28	**UPRVUNL**								

PM durations of REL is better compared with as many as eight other operators while those of CESC are better than 6 other operators. While the narrowest significant difference (3.65%) is that between RRVUNL and REL, the widest significant difference (15.95%) is between UPRVUNL and REL in both the cases REL plants have lowest PM.

5.2.3 Policy Interventions for Reducing PM Durations

In the current practice, in addition to AM of boiler spanning from 30 days for smaller units to 60 days for 500MW size units, CM of turbine is carried out every five years, which spans from 45 to 75 days. On an average, a power generating unit remains shut down for 33 to 63 days per year on account of PM activities. With the latest technological developments, there is a need to shift from reactive maintenance and planned maintenance to predictive maintenance. Major overhauls can be taken up in project mode to reduce cost and time overruns using state of the art project management tools. Realising the need for reducing the PM levels, a committee was constituted by MoP under the chairmanship of Shri P.K. Kukde, to suggest measures for reducing PM.

Kukde committee has recommended drastic changes in the AM schedules leading to substantial reduction in PM outages. The committee recommended boiler overhaul every alternate year instead of being practiced every year with provision for inspection to be carried out in the intervening years and major overhaul of boiler and turbine to be undertaken in each 5 years. This will lead to reduction of boiler outage by 23 days per year per unit in respect of 210 units and by 35 days for 500 MW units.

In line with the recommendations, Indian Boiler Regulations act has been suitably amended in 2007 for overhaul in 24 months and inspection after 12 months.

The committee has also recommended introduction of availability based monitoring system. Residual life assessment (RLA) of the sub 200 MW units is required to ascertain the health of these units and undertake major renovation and modernisation (R&M) exercises. Introduction of condition monitoring to detect the health of the equipments has also been suggested (TPR, 2008).

5.3 Forced Outage

Forced Outage (FO) compels a power generating unit to be taken off from the grid. This not only causes loss of revenue for the generating company but also grid disturbance for which the generator has to pay hefty penalty in form of Unscheduled Interchange (UI) charges. UI charges depend on the grid frequency. Compared to the weighted average cost of electricity traded which was `4.52 during FY08, maximum UI charge can be upto `8.73 per kWh of electricity. At all India level during FY04 to FY08, FO ranged from 7.71% to 9.48%. During FY08, 385 units reviewed by CEA registered 6426 outages causing generation loss to the tune of 46.53 BU. During FY04 to FY08, plant level FO ranged from 0.06% (Dahanu, FY04) to 62.75% (Chandrapura, FY04). Ranking of the power plants on the basis of FO reveal, the best performing (lower FO) plants occupying the 1^{st} decile have FO levels of 1.3% while the 10^{th} decile spans up to 27.174%. For a plant to be in the top 10% band, it has to maintain FO level below 1.3% (TPR, 2004; TPR, 2005; TPR, 2006; TPR, 2007; TPR, 2008). Capacity group wise FO varied from 2.15% (250 MW, FY07) to 49.46% (50-57.5 MW, FY06).

5.3.1 Month wise FO

Month wise variation of FO during FY99 to FY08, shown in Table 21 indicates month wise FO fluctuation between 5.59% (January, FY07) and 13.16% (July, FY02).

Table 21 : Month wise Average FO

	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
April	9.36	10.62	10.19	9.80	9.65	8.21	8.23	6.95	9.76	7.58
May	10.54	10.82	10.46	11.34	12.02	8.93	9.70	8.64	7.83	6.70
June	11.28	10.74	10.74	12.88	12.04	10.69	9.35	9.32	7.60	7.68
July	11.97	10.97	11.68	13.16	11.04	12.40	7.77	8.64	9.19	7.98
August	9.72	9.69	10.16	11.38	9.60	11.13	9.34	9.94	8.53	7.38
September	10.66	9.73	10.88	10.07	9.82	9.44	8.41	10.93	7.61	7.23
October	10.39	10.18	9.95	10.18	8.90	9.79	10.03	7.39	8.15	8.97
November	11.36	9.44	10.43	9.68	8.70	9.92	9.59	9.36	7.73	7.20
December	9.04	9.54	9.23	8.82	9.89	8.48	8.09	9.63	8.06	7.66
January	9.51	9.75	10.27	9.92	7.91	8.46	8.79	7.51	5.59	8.00
February	12.13	8.70	11.11	9.14	10.08	8.84	7.25	8.04	7.26	8.03
March	9.13	8.64	10.45	10.28	8.89	7.51	9.40	8.50	6.94	7.97

To check the statistical significance of the month wise variation of FO durations, the null hypothesis $\mathbf{H_{1\_4}}$ that "Forced outage durations are uniform round the year" is tested using one-way ANOVA. The ANOVA results are presented in Table 22.

Table 22 : One way ANOVA of Month wise FO

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	36.779	11	3.344	1.746	0.073
Within Groups	206.806	108	1.915		
Total	243.585	119			

It is observed that the difference in the FO levels during different months is not statistically significant, $F(11, 108) = 3.344$, $p > 0.01$. Thus the null hypothesis can not be rejected indicating FO variation across months is not significant.

Taken together it is found that average FO durations do not vary during different months while average PM durations vary. Planned maintenance activities which are mostly scheduled during June and November, avoided during January and March. These schedules pull down the OAF levels of the coal fired plants during July and November. The reason may be due to higher availability adequate water at the hydro power plants during the period. There is significant difference in the PM durations across operators indicating improved maintenance practices.

5.3.2 Equipments Responsible for FO

To understand the causes of outage and equipments responsible for it, number of outages and generation loss due to main equipments and auxiliaries during FY04 to FY08 for 200/210MW, 250MW and 500MW groups are analysed. The data is

compiled from the secondary data published by CEA in the thermal performance reviews. The findings are detailed below (TPR, 2004; TPR, 2005; TPR, 2006; TPR, 2007; TPR, 2008):

Maximum generation loss on account of FO to the tune of about 41% is attributable to boilers, followed by 15% to turbines and 8% to generators. Remaining duration of outage of about 9% is because of boiler and turbine auxiliaries and 27% due to other electrical and mechanical problems. Boiler-Turbine-Generator (BTG) trio are the major contributors of FO.

Maximum number of boiler outages occurs due to Water wall failure, Fire outs and Economiser problems. Maximum generation loss is attributable to Water wall, Super Heater and Economiser. Generation loss per outage is highest because of Reheater, Super Heater and Economiser problems.

Analyses of causes of turbine outages reveal maximum outages occur due to Condenser Low Vacuum, Condenser Cleaning / Tube Failure and Governing and Lube Oil System. Maximum generation loss encountered due to Eccentricity and Vibration, Cylinder and Control Valve, Condenser Cleaning / Tube Failure; and maximum generation loss per outage due to Rotor Blade Failure, Eccentricity and Vibration, and Cylinder and Control Valves.

Maximum Generator outages occur due to Exciter, Protection Relay Operation and Stator Earth Fault; causes responsible for maximum generation loss are Stator Earth Fault, Rotor Earth Fault and Generator Cooling System; resulting in maximum generation loss per outage because of Explosion, Rotor Earth Fault and Stator Earth Fault.

While ID Fan, PA Fan and Milling System cause Maximum Outages of boiler auxiliaries ID Fan, Milling System and PA Fan result in maximum generation loss and Precipitator , Others and Milling System are responsible for highest generation loss per outage.

Causes responsible for maximum outages of Turbine Auxiliaries are Boiler Feed Pump, CW Pump and Regenerative System; maximum Generation Loss are Other Failures, Boiler Feed Pump and CW Pump; Generation Loss per Outage caused by Others failures, Pipe and Valves and CW Pump.

Among the Other electrical and mechanical problems maximum outages is caused due to Switchyard / Transmission Constraints, Generator Transformer Tripping and Station / Unit Aux. Transformer leading to maximum generation loss because of Generator Transformer Tripping, Fuel Problems / Feeding Trouble and Coal Shortage; and the causes responsible for maximum generation loss per outage are Raw Water Problem, Coal Shortage and Fuel Problems / Feeding Trouble.

5.3.3 Reducing Forced Outages

It is observed that both the 250 MW and 500 MW groups of units have recorded no outage on account of AVR Problem, Explosion, Generator Winding Temperature High, Commissioning Period, Cooling Tower, DM Water Problem, Poor Coal Quality, Condenser, Curtis Wheel Pressure High and BFP Motor.

The 250 MW group of units have not recorded any unit outage on account of Hydrogen System, Other Boiler Problems, Miscellaneous Fire Problems, Stator Cooling Water Resistivity, Ash Handling System, Breaker / Isolator, Feeding Trouble, HT / LT Motors, Raw Water Problems, Wet Coal, Control Valve, Rotor Blade Failure / Fouling, Turbovisory System, Condensate Pump and De-aerator problems which are being experienced by 500 MW units.

Analysis of the number of outages and corresponding generation loss during FY00 and FY08 reveal (TPR, 2004; TPR, 2005; TPR, 2006; TPR, 2007; TPR, 2008):

During a year about 7000 outages observed causing generation loss of 49.4 BU. An outage causes average generation loss of 6.72 MU.

Boiler outages are maximum in number and result maximum generation loss.

While the minimum generation loss of 3.87 MUs per outage was recorded by equipments associated with Turbine Auxiliaries, maximum generation loss of 11.36 MU per outage observed for miscellaneous electrical and mechanical equipments.

Even though a number of units have been added over the years, there has been a decline in the number of outages (from 8400 outages to 6600). However the generation loss per outage has increased over the years (5.78 MU to 7.34 MU).

Outages due to boiler not only cause maximum outages but also cause highest loss of generation.

Single boiler outage caused average loss of generation to the tune of 6.03 MU during FY08.

Patrik *et al.* (2005) have observed that boiler tube leaks are universal problems and still remain the leading cause of forced outage in coal-fired boilers (Pfeuffer, 2009).

5.4 Power Generation and Plant Load Factor

5.4.1 Stations recording more than 100% PLF

Analysis of plant level generation performance indicates that PLF of more than 100% at station level was recorded since FY08. While 3 stations, Sabarmati of Torrent Power; Dahanu of REL and Budge Budge of CESC having aggregate capacity of 1330 MW achieved PLF of 101.42%, 101.24% and 100.43% respectively during FY08, out of which Dahanu and Budge Budge repeated the feat during FY09 also. All the power plants are in private sector. Achievement of PLF figures beyond 100% is remarkable. List of such stations is detailed in Table 23.

Table 23 : Power Stations Recording 100% or Above PLF

Year	Sl No	Power Station	Capacity	PLF	Region	Operator	Sector
FY09	1	Dahanu	500	100.99	Western	REL	Private
	2	Budge Budge	500	100.53	Eastern	CESC	
FY08	1	Sabarmati	330	101.42	Western	Torrent Power	
	2	Dahanu	500	101.24	Western	REL	
	3	Budge Budge	500	100.43	Eastern	CESC	

5.4.2 Units recording more than 100% PLF

As early as FY05, power-generating stations started generating more power than their designed capacity during a year. While during FY05, 250MW Dahanu Unit#1 of REL achieved PLF of 103.87%, during FY06 Sabarmati #1 of Torrent Power, Budge-Budge #2 of CESC and Singrauli #4 of NTPC achieved PLF of 102.81%, 101.56% and 101.54% respectively along with Dahanu Unit#1. During FY08, 10 units from 5 operators having aggregate capacity of 2255 MW achieved PLF above 100%.

5.4.3 PLF Band

Distribution of capacities in different PLF bands is shown in Figure 8. Analysis of the performance data for the period FY04 to FY08 indicates, generating units aggregating to 1761 MW, 2262 MW and 2207.5 MW respectively generated no power during the

year. The capacity added during this period was 945 MW, 2710 MW and 1210 MW. Thus more capacity was shut down than were added. This indicates that the operational aspects deserve far more focused attention than being paid currently. Generating units aggregating to 9230 MW, 8887 MW and 9913 MW operated at a PLF of less than 50 % during the years FY04, FY05 and FY06 respectively.

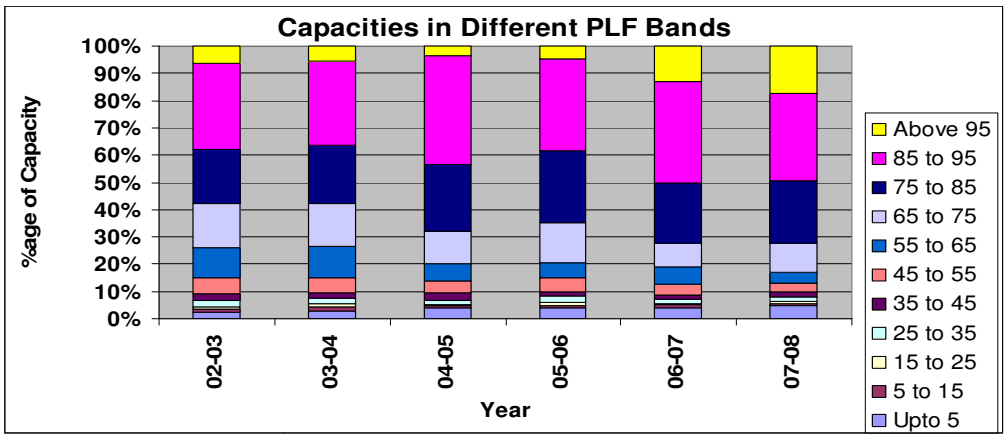

Figure 8 : Distribution of Capacities in Different PLF Bands

5.4.4 Sector wise PLF

Sector wise PLF of power stations during FY04 to FY08 is shown in Figure 9. Over the years, there has been consistent improvement in the PLF in Central and Private Sector. Power stations in State Sector also witnessed higher PLF during the period from 67.3% (FY06) to 72.09% (FY08). The performance of plants in Central and Private Sector has been consistently above national average. It is also observed that on the PLF front, power stations in the private Sector have outperformed those in the central and State Sector.

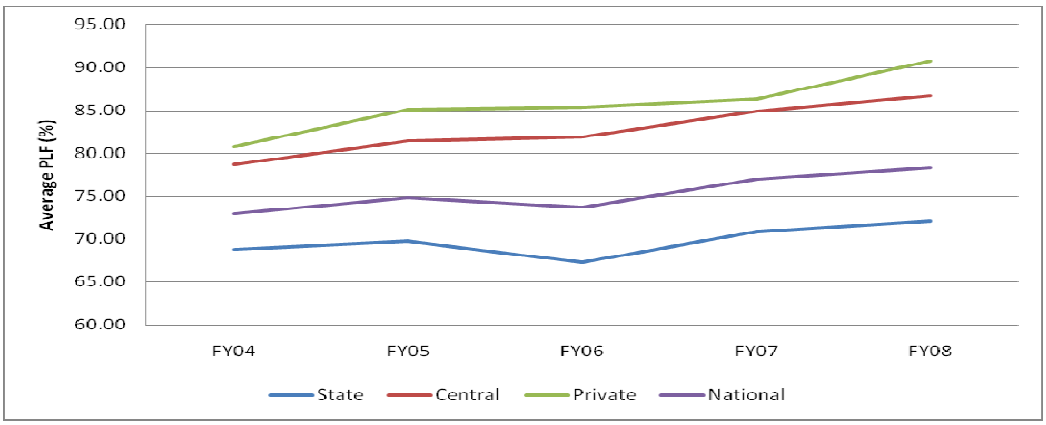

Figure 9 : Sector wise Average PLF during FY04 to FY08

5.4.5 Capacity group wise PLF

30 MW, coal fired unit #1 at New Cossipore which was commissioned on 31.10.1949 remains the oldest unit in the country in service and generated 76.41 MUs of electricity during FY08 @ 29.00 % PLF. As per the carbon baseline database, compiled by CEA as on 31.03.2009, there are 24 different capacity units in operation ranging from 20 MW to 500 MW. CEA grouped these units in 12 different categories till FY07 and reduced to five groups since FY08.

5.4.6 Partnership in Excellence

Partnership in Excellence (PIE) programme was launched by Govt. of India, in August'2005 to improve the performance of the power plants running at a PLF much below 60%. The three phased programme aimed to infuse better O&M practices of leading operators like NTPC, Tata Power etc. In the first phase it was envisaged to improve the station PLF by better O&M practices and training the site personnel. Improvement of PLF to at least 60% by undertaking capital maintenance, essential R&M works and making available critical spares from Original Equipment Manufacturers (OEM) was in the second phase followed by major R&M, Life Extension (LE) works based on Residual Life Assessment (RLA) in the third phase if found techno economically feasible (TPR, 2006).

CEA identified 26 thermal power plants consisting of 80 units having an aggregate installed capacity of 8.4 GW running below 60% PLF. PIE initiative have resulted in higher generation from the power plants. The initiative yielded encouraging results resulting in additional generation to the tune of 5 BUs and 6 BUs during FY07 and FY08. The scheme had been concluded in all identified thermal power stations from June 2008.

5.5 Auxiliary Power Consumption

Auxiliary Power Consumption (APC) denotes the power consumption by the unit auxiliaries and other equipments for meeting common station requirement such as station lighting, air conditioning etc. This is expressed as the ratio of electricity consumed to the electricity generated by the power-generating unit. Plant level analysis of APC during FY04 and FY08 indicate while Talcher-Kaniha consumed lowest APC of 5.34% (FY08), Amarkantak consumed highest APC at 18.14% (FY08). All India level APC stood at 9.05%, 8.57%, 8.44%, 8.29% and 8.17% during

FY04 to FY08. Region wise average APC figures compiled by CEA, during FY04 to FY08 are shown in Table 24. It is seen that APC on all India basis is above 8%; plants in Northern and Eastern region consume relative higher auxiliary power compared to national average.

Table 24: Region wise APC Figures During FY04 to FY08.

Region	FY04	FY05	FY06	FY07	FY08
Northern	8.85	9.03	8.89	8.62	8.57
Western	9.07	8.26	8.30	8.16	7.95
Southern	9.04	8.28	8.16	8.02	8.19
Eastern	9.31	8.90	8.39	8.37	7.98
North Eastern	N.A.	N.A.	6.42	6.33	1.89
All India	9.05	8.57	8.44	8.29	8.17

Thermal power plants are in fact the biggest consumer of electricity in the country and have earned a place among the designated consumers under energy conservation act, 2001 which mandates energy audit at regular intervals. Negawatt (NW) refers to a theoretical unit of power saved. In the Indian context average APC stands slightly above 8%. With about 80 GW of installed capacity, 1% savings of APC of coal fired power plants amounts capacity addition of about 640 NW.

5.6 Fuel Supply and Station Heat Rate

Coal is the essential input for running of power plants. Power plants are the major consumer of domestic coal consuming about 70% coal produced. In India, Singareni Collieries Company Ltd (SCCL) and Coal India Ltd. along with its subsidiaries are the lone producer of coal. However in the recent years captive coal blocks have been allotted to industries for their consumption. In the following sections coal supply position along with trends of SHR are discussed.

5.6.1 Coal Linkage, Supply and Consumption

Because of the criticality of the power sector, long term coal supply to these plants is assured through a multi disciplinary committee called Standing Linkage Committee - Long Term (SLC-LT) comprising of members from Ministry of Coal, representatives of CIL, SCCL, CMPDIL, Railways, Planning Commission, CEA, MoP etc. In spite of coal linkage being assured by an apex multidisciplinary committee, power stations in the country fail to get requisite amount of coal. As a result, power plants remain shut

down quite often on this count. Figure 10 depicts the coal linkage, receipt, import and consumption by coal based power plants at all India level during FY01 to FY08.

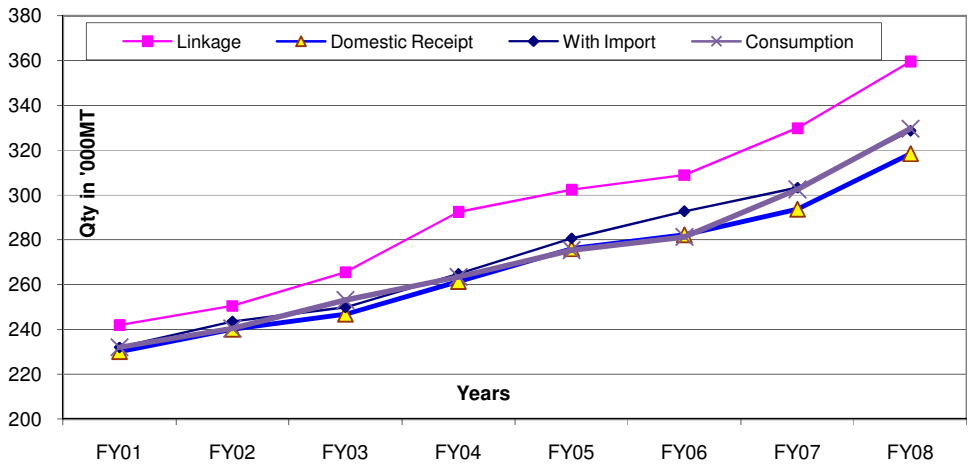

Figure 10 : Coal Linkage, Receipt, Import and Consumption by Power Plants

During FY08, against assured linkage of 369.73 MT, the power plants received 328.69 MT and consumed 329.63 MT of coal (TPR, 2008). It is observed that the coal companies are not able to meet the coal linkage assured to power plants resulting in coal shortage to the tune of 6.99 MMT during FY02 to 30.82MMT during FY08. In percentage terms this varies from 2.79% during FY02 to 9.43% during FY04. Even though Govt. of India have initiated certain measures like coal import by the power plants and allocation of captive mines, assured coal supply still remains a dream for the sector.

Cumulative coal shortage during FY02 to FY08 comes to about 155.616 MT. At a specific coal consumption of about 0.70 kg/kWh this translates to generation loss of about 222 BU, to the tune of 28 BU per annum which otherwise could have wiped out 40% of energy shortage. With an average PLF of 70% and capital cost of about ` 4.5 Cr/MW, and idle power generation capacity of 31.76 GW and investment of `1429 Billion. With the growing thrust on fossil fuelled power generation, the domestic coal supply and demand gap for the power sector is anticipated to widen further.

5.6.2 Critical Coal Stock at Power Stations

While the coal reserves are limited to selected areas in Bihar, West Bengal, Odisha, Chhattisgarh and MP, power plants are located all over the country and coal is transported through railways. Plants located near coal mines are called pit head

stations. Taking into account uncertainties associated with receipt of coal, plants maintain coal stock at their premises. CEA recommends, pit head coal stations to maintain at least one week's coal reserve and distant power stations to maintain coal stocks for one month. Due to lesser receipt and higher consumption, many of the plants are running hand to mouth and fail to maintain specified coal stock. Number of plants having critical coal stock at the end of the month during 2007 to 2010 is detailed in Figure 11.

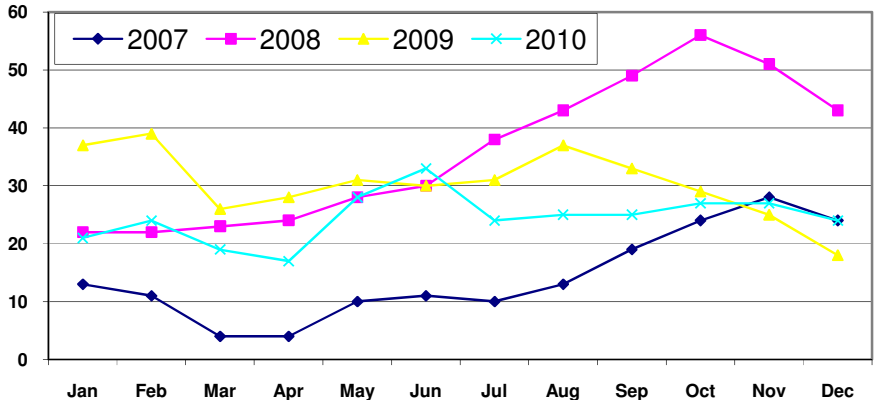

Figure 11 : Number of Plants having Critical Coal Stock

It is observed that coal stock at as many as 44 plants (October, 2008) were below critical stock. Over the years there has been a consistent reduction in number of such plants. Major causes of depleted coal stock are lesser delivery and higher consumption due to improved PLF. However this trend is going for a change in the recent years as more and more plants are facing acute coal shortage.

5.6.3 Station Heat Rate

Heat rate (HR) of a thermal power generating unit defined as the amount of heat energy required to generate one unit (kWh) of electrical energy and indicates how efficiently the chemical energy is converted to electrical energy. Units converting 100% of chemical energy to electrical energy would require about 860 kCal to generate one unit of electricity. However, because of the inherent inefficiencies associated with the power generation process, the actual heat rate is quite higher. The Station Heat Rate (SHR) of a power station is the aggregate heat rate of all power generating units in the stations. Ideally operating SHR (OSHR) should be as close as possible to Designed SHR (DSHR), but in practice it deviates from designed criteria causing more and more fuel to be burnt to generate electricity. Weighted average

operating station heat rate on all India basis for the FY08 was 2703.9 kcal/kWh against designed average of 2376.8 kcal/kWh, indicating that the fleet of power plants are designed to convert about 36.18% of chemical energy into electricity and actually consume 13.76% excess chemical energy. Thermal Performance Review (2008) provides detailed information regarding methods used for measurement and techniques for reducing SHR. Heat rate deviations in the band 0-10% are acceptable and considered good, deviations beyond 10% are considered as poorly operating ones. Region wise trend of SHR during FY04 to FY08 is detailed in Table 25.

Table 25 : Region wise Trend of Operating Heat Rate

Region		FY04	FY05	FY06	FY07	FY08
Eastern		3614.00	3148.00	2887.00	3109.00	2738.50
Northern		2844.00	2892.00	2793.00	2937.90	2603.20
Southern		2707.00	2700.00	2667.00	2679.20	2653.20
Western		2637.00	2712.00	2737.00	2833.80	2787.00
All India	**Design**	2407.00	2397.00	2398.00	2398.00	2376.00
	Operational	2762.00	2788.00	2747.00	2861.00	2703.90

From the SHR trend it is observed that operating SHR is higher than the design SHR and the deviation ranges from 13.8% during FY08 to 19.32% during FY07. It is observed that the average OSHR deviation from national averages have come down from 50.15% (FY04) to 15.26% (FY08). Region wise analysis of operating SHR deviations from national average, reveal the deviation in the band of 9.56% (Western, FY04; Northern, FY08) to 50.15% (Eastern, FY04). While the operational SHR of plants in Eastern Region is consistently above national average those in Southern Region performed consistently better during the period. SHR deviations beyond 10% are a matter of concern and calls for techno managerial intervention to plug energy leakages. Improvements of SHR by identifying and plugging energy leakages in various subsystems can go a long way in reallocation of these scarce resources to starved ones which can result proportionate increase in electricity generation in the country, reduce CO_2 emissions and reduce the cost of electricity. Induction of super critical technology in power generation sector is likely to reduce OSHR.

5.7 Findings at a Glance

Trend analysis of key performance parameters of coal fired thermal power plants is done at national, operator and plant/ unit level. Month wise analysis of availability

(OAF) and non-availability (FO and PM) of power plants during last decade are also done unearth the seasonal trends. Plant / unit level analysis are also done to find out the trends and causes of outages to facilitate managerial intervention. The key findings are detailed below:

- OAF increased from 64.68% (FY84) to 84.76% (FY08).
- Increased availability has resulted in higher PLF from 46.07% (FY84) to 78.75% (FY08). Gap between OAF and PLF narrowed down from 18.61% (FY84) to 6.01% (FY08).
- PM duration came down from 12.52% (FY83) to 5.66% (FY09).
- OAF is not uniform round the year; $F(11, 108) = 15.951$, $p < 0.01$. Highest OAF during March; higher by 8.46% than August.
- Maintenance activities are not planned uniformly round the year; $F(11, 108) = 27.623$, $p < 0.01$. Lowest PM of 5.93% during March and highest of 13.47% during August.
- Variation of Planned maintenance durations across operators is significant. While the PM durations of REL is lowest, that of UPRVUNL is highest.
- Variation of forced outage durations during the year is not statistically significant; $F(11, 108) = 1.746$, $p > 0.01$.
- During FY04 to FY08, 107 Units aggregating to 7 GW remained unavailable for PM during the whole year. Highest unit level OAF 99.98% (Dahanu #1, FY05; Budge Budge #2, FY08).
- About 2 GW and 10 GW of installed capacity operated below 5% above 95% OAF band respectively.
- Highest PM 82.77% (FY07) – Barauni. Implementation of Kukde Committee recommendations could reduce PM durations by 23 days (210 MW) and by 35 days (500 MW).
- During FY08, 385 units recorded 6426 outages resulting generation loss of 46.53 BUs @16.7 outages/ unit and 7.24 MU/ outage.
- 250 MW units have eliminated certain outages which 500 MW units could emulate.
- Generation loss ranges from 3.87 MUs (Turbine Aux) to 11.36 MUs (Misc Elect. and Mech. problems). No of outages have reduced from 8400 to 6600 but generation loss due to outages increased from 5.78 BUs to 7.34 BUs per outage.
- Coal shortage is acting as a bottleneck for the coal fired power plants in their attempt to fuel the Indian economy.