Minimization Of Auxiliary Power Consumption In Coal Fired Thermal Power Stations

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***Abstract*-Auxiliary power in coal fired power stations accounts for 7 % (500 MW units) to 12 % (30 MW units) of the gross generated power at the full plant load. The minimum AP varies between 4.5 % and 9.0 % for the same capacity range. The excessive power due to factors such as coal quality, excessive steam flow, internal leakage/ingress in equipment, inefficient drives, distribution network losses, reduced power quality, ageing, etc., is quantified. An experimental study has shown that 85.7 % of the AP in excess of the design value can be traced to coal quality and its indirect effects. The AP can be minimized even below the design value by operational optimization, overhaul of equipment and revamping. The paper discusses in detail the techniques for restoration of the AP to the designed value and further improvements.**

***Index terms-* Auxiliary power, thermal power plants, motors, pumps, fans, mills.**

I. Introduction

Coal fired thermal power stations in India consume between 7 % and 18 % of their gross generated power for the electric power requirements of the station (auxiliary power efficiency: 82 % to 93 %). This requirement is called as **auxiliary power (AP), works power** or **parasitic power** and can be classified into four broad groups as: Unit auxiliaries (in-plant HT motors), Unit auxiliaries (in-plant LT loads), Common station auxiliaries (out-lying HT motors) and Common station auxiliaries (out-lying LT loads)

The AP is high (design power: 4.5-9.0 % of the plant load) primarily because of handling high ash and moist coals. High ash content increases the power requirements for handling, crushing, milling, conveying of coal as also grinding, pumping and precipitation requirements of ash. The high abrasive index of Indian coals (20-110 mg/kg) [British and American coals: 2-10 mg/kg] results in rapid wear of coal handling and processing equipment with consequent increase in thespecific energy consumption (SEC). Apart from coal, factors such as high excess air, high specific steam consumption, leakage/ingress in pipes/ducts/valves/active flow elements, decreased electric power quality, lower equipment efficiencies, ageing and incompatibility of technology to operating conditions are also responsible for higher AP.

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II. Performance Indices

The performance of the AP system is quantified by performance indices as given below:

i. The **auxiliary plant load factor (APLF)** is defined as,

APLF = (auxiliary load)/(plant load) (1)

ii. The **auxiliary load factor (ALF)** is defined as,

ALF = (auxiliary load)/(rated auxiliary capacity) (2)

iii. AP at zero PL with unit synchronized.
iv. APLF at full PL.
v. Minimum AP in the entire load range of operation.
The excess margins (30-60 %) provided

vi. Auxiliary power efficiency (|) is given by,

$$\eta = P_{net}/P_{gross} \quad (3)$$

The share of the in-house and out-lying power for the units of various capacities is given in Table 1. The performance of in-house auxiliaries is given in Table 2 [1]. The comparative evaluation of mills, crushers, cooling water systems and firing systems is given in Tables 3,4,5 & 6. The network losses for the units studied are shown in Table 7 [1].

III. Observations

The observations regarding pumps and their motors are as follows:

i.HT Motors-Pumps:

High SEC of pumps also results from internal leakage (due to wear of impeller and casing rings), passing of re-circulation valves, etc.. Some of the motors of pumps which have completed over 20 years of service suffer from ageing of insulation.

Table 1: Share of in-house and out-lying auxiliary power.

Sl. No.	Particulars	Unit	500.0 MW	210.0 MW	120.0 MW	110.0 MW	62.5 MW	30.0 MW
01	Share of in- house auxiliary power	percent of auxiliary power	82.4 - 84.9	83.1 - 89.4	75.5 - 78.3	73.2 - 76.5	73.1 - 75.8	72.8 - 75.2
02	Share of out-lying auxiliary power		13.2 - 16.1	10.2 - 17.7	17.1 - 22.3	21.5 - 26.0	25.7 - 29.6	27.0 - 29.8

Table 2: Performance of in-house auxiliaries (Dn - Design; Op – Operating)

Particular	500.0 MW	210.0 MW	120.0 MW	110.0 MW	62.5 MW	30.0 MW
	Boiler feed pump + motor					
Efficiency (Dn), %	58.5	55.9	63.5	59.5	58.0	58.3
Efficiency (Op), %	55.0 - 57.9	54.9 - 59.5	44.5 - 52.5	53.5 - 54.8	55.2 - 58.4	47.5 - 54.5
Condensate Extraction Pump + motor						
Efficiency (Dn), %	57.3	59.5	50.3	50.3	52.5	55.2
Efficiency (Op), %	61.5 - 64.2	60.1 - 61.4	35.2 - 48.5	45.6 - 50.0	45.8 - 51.3	38.6 - 52.7
Induced Draft Fan + motor						
Efficiency (Dn), %	56.5	56.7	58.0	58.0	57.0	58.1
Efficiency (Op), %	55.1 - 55.8	45.4 - 50.5	37.54- 37.9	37.8 - 47.1	26.9 - 31.0	45.8 - 54.2
Forced Draft Fan + motor						
Efficiency (Dn), %	56.8	56.9	60.0	60.0	56.0	50.5
Efficiency (Op), %	30.66 - 34.54	37.4 - 59.2	25.77 - 29.99	35.3 - 36.0	25.9 - 28.4	38.5 - 51.8
Primary Air Fan + motor						
Efficiency (Dn), %	57.2	55.7	57.0	57.0	58.0	52.7
Efficiency (Op), %	31.5 - 33.9	34.0 - 37.2	39.0 - 51.6	50.1 - 55.7	32.9 - 41.9	39.1 - 45.3

Table 3: Comparative evaluation of mills.

Sl. No.	Particulars	Bowl	Drum	Ball & race
01	Share of milling capacity in Indian power stations (%).	75.0	15.0	10.0
02	Performance when grinding elements are worn out.	In-consistent	Consistent	Consistent
03	Presence of foreign materials.	Needs stoppage	No outage	No outage
04	Damage to the grinding elements due to foreign materials.	No effect	No effect	Susceptible
05	Sensitivity of coal quality to mill loading.	high	low	low
06	Chance of mill fires.	low	high	low
07	Frequency of adjustments of clearances.	high	low	low
08	Lubricant requirements.	low	high	low
09	Planned outages (days/year).	30	8	8
10	Reject rate (%).	5 - 8	0.0	0.3 - 0.5
11	Specific energy consumption (kWh/t).	7.75 - 8.55	10.20 - 23.00	8.40 - 10.25
12	Average specific energy consumption (kWh/t).	8.48	15.81	9.56

Table 4: Comparative evaluation of coal crushers.

Sl. No.	Type of crusher	Output coal size, mm	Specific energy consumption, kWh/t of coal	
			Design	Operating
01	Jaw type roller crusher	100	0.10	0.07 - 0.09
02	Bradford breaker	150	0.25	0.14 - 0.17
03	Double roller type crusher	300	0.23	0.13 - 0.24
04	Ring granulator	25	0.61	0.72 - 0.78
05	Hammer mill	25	0.50	0.36 - 0.61
06	Impactor beater	25	0.70	0.65 - 0.70

Table 5: Comparative evaluation of cooling water systems.

Particulars	Unit size (MW)	Percentage of plant load
Once through sea water	110.0	0.20 - 0.23
Once through river water	210.0	1.35 - 1.37
	120.0	2.31 - 2.59
	62.5	2.10 - 2.75
	30.0	2.10 - 2.30
Natural draft closed circuit	210.0	1.04 - 1.46
	110.0	1.90 - 2.00
	62.5	1.50 - 1.60
Induced draft closed circuit	500.0	1.31 - 1.35
	210.0	1.48 - 1.85
	110.0	2.50 - 2.60

Table 6: Comparative evaluation direct and indirect firing system.

Particulars	Unit size (MW)	Percentage of plant load [a]
Direct firing system with common PA fans	500.0	1.10 - 1.20
	210.0	0.96 - 1.12
Direct firing system with individual PA fans	210.0	1.05 - 1.14
	120.0	1.50 - 1.60
	62.5	2.00 - 2.15
	30.0	1.75 - 2.10
Indirect firing system with individual PA fans	110.0	1.73 - 2.69

[a]: Includes power drawn by PA fans, mills, coal feeders and vapor fans (PC system)

Table 7: Energy losses in the auxiliary network as a percentage of the gross auxiliary power.

Unit No.	Particular	500.0 MW	210.0 MW	120.0 MW	110.0 MW	62.5 MW	30.0 MW
01	Transformer losses [a], %	0.220	0.254	0.310	0.310	0.323	0.342
02	Cable and conductor losses, %	0.176	0.108	0.170	0.170	0.184	0.195
03	Joint losses [b], %	0.112	0.079	0.105	0.111	0.122	0.131
04	Low power factor loss, %	0.039	0.042	0.055	0.065	0.074	0.085
05	Unsymmetrical V & I, %	0.001	0.022	0.033	0.029	0.044	0.052
06	Miscellaneous losses [c], %	0.002	0.013	0.027	0.027	0.033	0.045
07	**Total losses, %**	**0.550**	**0.511**	**0.698**	**0.712**	**0.779**	**0.850**
08	**Distribution efficiency, %**	**99.45**	**99.49**	**99.30**	**99.29**	**99.22**	**99.15**

[a]: Copper and Iron losses in transformer; [b]: Losses due to low voltage and inadequate reactive compensation; [c]: Includes harmonics, earth leakage, non-optimum configuration of cables, etc..

ii. **HT Motors-Fans:**
ID fans: ingress, presence of ash in the flue gas path. FD and PA fans: Air leakage from the hot air duct, APH in-leakage Vapor fans (for indirect firing systems): air ingress in fan suction duct

iii. HT Motors-Mills & Crushers: Coal-air mixture temperature at the mill below 60 °C

iv. Bowl mills: Uneven wear rolls and bull ring segments, internal distances exceeding limits

v. Drum type ball mills: ball charge, ball size distribution, fuel HCV, level of coal loading, hardness index of coal, ball material and condition of armour plates

vi. Slow speed large ball mills: Differential pressure across the mill, outlet fuel-air mixture temperature, gap between the bottom ring and throat, etc..

vii. **Hammer mills:** Breakage of hammers.

viii. **Crushers:** SEC and PR decrease with increase of fines in the unprocessed coal.

IV. Energy Conservation Measures

A. Operational Optimization Pumps and fans:

Operating point and optimum efficiency point of pumps and fans must be in close proximity. Control of high bearing temperatures, tuning of coupling drives, minimizing excess air flow, load balancing in all fans and pumps, reducing water to ash ratio of ash slurry pumps from 20:1 to 10:1 or lower are some of the other measures.

1. Adjustment of the classifiers of mills, Coal size at mill inlet must be restricted to 25 mm, On-line removal of stones before the crusher, Minimizing un-synchronized/idle operation of conveyors.
2. **Bowl mills:** Constant adjustment of spring tension and internal gaps (30 mm) between rolls and bull ring segments.
3. **Drum type ball mills:** Minimization of ball charge hold up when the coal quality is better, ensuring a mill inlet air temperature of 300 °C and mill outlet fuel-air temperature of 85-90 °C.
4. Slow speed large ball mills: Balls of 660 mm can be allowed to reduce to 585 mm at which point a filler ball is to be inserted. When the size is below 560-570 mm, the balls must be replaced. The gap between the ring and throa must be adjusted to 10 mm.

General:

1. Attempts may be made to shift the auxiliary peak to a non-grid peak by scheduling of non real-time tasks where excess equipment capacity is available.
2. Change of auto change-over signal from primary to secondary side of stand-by transformer thereby keeping it de-energized. Operation may be alternated between the Main and Stand-by transformers on a weekly basis (cyclic de-energisation).
3. Review and minimization of compressed air pressure settings from 700 kPa to 550 kPa.
4. Isolation of non-essential cooling loads on theHVAC plant.
5. Water (raw water, soft water, treated water, demineralized water and blow down streams) waste reduction from 20 % to below 5 % can reduce the primary water pumping power (60- 120 kW per unit) by 15 %.

B. Overhaul & Repairs

Pumps:

1. Checking and restoration of clearance between impellers and casing rings, surface finish of impellers, entrance and exit joints of BFPs and CEPs.
2. Check clearances of suction valve, balance leak-off valve and re-circulation valve to minimize valve passing during operation.
3. Calibration of hydraulic scoop coupling for the BFPs.
4. Reduction in water contamination in the bearing cooling oil and reduction in high pressure drop in lube oil coolers.

Fans:

1. Clearing the ducts and passages of debris and ash.
2. Restoration of impellers/blades-casing clearance, surface finish and profile of fan blades.
3. Correction of shaft run-out by local filling,welding and machining.
4. Calibration of control vane/damper of fans.
5. Control of excessive noise and vibrations.
6. Inspection of blade profiles of ID, FD and PA fans and insurance of the original profile.
7. Audio frequency noise due to blade passing frequency and turbulence noise must be evaluated and minimized.
8. Renewal/re-conditioning of impeller casing, outlet blade casing liner plates and dampers.
9. Arresting air leaks and in hot and cold air ducts and connected repairs.

Mills and crushers:

1. Installation of low friction, high resistance polymeric lining in chutes and hoppers prone to hang-ups.
2. In ring granulators, the crusher rings must be ensured to be Mn steel castings with Mn steel to carbon ratio of 10:1. Radiographic tests on the crushing elements is required.
3. Installation of **rubber cushions** on stator plates of coal crushers to minimize impact wear.
4. Installation of 300 mm grids at the wagon tippler.
5. Checking and restoration of winding insulation, mechanical and electrical parameters of all HT and major LT motors.
6. Checking and restoration of healthiness of bearings of all HT and LT motors.
7. Identification and repair of spots of duct leakage/ingress.
8. Change of servo-gem grease to **lithium** or **silicon grease** in couplings, gear drives, bearings of vibratory screens, etc..
9. Capacity tests on DC batteries.
10. Calibration, evaluation and review of time delay for secondary side tripping.
11. Arresting leaks and overhaul of air compressors, non-return valves and compressed air lines.
12. Acid cleaning of oil coolers on the circulating water side, chemical cleaning of plate heat exchangers and other shell and tube heat exchangers.
13. Overhaul of compressors, air leak detection and elimination in the compressed air system can give saving of 20 % of the compressed air power (325 kW per 210 MW unit).

C. Simple modifications

Pumps & fans:

1. Replacement of vacuum pumps (electric power: 150-160 kW per 210 MW unit) for condenser air removal by steam jet ejectors.

2. Erosion, corrosion and abrasive resistance of ID fan internals can be improved by one of the following: **wear plates** (chromium carbide weld applied on mild steel sheet), thermal spray coatings (wire flame/powder flame/plasma spray/high velocity oxyacetylene spray/electric arc spray) using diamalloy powders/high carbon (0.8 %) spray steel of thickness 0.5-0.8 mm, **ceramic/tungsten carbide tiles** with epoxy grouting, hard facing with sacrificial electrodes, 1.5 mm **sweat-on-paste fusion** coating of chromium boride crystals on mild steel/carbon steel/low alloy steels, **vitreous** enamel coatings , etc..
3. Solid blades to replace hollow blades avoid internal accumulation of ash.
4. Introduction of soot blowing inside the ID fans is suggested to minimize vibration due to ash deposit on fan blades and uneven erosion of fan material.
5. Replacement of steel blades of cooling tower fans with fibre reinforced plastic blades will reduce the power drawn by the fan motors (350 kW per 210 MW unit) by 15-20 %.

Mills and crushers:

1. In general, erosion and abrasion resistance of mill and crusher elements can be increased by an order of 3-4 by use of nickel and cobalt based alloys, ceramic materials (Al_2O_3, Cr_3C_2, TiN, TiB_2, etc.), elastometric materials or self fluxing alloys.
2. In bowl mills, grinding rolls of Ni-hard, Stoody weld overlay, Combust alloy, hichrome, static cast chrome have a life of 1700- 5000 h. Bull ring segments modified Ni-hard, Mandatory Ni-hard, Hi-chrome have a life of 1500-4500 h. The two most popular methods of improving erosion resistance of bowl mill rolls- **weld overlays** and internal cladding of mild steel/carbon steel with alloy overlays give a life of 6000-8000 h. Other methods tried out **are alumina ceramics** laid with mortar **boronizing** (boron diffusion on surface leading of formation of borides with iron) but these are not very successful. Use of **hardened sleeves (to avoid collar formation) is quite effective.**
3. In bowl mills, **vane wheel assembly** in place of separator body liners and separator bottom liners can give up to 15 % capacity improvement.
4. In drum type ball mills, armour plates (liners) of Mn steel give a life of 5000-6000 h while Hi-chrome and Ni-hard II prolong the liner profile. Cast basalt overlays/ alumina zirconium cast ceramic profiles can be used partially on the armour plates and replace/recondition all armour plates in one lot annually. Optimally shaped armour plates can enhance the capacity by 15-17 %.
5. In drum mills, grinding balls must be changed from Mn steel (life: 3000-4000 h for large sized balls and 700-800 h for small sized balls) to Hi-chrome or forged steel balls (life: 6000- 7000 h for large sized balls and 1000-1200 h for small sized balls). The ball consumption is 450 g/t of coal for Mn steel balls, 50-60 g/t for Hi-chrome balls and 30-40 g/t for forged steel balls.
6. In drum mills, use of flue gas (drawn before APH at 350-370 °C) and entering the mill at 330-340 °C for heating the mill internals in addition to primary air will decrease the SEC of the mill beside aiding in minimizing mill fires.

Coal handling plant:

1. **Automatic photocell wagon positioning** system to enhance the disposal rate of coal wagons thereby reducing conveyor running time. The disposal rate of 3-4 wagons/h/tippler with manual positioning can be enhanced to 6 wagons/h/tippler giving a saving of 10-12 % in conveyor SEC.
2. 20 mm dish type vibratory screens before crushers to bypass undersized particles and also after the coal crusher to minimize the milling power.
3. Isolation of the reclamation yard from the unprocessed coal yard and double conveyor for handling output of reclamation yard.
4. Coal from the reclamation yard to directly go to the bunker rather than pass through the crusher again.
5. Revision of slopes of conveyors.

General:

1. Auto change over of load on station transformers and unit auxiliary transformers. Magnetic steel shields inside the tank will reduce stray losses.
2. Additional capacity (450 m2, 300 plates of SS 316/titanium) of plate heat exchangers to provide better control over shooting bearing temperatures during summer months.
3. Thermostatic controllers incorporating **fuzzy** logic features with interlocks for refrigerant circuits, chilled water circuits and conditioned air circuits.
4. **Programmable lighting controllers** (lumen control, on-off control and programmable features) for in-plant, out-lying and out-station lighting systems (electric load: 150-160 kW per 210 MW unit).
5. Flat belts or mono-block couplings as replacements for V belts in small motor drives below 5 kW (there are about 1000 small capacity motors).

D. Retrofitting

1. Noise monitoring inside tube mills to estimate the level of loading.
2. Steam supply system for mills for quenching of mill fires. to the bunker rather than pass through the crusher again.

3. Automatic static switchable capacitor banks (in binary fashion) for HT and LT motors for control of power factor to within 1 % point of unity.
4. **Bell mouthed inlets** for ID fans, FD fans and PA fans and decrease pressure drop by as much as 25 %.
5. During rainy season, a heating scheme based on drawing of flue gas from the nearest ID fan discharge for reducing the moisture content of un-processed coal before its entry into the crusher.
6. **Heat wheels** for recuperation of cooling effect from air handling unit circuits.

E. Modernisation

1. The drives for fans (ID, FD and PA) and pumps (BFP, CWP) may be reviewed and changed from solid couplings to scoop control, VSD or steam turbo dries.
2. Advanced with **cartridge construction** concepts, short and stiff shafts, capability of continued running under vapor bound transients, high capacity thrust bearings, reliable balancing system, journal bearings with anti-whirl features, hydraulic stud tensioner, etc. for 210 MW and 500 MW units shortens the down time, reduces the number of components by 40 % and give pump efficiencies of around 86-90 % as compared to the present values of 43.2 to 63.5 %.
3. **DELSTAR controllers** for LT motors (total capacity: 1800 kW per 210 MW unit) above 10 kW where load variation is present. These constantly sense the load and change over to star when the load is below a pre-programmed value (50-60 % load) and otherwise to delta.
4. Microprocessor based ESPs.
5. **Vapour absorption chillers** for comfort air conditioners (electric load: 150 kW per 210 MW unit).
6. Automation of raw water pumping, water distribution system, blow down, operation and control CT fans and electrical distribution system.
7. **Transformers: On-load tap changers, amorphous metal transformers** (losses reduced from 0.65 W/kg for silicon steel transformers to 0.20 W/kg) and automation of monitoring and control.
8. **Super-conducting technology** for generators and transformers for 500 MW units as a long term measure.

V. Achieved Improvement

After overhauling and operational optimization, the power (for the same throughput) of mills has been reduced as follows: bowl mills-24.45 % (from 1067.3 kW to 806.2 kW), drum mills- 19.58 % (from 766.1 kW to 616.1 kW), slow speed large ball mill-18.1 % (from 539.5 kW to 441.7 kW).

Similarly, there is reduction in 15-25 % of SEC for pumps and fans. The improvement in AP efficiency before and after overhauling and by operational optimization is between 1.2 to 4.5 percentage points for units of all sizes studied. In order to pin point the reasons for high AP due to poor coal quality and its secondary effects on one hand and other factors (valve leaks, seal leaks, etc.) on the other hand, a comparative study was conducted on 210 MW units using good coal with ash below 10 % and the normally used local coal at a load of 200 MW. There was a saving of 2.68 MW (BFP: 0.12 MW, CEP: 0.11 MW, ID fan: 0.73 MW, FD + PA fans: 0.93 MW, mills: 0.71 MW) in the in-house auxiliaries. The AP efficiency increased from 90.2 % to 92.9 % (design: 93.35 %). Thus it can be said that 85.7 % of excess power drawn is due to deterioration in coal quality and the balance (14.3 %) is due to other effects.

VI. Conclusions

The main conclusions of the study are as follows: The AP efficiencies is in the range 82-93 % for the plants studied. The design auxiliary efficiencies are in the range 91.0-95.5 %. The causes for the deviation are high ash in coal, excessive steam flows, internal leakage/ingress, inefficient drives, reduced power quality, ageing, etc.. 85.7 % of the AP drawn in excess of the design value is due to deteriorated coal quality and its indirect effects.

i. The AP efficiency can beenhanced by replacement of electric motor drives by steam actuated systems (such as steam turbines, steam jet ejectors, vapour absorption chillers, etc.).
ii. The performance of active flow elements like pumps and fans can be enhanced by higher equipment efficiency, operation at the optimal point, optimized capacity modulation techniques, reduction in excessive flows (air, flue gas, steam and water) and minimization of the conduit hydrodynamic resistance.
iii. Improvement in the internal sealing technology can bring about reduction in specific energy consumption.
iv. Improvement in material and production technologies of grinding elements of mills and crushers can result in lower AP.
v. Power quality improvement, automation and control of the distribution network will enhance the AP efficiency.
vi. The AP efficiencies can surpass the design values by a total approach involving operational optimization, overhauling and modernization.

References

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