Performance Improvement of Process Draft Fans in Coal Based Power Plants

Rajashekar P. Mandi, Udaykumar R. Yaragatti

Abstract: Indian energy sector mainly depends on the fossil fuel based power plants especially coal based power plants. The performance of coal based power plants in India is poor compared to other advanced countries due to prolonged use of smaller size power plants who have served more than 35 – 40 year with refurbishments and poor coal quality. The auxiliary power in thermal power plant plays a major role in performance of plants because the average auxiliary power consumption varies between 7.5 – 14.3% of plant load depending on the plant size. In this paper the avenues for improving the power plant performance by implementing the energy conservation measures like reducing the hydrodynamic resistance in flue gas & air ducts through clearing the debris, control of illegal furnace ingress, efficient control techniques, cleaning air baskets in air pre-heaters, operational optimization, variable frequency drives, etc. that reduces the energy consumption by 5.5 to 6.5 MU/year which reduces the overall auxiliary power by 0.5% of plant load.

Keywords: auxiliary power; energy conservation; induced draft fans: forced draft fans; primary air fans; air pre-heaters;

I. INTRODUCTION

The power generation capacity in India is about 357 GW as on 31st March 2019 out of which 61% of power is being added by coal fired power plants in India and the energy share by coal fired power plants is 74.5% of total energy consumption. Therefore, in Indian power sector development, thermal power generation play a major role in energy security [1, 2].

The performance, reliability and availability of thermal power plant (TPP) depend on the coal quality, water quality and the operational reliability of auxiliary power equipment [3, 4]. The boilers used are of balanced draft corner fired pulverized coal type. Therefore, the draft system plays an important role in maintaining the energy efficiency, operational optimization and safety of boilers. The draft system consists of forced draft fans (FDF) to provide the secondary air for proper combustion, primary air fans (PAF) fans to lift the coal from mills to burner for proper combustion and induced draft fans (IDF) to extract the flue gas from boiler and to throw out the flue gas through chimney to atmosphere.

The auxiliary power (AP) is the power used to operate all the auxiliary equipment to generate the power at TPP. In Indian power plants, the AP is on higher side due to use of high ash content (30 - 50%) and low calorific value coal (2600 – 3900 kcal/kg), higher air ingress in furnace due to erosion due to high ash content coal, higher hydrodynamic resistance in air and flue gas ducts accumulated debris, poor efficiency of drives, mismatch of equipment drives, ageing of equipment, obsolete equipment, etc. [5, 6, 7].

II. AUXILIARY POWER

The test is conducted on the boiler of 500 MW power plants as per BIS standard by maintaining the plant load constant for minimum of 120 minutes. The auxiliary power of process draft fans is measured by using power analyser and computed the specific auxiliary power (SAP) and is presented in Figure 1. As the PLF increases, the auxiliary power consumption decreases. Therefore, the plants have to be operated near to their full load [8]. The total specific auxiliary power for draft fans is computed by using the following curve fit:

$$SAP_{draft\ fans} = 0.0008 \times PL^2 - 0.1502 \times PL + 9.21\,\% \ldots\ldots\ldots\ldots\ldots [1]$$

The power for ID fans is computed by using following curve fit:

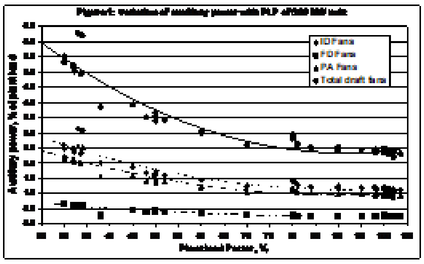
$$SAP_{IDF} = 0.0004 \times PL^2 - 0.0721 \times PL + 4.41\,\% \ldots\ldots\ldots\ldots\ldots [2]$$

The power used by FD fans is computed by using following curve fit:

$$SAP_{FDF} = 9E - 05 \times PL^2 - 0.017 \times PL + 1.0591\,\% \ldots\ldots\ldots\ldots\ldots [3]$$

The power used by PA fans is computed by using following curve fit:

$$SAP_{FDF} = 0.0003 \times PL^2 - 0.61 \times PL + 3.7409\,\% \ldots\ldots\ldots\ldots\ldots [4]$$



The various reasons for higher specific auxiliary power are

a) Operational parameters:
   - Design constraints: equipment oversize
   - Hesitation in adopting new advanced technologies.
   - Sub-optimal equipment performance due to poor loading
   - Age old control techniques and poor Instrumentation & control.
   - Forced outages
   - Poor capabilities of operators for optimum operation due to lack of training and motivation

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b) External factors like coal shortages, inferior water quality, poor coal quality, etc. which are not in the control of power plant officials.
c) Grid specific factors like backing down of plants due to surplus power & support of reactive power by the units also not directly in the control of plant officials.

A Design constraints

In coal fired power plants two streams of air cycle and flue gas cycle (left & right or A side B side) are used in most of the power plants to operate the power plant at least at 60% of plant load with one stream of both air & flue as cycle whenever there is problem in second stream [9, 10]. To accommodate this constraint, the draft fans are designed with high reserve capacities depending on nature of equipment.

The design and operating capacities of draft fans are given in Tables 1 to 3 for typical 500 MW & 210 MW power plants. Figure 2 gives the variation of capacities of major fans.

Table 1: Capacity utilization of ID fans

Sl No.	Particulars	Unit	500 MW plant		210 MW plant	
			100 % fan cap.	100 % MCR	100 % fan cap.	100 % MCR
01	Motor rating & Nos.	kW (nos)	1800 (4)		1400 (2)	
02	Flue gas flow	m^3/s	255	204	228	192.2
03	Total head	mmWC	480	343	384	295
04	Fan efficiency	%	84.50	72.90	76.50	63.91
05	Fan output power	kW	1200	686.4	858.9	556.2
06	Motor efficiency	%	95.06	94.48	94.96	94.46
07	Motor input power	kW	1493.9	996.6	1182.3	921.4
08	Overall efficiency	%	80.33	68.88	72.64	60.37
09	Reduction in overall efficiency	%	11.45		12.27	

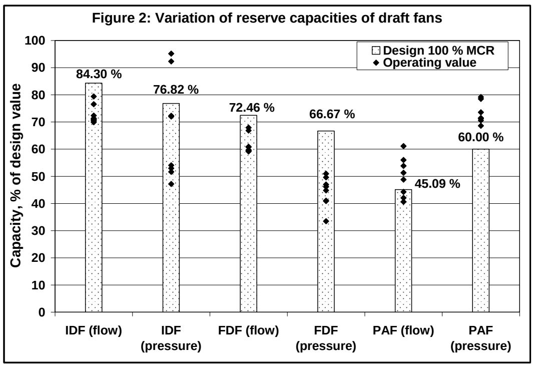
Table 2: Capacity utilization of FD fans

Sl No.	Particulars	Unit	500 MW plant		210 MW plant	
			100 % fan cap.	100 % MCR	100 % fan cap.	100 % MCR
01	Motor rating & Nos.	kW (nos)	1750 (2)		600 (2)	
02	Sec. air flow	m^3/s	249	176.9	90.1	65.29
03	Total head	mmWC	430	287.62	480	320
04	Fan efficiency	%	88.00	76.50	76.48	68.95
05	Fan output power	kW	1050.4	499.1	424.3	205.0
06	Motor efficiency	%	92.80	84.26	93.65	86.54
07	Motor input power	kW	1286.2	774.34	592.35	343.5
08	Overall efficiency	%	81.66	64.46	71.62	59.67
09	Reduction in overall efficiency	%	17.20		11.95	

Table 3: Capacity utilization of PA fans

Sl No.	Particulars	Unit	500 MW plant		210 MW plant	
			100 % fan cap.	100 % MCR	100 % fan cap.	100 % MCR
01	Motor rating & Nos.	kW (nos)	2800 (2)		1300 (2)	
02	Primary air flow	m^3/s	169	88.9	74.0	33.37
03	Total head	mmWC	1270	746.82	1250	750
04	Fan efficiency	%	88.00	72.50	78.50	70.38
05	Fan output power	kW	2105.5	651.31	907.43	245.5
06	Motor efficiency	%	93.70	85.84	93.65	82.45
07	Motor input power	kW	2553.5	1046.6	1243.3	423.1
08	Overall efficiency	%	82.46	62.23	73.51	58.03
09	Reduction in overall efficiency	%	20.23		15.48	

Induced draft fans have an additional capacity (for 210 & 500 MW plants) for flow in the range of 20 – 23.2 %, pressure in the range of 23.2 – 28.5 % and output power in the range of 35.2 – 42.8 %. The overall efficiency of ID fans is lowered by about 11.45 – 12.27 % due to oversizing cause higher auxiliary power of ID fans is about 311.3 – 568.4 kW.



Forced draft fans have an additional capacity (for 210 & 500 MW plants) for flow in the range of 27.5 – 29 %, pressure in the range of 33.1 – 33.3 % and output power in the range of 51.7 – 52.5 %. The use of higher sized fans, had reduced the fan overall efficiency by about 11.95 – 17.2 % due to oversizing cause higher auxiliary power of FD fans is about 114.6 – 326.2 kW.

Primary air fans have an additional capacity (for 210 & 500 MW plants) for flow in the range of 47.4 – 54.9 %, pressure in the range of 40 – 41.2 % and output power in the range of 69.1 – 72.9 %. The higher sizing of PA fans cause reduction in efficiency by about 11.45 – 12.27 % due to oversizing cause higher auxiliary power of PA fans is about 178.2 – 513.4 kW [11, 12].

B. Technology adoption

In most of coal fired thermal plants, FD fans are provided with blade pitch control or IGV (few plants), PA fans and ID fans are provided with either hydraulic scoop coupling or IGV control. The specific auxiliary power consumption of these fans at partial loading is very high. The load factor of ID fans will be varying continuously in the range 60 – 75 % that cause the reduced overall efficiency and higher auxiliary power. The installation of variable frequency drives (VFD) for these ID fans will reduce the auxiliary power. VFDs are installed for 210 MW & 500 MW typical power plants and the comparative performance results are presented in Table 4. The energy saving in 210 MW power plants is about 2.12 MU/year per fan and 4.51 MU/year per fan for 500 MW plants. The payback period for replacement of IGV to VFD for ID fans is about 3 – 4 years. The Variable frequency drives can also be implemented for FD and PA fans also.

C. Performance of equipment and energy conservation measures

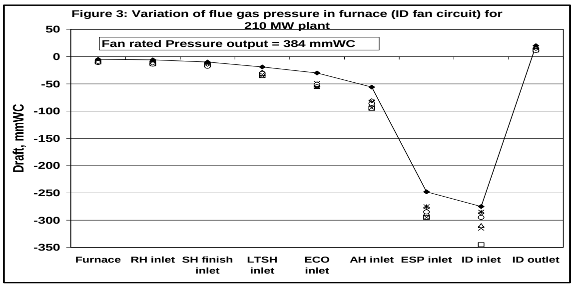
i) ID fans

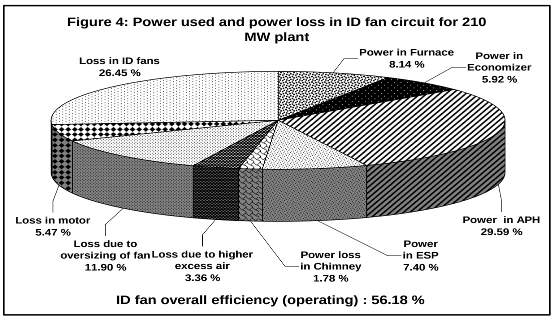
ID fan circuit consists of flue gas flow through Furnace water walls, Superheater (SH), Reheater (RH), Platen superheater, LTSH, Economizer, Air-preheater (APH) and Electro Static Precipitator (ESP). These ID fans will create negative pressure in the furnace in the range of -5 to -10 mmWC. Because these boilers are working with balanced draft system and the furnace pressure must be maintained slightly negative for safety of operation [13]. If the pressure becomes positive the furnace may explode and also may cause puffing of ash surrounding the boiler which is hazardous. The auxiliary power used by ID fans is about 1.41 % of plant load for 500 MW, 1.52 % for 210 MW and 1.63 % for 110 MW of typical power plants.

Table 4: performance results of ID fans with and without VFD.

Sl. No	Particulars	Unit	500 MW plant		210 MW plant	
			Without VFD	With VFD	Without VFD	With VFD
01	Suction Pressure	mmWC	-256.6	-246.0	-265.00	-266.0
02	Discharge Pressure	mmWC	4.20	-47.88	8.00	4.50
03	Flue gas flow	t/h	474.2	511.8	439.41	427.5
04	Electrical power input	kW	1436.9	867.1	889.35	621.9
05	Mech. power output	kW	406.98	333.7	439.37	423.5
06	Operating overall eff.	%	**28.32**	**38.48**	**49.40**	**68.09**
07	Specific energy consumption (SEC)	kWh/t of flue gas	3.03	1.69	2.02	1.45
08	Energy saving per fan	MU/year	4.51		2.12	

The flue gas pressure in furnace and flue gas duct is maintained negative till the suction of ID fans and at the ID fan exit it will become slightly positive to throw out the flue gases to atmosphere [14]. The flue gas draft profile of ID fan circuit is presented in Figure 3. The power and loss in different components in ID fan circuit for a typical 210 MW plant is given in Figure 4. Some of the energy conservation measures to enhance the performance of ID fans are as follows:





i) The flue gas pressure drop (PD) across furnace (i.e., in SH, RH, Platen SH, LTSH, etc.,) is measured in the range of 49 – 55 mmWC which is higher compared to design value of 30 mmWC that increases the energy consumption by 0.73 MU/year. This can be reduced by clearing the debris in flue gas ducts during overhaul.

ii) The PD across Economizer coils is measured in the range of 27 – 40 mmWC which is on higher side as compared to the design value of 26 mmWC. This pressure drop can be reduced by clearing the debris in the economizer section that will help in reducing the energy consumption by 0.41 MU/year.

iii) The PD across APH is measured in the range of 192 – 201 mmWC as compared to the design value of 192 mmWC. The higher pressure drop may be due to blockage in APH baskets. The cleaning & clearing the blockage in APH baskets will reduce the energy consumption by 0.26 MU/year.

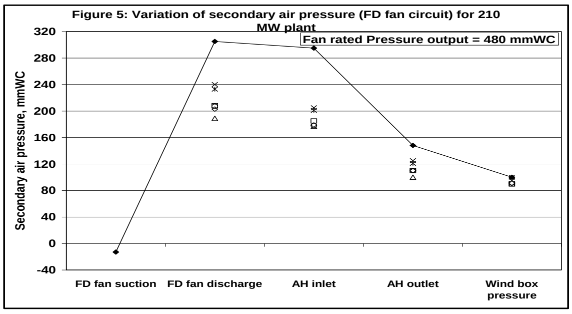
iv) The Electrostatic precipitator (ESP) is used to extract the fly ash from the flue gas just before flue gas entering ID fans. The ESP cause the pressure in flue gas which is measured in the range of 10 – 50 mmWC which is on higher than the design value of 27 mmWC. The flue gas PD in ESP is reduced near to design value will reduce the energy consumption by 0.67 MU/year.

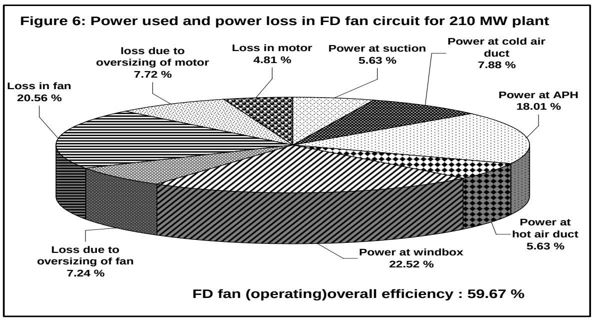
v) The measure of the oxygen content in flue gas gives the healthiness of combustion in furnace. The optimum oxygen content at furnace exit i.e., before air pre-heater (APH) is 3.5%, after APH is 4.5% and before ID fans is 5.5%. But in many power plants, the oxygen content in flue gas was measured as high as 6.2 – 9.9%. This higher oxygen content due to higher excess air, illegal furnace ingress, air leakage in APH, illegal air ingress in ESP & flue gas ducts increases the energy consumption of ID fans by 0.66 MU/year.

ii) FD fans

FD fan circuit consists of secondary air path through cold air duct, APH, hot air duct and Windbox. FD fans supply secondary air for proper coal combustion to convert carbon to carbon dioxide (CO_2) and also to maintain the windbox differential pressure (DP) to about 100 mmWC [15]. FD fans consume auxiliary power of about 0.34 to 0.36% of plant load for the power plants of 110 MW to 500 MW.

Figure 5 gives the variation of secondary air pressure profile in secondary air circuit. The power used by fan and the associated power loss in FD fan circuit is presented in Figure 6. The energy conservation measures are discussed below:





i) The measured secondary air pressure in cold air duct from FD fan discharge to APH inlet is varying between 12 – 35 mmWC and is more than the design value of 10 mmWC in a typical 210 MW power plant. The higher pressure drop causes increased energy consumption of 0.26 MU/year. This can be reduced by clearing the debris in the cold air duct during overhaul.

ii) The PD in APH is measured in the range of 68 – 80 mmWC in a typical power plant which is lower than the design value of 147 mmWC.

iii) The PD in hot air duct from APH to windbox is varying between 10 – 26 mmWC which is slightly lower than the design value of 48 mmWC.

iii) PA fans

PA fan circuit consists of primary air path through cold air duct, APH, hot air duct and mills [16, 17]. The main purpose of PA fans is to provide the primary air to carry the pulverized coal from mills to burners and to maintain the coal-air mixture temperature to around 85 – 90 ^oC. The auxiliary power consumed by PA fans is about 0.72 % of plant load for 500 MW, 0.76 % for 210 MW and 0.88 % for 110 MW power plants.

The primary pressure profile in PA circuit is presented in Figure 7. The auxiliary power used by PA fans and losses in PA ducts for typical 210 MW power plant is given in Figure 8. The energy conservation measures for PA circuit are as follows:

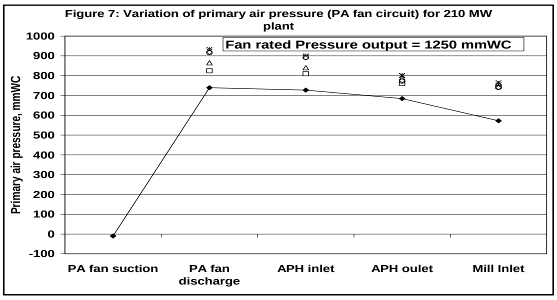


Figure 7: Variation of primary air pressure (PA fan circuit) for 210 MW plant

i) The measured primary air pressure in cold air duct from PA fan discharge to APH inlet is varying between 15 – 33 mmWC is higher compared to design value of 12 mmWC which cause an additional energy consumption of 0.15 MU/year. This can be reduced by clearing the debris in the cold air duct during overhaul.

ii) The pressure drop in APH is measured in the range of 49 – 120 mmWC and is higher than the design value of 43 mmWC due to blockage of APH baskets which cause and additional energy consumption of 0.56 MU/year. This can be reduced by cleaning the APH baskets during overhaul.

iii) The pressure drop in hot air duct from APH to mills is measured in the range of 16 – 47 mmWC which is slightly lower side compared to design value of 112 mmWC.

iv) The pressure drop across mills is varying between 216 – 245 mmWC and is lower side compared to design value of 299 mmWC.

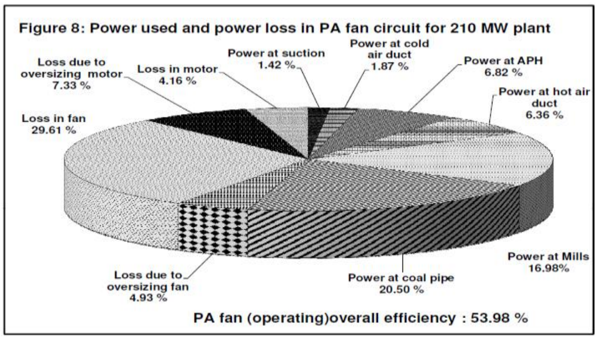


Figure 8: Power used and power loss in PA fan circuit for 210 MW plant

D. Operational optimization.

Some of the operational parameters to be monitored on-line continuously to keep the plant healthy and operate with energy efficient and are as follows:

- Motor current with different frequency and voltage.
- O_2 in flue gas at APH inlet with different load.
- Suction pressure and discharge pressure of fans with different loading.
- Winding temperature of motors.
- Bearing temperature of motors
- Air – coal ratio in mills
- Primary and secondary air flow
- Furnace draft, windbox pressure and flue gas pressure at different locations for different plant load

III. CONCLUSIONS

Some of conclusions from the study are as follows:

i. Optimizing & reducing size of fan and motor to appropriate size reduces the auxiliary power considerably.

ii. Introducing the variable frequency drives for fans will reduce the energy consumption and the techno-economics of implementation of VFD is quite attractive.

iii. Reduction of hydrodynamic resistance of ducts will reduce the energy consumption at ID fans, FD fans and PA fans.

iv. Operation optimization of auxiliary equipment will help in reduction of auxiliary power.

v. Minimization of furnace ingress and air leakage through APH and ducts will reduce the auxiliary power by about 0.2 to 0.3 %.

vi. Implementation of energy conservation measures reduces the energy consumption by 5.5 to 6.5 MU/year which reduces the overall auxiliary power by 0.5% of plant load.

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