Enhancing energy efficiency of auxiliary power system in a 210 MW coal fired power plant through energy efficiency

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Abstract- **This paper describes the results of energy conservation measures in various thermal power plants spread over the country. Energy savings in various major auxiliaries are summarized here with improved performance. Staggering of auxiliary loads, reduction in hydrodynamic resistance of pipes and ducts, adoption of new energy efficient technologies, efficient control techniques, reduction in furnace ingress and monitoring of coal size at mill inlets will lead to substantial amount of energy savings. The energy conservation schemes are economically attractive with a break even period of 1 to 5 years.**

Keywords-auxiliary power, plant load factor, energy conservation

I. INTRODUCTION

The installed capacity of power generation in India is reached 1.50 lakh MW by end of Sept. 2009 and is being planned to achieve 2.50 lakh MW by year 2020 [1]. The energy supplied by thermal plants form about 63.89 % and coal fired power plants form about 52.19 % of total generation. The auxiliary power used for coal fired power plants is about 7400 MW that forms about 4.96 % of total generation [2]. The thermal power plant availability depends largely upon the operational reliability of the auxiliary equipment and the capability of the auxiliary system [3, 4]. The net overall efficiency of the coal fired thermal power plants are in the range of 19.23 % (30 MW plant) and 30.69 % (500 MW plant). The auxiliary power consumption is varying between 7 % (500 MW plant) and 12 % (30 MW plant). The auxiliary power consumption is on higher side as compared to other developed countries due to poor plant load factor, the use of poor coal quality, excessive steam flow, excessive water flow, internal leakage in equipment, inefficient drives, lack of operational optimization of equipment, ageing of equipment, hesitation in technology upgradation, obsolete equipment, design deficiencies, oversizing of equipment, use of inefficient controls, etc.,

The auxiliary power consumption can be reduced, by improving the plant load factor of the plants, review of design of the equipment, by operational optimization, adoption of advanced control techniques and implementation of energy conservation measures [5]. By reducing the auxiliary power additional power will be available at grid. The saved energy can be pumped into the grid with nominal investment.

II. AUXILIARY POWER CONSUMPTION

The auxiliary power is the essential power used by in-house and out-lying auxiliaries to run the drives. The auxiliary power is tapped at Unit Auxiliary Transformers (UAT) during normal running of the plant and from Station Transformers (ST) during starting of the plant. The UAT steps down the generator voltage from 15.75 kV to 6.6 kV whereas the ST steps down the grid voltage (either 220 kV or 400 kV or 132 kV) to 6.6 kV. The major HT auxiliaries are fed from 6.6 kV bus whereas LT auxiliaries are fed from 415 V LT bus (stepped down from HT bus voltage to LT bus voltage by auxiliary transformers).

The auxiliary power is the difference between the gross energy generation and net energy export into the grid. The station auxiliary power is computed by:

$$AP = \left[1 - \left\{ \frac{\left(\sum_{k=1}^{k=m} (E_F)_k - \sum_{j=1}^{j=p} (E_{ST})_j \right)}{\left(\sum_{i=1}^{i=n} (E_G)_i \right)} \right\} \right] * 100 \quad \% \qquad (1)$$

Where E_G is the gross energy generation by the individual unit in MWh/month, i is the number of generators in the station (i varies from 1 to n units), E_F is the energy sent (export) by the individual feeder into grid in MWh/month, k is the number of outgoing feeders in the station (k varies from 1 to m feeders), E_{ST} is the energy consumption by the station transformers in MWh/month, j is the number of station transformers in the station (j varies from 1 to p station transformers)

The auxiliary power can be broadly classified into in-house auxiliary power and out-lying or common auxiliary power. The in-house auxiliary power is the power used for major in-house equipment whose loading vary with change in plant load of particular unit and does not affect the loading of other units. The typical in-house auxiliary equipment are: Boiler feed pumps (BFP), Condensate Extraction pumps (CEP), Induced draft fans (ID), Forced draft fans (FD), Primary

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air fans (PA), Mills, etc. The out-lying or common auxiliary power is the power used by the common auxiliary equipment i.e., they cater the services to more than one particular units. The typical out-lying auxiliary equipment are: Circulating water pumps (CWP), Ash slurry disposal pumps, HP & LP water pumps, DM transfer pumps, Coal Crushers, etc..

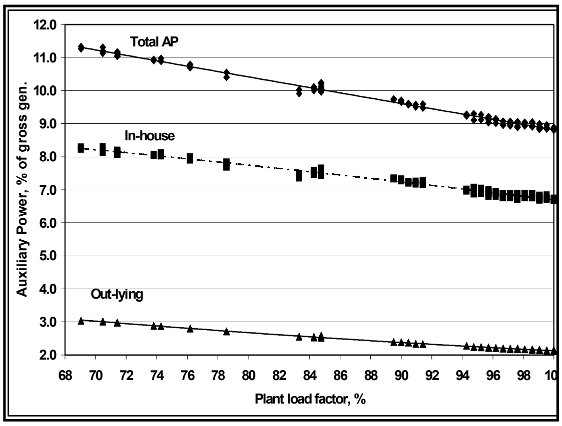

Figure 1: Variation of AP with plant load

Figure 1 gives the variation of in-house, out-lying and total auxiliary power as a percentage of gross generation with plant load [6].

The auxiliary power is greatly influenced by the Load Factor (LF) of units. It can be seen from the Figure that as the load factor increases, the percentage of auxiliary power decreases. The total auxiliary power can be curve fitted to:

$$AP = 5*10^{-5} * LF^2 - 0.0893*LF + 17.228 \quad \% \qquad (2)$$

Where AP is the total auxiliary power in percentage of gross power generation and LF is load factor of unit in percentage and is computed as:

$$LF = \frac{P_{Gen}}{P_{Rating}} * 100 \quad \% \qquad (3)$$

Where P_{Gen} is the average power generation by the individual generator in MW, P_{Rating} is the Maximum Continuous Rating (MCR) of particular generator in MW.

III. PLANT LOAD FACTOR

The auxiliary power in Indian power stations is on higher side due to operating the plants at sub-optimal plant load factor, poor coal quality, higher excess air, higher specific fuel consumption, lower boiler & turbine efficiencies, prolonged operation of plants without annual & capital overhauls, etc.

As per the plant performance reports published by ICRA, 2003 [7], MECON Ltd. report for MSPGCL plants, 2007 [8], RTPS, 2008 [9], DVC, 2005 [10], the percentage of auxiliary power vary with PLF.

The annual plant load factor is generally computed by

$$PLF = \frac{E_{gen} * 100}{P_{rating} * 8760 * 1000} \quad \% \qquad (4)$$

Where E_{gen} is energy generated MU/year and P_{rating} is the rated capacity of plant in MW.

The instantaneous plant load factor is computed by

$$PLF = \frac{P_{Gen} * 100}{P_{rating}} \quad \% \qquad (5)$$

The Boiler output is directly proportional to feed water flow & pressure, air flow & pressure and coal flow. Therefore, the increase in Boiler output will increase the auxiliary power of BFP, CEP, ID fans, FD fans, PA fans, Mills and In-house LT equipments.

The turbine output is directly proportional to main steam flow, pressure & enthalpy and condenser vacuum. The main steam pressure & flow are depending on the feed water flow & pressure. The condenser vacuum is dependant on the circulating water temperature & flow at condenser inlet. Therefore, the increase in turbine output will increase the auxiliary power of BFP, CEP, CWP and other out-lying auxiliary equipment.

Therefore, the plant load factor will influence the auxiliary power of major in-house equipment like BFP, CEP, ID fans, FD fans, PA fans & Mills and in-house LT equipments [11, 12, and 13]

The auxiliary power of individual equipment is computed by

$$AP_{Equipment} = \frac{P_{Equipment} * 100}{PL * 1000} \quad \% \qquad (6)$$

Where $P_{Equipment}$ is the measured power at individual equipment in kW.

The percentage of auxiliary power with gross energy generation is greatly influenced by the PLF. Figure 2 gives the deviation of total, in-house and out-lying auxiliary power with plant load factor.

The deviation in total auxiliary power is curve fitted to

$$DAP = 0.0026*LF^2 - 0.9783*LF + 71.637 \ \% \ of \ 100\% \ PL \qquad (7)$$

The deviation in in-house auxiliary (HT+LT) power is curve fitted to

$$DAP_{In-house} = -0.0029*LF^2 - 0.2663*LF + 55.52\% \ of \ 100\% \ PL \qquad (8)$$

The deviation in out-lying auxiliary (HT+LT) power is curve fitted to

$$DAP_{Out-lying} = 0.0115*LF^2 - 3.3698*LF + 221.87 \ \% \ of \ 100\% \ PL \qquad (9)$$

It can be seen from the Figure that at a plant load factor of 69 %, the in-house auxiliary power is increased by 23.0 % in comparison to MCR condition (210 MW), the out-lying auxiliary power is increased by 43.5 % and total auxiliary power is increased by 28.2 %. The variation in out-lying auxiliary power is sharp because the power for out-lying auxiliary will be almost same for different unit load.

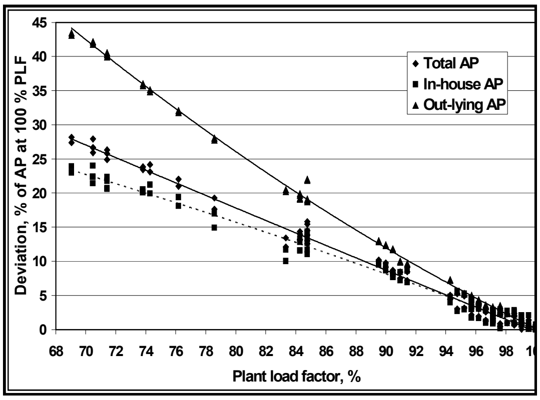

Figure 2: Deviation in total, in-house & out-lying auxiliary power

A. Boiler feed pumps

The auxiliary power used by BFP accounts for 2.46 % of gross energy generation at MCR. As the plant load factor on unit increases, the feed water flow and BFP discharge pressure increases. The output power of BFP is increased with the plant load factor. The variation of feed water flow is curve fitted to

$$FW\ Flow = -0.1319 * LF^2 + 29.22 * LF - 902.78\ t/h \quad (10)$$

Since the 210 MW power plants are being operated on constant pressure mode operation, the steam pressure will not vary much and the feed water pressure will vary marginally with change in plant load factor. Therefore, the change in FW pressure will not have much influence on auxiliary power.

Due to the change in FW flow, the BFP power will vary with plant load factor and is curve fitted to:

$$AP_{BFP} = 6*10^{-5} * LF^2 - 0.0243 * LF + 4.2566\ \% \quad (11)$$

The deviation in feed water flow and power of BFP with change in plant load factor is presented in Figure 3. The base for FW flow is taken at the actual operating FW flow at MCR (210 MW) and the deviation is computed as

$$Deviation\,in\,FW_{BFP} = \frac{\left(\overset{o}{m}FW_{210} - \overset{o}{m}FW_{operating}\right)*100}{\overset{o}{m}FW_{210}}\ \% \quad (12)$$

Where $\overset{o}{m}FW_{210}$ is the measured operating feed water flow at 210 MW in t/h and $\overset{o}{m}FW_{operating}$ is the Feed water flow at different plant load factor in t/h.

Similarly, the deviation in auxiliary power for BFP is computed at different plant load factors.

$$Deviation\ in\ AP_{BFP} = \frac{\left(AP_{BFP-210} - AP_{BFP-operating}\right)*100}{AP_{BFP-210}}\ \% \quad (13)$$

The deviation in feed water flow is curve fitted to

$$DFW_{BFP} = -0.0185 * LF^2 + 4.1039 * LF - 22679\ \%\,of\,100\%\,PL \quad (14)$$

The deviation in auxiliary power of BFP is curve fitted to

$$DAP_{BFP} = 0.0026 * LF^2 - 0.9783 * LF + 71.637\ \%\,of\ 100\%\ PL \quad (15)$$

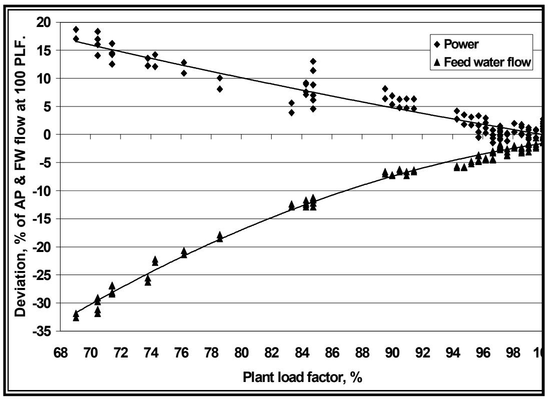

Figure 3: Deviation in FW flow & auxiliary power of BFP

It can be seen from the Figure that at a PLF of 69 %, the FW flow is decreased by about 31.88 % whereas the auxiliary power is increased by 17.02 %. The variation in change of FW flow and auxiliary power is due to slightly variation in FW pressure, operation of re-circulation valve at partial loading, reduced pump efficiency at partial loading, problems in pump internals, etc..

B. Condensate Extraction pumps

The auxiliary power used by CEP accounts for 0.22 % of gross energy generation at MCR. As the PLF on unit increases, the condensate flow and CEP discharge pressure increases. The output power of CEP is increased with PLF. The variation of condensate flow is curve fitted to

$$Cond\,Flow = 0.0342 * LF^2 - 4.0665 * LF + 50223\ t/h \quad (16)$$

Due to the change in condensate flow, the CEP power will vary with plant load factor and is curve fitted to:

$$AP_{CEP} = 4*10^{-6} * LF^2 - 0.022 * LF + 0.4009\ \% \quad (17)$$

The deviation in condensate flow and power of CEP with change in PLF is presented in Figure 4. The deviation in condensate flow is curve fitted to

$$DCOND_{CEP} = 0.0078 * LF^2 - 0.9242 * LF + 14.143\ \%\,of\ 100\%\ PL \quad (18)$$

The deviation in auxiliary power of CEP is curve fitted to

$$DAP_{CFP} = 0.0019 * LF^2 - 0.9724 * LF + 78.986\ \%\ of\ 100\%\ PL \quad (19)$$

It can be seen from the Figure that at a plant load factor of 69 %, the condensate flow is decreased by about 13.0 % whereas the auxiliary power is increased by 20.5 %.

C. Induced draft fans

The auxiliary power used by ID fans account for 1.14 % of gross energy generation at MCR. As the plant load factor on unit increases, the flue gas flow and ID fan suction & discharge pressure increases. The output power of ID fan is increased with the plant load factor. The variation of flue gas flow is curve fitted to

$$FG\,Flow = 0.0569 * LF^2 + 1.039 * LF + 406.01\ t/h \qquad (20)$$

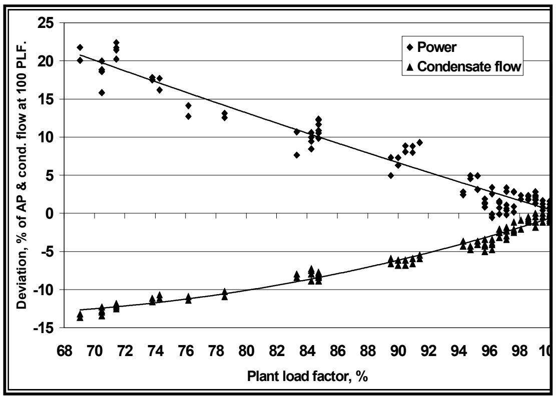

Figure 4: Deviation in Condensate flow & auxiliary power of CEP

The variation of ID fan suction pressure is curve fitted to

$$Suct\,Pressure = -0.0201 * LF^2 + 0.1542 * LF - 118.18\ mmWC \qquad (21)$$

The variation of ID fan discharge pressure is curve fitted to

$$Disch\,Pressure = -0.0223 * LF^2 + 3.1036 * LF - 73.153\ mmWC \qquad (22)$$

The variation of pressure gain in ID fan is curve fitted to

$$Pressure\,gain = -0.0019 * LF^2 + 2.8862 * LF + 47.826\ mmWC \qquad (23)$$

Due to the change in flue gas pressure and flue gas flow, the ID fan power will vary with plant load factor and is curve fitted to:

$$AP_{IDF} = 9*10^{-5} * LF^2 - 0.0207 * LF + 2.2894 \quad \% \qquad (24)$$

The deviation in flue gas flow, pressure gain across fan and power of ID fans with change in PLF is presented in Figure 5. The deviation in flue gas flow is curve fitted to

$$DFGFLOW_{IDF} = 0.0051 * LF^2 + 0.0936 * LF - 63.422\ \%\,of\ 100\%\,PL \qquad (25)$$

The deviation in flue gas pressure gain in ID fan is curve fitted to

$$DFGPR_{IDF} = -0.0006 * LF^2 + 0.8826 * LF - 85.374\ \%\,of\ 100\%\,PL \qquad (26)$$

And the deviation in auxiliary power of ID fans is curve fitted to

$$DAP_{IDF} = 0.0043 * LF^2 - 1.3026 * LF + 89.09\ \%\,of\ 100\%\,PL \qquad (27)$$

It can be seen from the Figure that at a plant load factor of 69 %, the flue gas flow is decreased by about 32.43 % and the pressure gain in ID fan is decreased by 26.61 % whereas the auxiliary power is increased by 20 %.

D. Forced draft fans

The auxiliary power used by FD fans account for 0.23 % of gross energy generation at MCR. Forced draft fans supply the secondary air for combustion in Boilers. As the PLF on unit increases, the secondary air flow increases. The output power of FD fans is increased with the PLF. The variation of secondary air flow is curve fitted to

$$SA\,Flow = 0.0387 * LF^2 - 5.359 * LF + 600.39 \quad t/h \qquad (28)$$

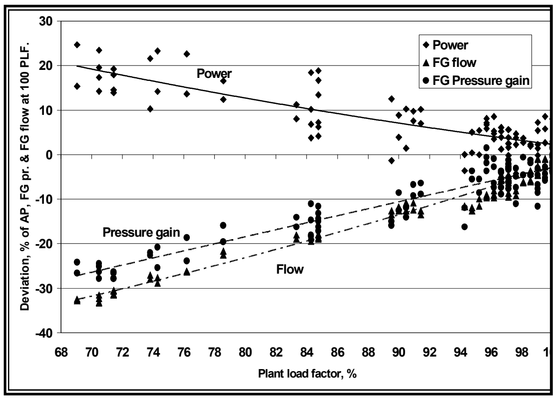

Figure 5: Deviation in FG pressure, flow & auxiliary power of IDF

The FD fan discharge pressure will be nearly constant with change in PLF. Due to the change in secondary air flow, the FD fan power varies with PLF and is curve fitted to:

$$AP_{FDF} = 3*10^{-5} * LF^2 - 0.0075 * LF + 0.6736 \quad \% \qquad (29)$$

The deviation in secondary air flow and power of FD fan with change in PLF is presented in Figure 6. The deviation in secondary air flow is curve fitted to

$$DSAFLOW_{IDF} = 0.014 * LF^2 - 3.582 * LF + 220.74\ \%\,of\ 100\%\,PL \qquad (30)$$

Deviation in auxiliary power of FD fan is curve fitted to

$$DAP_{FDF} = 0.0085 * LF^2 - 1.1804 * LF + 32.244\ \%\,of\ 100\%\,PL \qquad (31)$$

It can be seen from the Figure that at a PLF of 69 %, the secondary air flow is decreased by about 8.81 % whereas the auxiliary power is increased by 39.9 %.

E. Primary air fans

The auxiliary power used by PA fans account for 0.95 % of gross energy generation at MCR. Primary air fans supply the primary air to mills for lifting the coal from mill to burners in Boilers. As the plant load factor on unit increases, the primary air flow increases. The output power of PA fans is increased with the plant load factor. The variation of secondary air flow is curve fitted to

$$PA\,Flow = -0.0141 * LF^2 + 4.545 * LF + 4.9971 \quad t/h \qquad (32)$$

The PA fan discharge pressure will nearly constant with change in plant load. Due to the change in primary air flow, the PA fan power will vary with plant load factor and is curve fitted to:

$$AP_{PAF} = -8*10^{-5} * LF^2 + 0.0062 * LF + 1.1123 \quad \% \qquad (33)$$

The deviation in primary air flow and power of PA fans with change in plant load factor is presented in

Figure 7. The deviation in primary air flow is curve fitted to

$$DPAFLOW_{PAF} = -0.0044 * LF^2 + 1.4028 * LF - 98.458\ \%\ of\ 100\%\ PL \quad (34)$$

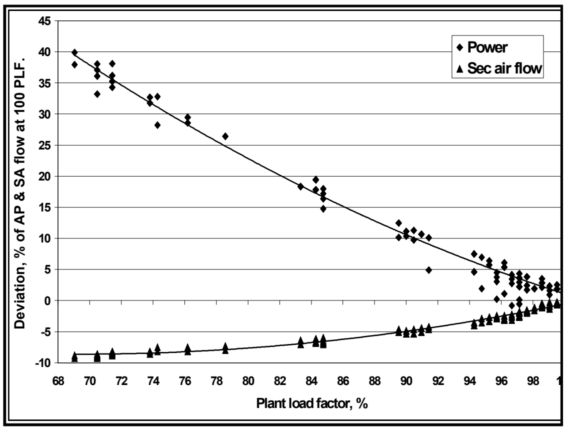

Figure 6: Deviation in SA flow & auxiliary power of FDF

Deviation in auxiliary power of PA fan is curve fitted to

$$DAP_{PAF} = -0.0085 * LF^2 + 0.6628 * LF + 19.605\ \%\ of\ 100\%\ PL (35)$$

It can be seen from the Figure that at a plant load factor of 69 %, the primary air flow is decreased by about 22.6 % whereas the auxiliary power is increased by 24.9 %.

F. Mills

The auxiliary power used by Mills accounts for 0.57 % of gross energy generation at MCR for Bowl mills. As the plant load factor on unit increases, the coal flow increases. The output power of Mills is increased with the plant load factor. The variation of coal flow is curve fitted to

$$COALFlow = -0.0294 * LF^2 + 6.255 * LF - 197.34 \quad t/h \quad (36)$$

Due to change is coal flow, the Mills power will vary with plant load factor and is curve fitted to:

$$AP_{Mills} = -5 * 10^{-5} * LF^2 - 0.0005 * LF + 1.1115 \quad \% \quad (37)$$

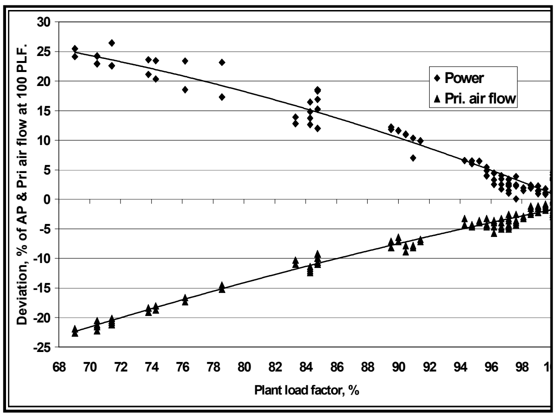

Figure 7: Deviation in PA flow & auxiliary power of PAF

The deviation in coal flow and power of Mills with change in plant load factor is presented in Figure 8. The deviation in coal flow is curve fitted to

$$DCOAlFLOW_{Mills} = -0215 * LF^2 + 4.5657 * LF - 24405\ \%\ of\ 100\%\ PL (38)$$

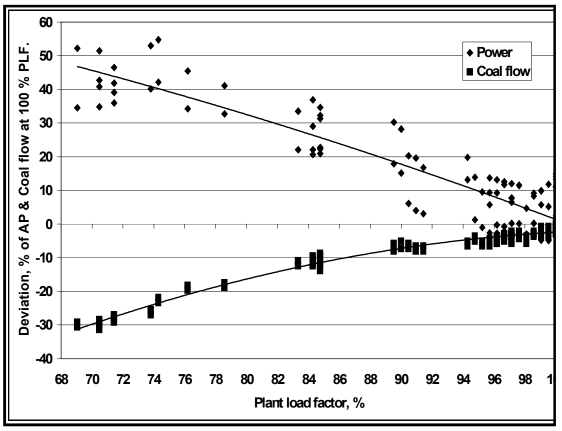

Figure 8: Deviation in Coal flow & auxiliary power of Mills

The deviation in auxiliary power of Mills is curve fitted to

$$DAP_{Mills} = -0.0082 * LF^2 - 0.0842 * LF + 91.644\%\ of\ 100\%\ PL (39)$$

It can be seen from the Figure that at a plant load factor of 69 %, the coal flow is decreased by about 30.75 % whereas the auxiliary power is increased by 46.55 %.

G. In-house LT

In-house LT power consists of power used by LT motors that are unit specific i.e., seal air fans, vacuum pumps, stator water pumps, H_2 cooling pumps, etc. The power used by LT motors accounts for 0.57 % of gross generation at 210 MW. As the plant load factor on unit increases, the output power of LT motors is increased with the plant load factor. The variation of power at LT motors will vary with plant load factor and is curve fitted to:

$$AP_{LT} = -5 * 10^{-5} * LF^2 - 0.0081 * LF + 2.8094 \quad \% \quad (40)$$

The deviation in power of In-house LT motors with change in plant load factor is curve fitted to

$$DAP_{LT} = -0.003 * LF^2 - 0.5209 * LF + 81.249\ \%\ of\ 100\%\ PL (41)$$

IV. FACTORS AFFECTING PLANT LOAD FACTOR

Most of the older units operate at lower plant load factor mainly due to:

a) Inferior coal quality increases the loading of Mills, PA fans, FD fans and ID fans that leads to reduction of power output.
b) The higher ash content in coal will increase the loading of ESP and reduce the collection efficiency of ESP. This will increase the erosion rate of ID fan impeller that will reduce the capacity of ID fans.
c) The higher flue gas pressure drop across APH, ESP and duct will reduce the capacity of ID fans that will reduce the power output.

d) The continuous operation of units without undergoing overhaul will increase the furnace illegal ingress, duct leakages, flue gas leakages, water leakages, etc., will reduce the power output.
e) Higher CW temperature at condenser inlet will reduce the condenser vacuum that will reduce the capacity of turbine.
f) Higher specific fuel consumption (SFC) will reduce the capacity of mills, air fans and ID fans that reduces the power output.
g) Higher flue gas exit temperature will increase the dry flue gas losses and reduce the boiler efficiency that reduces the capacity of Boiler.
h) Higher specific steam consumption (SSC) increases the loading of BFP and CEP which will reduce the power output.
i) Higher winding & bearing temperatures of generator stator, generator transformer (GT) and HT motors of all major auxiliary equipments will increase the auxiliary power.

V. ENERGY CONSERVATION MEASURES

The various energy conservation measures to enhance the plant load factor of unit are:

a) Washed coal will reduce the ash content in coal that reduces the loading of Mills, PA fans, FD fans and ID fans which enhance the unit capacity.
b) The lower ash content in coal will improve the performance of ESP and reduce the erosion of ID fan impellers.
c) Clearing the debris in flue gas duct, reducing the flue gas pressure in APH, ESP & flue gas ducts will enhance the capacity of ID fans [14].
d) Optimum oxygen content will enhance the capacity of ID fans and air fans [15].
e) Reducing SFC by optimizing the combustion will enhance the capacity of mills, air fans & ID fans.
f) Improving the vacuum and optimizing the SSC will enhance the capacity of turbine that will reduce the auxiliary power of BFP & CEP.
g) Optimization of pulverized coal size at mill outlet will enhance the performance of boiler and mills that will enhance the output power [16].
h) Improving the performance of pumps and fans by use of energy efficient Impellers enhance the capacity of equipments that will increase the power output and reduce the auxiliary power.
i) Periodic preventive maintenance will improve the performance of equipment that will enhance the power output [17].

VI. CONCLUSIONS

Operating the plant at MCR condition (100 % PLF) will reduce the auxiliary power from 12.05 % to 8.74 %. The use of washed coal will improve the performance of auxiliary equipments and reduce the auxiliary power by about 0.5 – 0.6 % of gross energy generation. Reducing the hydrodynamic resistance in flue gas circuit, water circuit, air circuit and CW circuit will reduce the auxiliary power by about 0.4 – 0.5 % of gross energy generation. Operating the plant at optimum excess air, controlling the furnace ingress, improving the performance of individual equipment by proper maintenance, etc., will reduce the auxiliary power by about 0.2 – 0.5 % of gross energy generation.

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