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Energy Efficiency Enhancement of Fossil-Fuelled Power Systems

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ABSTRACT

Energy efficiency is the simplest and cost-effective approach for power and process industries to meet a growing demand for cleaner energy, and this applies to the power generating industries as well. Energy efficiency of fossil-fuelled power systems in developed as well as developing countries is abnormally low, consuming high quantity of fuel to generate per unit electricity, which is a fundamental issue throughout the globe. Though energy efficiency improvements are possible at all sections of a power system, this paper put forward an energy efficiency enhancement opportunity at the power generation station itself by proper scheduling of the generating units. To show the efficacy of the proposed strategy, an economic dispatch algorithm has been applied to several dissimilar realistic systems at different load conditions and the outcome of one such realistic system is presented in this paper.

Keywords: Energy Efficiency Enhancement, Fossil-Fuelled Power Systems, Generation Scheduling
JEL Classifications: B4, C8, L8, O1, O3

1. INTRODUCTION

Fossil-fuelled power plants constitute the largest proportion of installed capability in global power generation system, which consumes large quantities of fuels (IEA, 2012; Birol, 2013). Therefore achieving optimal operation of fossil-fueled power plants, improving its efficiency and reducing the fuel consumption is of great significance for the reduction of greenhouse gas and pollutants emissions (Sinha, 2015; Liu et al., 2011; Jorge et al., 2012). In pragmatism, fossil-fuelled power plants face a number of challenges such as requirement of more capital investment, takes longer time to build up, harder to transport fuel generating stations, public concern about the environmental effects of the emissions, depleting reserves and poor energy efficiency. As a solution to depleting fuel reserves and environmental issues, the widespread deployment of more efficient fossil-fuelled power plants is an essential first step for the longer term use of fuel such as coal (Jorge et al., 2012; Kim, 2007). This might be a solution while going for installing new fossil-fuelled generating stations; but the existing fossil-fuelled power plants have a major share in power generation. Most of these power plants were found to be aged more than 30 years (Ackerman et al., 1999). These power plants provide a significant portion of hazardous emissions in many parts of the world, because they are not required to meet the same emission standards as new sources under the Clean Air Act. This has created economic incentives to continue the usage of older facilities and discouraged new entrants in the power sector. Hence, instead of discarding the existing power plants, efficiently using them would be an economical and timely solution.

In fossil-fuelled power stations, there is incredible potential for energy saving (Gellings, 2011; Kama and Kaplan, 2013). In order to curtail the fuel cost, power losses and power plant emissions, usually energy conservation measures such as increasing plant load factor, improving plant heat rate, reducing auxiliary power consumption (APC), reduction in O and M expenditure etc. are practiced (Mestry, 2008; Palanichamy et al., 2001;

Palanichamy et al., 2004) at the power plants level so that more of the energy content of the input fuel is carried out as electrical output to end-use. On technical grounds, energy conservation and energy efficiency are separate, but related concepts (Energy DSM, 2010; Freire-González and Puig-Ventosa, 2015; The EP Act, 2005). Energy conservation is achieved when growth of energy consumption is reduced, measured in physical terms. Energy conservation can, therefore, be the result of several processes or developments, such as productivity increase or technological progress. On the other hand, energy efficiency is achieved when energy intensity in a specific product, process or area of production or consumption is reduced without affecting output, consumption or comfort levels. Promotion of energy efficiency will contribute to energy conservation and is therefore an integral part of energy conservation promotional policies. Energy efficiency is often viewed as a resource option like fossil fuel and it provides additional economic value by preserving the resource base and reducing pollution.

This paper deals with energy efficiency enhancements of fossil-fuelled power plants by incorporating the APC of their auxiliary equipment in their fuel cost characteristics and then performing economic power dispatch. Here the efficiency improvement is envisaged in terms of reduced power generation for the same power output (load demand) subject to power balance and generator capacity constraints. To perform the economic power dispatch, though several techniques are available (Jorge et al., 2012; Abido, 2005; Xiao-Hua et al., 2010), a non-iterative analytical approach is adapted and applied to several dissimilar test systems and the study outcome of one such system is presented here.

2. TARGETTING ON APC

Auxiliary systems are a major part of a power generation facility. Their purpose is to power the plant using a minimum of input energy to achieve maximum output and availability. They include all the drive power applications (pumps, fans, motors, drives), electrical balance of plant and instrumentation, control and optimization systems as shown in Figure 1.

Auxiliaries consume the highest quality energy in the plant, namely electrical energy (ABB Ltd., 2006; ABB Inc., 2013). The power supplied to in-house loads is power that could otherwise have been saved (or sold, in the case of a power plant operating at full load). The share of auxiliary drive power of the total plant power has been increasing for reasons such as:

- Plant load factor
- Operational efficiency of equipment
- Start up and shut down
- Age and size of the plant
- Fuel quality
- Leakages in the combustion air system
- Lack of maintenance in the fuel mills
- Addition of anti-pollution devices such as precipitators and sulphur dioxide scrubbers which restrict stack flow and require in-plant electric drive power
- Additional cooling water pumping demands to satisfy environmental thermal discharge norms
- A trend away from mechanical (e.g. condensing steam turbine) drives toward electrical motors as the prime mover for in-plant auxiliary pump and fan drives.

Figure 1 shows the major APC components of a coal-fired power plant and Figure 2 presents the typical values of a 210 MW coal-fired power plant. From Figure 2, it could be seen that the individual auxiliary component consumption varies from a minimum of 0.1% (compressed air system) to a maximum of 4.8% (feed water system) and the total APC is 12.48% of the total generation of the plant. Or in other words, the net power output from the power station is technically 87.52% of the total generation.

APC is "downstream" power; efficiency improvements in auxiliary loads have a multiplier effect as one move upstream to the primary energy source, within or outside the plant. Based on the typical 33% thermal efficiency that many older power plants achieve, the generated electricity is at least three times the price of the input fuel energy, when all the added fixed and financial costs of electricity generation are also included (Bhatia, 2010). Hence, it is judicious to improve the energy efficiency at the source itself to avail benefits such as extended life of fuel reserves, lengthened life of generators by reduced consumption, reduction in emissions, increase in power output from a given size of power plant, and reduced operating costs (Bozkurt and Akan, 2014).

Figure 1: Major auxiliary power consumption components

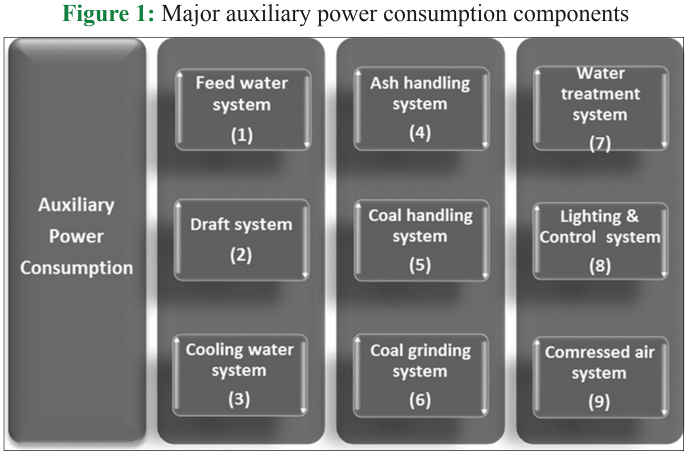
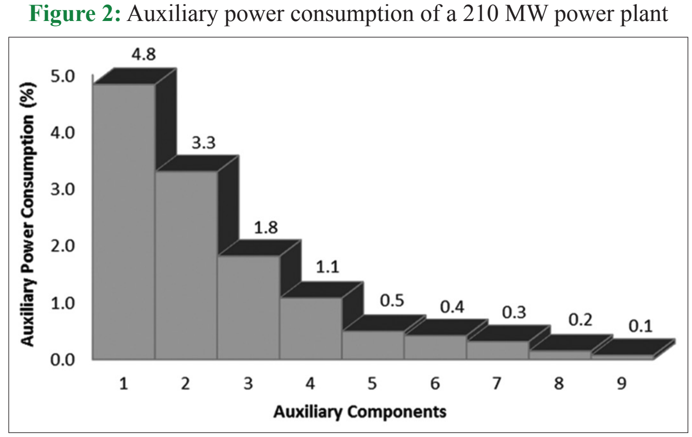


Figure 2: Auxiliary power consumption of a 210 MW power plant



3. ECONOMIC DISPATCH PROGRAM FORMULATION

3.1. The Objective Function

Economic dispatch is the short-term determination of the optimal power output of a number of electricity generation facilities, to meet the system demand, at the lowest possible cost, subject to transmission and operational constraints. The methodology for economic dispatch was developed to manage fossil fuel burning power plants, relying on calculations involving the input/output characteristics of power stations (Kirschen, 2010; Wood and Wollenberg, 1996). For such optimization purposes, the fuel cost curve of fossil-fuelled power plants are assumed to be a quadratic function of generator power output, and the objective function for economic power dispatch is mathematically stated as:

$$F_T = \sum_{i=1}^{n}\left(a_i P_{Gi}^2 + b_i P_{Gi} + c_i\right) \ \$/h \tag{1}$$

Where,
F_T: Total fuel cost ($/h),
P_{Gi}: Generation of plant i (MW),
a_i, b_i, c_i: Fuel cost coefficients of plant i, and
n: Number of generating plants.

The essential operational constraints are the power balance constraint, where the total generated power must be equal to the load demand plus the transmission losses, and the generator capacity constraints, where individual generator units must be operated within their specified range. Or in other words, the economic dispatch problem is optimized subject to:

3.1.1. Power balance constraint

The total power generated must supply total load demand and transmission losses.

$$\sum_{i=1}^{n} P_{Gi} = P_D + P_L \ \text{MW} \tag{2}$$

Where,
P_D: Total load demand (MW), and
P_L: Total transmission losses (MW), and

3.1.2. Generator capacity constraints

The power generated, P_{Gi} by each generating plant is constrained between its minimum and maximum limits, i.e.

$$P_{Gi\,min} \le P_{Gi} \le P_{Gi\,max} \tag{3}$$

Where,
$P_{Gi\,min}$: Minimum generation limit, and
$P_{Gi\,max}$: Maximum generation limit

3.2. Modified Coordination Equation with APC

The dispatch algorithm is a modified version of (Srikrishna and Palanichamy, 1989; Palanichamy and Srikrishna, 1991) developed by the author. It is a Lagrange equation based classical dispatch method that uses the following coordination equations with transmission losses considered as

$$(dFi/dP_{Gi})/(1-\partial P_L/\partial P_{Gi}) = \lambda \tag{4}$$

Where,
$\partial P_L/\partial P_{Gi}$: Incremental transmission loss of plant i (expressed in terms of transmission loss B_{mn} coefficients), and λ: The incremental cost of received power, $/MWh.

The B_{mn} coefficient matrix is a square matrix consisting of self and mutual terms. It is diagonalized for operational convenience without loss of accuracy. As an example, for a three plant system, the diagonalized matrix elements (B'_{ii}) are shown as:

$B'_{11}=B_{11}+(B_{12}+B_{13})/2$; $B'_{22}=B_{22}+(B_{21}+B_{23})/2$ and
$B'_{33}=B_{33}+(B_{31}+B_{32})/2$

This logic could be followed for any number of plants in a system. Introducing the diagonalized term in equation (4) and rewriting it in terms of its coefficients, we get:

$$(2a_i P_{Gi}+b_i)/(1-2\,B'_{ii}\,P_{Gi})=\lambda \tag{5}$$

By applying binomial expression and simplifying, equation (5) becomes,

$$4(a_i\ B'_{ii}+b_i\,B'^2_{ii})\,P_{Gi}^{\ 2} + 2(a_i+b_i\ B'_{ii})\,P_{Gi}+b_i=\lambda \tag{6}$$

Equation 6 is the coordination equation without incorporating the APC, η_{ai}.

The net power available from the generating plant *i* after the plant's APC (η_{ai}) is mathematically written as

$$P_{Gi}(1-\eta_{ai}) \quad \text{MW} \tag{7}$$

Where η_{ai} is the % APC of plant *i*. Hence to account for the APC for economic dispatching, the coordination equation of plant *i* is duly modified as:

$$4(a_i B'_{ii} + b_i B'^2_{ii})(1-\eta_{ai})^2 P_{Gi}^2 + 2(a_i + \mathrm{b}_i B'_{ii})(1-\eta_{ai})P_{Gi} + b_i = \lambda \tag{8}$$

Recalling

$$4(a_i B'_{ii} + b_i B'^2_{ii})(1-\eta_{ai})^2 = A_i$$

$$2(a_i + b_i B'_{ii})(1-\eta_{ai}) = B_i \tag{9}$$

$b_i=C_i$

Equation (8) becomes

$$A_i P_{Gi}^2 + B_i P_{Gi} + \left(C_i - \lambda\right) = 0 \tag{10}$$

3.3. Economic Dispatching

Equation (10) is quadratic in terms of individual plant generations. The solution of the quadratic equation has two roots and only the positive value is considered since plant generations can't be negative. The positive value of the plant generation is given as:

$$P_{Gi} = -\left(B_i / 2A_i\right) + \left(B_i / 2A_i\right)\sqrt{\{1+\left(4A_i / B_i^2\right)(\lambda - C_i)\}} \quad (11)$$

Equation (11) is of the form $(1+x)^{½}=1+(1/2)x-(1/8)x^2+\ldots$; since x is a small fraction, the first three terms gives the value of the function of acceptable accuracy, and so equation (11) takes a new shape after mathematical manipulations and simplifications as:

$$P_{Gi} = (\lambda - C_i)/B_i - A_i(\lambda - C_i)^2/B_i^3 \quad (12)$$

Hence equation (12) gives the individual plant generations in terms of λ.

While considering the transmission losses, the power balance equation must be satisfied and it is expressed as:

$$\sum_{i=1}^{n} P_{Gi} - \sum_{i=1}^{n} P_{Gi}^2 B'_{ii} - P_D = 0 \quad (13)$$

Substituting the value of P_{Gi}^2 from equation (10) and the value of P_{Gi} from equation (12) in equation (13) and simplifying, we get:

$$\lambda^2 \sum_{i=1}^{n}\left(-B_{ii}'/B_i^2 - A_i/B_i^3\right) + \lambda\left(1/B_i + 2B_{ii}'C_i/B_i^2 + 2A_iC_i/B_i^3\right)$$

$$+\sum_{i=1}^{n}\left(-C/B_i - B_{ii}'C_i^2/B_i^2 - A_iC_i^2/B_i^3\right) - P_D = 0 \quad (14)$$

Recalling

$$\sum_{i=1}^{n}\left(-B_{ii}'/B_i^2 - A_i/B_i^3\right) = \alpha\ ;\ \sum_{i=1}^{n}\left(1/B_i + 2B_{ii}'C_i/B_i^2 + 2A_iC_i/B_i^3\right) = \beta$$

and $\sum_{i=1}^{n}\left(-C_i/B_i - B_{ii}'C_i^2/B_i^2 - A_iC_i^2/B_i^3\right) = \gamma$

Equation (14) becomes

$$\alpha\,\lambda^2 + \beta\,\lambda + \gamma - P_D = 0 \quad (15)$$

Considering only the positive value of λ

$$\lambda = \{-\beta + \sqrt{[\beta^2 - 4\,\alpha\,(\gamma - P_D)]}\}/(2\alpha)\ \$/\text{MWh} \quad (16)$$

Once the value of λ is known for a particular load demand, equation (12) gives the individual plant generations and equation (1) gives the total fuel cost. The proposed dispatch algorithm is accommodative to load changes, changes in system configuration, transmission line outages, multiple fuel options, fuel constrained situations, and emission target. It is a non-iterative technique and it is fast since all the derived parameters such as A_i, B_i, C_i, α, β and γ remain as constants for the given system and depending upon the load changes, the economic dispatch can be obtained directly. No sophisticated software is needed and the algorithm could be in Microsoft Excel as a template. No restriction on size of the system and the computational strategy is shown in Figure 3.

4. AN ILLUSTRATIVE EXAMPLE

The energy efficiency based economic power dispatch strategy has been applied to a coal-fired test system with the prevailing APC magnitudes as shown the following sections.

4.1. Power Plant and Load Data

Table 1 depicts the fuel cost characteristics and the percentage APCs of the coal-based power plants. To account for the transmission losses, the loss coefficients of the test system are presented in Table 2. The loss coefficients are updateable periodically depending on the system configuration changes; however, they remain constant while performing the economic power dispatch. Day and night 24 h duration is considered for the

Figure 3: Computational flow chart

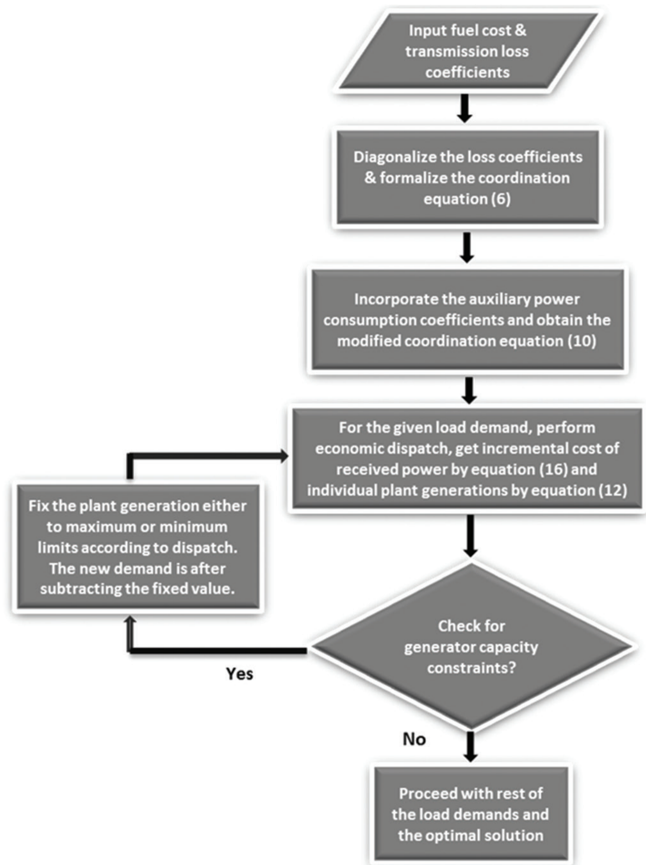


Table 1: Fuel cost coefficients and APC

Plant	Fuel cost coefficients			P_{min}	P_{max}	APC (%)
	a_i	b_i	c_i			
1	0.03546	38.30553	1243.5311	35	210	12.48
2	0.02111	36.32782	1658.5696	130	325	10.54
3	0.01799	38.27041	1356.6592	125	315	10.13

APC: Auxiliary power consumption

Table 2: Transmission loss coefficients

0.000071	0.000030	0.000025
0.000030	0.000069	0.000032
0.000025	0.000032	0.000080

study and the load demand data are presented in Table 3 whereas Figure 4 displays the load variations during the 24 h period.

4.2. Economic Power Dispatch and Analysis

From Table 1, it is understood that the Plant 1 with a maximum generating capacity of 210 MW has the highest APC and Plants 2 and 3 are of higher capacity machines than Plant 1 and having lesser APCs. The study is conducted in two routines: (i) with APC included in the dispatch and, (ii) without including APC in the dispatch (in study outcome results, it is indicated as no APC). The dispatch is carried out on every hour basis and the results are presented in Tables 4-6. From the dispatch results of Tables 4-6, it is apparent that all the plant generations are changed (either increased or decreased) with respect to routine (ii), the no APC dispatch condition at all load levels during the 24 h period.

Figure 4: 24 h load curve

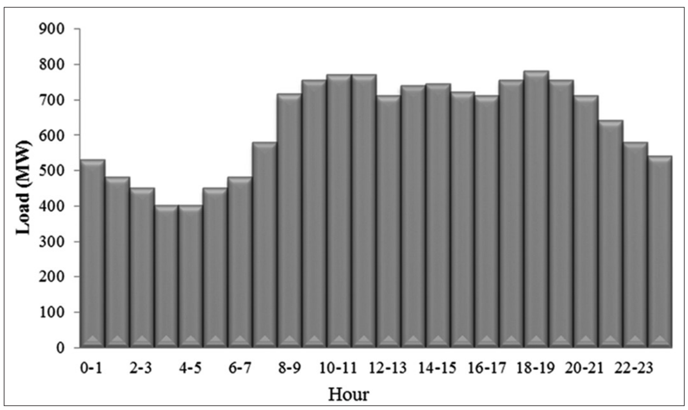


Table 3: 24 h load data

Time	MW	Time	MW	Time	MW
0-1	530	8-9	715	16-17	710
1-2	480	9-10	755	17-18	755
2-3	450	10-11	770	18-19	780
3-4	400	11-12	770	19-20	755
4-5	400	12-13	710	20-21	710
5-6	450	13-14	740	21-22	640
6-7	480	14-15	745	22-23	580
7-8	580	15-16	720	23-24	540

In the case of Plant 1 which has the highest level of APC (12.48%), the generations have been increased with respect to the no APC dispatch generations at all load levels. The increase in generation ranges from a minimum of 0.35 MW for a load level of 400 MW (minimum load) and to a maximum of 1.56 MW for a load level of 780 MW (maximum load). In the case of Plant 2 which has an APC of 10.54%, the generations have been increased with respect to the no APC dispatch generations at all load levels like the case of Plant 1. The increase in generation ranges from a minimum of 1.86 MW for a load level of 780 MW (maximum load) and to a maximum of 2.51 MW for a load level of 400 MW (minimum load). It is worth noticing that the minimum increase in generation of Plant 1 (the minimum generating capacity machine, 210 MW) occurred during the minimum load condition (400 MW) and the maximum increase in generation occurred during the maximum load condition (780 MW). Whereas in the case of Plant 2 (the maximum generating capacity machine, 325 MW), it is just reversed. In the case of Plant 3 which has an APC of 10.13%, the generations have been decreased with respect to the no APC dispatch generations at all load levels. Plant 3 is the one which has the lowest APC among all the three plants but its maximum generating capacity lies between the capacities of Plants 1 and 2. The decrease in generation ranges from a minimum of 2.90 MW for a load level of 400 MW (minimum load) and to a maximum of 3.96 MW for a load level of 780 MW (maximum load). From these results it is implicit that due to introduction of the APC component in the generators fuel cost characteristics, there are changes in their generations. Plants 1 and 2 experienced an increase in generations at all load levels and plant 3 experienced a decrease in its generation with respect to the no APC dispatch condition. Another observation is that Plant 1 which has the highest APC has undergone the minimum level of change in generation (to a maximum of 1.56 MW) and Plant 3 which has the lowest APC has experienced a maximum level of change in generation (to a maximum of 3.96 MW). Plant 2 experienced a maximum change of 2.51 MW which lies between changes of Plants 1 and 3. Or in other words, it is comprehensible that the shifts or changes in generations follow the level of APC - lesser the APC, higher the changes and *vice versa*.

Table 4: Dispatch results - h 0-1 to 7-8

Hour and load	Dispatch	P_{G1} MW	P_{G2} MW	P_{G3} MW	P_G MW	F_T \$/h
0-1	APC	118.30	222.46	200.82	541.58	26823.77
530 MW	No APC	117.49	220.14	204.09	541.72	26829.09
1-2	APC	105.72	203.75	179.95	489.41	24451.83
480 MW	No APC	105.08	201.35	183.08	489.51	24455.48
2-3	APC	98.21	192.56	167.46	458.23	23054.08
450 MW	No APC	97.68	190.12	170.51	458.31	23056.92
3-4	APC	85.78	173.98	146.70	406.46	20766.14
400 MW	No APC	85.43	171.47	149.60	406.51	20767.91
4-5	APC	85.78	173.98	146.70	406.46	20766.14
400 MW	No APC	85.43	171.47	149.60	406.51	20767.91
5-6	APC	98.21	192.56	167.46	458.23	23054.08
450 MW	No APC	97.68	190.12	170.51	458.31	23056.92
6-7	APC	105.72	203.75	179.95	489.41	24451.83
480 MW	No APC	105.08	201.35	183.08	489.51	24455.48
7-8	APC	131.00	241.27	221.75	594.01	29249.58
580 MW	No APC	130.02	239.03	225.16	594.21	29257.08

APC: Auxiliary power consumption

Table 5: Dispatch results – H 8-9 to 15-16

Hour and load	Dispatch	P_{G1} MW	P_{G2} MW	P_{G3} MW	P_G MW	F_T $/h
8-9	APC	165.81	292.53	278.62	736.95	36077.51
715 MW	No APC	164.42	290.53	282.40	737.35	36094.17
9-10	APC	176.28	307.86	295.57	779.71	38181.26
755 MW	No APC	174.79	305.94	299.47	780.20	38201.83
10-11	APC	180.23	313.63	301.95	795.80	38979.96
770 MW	No APC	178.70	311.74	305.88	796.32	39002.17
11-12	APC	180.23	313.63	301.95	795.80	38979.96
770 MW	No APC	178.70	311.74	305.88	796.32	39002.17
12-13	APC	164.50	290.61	276.50	731.62	35817.18
710 MW	No APC	163.13	288.61	280.27	732.01	35833.40
13-14	APC	172.34	302.10	289.21	763.65	37387.92
740 MW	No APC	170.89	300.16	293.06	764.11	37406.95
14-15	APC	173.66	304.02	291.33	769.01	37651.77
745 MW	No APC	172.19	302.08	295.20	769.47	37671.31
15-16	APC	167.11	294.44	280.74	742.29	36338.42
720 MW	No APC	165.71	292.45	284.53	742.70	36355.53

APC: Auxiliary power consumption

Table 6: Dispatch results - h 16-17 to 23-24

Hour and load	Dispatch	P_{G1} MW	P_{G2} MW	P_{G3} MW	P_G MW	F_T $/h
16-17	APC	164.50	290.61	276.50	731.62	35817.18
710 MW	No APC	163.13	288.61	280.27	732.01	35833.40
17-18	APC	176.28	307.86	295.57	779.71	38181.26
755 MW	No APC	174.79	305.94	299.47	780.20	38201.83
18-19	APC	182.87	317.48	306.20	806.54	39515.43
780 MW	No APC	181.31	315.62	310.16	807.09	39538.79
19-20	APC	176.28	307.86	295.57	779.71	38181.26
755 MW	No APC	174.79	305.94	299.47	780.20	38201.83
20-21	APC	164.50	290.61	276.50	731.62	35817.18
710 MW	No APC	163.13	288.61	280.27	732.01	35833.40
21-22	APC	146.37	263.96	246.96	657.28	32233.27
640 MW	No APC	145.20	261.82	250.54	657.56	32244.17
22-23	APC	131.00	241.27	221.75	594.01	29249.58
580 MW	No APC	130.02	239.03	225.16	594.21	29257.08
23-24	APC	120.83	226.21	205.00	552.05	27304.59
540 MW	No APC	119.99	223.91	208.30	552.20	27310.30

APC: Auxiliary power consumption

4.3. Benefits in Terms of Cost and Efficiency Improvement

Due to the introduction of APC of the plants in their fuel cost characteristics, all the plants have undergone changes either increase or decrease in their generations and the magnitude of the change depends on the level of APC. This is factual from the test results. Always changes in generation result in changes in the operating cost of power plants. The operating cost might be higher or lower or no change depending upon the system and its operating strategy. The consolidated results of the economic power dispatch are presented in Table 7.

The Table 7 highlights the reduction in total generation of the power system incorporating the three power Plants 1, 2 and 3 and also the reduction in hourly fuel cost of all the plants put together. During every hour and every load condition, there is reduction in power generation to meet the hourly demand. That is for the same work done, less input means increase in system efficiency! It is also evident that there is reduction or saving in hourly operating fuel cost at every hour and load condition. It is worth mentioning that for a 24 h period, a reduction in power system generation of 7.39 MW and saving in fuel cost of $ 303.94 which is nothing but an efficient and economical solution simply by incorporating the APC component in the plants operating characteristics. A reduction in generation by 7.39 MW means, equivalent to adding a new power plant of the same capacity. In today's market value, the cost to build one new MW of coal-fired capacity is approximately 1.3-2.2 MUSD. Another point of interest is that since the generation is less, the burden on the machines is less; hence improvement in life-time and also reduction in NOx emission by 2105.68 kg for a 24 h period.

5. CONCLUSIONS

Though energy efficiency improvements are possible at all sections of an energy sector, this paper attempted an efficiency enhancement opportunity for economic operation of coal-fired power stations. The strategy followed is incorporating the APC in the fuel cost characteristics of the power plants and then performing economic power dispatch. A direct optimization technique is used for the study purpose and the test results are supporting the logic followed. Plant generations got modified and the magnitude of the shift in generation either increase or decrease in nature correlates with

Table 7: Benefits over 24 h period

H	Demand, MW	Benefits due to reduction w.r.t no APC dispatch	
		Generation, MW	Total fuel cost, S/h
0-1	530	0.14	5.32
1-2	480	0.10	3.65
2-3	450	0.08	2.84
3-4	400	0.05	1.77
4-5	400	0.05	1.77
5-6	450	0.08	2.84
6-7	480	0.10	3.65
7-8	580	0.20	7.50
8-9	715	0.40	16.66
9-10	755	0.49	20.57
10-11	770	0.52	22.21
11-12	770	0.52	22.21
12-13	710	0.39	16.22
13-14	740	0.46	19.03
14-15	745	0.46	19.54
15-16	720	0.41	17.11
16-17	710	0.39	16.22
17-18	755	0.49	20.57
18-19	780	0.55	23.36
19-20	755	0.49	20.57
20-21	710	0.39	16.22
21-22	640	0.28	10.90
22-23	580	0.20	7.50
23-24	540	0.15	5.71
	Total	7.39 MW	$ 303.94

APC: Auxiliary power consumption

the magnitude of the APC of the respective plants. Efficiency improvement in terms of reduction in plant generations for the same delivered power has been achieved and in addition saving in fuel cost is also accomplished. The energy efficiency improvement at the generating station level or at the source itself is followed since the generated electricity is at least three times the price of the input fuel energy. The strategy developed is extendable to emission dispatches as well as to combined economic and emission dispatches of fossil-fuelled power systems.

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