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Emission and Environmental Goals in Decision Making Modeling for Load Dispatch

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ABSTRACT: The main purpose of this research is to determine the generation quantity of each generator in a power system. In this way, not only will the electricity demanded by the system be supplied, but the cost of fuel along with the level of pollution can be minimized. Obviously, calculation of the optimal layout of power plants with the aim of minimizing fuel costs and pollutants level contributes to sustainable socio-economic development. For this purpose, modeling a multi-objective decision making framework by means of the weighting method makes it possible to attain the mentioned goals. After modeling the goals and constraints of the power system, the problem associated with economic-environmental load dispatch with the Institute of Electrical and Electronics Engineers 30-Bus data is optimized by means of the Lagrange approach. Moreover, the sensitivity analysis in connection with the weight of short-term costs is conducted to determine the final point of the system usage. Results show that if the importance coefficient of the fuel cost reduction is 1 (W=1), the economic and environmental load dispatch will pose some problems for the economic load dispatch. In contrast, if the importance coefficient of the reducing fuel cost is zero (W=0), the economic and environmental load dispatch will become problematic for environmental load dispatch. Incidentally, the trade off curve of the fuel cost and the pollutant amount involves the functional information for the system operator. The current research is mainly innovative in its use of a method to reduce fuel consumption and environmental impacts on emission at optimization process. This can, in turn, lead to generation of sustainable energy.

Keywords: Economic environmental load dispatch (EED), multi-objective decision making, optimum formation of plant production, decision making management, emission.

INTRODUCTION

The main purpose of this research is to determine the generation quantity of each generator in a power system so that in addition to supplying the electricity demanded by the system, the cost of fuel along with the level of pollution will minimize and reach to its lowest point. Obviously, calculating the optimal layout of power plants with the goal of minimizing fuel costs and the degree of pollutants will contribute to sustainable socio-economic development. One of the most important problems in utilizing power systems is the economic load dispatch (ED). This problem should be solved to minimize the cost of fuel under the system's practical limitations. Consequently, the optimum arrangement of power plants is determined (Mandal et al. 2014). In recent decades, fossil fuel plants have generally responded the demand

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increment for electricity. Thus, the share of power plant pollutants, such as carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x), has increased and caused anxiety and social reactions. In this regard, paying subsidies for fuel in power plants and paying not enough attention to the external cost are the most important reasons for the lack of economic competitiveness of renewable electricity (REPN 2018) and have made it unavoidable to use fossil fuel power plants (Motahari et al. 2014). Therefore, the policy for reducing the pollutant emissions to control the environmental sensitivities and hazards is considered as an important factor in most of the countries, and hence, various strategies have been adopted for it.This policy can be followed in three steps:1) Installing filtration equipment in power plants,2) Replacing old equipment with up-to-date equipment, and 3) Utilizing the power plants considering the environmental pollutants. In the first two steps, the new equipment need to be installed or the existing structure of power plants need to be modified. Therefore, these steps require high amount of investment and long-term planning. However, inclusion of environmental considerations in utilization of power plants in the form of load dispatch needs a short-term planning (Hooshmand et al. 2012). There are various approaches which consider the pollution from power plants in the process of load dispatch. Gent and Lamont (1971) presented the most ideal form of environmental protection solution under the environmental load dispatch. This strategy has been used in other studies to minimize the pollutants from power plants (Delson 1974; Lamont and Obessis 1995). The major disadvantage of environmental load dispatch is the unacceptable cost of fuel imposed on the system. Finnigan and Fouad (1973) considered the environmental factors in exploiting power plants as practical limitations of the system, in a way that the amount of each pollutant did not exceed the maximum limitation (Sáenz et al. 2013). This strategy has been used in other studies in order to control the pollutants from power plants (Granelli et al. 1992; Brodsky and Hahn 1986). In this case, although the pollutant in a power plant is controlled, but the emission of gases is not minimized. Usually it is not easy to determine the permissible level of pollutants. Power systems tend to minimize both the short-term costs of production and the amount of pollutants through modeling the multiple objective decision making of solution for the intended problem. Since the system operator is more than the goals, weighting method is mainly based on the normal human performance in multi-criteria decision making. Therefore, knowledge of the system operator is relatively more important than the goals and determins the final point of system operation (Sivasubramani and Swarup 2011). For this reason, the sensitivity analysis of the optimal target values is of great importance as short-term cost of production (Bhattacharjee et al. 2014). The output of this sensitivity analysis is a trade off curve of the fuel cost of pollutant. In this study, modeling of the economic and environmental goals of load dispatch is proposed by considering the transmission network losses in the 6-generator IEEE 30-Bussystem. The Lagrange classical method in MATLAB software has been used to solve the mathematical model. The IEEE 30-Bus Test Case represents a portion of the American Electric Power System (in the Midwestern US). A hardcopy data was provided by Iraj Dabbagchi in American Electric Power (AEP) and entered in IEEE Common Data Format by Rich Christie at the University of Washington (Francisco and Gonzalez 2015). In the last decades, these data have been used for modeling and optimizationin many studies (E-Silva et al. 2013; Chen et al. 2016; De et al.

2018).This study has been carried out in a portion of the American Electric Power System (in the Midwestern US) with IEEE 30-bus Test Case Data as of 1961.

MATERIALS AND METHODS

Duality theory is an important step in estimating the cost and production functions. Accordingly, under certain rules, there are production and cost functions that are dual to each other (Ciornei and Kyriakides 2013). Therefore, production costs can be analyzed in the form of production function. Electricity at steam power plants is achieved through the process of converting fuel energy. After constructing a power plant, its capacity and technology cannot be changed in a short term. In other words, production of a unit is a function of the amount of consumed fuel, maintenance equipment, manpower and technical specifications. Consequently, Eq.1 can be considered for the constructed unit.

$$P_t = f\left(X_t, \bar{X}_t\right) \tag{1}$$

where, $\bar{X}_t$ and $X_t$show the vector of constant inputs and variable inputs of production, respectively. Therefore, the short-term cost function of the unit can begiven by Eq. 2 with respect to the fixed value of $\bar{X}_t$ as below:

$$F_t\left(P_t, Y_t\right) = Y_t\, f^{-1}\left(P_t\right) \tag{2}$$

where, $F_t(P_t, Y_t)$ and Y_t are the short-term cost function and the input price vector at the time t for the specified unit, respectively. Therefore, the equation between fuel and production amount can explain the production cost function variable in a short termat the electricity power industry. In specifying the relationship between fuel consumption and electricity production, a thermodynamic equation is used to match the properties of the thermal units. This equation is called the input and output curves of the thermal unit and shows the conversion rate of input and output energies according to the second-order or the third-order non linear equation.The most important factor that generates a non linear section of the curve is initial cost or fuel consumption without production. This cost leads to an increase in the level of production on the unit efficiency, and the cost function becomes a non linear form. Eq. 3 shows the fuel cost function of a power plant unit as a second-order function in terms of output active power (Hosseinnezhad and Babaei 2013; He et al. 2016).

$$F_i^{Cost} = \alpha_i P_i^2 + \beta_i P_i + \gamma_i \qquad i: 1,2,\ldots,\mathrm{M} \tag{3}$$

where, F_i^{cost} is fuel cost of the i-th generator in dollar per hour (\$/h); and α_i , β_i and γ_i are unit costs of the i-th power plant unit, which are calculated in \$/MW^{2}h, \$/MWh and \$/h, respectively. Production of the i-th power plant is considered in MW, and M is the number of power plants in the circuit of the system. The main factor affecting the amount of pollutant emissions from power plants is the type of used fuel and the active production in power plants. The relationship between the amount of released pollutant and the active power production is non linear. It means that by increasing the production in different intervals, the amount of pollutant emissions will not be the same, and a second-order non linear equation in terms of active power production will most closely match the pollutant function (Bhattacharya and Chattopadhyay 2011; Kothari 2012) as presented by Eq. 4.

$$E_i^{Quantity} = a_i P_i^2 + b_i P_i + c_i \qquad i: 1,2,\ldots,\mathrm{M} \tag{4}$$

where, $E_i^{Quantity}$ is the pollutant amount of the i-th generator in kg/h; and a_i, b_i and c_i are the pollutant function coefficients of the i-th power plant in kg/MW^{2}h, kg/MWh and kg/h, respectively. The load dispatch problem considering the objectives can be divided into three categories of economic load dispatch, environmental load dispatch, and economic and environmental load dispatch.

Economic load dispatch is solved to determine the optimal arrangement of production in power plants, so that the cost of fuel for the total power plants is minimized in terms of practical limitations of the system. The objective function of economic load dispatch is represented by Eq. 5.

$$Min\ F^{Cost} = Min\sum_{i=1}^{M} F_i\left(P_i\right) \quad (5)$$

Despite the fact that the cost of fuel for the total system is minimized in the economic load dispatch problem, the amount of unacceptable pollutant is imposed on the total system.

Environmentalload dispatch is solved to determine the optimal arrangement of production in power plants, so that the cost of fuel for the total power plants is minimized in terms of practical limitations of the system. Eq. 6 presents the objective function of the problem of economic load dispatch.

$$Min\ \mathrm{E}^{Quantity} = Min\sum_{i=1}^{M} E_i\left(P_i\right) \quad (6)$$

Despite the fact that the emission of total system is minimized in the environmental load dispatch problem, unacceptable fuel cost is imposed on the total system.

Economic and environmental load dispatch is solved to determine the optimal arrangement of production in power plants, so that both the fuel cost and total pollutants of total power plantsareminimized in terms of practical limitations of the system. In fact, from the perspective of the system operator, the prevalence coefficients of the objectives are not the same. Thus, the weights of objectives must be determined. Eq. 7 represents the objective function of economic and environmental load dispatch.

$$Min\varphi = w\sum_{i=1}^{M} F_i^{Cost} + \left(1-w\right)\sum_{i=1}^{M} h_i \times E_i^{Quantity} \quad (7)$$

where, W is the weight coefficient of reducing fuel costs, which can change the importance of problem objectives; and h_i is the pollutant penalty coefficient for the i-th generator in \$/kg, which may have different values according to the operator's view point and the pollutant value. Various methods have been proposed to define the pollutant penalty coefficient (Balamurugan and Subramanian,2007). The most common approach is obtained via dividing the amount of fuel cost by the amount of pollutant at the maximum output power of that unit (Dixit et al. 2011; Hamedi 2013) as expressed by Eq. 8.

$$h_i = \frac{\alpha_i P_{i,\max}^2 + \beta_i P_{i,\max} + \gamma_i}{a_i P_{i,\max}^2 + b_i P_{i,\max} + c_i} \quad \text{i: 1,2,...,M} \quad (8)$$

where, h_i is the pollutant penalty coefficient for the i-th generator, and $P_{i,max}$ is the maximum output power of the i-th generator. Following limitations are considered in the load dispatch problems:

1. Minimum and maximum constraints of production capacity

The power assigned to each generator must be within the range allowed by the generator. If P_i^{min} and P_i^{max} are the minimum and maximum production of the i-th generator, this limitation is considered using Eq. 9.

$$P_i^{\min} \le P_i \le P_i^{\max} \quad i:1,2,...,\mathrm{M} \quad (9)$$

2. Power balance constraint

The total production power of active generators should be equal to the total power of system loads and transmission network losses. If P_D is the total system load and P_{Loss} is a transmission network loss, then this constraint is modeled according to Eq. 10(Reddy 2012).

$$\sum_{i=1}^{M} P_i = P_D + P_{Loss} \quad (10)$$

In Eq. 10, P_{Loss} depends on the physical structure of the network, the power generated in the system and the transmission network losses. It can be computed using Eq. 11(Dogra et al. 2014).

$$P_{Loss} = \sum_{i=1}^{M}\sum_{j=1}^{M} P_i B_{ij} P_j + \sum_{i=1}^{M} B_{0i} P_i + B_{00} \qquad (11)$$

where, B_{00}, B_{i0}, and B_{ij} are the loss coefficients which are constant under certain assumed conditions.

3. Constraintof changerate in production

The practical range of production in generators at any time is determined by the change in production. In fact, this constraint causes high and low limitations for productionin generators, depending on initial production at any given time as presented by Eq. 12 (Pradhan et al. 2016).

$$\max\left\{P_i^{\min}, P_i^0 - DR_i\right\} \le P_i \le \min\left\{P_i^{\max}, P_i^0 - UR_i\right\} \qquad (12)$$

where, P_i^0, DR_i and UR_i are the initial output power, the rate of decrease, and the rate of increase in the production of the i-th generator, respectively.

Model setup and data set

To optimize the modeling of economic and environmental load dispatch by weighting approach, the Institute of Electrical and Electronics Engineers (IEEE) 30-Bus system data were used according to Tables 1 and Matrixs B_{i0}, B_{00} and B_{ij}.

Basbur is a conductor joined to production sources and consumption centers by multiple branches. The diagram of this system is shown in Fig. 1. The system contains 6 generator buses, 24 load buses (6 generator buses + 24 load buses= 30 buses) and 41 transmission lines (including 4 transformers) with the initial load of 283.4 MW (Mei et al. 2011).

Table 1. Generator cost, emission coefficientsand other technical specifications (Balamurugan and Subramanian 2007)

Gen No.	Coefficients										
	α_i	β_i	γ_i	a_i	b_i	c_i	P_i^0	$P_{i,max}$	$P_{i,min}$	DR_i	UR_i
1.	22.983	-1.1000	0.0126	0	2.00	0.00375	85	65	135	200	50
2.	25.313	-0.1000	0.0200	0	1.75	0.01750	22	12	65	80	20
3.	25.505	-0.0100	0.0270	0	1.00	0.06250	15	12	35	50	15
4.	24.900	-0.0050	0.0291	0	3.25	0.00834	16	0.08	25	35	10
5.	24.700	-0.0040	0.0290	0	3.00	0.02500	0.09	0.06	20	30	10
6.	25.300	-0.0055	0.0271	0	3.00	0.02500	16	0.08	30	40	12

Matrix B_{0i}: Transmission line data (10^{-5} MW) (Balamurugan and Balamurugan 2007)

B_{0i}=	-0.3	21	-56	34	15	78

Matrix B_{00}: Transmission line data(10^{-5} MW) (Balamurugan and Subramanian 2007)

B_{00}=	14

Matrix B_{ij}: Transmission line data(10^{-5} MW) (Balamurugan and Subramanian 2007)

B_{ij}=	218	103	0.9	-10	-0.2	27
	103	181	0.4	-15	-0.2	30
	0.9	0.4	17	-131	-153	-107
	-10	-15	-131	221	94	50
	0.2	0.2	-153	94	243	-0.0
	27	30	-107	50	-0.0	358

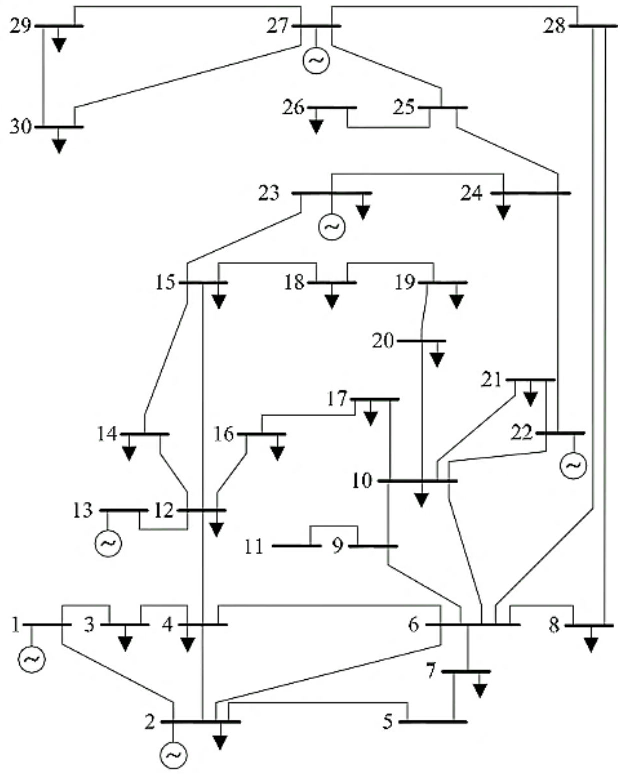

Fig. 1. Diagram of the IEEE 30-bus system (Mei et al. 2011)

Optimization method based on Lagrange coefficients

This approach is one of most important methods to solve the classical planning problem. Since the objective function is non linear and smooth, the use of Lagrange coefficients is sufficient for optimization (Xia and Elaiw 2010). However, if the objective function is non linear and non smooth, meta-heuristic algorithms must be used for optimization (Rao and Yesuratnam 2013). Lagrange coefficient is used in many economic optimization problems, because valuable information yields the sensitivity of the optimal values when the constants of constraints change. These sensitivities have important economic commentary on optimization problems. In Eq. 13, optimizations are provided with Lagrange coefficients method using unequal constraints for a system with two generators, in which $C_i(P_i)$ is the fuel cost and pollutant of the i-th generator for a penalty coefficient.

$$
\begin{aligned}
&f\ (p_1,p_2)=C_1(p_1)+C_2(p_2)\\
&1)\ \omega(p_1,p_2)=p_D-p_1-p_2=0\\
&2)\ \mathrm{p}_1^{\min}\le p_1\le p_1^{\max}\Rightarrow\begin{cases}g_1(p_1)=p_1-\mathrm{p}_1^{\max}\le 0\\ g_2(p_1)=\mathrm{p}_1^{\min}-p_1\le 0\end{cases}\\
&3)\ \mathrm{p}_2^{\min}\le p_2\le p_2^{\max}\Rightarrow\begin{cases}g_3(p_2)=p_2-\mathrm{p}_2^{\max}\le 0\\ g_4(p_2)=\mathrm{p}_2^{\min}-p_2\le 0\end{cases}
\end{aligned}
\tag{13}
$$

$$
\begin{aligned}
&L=f\ (p_1,p_2)+\lambda\omega(p_1,p_2)+\mu_1 g_1(p_1)\rightarrow\\
&+\mu_2 g_2(p_1)+\mu_3 g_3(p_2)+\mu_4 g_4(p_2)
\end{aligned}
\tag{14}
$$

Kuhn-Tucker condition is a necessary condition for the optimization problem in the above-mentioned lemmatization. To find solutions for optimization problem, it is needed to test different responses in order to provide answers to all conditions (Alsumait et al. 2010).

RESULTS AND DISCUSSION

The final point of system operation in the weighting approach depends on the adoption of weight coefficients by the system operator. Therefore, for different importance coefficients, the purpose is reducing fuel cost (W), optimal arrangement of power plants and reaching optimal values of targets according to Tables 2 and 3.

If value of W changes continuously in the interval of 0-1, an appropriate analysis will be obtained by plotting the optimal values of the goals vs. each value of W. According to Fig. 2, the total cost of fuel system is decreased and the total system pollutants are increased with the increase of the value of importance coefficients in reducing fuel costs (W). Furthermore,the fuel cost of the total system and the pollutant amount in the total system are decreased when the value of the importance coefficients in reducing fuel costs (W) is decreased or the importance coefficients of the reducing pollutant value (1-W) is increased (Wu et al. 2010; Pandi et al. 2014).

Table 2. Optimal arrangement of power plants

W	P_1	P_2	P_3	P_4	P_5	P_6
0.0	131.14	57.62	41.02	20.08	20.06	30.08
0.1	134.75	57.78	37.25	20.08	20.06	30.08
0.2	138.21	57.53	34.04	20.08	20.06	30.08
0.3	141.60	56.92	31.25	20.08	20.06	30.08
0.4	145.08	56.02	28.82	20.08	20.06	29.93
0.5	150.30	55.53	26.96	20.08	20.06	27.07
0.6	155.98	54.71	25.24	20.08	20.06	23.93
0.7	162.25	53.52	23.64	20.08	20.03	20.48
0.8	169.27	51.91	22.12	20.08	19.91	16.72
0.9	176.56	49.63	20.59	19.31	19.91	14.00
1.0	188.54	47.55	20.00	10.00	19.91	14.00

Table 3. Optimal values of goals

W	F^{Cost}	$E^{Quantity}$
0.0	883.60	374.38
0.1	872.83	374.92
0.2	864.84	376.32
0.3	858.75	378.34
0.4	853.87	380.97
0.5	847.23	386.42
0.6	841.34	393.63
0.7	836.25	403.15
0.8	832.06	415.73
0.9	829.47	430.22
1.0	828.04	459.79

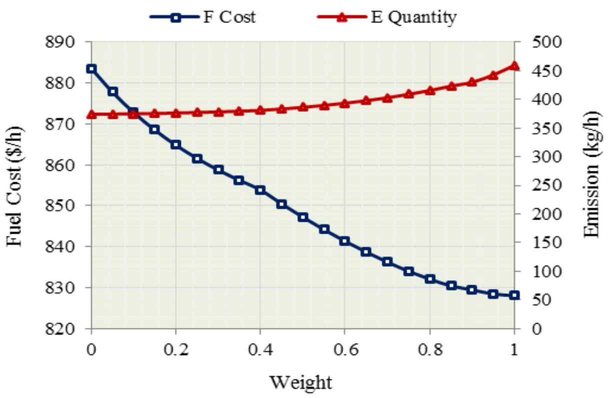

Fig. 2. Optimal values for the goalsvs. different W values

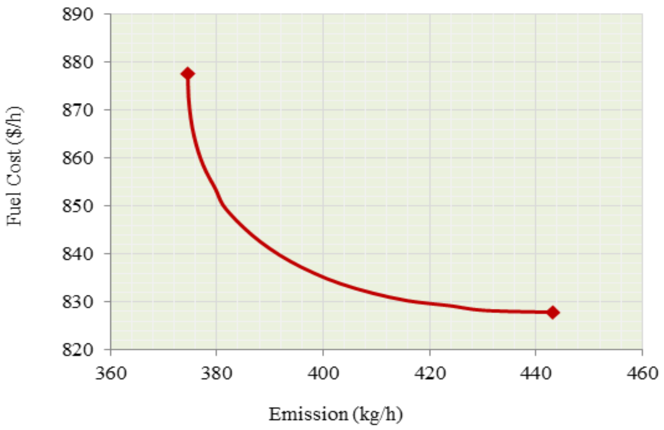

Fig. 3. The trade off curvefor fuel cost and amount of pollutant

Consifdering the fuel cost and the corresponding pollutant level in each weight coefficient, trade off curves among the objectives of the problem can be extract (Fig. 3).

The trade off curve enables the operator to choose the final point of system operation as an answer to the economic and environmental load dispatch, given that the importance of each objective and the way that cost and pollutant impact each otherare known (Turgut and Demir 2017).

CONCLUSION

In a power system to supply the on-demand electrical load, there is only one unique arrangement of generators that minimizes both fuel costs and the amount of total system emissions. This unique arrangement of generators is optimum production values, which is just one case of the infinite state the system operator, can take as a decision maker. In fact, in other cases, the fuel cost and the amount of contamination of the whole system are far from the minimum, so there is only one way to generate n power plants in a power system that can be P = (p1 *, p2 *,…, pn *) showed that the final costs of generating electricity with least marginal cost and consequently the social costs of consuming hydrocarbons are at their best.

In this paper, the load dispatch among the generators in the IEEE 30-Bus system was designed to reduce the cost of short-term production and the amount of pollutant under the operating constraints in the system. The problem of the economic and environmental load dispatch regarding assuming the relative advantage of the objectives from the operator's viewpoint was modeled by multi-objective decision making based on weight allocation. The knowledge of the system operator based on the relative importance of the objectives determined the final point of system operation, so that if the importance coefficient of reducing fuel cost was 1 (W=1), the economic and environmental load dispatch became the problem of economic load dispatch. Conversely, if the importance coefficient of reducing fuel cost was zero (W=0), the economic and environmental load dispatch would become the problem of environmental load dispatch. In this regard, the trade off curve of fuel cost and pollutant amount contained useful information for the system operator. The tangent gradient at each point of this curve showed the emission reduction rate (ERR). Emission reduction rate interprets marginal rate of substitution (MRS) in economics, which means that in each point of in difference curvea unit of emission reduction leads to the amount fuel cost for the whole system (Chen and Wang 2009). The final point of system operation can be determined based on the market mechanism in the future studies.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

ABBREVIATIONS

B_{ij}, B_{oi}, B_{00}	Matrix of coefficients in the network loss
CO_2	Carbon dioxide
DR_i	Decrease rate in the production of the i-th generator
ED	Economic load dispatch
EED	Economic environmental load dispatch
ERR	Emission reduction rate
$E_i^{Quantity}$	Pollutant amount of the i-th generator
F_i^{cost}	Fuel cost of the i-th generator
h_i	Pollutant penalty coefficient for the i-th generator
IEEE Bus 30	Institute of Electrical and Electronics Engineers Bus 30
kg/h	Kilogram per hour
M	Number of generator in the circuit of the system
MATLAB	Matrix Laboratory
MRS	Marginal Rate of Substitution
NO_x	Nitrogen oxide
P_i	Production of the i-th generator
P_i^0	Initial output power
P_i^{Max}	Maximum output power of the i-th generator
P_i^{Min}	Minimum output power of the i-th generator
P_{Loss}	Power loss in the transmission network
SO_2	Sulfur dioxide
UR_i	Increase rate in the production of the i-th generator
W	Importance coefficient for reducing fuel cost
$/kg	Dollar per kilogram
$/h	Dollar per hour
$/MWh	Dollar per megawatt hour
α_i , β_i , γ_i	Fuel cost function coefficients of the i-th generator
a_i, b_i, c_i	Emission function coefficients of the i-th generator

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