

APPLICATION OF PARTICLE SWARM OPTIMIZATION ALGORITHM TO THE DISTRIBUTED MULTI-AREA SERVICE DEMANDS AND EMISSION CONTROLLED

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Recently, energy saving/emission reduction has been a very important issue for electricity service operations management. The purpose of this study is to analyze impacts of distributed multi-area demand on the environmentally constrained economic dispatch. This paper proposed the particle swarm optimization (PSO) algorithm to minimize the total fuel cost of generation and environmental pollution caused by fossil based thermal generating units and also maintain an acceptable controlling emission for each area limit. In conclusion, we should note that it is important to be able to determine the different needs of transfer capacity among some countries/regions for cost-effective pollution reduction.

Keywords: Electricity supply industry, Particle Swarm Optimization, Emission Controlled

(Received 10 Nov 2008; Accepted in revised form 9 Sept 2010)

1. INTRODUCTION

Electrical power operation is moving toward liberalization as well as energy saving/emission reduction due to the influence of the global economic trend and environmental awareness. The liberalization is the desire to improve the perceived poor performance of the electricity supply industry (ESI). Traditionally, the ESI consists of four vertically related business activities: *generation, transmission, distribution, and supply*. More extensive liberalization may allow independent private generators to enter the market, the vertical disintegration of state owned monopolies into generation, transmission and distribution businesses, the creation of power pool and the horizontal separation of incumbent generators. In addition, the ESI also plays an important role in stabilizing an atmospheric concentration of greenhouse gas emissions.

Power generation plants operation, which are distributed nationwide, are not always placed as a single demand node to operate optimal way. In the conventional service operations management, most of the results show incorrect solution for site and operating power plants. The results mislead the ESI to inefficient service operations management, such as excess investments and the bottleneck of operation. Under the deregulation of ESI, it is necessary for each utility to operate their power plants with optimal way to meet distributed demand and regional emission allowance. Therefore, it is necessary for the new way for ESI to operate the utilities with less impact on the global environment to improved operating efficiency and customer service. For these purposes, it is important to develop an analytical model considering distributed multi-area demand, capacity of power plants and their emission different allowances. There is, for instance, a large possibility of demand to decrease CO₂ emissions in the residential and commercial area.

The ESI problem is studied in here focus on multi-area environmental/economic dispatch to achieve simultaneously the minimization of fuel cost and pollutant emission. The harmful ecological effect caused by the emission of gaseous pollution can be reduced by adequate distribution of load between the plants of power system subjected to several constraints. These lead to determine the "optimal" development of the interconnections, taking into account the controlling emission limits for each area, with the possible resources to flexibility mechanism such as emission trading, and to develop a multi-area generation scheduling algorithm to ensure security and reliability of the system. The environmental/economic dispatch is a multi-objective problem with conflicting objectives because pollution minimization is conflicting with minimum cost of generation. Many researchers have considered emissions either in the objective function or treated them as additional constraints. Since the various methods have been proposed [1],[2], an excellent summary on the various techniques and emission models to reduce emissions into atmosphere was presented by [3]. However, the environmental/economic dispatch problem is a highly nonlinear optimization problem. Therefore, conventional optimization methods that make use of derivatives and gradients, in general, are not able to locate or identify the global optimum [4]. In other research direction, the environmental/economic dispatch problem was converted to a single objective problem by linear combination of different objectives as a weighted sum [5],[6]. Unfortunately, this requires multiple runs as many times as the number of desired Pareto-optimal solutions. Because evolutionary algorithms deal with a group of candidate solutions, it seems naturally to use it to find a group of Pareto optimal solutions simultaneously. There are many papers that have reviewed the evolutionary algorithms based optimizations techniques [7]-[9], most of them based on genetic algorithms (GA). Recently, PSO algorithm is successfully used to solve economic dispatch problem [10],[11].

This paper focuses on single pollutant, carbon dioxide(CO₂), because its control is a significant issue at the global level. It uses Particle Swarm Optimization (PSO) algorithm to solve multi-area environmental/economic dispatch problem. A price penalty factor (h) is defined which blends the emission costs with the fuel costs. This avoids the use of two classes of dispatching and need to switch over between them. The heuristic method of price penalty factor was being introduced which gives the suitable solution directly. Another factor called power balance penalty factor (pf) is introduced to penalize the violation of constraints and forces that unconstrained optima towards the feasible region. The capacity limits (lower and upper) of plants are treated as the operating constraints and the total generation which is a function of load plus transmission losses is considered as the demand constraint. In this paper, the multi-area environmental/economic dispatch problem that determines the “optimal” development of the interconnections, taking into account the controlling emission limits for each area, with the possible resources to flexibility ESI. The remainder of the paper is organized as follows: In Section 2, the multi-area environmental/economic dispatch problem was formulated. The proposed particle swarm optimization (PSO) algorithm is discussed in Section 3. Computation results and comparison analysis are given in Section 4. Finally, conclusions are drawn and future research directions are suggested.

2. PROBLEM DESCRIPTION

The problem formulates the optimal multi-area environmental/economic dispatch problem which takes into account the environmental issue. The objective of multi-area dispatch is to determine the generation levels and the interchange power between areas that minimize both of the fuel and emission costs while satisfying a set of constraints. The problem is as follows:

2.1 Formulation for Objective Function

The Objective function is both fuel and emission costs as below:

$$\begin{aligned} \text{Minimize } \phi &= \sum_{m=1}^M \sum_{i=1}^n FC_{mi} + \sum_{m=1}^M (h_m \cdot \sum_{i=1}^n E_{mi}) \quad \dots \quad (1) \\ &= \sum_{m=1}^M \sum_{i=1}^n FC_{mi} + \sum_{m=1}^M \left[h_m \cdot \sum_{i=1}^n CF_i \cdot FC(P_{mi}) \right] \end{aligned}$$

Where n is the number of on-line generators for the area m in M nationwide region, In the m^{th} area, FC_{mi} ($= a_{mi} \cdot P_{mi}^2 + b_{mi} \cdot P_{mi} + c_{mi}$) is the fuel cost of unit i , which a_{mi} , b_{mi} and c_{mi} are the fuel cost coefficients. P_{mi} is the power generation of unit i and h_m is the price penalty factor in the m^{th} area. h is the price penalty factor, which blends the emission cost with the fuel costs. After the introduction of the price penalty factor; E is the expected CO₂ emission (as an example only CO₂ reduction is considered) which may be related the cost curve through the emission rate per MBtu, and referred to the formula of Intergovernmental Panel on Climate Change (IPCC)[12]. The formula is deduced as follows:

$$E(P_i) = Fuel(P_i) \cdot NCV_i \cdot EF_i \cdot OF_i \quad \dots \quad (2)$$

Where $Fuel(P_i)$ is the fuel consumed (ton or m^3) by unit i , NCV_i is the net calorific value (TJ/ton or TJ/m^3) of the fuel used, EF_i is the emission factor (tCO_2/TJ) of unit i and OF_i is the oxidation factor of unit i . Moreover, the fuel consumed is given by:

$$Fuel(P_i) = FC(P_i) / FSC_i \quad \dots \quad (3)$$

Using (1) and (2), (3) can be translated into:

$$E(P_i) = CF_i \cdot FC(P_i) \quad \dots \quad (4)$$

Where $CF_i = (NCV_i \cdot EF_i \cdot OF_i) / FSC_i$ is the emission conversion factor of unit i .

Now, the next step is to find the price penalty factor in equation (1). In fact, it is very difficult to suitably select this penalty values. If the penalty values are high, the minimization algorithms usually get trapped in local minima. On the other hand, if penalty values are low, they can hardly detect feasible optimal solutions. The penalty values are dynamically modified according to equality constraints and inequality constraints. The value of h , is determined from the heuristic method given in [1]. The major steps determine the suitable h_m values as the following:

(1) Evaluate the average cost of each generator at its maximum output; i.e.,

$$\frac{FC(P_{mi}^{max})}{(P_{mi}^{max})} \quad (Rs / MWhr) \quad \dots \quad (5)$$

(2) Evaluate the average CO₂ emission of each generator at its maximum output; i.e.,

$$\frac{FC(P_{mi}^{max})}{(P_{mi}^{max})} \quad (kg / MWhr) \quad \dots \quad (6)$$

(3) Divide the average cost of each generator by its average CO₂ emission; i.e.,

$$\frac{\text{Equ.(5)}}{\text{Equ.(6)}} = \frac{FC(P_{mi}^{max})}{E(P_{mi}^{max})} = h_{mi} \quad (Rs / kg) \quad \dots \quad (7)$$

(4) Arrange the values of price penalty factor ($h_{mi}, i = 1, \dots, n$) in ascending order.

(5) Add the maximum capacity of each unit (P_{mi}^{max}) one at a time, starting from the smallest h_{mi} unit until

$$\sum_{i=1}^n P_{mi}^{max} \geq P_m^{demand}, \text{ where } P_m^{demand} \text{ are the power demand at } m \text{ area.}$$

(6) At this step, h_{mi} associated with the last generator in the process is the price penalty factor h_m (Rs/kg) for the given power demand.

Nevertheless, the procedure just shown gives the approximate value of price penalty factor computation for the corresponding power demand. The change of values was not displaying the continuous sequence. So the modified price penalty factor is computed by interpolating the values of for last two units by satisfying the corresponding load demand. In the m^{th} area, h_m is modified for the 4th-6th step of above six-step procedure, which modified calculation showed as:

$$\begin{bmatrix} h_{mi} \\ P_{mi}^{max} \end{bmatrix} = \begin{bmatrix} h_{m1} \leq \dots \leq h_{mj} \leq h_{mi} \leq \dots \leq h_{mn} \\ P_{m1}^{max} \dots, P_{mj}^{max}, P_{mi}^{max}, \dots, P_{mn}^{max} \end{bmatrix}, i = 1, \dots, n \text{ (arrange } h_{mi} \text{ in ascending order)}$$

where h_{mi} was obtained from six steps, the equation of modified h_m shown as:

$$h_m = h_{mj} + \frac{h_{mi} - h_{mj}}{P_{mi}^{max}} \times (P_m^{demand} - \sum_{j=1}^j P_{mj}^{max}) \quad \dots \quad (8)$$

Hence, a heuristic price penalty factor is introduced in this paper to give the exact value for the particular load demand in each area.

2.2 The constraints of environmental/economic dispatch

The objective of the multi-area environmental/economic dispatch problem is minimizing both fuel and emission costs subject to the following constraints:

(1) Area demand balance

In area m , the total power generation must cover the local area demand P_m^{demand} and the transmission loss P_m^{loss} with the consideration of imported and exported power. This relation an expressed as:

$$\sum_{i=1}^n P_{mi} - \sum_{\substack{m=1 \\ m \neq k}}^M [t_{mk} - (1 - \rho_{km}) \cdot t_{km}] - P_m^{demand} - P_m^{loss} = 0 \quad (9)$$

where P_m^{loss} is transmissions losses of the power flow on lines. A common approach to model transmissions losses use Kron's approximated loss formula with B -coefficients [13] which shown as:

$$P_m^{loss} = \sum_{i=1}^n \sum_{j=1}^n P_{mi} \cdot B_{m(i,j)} \cdot P_{mj} \quad \dots \quad (10)$$

where $B_{m(i,j)}$ is the elements of loss coefficient matrix B_m on transmission lines in the m^{th} area.

(2) Area generations capacity

$$P_{mi}^{min} \leq P_{mi} \leq P_{mi}^{max} \quad \dots \quad (11)$$

(4) Tie line capacity limits

$$t_{km}^{min} \leq t_{km} \leq t_{km}^{max} \quad \dots \quad (12)$$

where t_{km} , ρ_{km} are the economic tie transfer power and the tie line transfer loss ratio from area k to area m . P_m^{demand} , P_m^{loss} is the local demand and transmission loss for area m . t_{km}^{min} , t_{km}^{max} are the tie line minimum and maximum capacity limits from area k to area m . P_{mi}^{min} , P_{mi}^{max} are the minimum and maximum power output of generator i in area m .

3. PSO ALGORITHM FOR THE MULTI-AREA ENVIRONMENTAL/ECONOMIC DISPATCH

The multi-area environmental/economic dispatch problem was represented as a nonlinear programming problem with equality and inequality constraints, and this makes the problem of finding the global optimum difficult. The particle swarm optimization (PSO) method is a member of the wide category of swarm intelligence methods [14]. Kennedy original PSO as a simulation of social behavior, and it was initially introduced as an optimization method in 1995 [15]. [16] provide more details of the PSO algorithm mentioned above.

This study presents an optimal solution to the environmental/economic dispatch problem in multi-area using the PSO algorithm. The algorithm implementation consists of the following steps:

Step 1. Set the parameter of units, power demand, and initialize the power balance penalty factor (pf).

Step 2. In the m^{th} area, the number of on-line generating units is the dimension of this problem, ex.

$$P_{Gi} = [P_{i1}, P_{i2}, \dots, P_{id}] \quad i = 1, 2, \dots, n, \text{ each particle would be extended to the } C_2^m \text{ combination dimensions of power transfer variable } (P_{Ti}) \text{ between areas. Then the population of individuals would be extended as:}$$

$$P_{mi} = [P_{Gi}, P_{Ti}], \quad i = 1, 2, \dots, n \quad \dots \quad (13)$$

These particles are randomly initial generated, and the range of P_{mi} must be to satisfied the limit of Eq. (11) and Eq. (12).

Step 3. Calculate h_m using the six step procedure and Eq. (8) in Section 2.1.

Step 4. Evaluate the fitness of each individual P_{mi} in the population based on:

$$Fitness = Eq. (1) + pf \cdot [Eq.(9)] \quad \dots \quad (14)$$

where the power balance penalty factor (pf) is introduced in such a way that it penalizes any violation of the constraints and forces that unconstrained optima towards the feasible region.

Step 5. If the stopping criteria are met, then go to Step 9. Otherwise, next step.

Step 6. The best value among. All the P_{best} value, G_{best} , is identified. The objective function values are calculated for the updated position of particles. If the new value is better than the previous P_{best} , the new value is set to P_{best} .

Step 7. New velocities for all the dimensions in each particle are calculated using equation as:

$$V_i(t+1) = w \times V_i(t) + c_1 \times rand() \times (Pbest_i(t) - P_i(t)) \quad \dots \quad (15)$$

$$+ c_2 \times rand() \times (Gbest_i(t) - P_i(t))$$

The position of each particle is updated using equation as shows:

$$P_i(t+1) = P_i(t) + V_i(t+1) \quad \dots \quad (16)$$

Step 8. Check the variables of each individual and adjust to max/min bound for exceed/less than the limit bound of Eq. (11) and Eq. (12). Go to Step 4.

Step 9. If Eq. (9) has been smaller than ϵ ($\epsilon = 1 \times 10^{-5}$). The positions of particles represented by G_{best} are the optimal solution, and stop. Otherwise, then $pf = pf + 1$ and the procedure is repeated form Step 2.

4. NUMERICAL COMPUTATION EXPERIMENT

The multi-area environmental/economic dispatch problem using the proposed PSO algorithm has been developed by the use of Matlab version 7.0 tested with P4, 1.5 GHz platform.

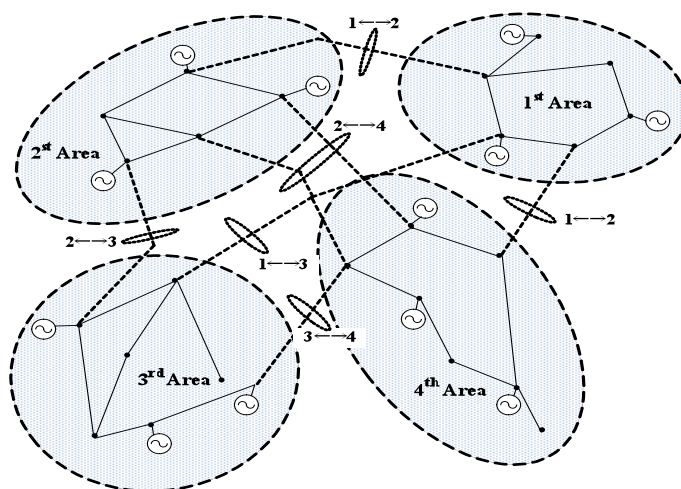


Figure 1. Test example of the representation of the multi-area environmental/economic dispatch

In this study, a four-area test problem interconnected by six tie lines (Figure 1). There are three generators in each area with different fuel, CO₂ emission and transmission loss characteristics, which coefficients are shown in Table 1, 2 and 3, respectively. Considering of the tie line capacity between power plants in multi-area systems is one of the important issues in problem analysis. The analysis is able to give a suitable index to site new power plants or to invest on transmission system in capacity constrained conditions. In this research a distributed electricity demand with more buses and lines is considered that has been divided in four areas, which have been connected together. A portion of the total load exists in each area; a portion of this area's load is generated in it and what is left in area's load demand is fed and supported by other areas where loss are given in Table 4. The power demand in the 1st~4th area are 500, 410, 580 and 600 MW, respectively.

Table 1. Test data of fuel cost for the environmental/economic dispatch in four areas

Area	Unit i	Plant Type	P_i^{Max} (MW)	P_i^{Min} (MW)	Coefficients of fuel cost function		
					a_i	b_i	c_i
1	1	Gas	35	210	0.03546	38.30553	1243.5311
	2	Coal	130	425	0.02111	36.32782	1658.5696
	3	Oil	125	315	0.01799	38.27041	1356.6592
2	1	Gas	35	110	0.15247	38.53973	756.7989
	2	Coal	10	350	0.02803	40.39655	449.9977
	3	Oil	125	215	0.14834	38.34001	558.5696
3	1	Gas	15	175	0.10587	46.15916	451.3251
	2	Coal	30	375	0.07505	43.83562	673.0267
	3	Oil	50	200	0.11934	50.63211	530.7199
4	1	Gas	15	230	0.10587	46.15916	851.3251
	2	Coal	50	450	0.13552	41.03782	1038.533
	3	Oil	30	260	0.08963	33.56211	1285.907

Table 2. Emission conversion factors for the test problem

Plant Type	NCV (kJ/kg or kJ/m ³)	EF (tCO ₂ /TJ)	OF	FSC (€/t or \$/m ³)	CF (tCO ₂ /€)
Gas	31736	56.1	0.995	157	0.02013
Coal	29308	98.3	0.99	0.23	0.008
Oil	41031	77.4	0.995	51.3	0.0556

Table 3. The B_{mm} matrix of the loss coefficients of all area

$$\begin{aligned}
 B_{mm}^{Area-1} &= \begin{bmatrix} 0.000071 & 0.00003 & 0.000025 \\ 0.00003 & 0.000069 & 0.000032 \\ 0.000025 & 0.000032 & 0.00008 \end{bmatrix} & B_{mm}^{Area-2} &= \begin{bmatrix} 0.000056 & 0.000045 & 0.000015 \\ 0.000023 & 0.000042 & 0.000047 \\ 0.000032 & 0.000023 & 0.000027 \end{bmatrix} \\
 B_{mm}^{Area-3} &= \begin{bmatrix} 0.00002 & 0.000028 & 0.000053 \\ 0.000086 & 0.000034 & 0.000016 \\ 0.000053 & 0.000016 & 0.000028 \end{bmatrix} & B_{mm}^{Area-4} &= \begin{bmatrix} 0.000074 & 0.00003 & 0.000025 \\ 0.000049 & 0.000069 & 0.000037 \\ 0.000022 & 0.000032 & 0.000083 \end{bmatrix}
 \end{aligned}$$

Table 4. The flow limits and the percentage of transfer loss on the tie lines

Area		Tie Line Capacity		Tie Line Transfer Loss
From	To	$t_{km,min}$	$t_{km,max}$	(ρ _{km})
1	2	5	60	13 %
1	3	5	50	19 %
1	4	5	60	14 %
2	1	5	60	11 %
2	3	5	60	12 %
2	4	5	50	20 %
3	1	5	50	21 %
3	2	5	60	14 %
3	4	5	60	13 %
4	1	5	60	16 %
4	2	5	50	22 %
4	3	5	60	11 %

From the computation results, it is evident that both fuel costs and emissions of the environmental/economic dispatch with inter-area aid dominate which superior to those of the separate areas without inter-area aid case. The minimum both fuel and emission costs obtained with and without inter-area aid are shown in Table 5 and Table 6, respectively. Thus, it is desirable to connect the multiple areas for achieving lower fuel costs and emissions while satisfying the power demands of different areas. Based on the above computation results, we can also find that except for area 3, other three areas are all capable of satisfying the allowable emission limit (e.g. $E_m^{limit} = 1000$ kg's) by themselves. Only the 3rd area needs emission controlled and economic dispatch sharing from other area in order to cover the additional power for emission limit satisfaction.

The environmental/economic dispatch problem will become more complicated when the impact of emissions controlled must be considered. So, this problem must addition to the emission constraint which shown in equation (17):

Table 5. Minimum fuel and emission costs without inter-area aid

Area	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_{Loss} (MW)	Fuel Cost (Rs/h)	Emission (kg/h)	h_m	Total Operation Cost (Rs/hr)
1	210	130	171.52	11.52	26039.3	631.28	25.55	42167.9
2	110	90.66	215	5.66	26395.2	662.63	26.85	44187.1
3	175	217.79	200	12.79	40982.3	1170.50	51.90	101732.9
4	230	134.45	253.53	17.98	44639.0	954.07	51.39	93666.0
Total				47.92	138055.8	3418.48		281753.9

Table 6. Minimum fuel and emission costs with inter-area aid

Area	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_{Loss} (MW)	Fuel Cost (Rs/h)	Emission (kg/h)	h_m	Total Operation Cost (Rs/hr)
1	160.9	163.3	289.4	13.23	30417.3	800.04	25.55	50858.2
2	109.6	117.1	184.4	5.58	25247.2	705.75	26.85	44196.6
3	171.5	197.5	198.3	13.10	39006.2	1080.36	51.90	95076.9
4	230.0	144.8	211.5	16.31	40875.8	899.99	51.39	87126.4
Total				48.22	136598.3	3713.93		277258.2

$$\sum_{i=1}^n CF_i \cdot FC(P_i) \leq E_{limit} \quad \dots \quad (17)$$

Table 7 illustrates the emission controlled for the test problem. From the results, we can see that when the area emission controlled limits requirements are considered, higher operation cost are inevitably caused for achieving economic dispatch. The tie-line transfers between areas with/without emission controlled are shown in Table 8.

From the aforementioned computation results, it is evident that both fuel costs and emissions of the environmental/economic dispatch with inter-area aid dominate those of the separate areas case. Thus, it is desirable to connect the multiple areas for achieving lower fuel costs and emissions while satisfying the power demands and allowable emission limits of different areas.

Table 7. The results of emission controlled for MEED problem in multi-area
(E_m^{limit} =1000 kg/hr for each area)

Area	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_{Loss} (MW)	Fuel Cost (Rs/h)	Emission (kg/h)	h_m	Total Operation Cost (Rs/hr)
1	145.5	206.1	193.6	13.23	27049.2	808.7	25.55	47711.6
2	109.0	126.9	208.5	5.58	28291.8	793.5	26.85	49597.8
3	174.9	192.4	165.6	13.10	35835.0	1000.0	51.9	87735.0
4	230.0	146.7	256.2	16.31	45651.3	1000.0	51.39	97041.3
Total				48.21	136827.4	3602.2		282085.7

Table 8. The tie-line transfer between areas with/without emission controlled
(E_m^{limit} =1000 kg/hr for each area)

Area		Without Emission Controlled	With Emission Controlled
From	To		
1	2	77.94	0
1	3	0	31.99
1	4	18.35	0
2	3	46.99	17.96
2	4	8.45	9.88
4	3	12.25	-21.93

5. CONCLUSIONS

The traditional ESI for economic dispatch has only one objective for minimizing fuel costs. With the increasing awareness of environmental protection in recent years, environmental/economic dispatch is proposed as an alternative to achieve simultaneously the minimization of fuel costs and pollutant emissions. At the same time, we further extend the concept of environmental/economic dispatch into the new concept termed multi-area environmental/economic dispatch is proposed by also minimizing the pollutant emissions in the emission controlled context. The application of the PSO algorithm to the multi-area environmental/economic dispatch problem is demonstrated in this paper. The test results for the multi-area environmental/economic dispatch to meet distributed demand and regional emission allowance, which bring out the new way of ESI. It achieved an optimal way with less impact on the global environment to improved operating efficiency and customer service. In the future work, the applications can be

considered to further increase the system security. Other issues such as emission quota trade, transmission costs, and buying and selling policies between areas can also be considered to reflect more realistic situations in ESI problems.

6. REFERENCES

- [1] C. Palanichamy and K. Srikrishna, "Economic Thermal Power Dispatch with Emission Constraint", *Journal of Institution of Engineers*, vol. 72, pp. 11-18, April 1991.
- [2] J.S. Dhillon, S. C. Parti and D. P. Kothari, "Stochastic Economic Emission Load Dispatch", *Electric Power Systems Research*, pp. 179-186, 1993.
- [3] J. H. Talaq, F. El-Hawary and M. E. El-Hawary, "A Summary of Environmental/Economic Dispatch Algorithms", *IEEE Transactions on Power Systems*, Vol. 9, No. 3, pp. 1508-1516, Aug. 1994.
- [4] A. Farag, S. Al-Baiyat, and T. C. Cheng, "Economic load dispatch multiobjective optimization procedures using linear programming techniques", *IEEE Trans. Power Syst.*, vol. 10, pp. 731-738, May 1995.
- [5] J. S. Dhillon, S. C. Parti, and D. P. Kothari, "Stochastic economic emission load dispatch", *Electric Power Syst. Res.*, vol. 26, pp. 186-197, 1993.
- [6] C. S. Chang, K. P. Wong, and B. Fan, "Security-Constrained multiobjective generation dispatch using bicriterion global optimization", *Proc. Inst. Elect. Eng.-Gen. Transm. Dist.*, vol. 142, no. 4, pp. 406-414, 1995.
- [7] M. A. Abido, "Environmental/economic power dispatch using multiobjective evolutionary algorithms". *IEEE Trans. on Power System*, vol.18, no.4, pp. 1529-1537, 2003.
- [8] M. Sudhakaran and S. M. Slochanal, "Application of Refined Genetic Algorithm to Combined Economic and Emission Dispatch", *Journal of the Institution of Engineer (EL)*, vol. 85, Sept. 2004.
- [9] T. Yalcinoz and H. Altun, "A new genetic algorithm with arithmetic crossover to economic and environmental economic dispatch", *Eng Int Syst* (2005) 3: 173-180 c 2005 CRL Publishing Ltd.
- [10] Z. L. Gaing, "Particle swarm optimization to solving the economic dispatch considering the generator constraints", *IEEE Trans. on Power System*, vol.18, no.3, pp. 1187-1195, Aug. 2003.
- [11] L. F. Wang, and C. Singh, "Multi-objective stochastic power dispatch through a modified particle swarm optimization algorithm", *Special Session on Applications of Swarm Intelligence to Power Systems, Proceedings of IEEE Swarm Intelligence Symposium*, 2006.
- [12] IPCC (2007, November 15), "Panel negotiates climate - synthesis report", *Nature*, No.450, pp. 327.
- [13] J.S. Dhillon, S. C. Parti and D. P. Kothari, "Fuzzy decision-making in stochastic multiobjective short-term hydrothermal scheduling", *IEE Proc.-Gener. Transm.Distrib.*, vol. 149, no. 2, pp. 191-200, March 2002.
- [14] J. Kennedy, R. C. Eberhart, "Swarm intelligence", San Francisco: Morgan Kaufmann Publisher, 2001.
- [15] J. Kennedy and R. C. Eberhart, "Particle swarm optimization", *Neural Networks, 1995. Proceedings., IEEE International Conference on*, vol. 4, pp. 1942-1948, 1995.
- [16] Y. M. Chen and Wen-Shiang Wang, "Fast solution technique for unit commitment by particle swarm optimisation and genetic algorithm", *Int. J. Energy Technology and Policy*, Vol. 5, No. 4, 2007.

BIOGRAPHICAL SKETCH



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