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Combined Economic Emission Dispatch for Wind: Thermal Generation Units

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Abstract: The main aim of Combined Economic and Emission Dispatch is to minimize both the operating fuel cost and emission level simultaneously while satisfying the operational constraints and load demand. An important criterion in power system operation is to meet the power demand at minimum fuel cost using an optimal mix of different power plants. The day ahead scheduling of generating units in the power system are feasible and consistent with the long term planning. This problem is a multi-objective optimization approach in which total electrical power generation costs and combustion emissions are simultaneously minimized over the scheduling time. To find the optimum emission dispatch, optimum fuel cost, best compromising emission and fuel cost, a stochastic approach of Particle Swarm Optimization (PSO) is used here. A stochastic optimization model for dynamic economic dispatch of wind-thermal power system is established to minimize the comprehensive operation expected cost. By using a price penalty factor approach the multi-objective CEED problem is changed to a single objective function. The effects of wind power on overall emission are also investigated here. The proposed model helps operator to make decisions on the quantity of power and reserve that must be put up for generation in each of the unit for the respective hour and also to schedule generators in order to minimize power generation costs with environmental considerations. The proposed approach can provide better solutions than other stochastic search algorithms in the literature. The scheduling can be extended with solar and storages. The IEEE 30 bus system has been taken for the simulation work of the proposed method with wind farms.

Keywords: Price Penalty Factor, Combined Economic and Emission Dispatch**,** Particle Swarm Optimization (PSO).

1. INTRODUCTION

Combined Economic and Emission Dispatch (CEED) for wind thermal power plants is a nonlinear mixed integer optimization problem to schedule the generating units and operate it by satisfying the demand and other equality and inequality constraints at minimum operating cost. CEED is the most significant optimization task in the power systems operation. Solving the CEED problem for large power systems is computationally expensive. The complexity of the CEED problems grows exponentially to the number of generating units.

Previously economic dispatch was mainly bothered but now a days as the air pollution is drastically increasing it is important to minimize the solution, but emission minimization alone is not good so in this we go for combined economic and emission dispatch along with the utilization of wind generation units to reduce the stress on thermal generating units.

Several solution strategies have been proposed to increase the potential savings of the power system operation by providing the quality solutions to the CEED problem. These include deterministic and stochastic search approaches. The priority list method, dynamic programming, lagrangian relaxation and the branch and bound methods are deterministic approaches. Although these methods are simple and fast, they suffer from numerical convergence and solution quality problems. The stochastic search algorithm scan able to overcome the shortcomings of traditional optimization techniques. Particle swarm optimization, genetic algorithms, evolutionary programming, simulated annealing, ant colony optimization and tabu search are some of the stochastic search algorithms.

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These methods can provide high quality solutions for complex nonlinear constraints problems. This drastically reduces the number of decision variables and hence can overcome the shortcomings of stochastic search algorithms for CEED problems. The conventional operation at minimum fuel cost can no longer be the only basis for dispatching electric power because of the strict governmental regulations on environmental protection. The total fuel cost minimization is done by economic dispatch and on the other hand the total emission of CO_2, SO_2, NO_X from the system violating the economic constraints can be minimized by emission dispatch. The combined economic and emission dispatch (CEED) finds a balance between cost and emission dispatch and hence it is an optimum point to operate the system with reduced cost and emission.

The stress on coal based thermal power plant in terms of consumption of coal reflects on environmental emissions reduced by electric generation by renewable resources in combination with coal based thermal power plant. Wind generation is clean and cheap in reducing the environmental emission, generation cost, greenhouse effect and global warming. In this regard wind power is rapidly becoming a generation technology of significance. This becomes the common problem for power system operation due to its limited predictability, uncertainty and variability [2].

Doubly Fed Induction Generator (DFIG) is the most commonly used wound rotor type generator for wind power generation. In DFIG, the stator winding is directly coupled with grid and bidirectional power converter feeding the rotor winding made up of two back to back IGBT based power electronic circuit linked by a DC bus i.e. symmetrical three phase variable voltage and frequency is fed to the rotor circuit. As coal and emission are directly related with the economy of system, it results in the reduction of generation cost and environmental emissions. Coal required for the generation of electrical energy depends on the quality of coal. Washed coal can be used to improve the quality of the coal which increases the calorific value and reduces the ash content.

2. PROBLEM FORMULATION

Economic Dispatch: The objective of the Economic Dispatch is to minimize the total system cost by adjusting the power output of each of the generators connected to the grid. The total system cost is modelled as the sum of the cost function of each generator.

$$F_T = \sum_{i=1}^{n} F_i(P_i) \tag{1}$$

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \tag{2}$$

Where

F_T : total generating cost;

$F_i(P_i)$ is cost function of generating unit;

a_i, b_i, c_i are cost coefficients of generator i,

P_i : power of generator i^{th} unit,

n : number of generator.

A. Emission Dispatch

The quantity of pollutant emission resulting from a fossil-fired thermal generating unit is based on the amount of power generated by every unit. For reducing the complexity, the total emission produced can be modelled as a direct sum of a quadratic function and an exponential term of the active power output of the generating units. The pollutant emission dispatch problem can be described as the optimization of total amount of pollutant emission given as below:

$$E_T = \sum_{i=1}^{n} E_i(P_i) \tag{3}$$

$$E_i(P_i) = d_i + e_iP_i + f_iP_i^2 \tag{4}$$

Where

E_T: total Emission;

$E_i(P_i)$ is Emission function of generating unit;

d_i, e_i, f_i are Emission coefficients of generator i,

B. Combined Economic and Emission Dispatch

The economic dispatch and emission dispatch are two various problems as discussed previously. Emission dispatch can be included in conventional economic load dispatch problems by merging an emission constraint with the economic load dispatch problem. The two objectives can be converted into a single objective function by introducing a price penalty factor as defined follows.

$$h = \frac{F_T(P_i^{\max})/P_i^{\max}}{E_T(P_j^{\max})/P_j^{\max}} \tag{5}$$

Where 'h' is the price penalty factor, 'i' is the highest fuel-cost unit; 'j' is the highest pollutant-emission unit.

The multi objective function to be minimized is given by

$$\text{Min } F = \sum_{i=1}^{n} (a_i + b_iP_i + c_iP_i^2) + h_i(d_i + e_iP_i + f_iP_i^2) \tag{6}$$

The minimization should be done subject to the constraints

C. Constraints

1. *Equality constraints*: The equality constraint is represented by the power balance constraint that reduces the power system to a basic principle of equilibrium between total system generation and total system loads. Equilibrium is only met when the total system generation equals the total system load (P_D) plus system losses (P_L).

$$\sum_{i=1}^{n} (P_i + P_w) - (P_D + P_L) = 0 \tag{7}$$

The exact value of the system losses can only be determined by means of a power flow solution. The most popular approach for finding an approximate value of the losses is by way of Kron's loss formula.

The Kron's formula is given by

$$P_L = B_{oo} + \sum_{i=1}^{n} B_{io}P_i + \sum_{i=1}^{n}\sum_{j=1}^{n} P_iB_{ij}P_j \tag{8}$$

2. *Inequality constraints*: Generating units have lower and upper production limits of power output of the unit. These bounds can be defined as a pair of inequality constraints, as follows:

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{9}$$

The generation output should be within the minimum and maximum limits of the generation constraints.

D. Wind Power Plant

Underestimation and overestimation of the available wind energy, which may happen as a result of WF's imperfect modelling, can impose additional costs on a private owner who participates in the electricity market. For this reason, it is necessary to model WF in a more detailed and accurate manner. In this study, a new WF cost function has been proposed in the ED formulation, which is composed of three sub-objective terms.

$$\mathrm{C} = \sum_{i=1}^{\mathrm{N}_{wf}} \mathrm{C}_{w,i}(w_i) + \sum_{i=1}^{\mathrm{N}_{wf}} \mathrm{C}_{p,w,i}(\mathrm{W}_{i,av} - w_i) + \sum_{i=1}^{\mathrm{N}_{wf}} \mathrm{C}_{r,w,i}(w_i - \mathrm{W}_{i,av}) \tag{10}$$

Where,

w_i = scheduled wind power for wind farm,

$\mathrm{W}_{i,\,av}$ = available wind power for wind farm,

$\mathrm{C}_{w,\,i}(\mathrm{W}_i)$ = cost function for wind farm,

$\mathrm{C}_{p,\,w,\,i}(\mathrm{W}_{i,\,av} - w_i)$ = penalty cost because of under estimation of wind power for wind farm,

$\mathrm{C}_{p,\,w,\,i}(w_i - \mathrm{W}_{i,\,av})$ = reserve cost because of over estimation of wind power for wind farm.

$$\mathrm{C}_w = d_i\mathrm{P}_w \tag{11}$$

For direct cost calculations, where the wind power plant is owned by the operator.

3. PARTICLE SWARM OPTIMIZATION TECHNIQUE FOR SOLVING CEED PROBLEM

Particle Swarm Optimization is a heuristic global optimization method put forward originally by Doctor Kennedy and Eberhart in 1995. It is developed from Swarm Intelligence and is based on the research of bird and fish flock movement behavior. While searching for food, the birds are either scattered or go together before they locate the place where they can find the food. While the birds are searching for food from one place to another, there is always a bird that can smell the food very well, that is, the bird is perceptible of the place where the food can be found, having the better food resource information. Because they are transmitting the information,especially the good information at any time while searching the food from one place to another, conducted by the good information, the birds will eventually flock to the place where food can be found. The most optimist solution can be worked out in particle swarm optimization algorithm by the cooperation of each individual. The particle without quality and volume serves as each individual, and the simple behavioral pattern is regulated for each particle to show the complexity of the whole particle swarm. This algorithm can be used to work out the complex optimist problems. Due to its many advantages including its simplicity and easy implementation, the algorithm can be used widely in the fields such as function optimization, model classification, machine study, neutral network training, signal procession, vague system control, automatic adaptation control and etc.

In the basic particle swarm optimization algorithm, particle swarm consists of "*n*" particles, and the position of each particle stands for the potential solution in D-dimensional space. The particles change its condition according to the following three principles:

1. To keep its inertia
2. To change the condition according to its most optimist position
3. To change the condition according to the swarm's most optimist position.

The position of each particle in the swarm is affected both by the most optimist position during its movement (individual experience) and the position of the most optimist particle in its surrounding (near experience). When the whole particle swarm is surrounding the particle, the most optimist position of the surrounding is equal to the one of the whole most optimist particle; this algorithm is called the whole PSO. If the narrow surrounding is used in the algorithm, this algorithm is called the partial PSO. Each particle can be shown by its current speed and position, the most optimist position of each individual and the most optimist position of the surrounding. In the partial PSO, the speed and position of each particle change according the following equality.

Velocity update rule is applied:

$$v_{id}^{k+1} = v_{id}^{k} + c_1 r_1^k (pbest_{id}^{k} - x_{id}^{k}) + c_2 r_2^k (gbest_{d}^{k} - x_{id}^{k}) \tag{12}$$

Next, the position update rule is applied:

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1}$$

4. ALGORITHM & FLOWCHART

Step 1: Randomly initialize the population individuals of all units other than the reference unit according to the limit of each unit. Many such population can be generated randomly for better sharing nature.

Step 2: To each individual population of the population array, employ B-coefficient loss formula to calculate the transmission losses P_L.

Step 3: The individuals of the reference unit is obtained from the equality constraint $P_1 = (P_D + P_L) - (P_T + P_W)$.

Step 4: Calculate the evaluation value of each population Pg using the evaluation equations. Calculate the price penalty factor.

Step 5: Compute the new evaluation function.

Step 6: Compare each population's evaluation value with its p best. The best evaluation value among the pbest is denoted as gbest.

Step 7: Modify the member velocity V of each individual Pg.

Step 8: Modify the velocity V of each particle

Step 9: Modify the member position of each individual Pg, If Pg violates the constraints then it must be set to the near margin of that particular unit.

Step 10: If the evaluation value of each population is better than the previous pbest the current value is set to be pbest. If the best pbest is better than the gbest the value is set to be gbest.

Step 11: If the number of iterations reaches the maximum then go to step 12, otherwise go to step 2.

Step 12: The individual that generates the latest gbest is the optimal generation power of each unit.

5. NUMERICAL SIMULATION

The above method is implemented in MATLAB on an Intel core i5 machine with 4 GB of RAM. The Simulation is run by considering a base six thermal units system and one wind unit (comprising of 25 wind turbines).

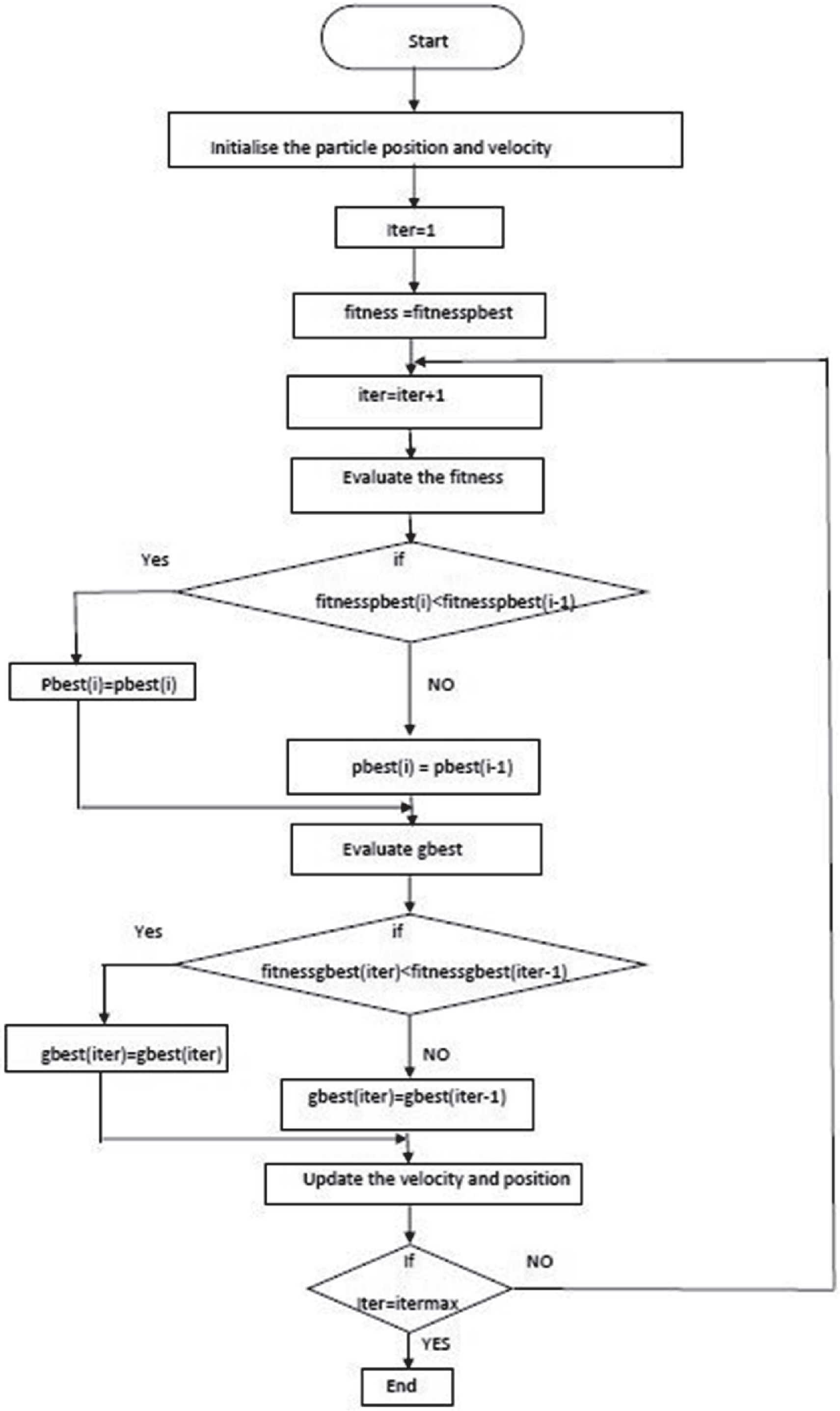

Figure 1: Flow chart for CEED using PSO

The following Figure 2 shows the convergence plot for different number of iterations using PSO technique. As the number of iterations are increasing the global best value almost becomes constant. At the beginning of the iterations the solution exists at afar end hence the velocity of the particles increases when they are nearer to the solution the velocity gets reduced. Hence the reduction in the change of position in Figure 3 shows the fuel cost curves for Economic load dispatch and CEED problem solution and we can clearly infer from the graph that there is a little amount of increase in the fuel cost because of the CEED. This is because of the fact that we have to decrease the emission in compromising the cost to an extent and hence the common point of the emission and fuel increases the fuel cost.

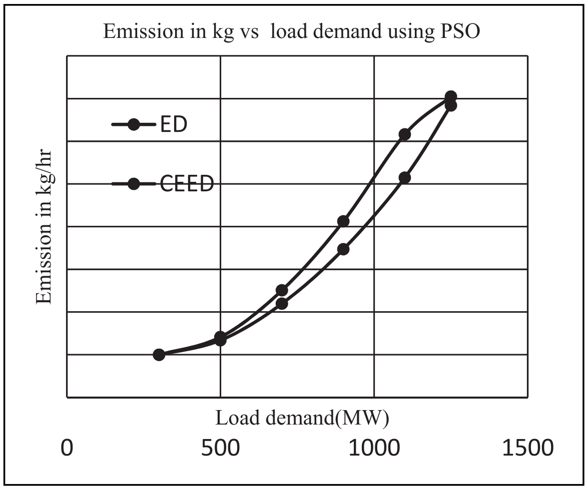

Figure 2: Minimised cost vs No. of iterations

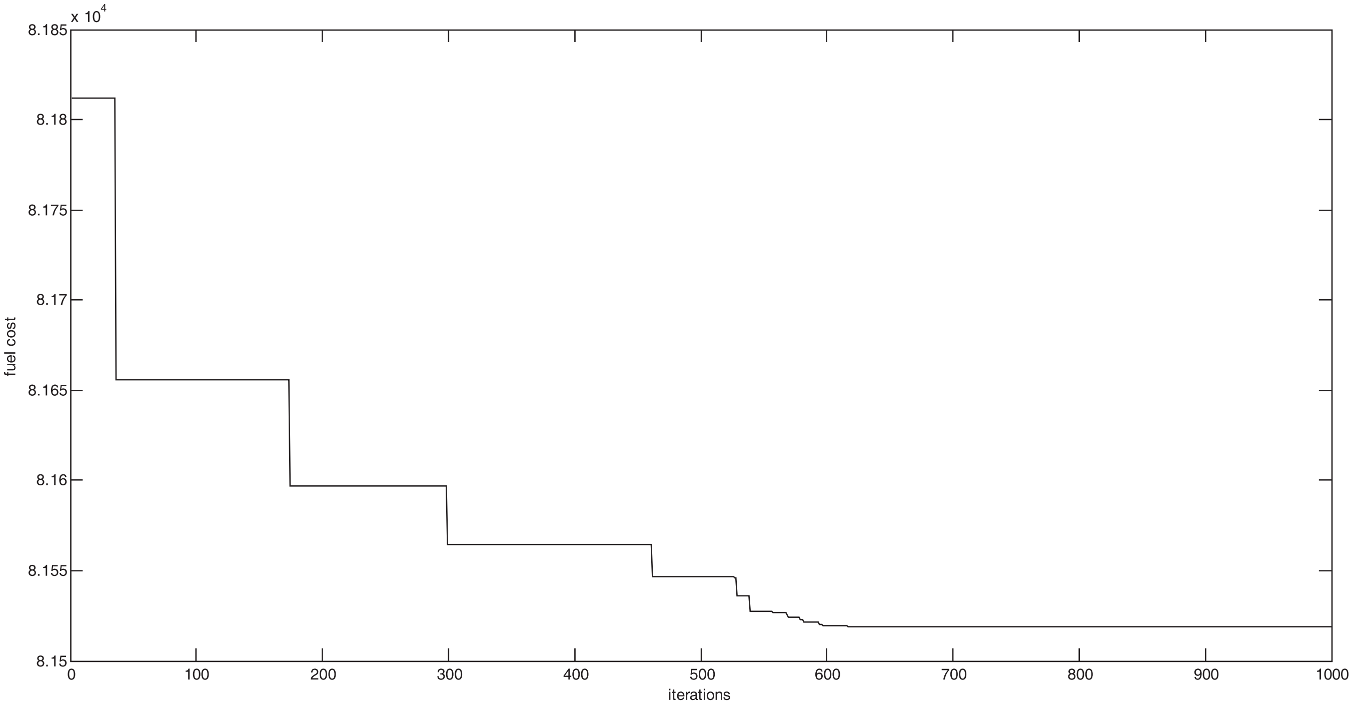

Figure 3: Fuel cost vs Load demand using PSO for ELD and CEED

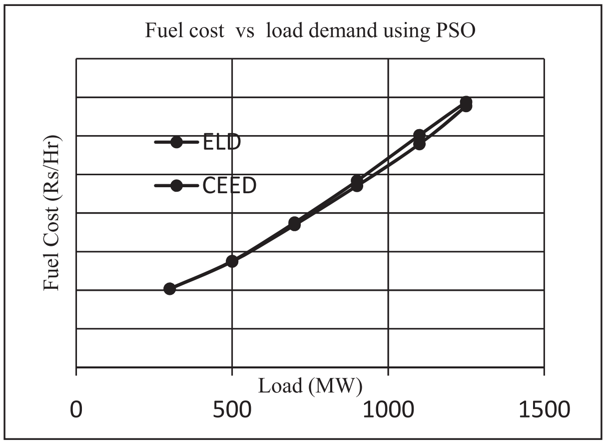

Figure 4: Emission in kg vs load demand using PSO for ELD and CEED

The Figure 4 gives the complete understanding of the difference between ELD and CEED as we can see that the emission (kg/hr) has decreased to an appreciable amount and the results obtained are in the generation limits.

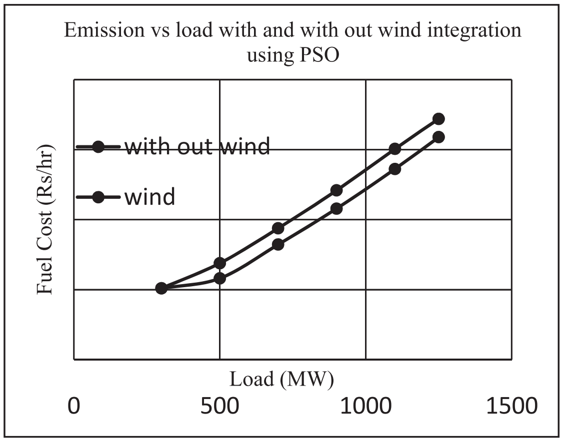

Figure 5: Emission in kg vs load demand using PSO for CEED

The Combined Economic Emission Dispatch solution is compared with and without integration of wind to estimate the level of savings and emissions. It is inferred that the obtained solutions for IEEE 30 bus system are within the acceptable limits and the solutions obtained can be used to reduce the emission pollutants from the thermal power plants.

Table 1
Generation limits and fuel cost coefficients for six unit generator system

S.No.	*a(Rs/MWH^2)*	*b(Rs/MWH)*	*c(Rs)*	*P_{min}*	*P_{max}*	*f(kg/MWH^2)*	*e(Kg/MWH)*	*d(kg)*
1	0.1524	38.5397	756.798	10	125	0.00419	0.3276	13.85932
2	0.1058	46.1591	451.325	10	150	0.00419	0.3276	13.85932
3	0.028	40.3965	1049.99	35	225	0.00683	–0.54551	40.2669
4	0.0354	38.3055	1243.53	35	210	0.00683	–0.54551	40.2669
5	0.0211	36.3278	1658.55	130	325	0.00461	–0.51116	42.89553
6	0.0179	38.2704	1356.65	125	315	0.00461	–0.51116	42.89553

Table 2
Wind Power Output from the Wind Farm

Hour	*Wind Speed (m/s)*	*Efficiency*	*Power developed (MW)*	*Hour*	*Wind Speed (m/s)*	*Efficiency*	*Power developed (MW)*
1	3.5	0	0	13	0.4	0.233	5.6054
2	3.6	0	0	14	8.4	0.190	5.622
3	1.5	0.223	0.1251	15	9.9	0.157	5.638
4	1.4	0.388	0.4252	16	10.1	0.131	5.6426
5	0.1	0.436	0.8257	17	9.7	0.110	5.6244
6	1.8	0.457	1.3743	18	9.2	0.094	5.6527
7	1.3	0.462	2.0738	19	9.6	0.080	5.611
8	2.2	0.450	2.8761	20	10	0.069	5.6024
9	3.8	0.425	3.7261	21	10	0.060	5.6012
10	3.7	0.388	4.5277	22	9.5	0.053	5.6536
11	2.0	0.340	5.1509	23	9.9	0.046	5.5751
12	0.6	0.284	5.4703	24	12.6	0.041	5.6165

Table 3
ELD solution for 6 unit system using PSO without wind integration

S.No.	*Load*	*P1 (MW)*	*P2 (MW)*	*P3 (MW)*	*P4 (MW)*	*P5 (MW)*	*P6 (MW)*	*PL (MW)*	*Fuel cost (Rs/Hr)*	*Emission (Kg/Hr)*
1	300	10	10	35	35	130	125	4.89798	20364.6	199.576
2	500	19.7194	10	71.1529	84.0893	174.844	150.083	9.89375	27439.4	282.696
3	700	28.583	10	116.289	120.186	231.499	212.901	19.462	36906.3	501.401
4	900	37.2607	19.6133	160.176	155.336	286.354	273.364	32.1103	47035.9	824.428
5	1100	48.9371	36.8888	218.759	202.337	325	315	46.9143	57858	1231.87
6	1250	107.262	123.831	225	210	325	315	56.0942	67720.9	1409.1

Table 4
ELD solution for 6 unit system using PSO with wind integration

S.No.	*Load*	P_W *(MW)*	*P1 (MW)*	*P2 (MW)*	*P3 (MW)*	*P4 (MW)*	*P5 (MW)*	*P6 (MW)*	*PL (MW)*	*Fuel cost (Rs/Hr)*	*Emission (Kg/Hr)*
1	300	94.02	10	10	35	35	130	125	4.89798	20364.6	199.576
2	500	94.02	15.381	10	48.9455	66.348	146.88	125	6.58325	23214.1	219.816
3	700	94.02	24.3872	10	94.962	103.12	204.75	183.3	14.5433	32374.3	384.198
4	900	94.02	33.217	13.640	139.762	138.98	260.86	245.31	25.7964	42192.8	660.48
5	1100	94.02	41.8779	26.439	183.405	173.96	315.29	305.12	40.1246	52673.7	1038.55
6	1250	94.02	67.1992	63.994	225	210	325	315	50.2239	61160.6	1299.99

Table 5
CEED solution for 6 unit system using PSO without wind integration

S.No.	*Load*	*P1 (MW)*	*P2 (MW)*	*P3 (MW)*	*P4 (MW)*	*P5 (MW)*	*P6 (MW)*	*PL (MW)*	*Fuel cost (Rs/Hr)*	*Emission (Kg/Hr)*
1	300	10	10	35	35	130	125	4.9	20365	199.576
2	500	38.85	10	95.59	96	144	125	9.14	27557	267.5
3	700	62.85	62.647	119.7	119	177	175.1	17	37518	439.119
4	900	92.33	98.388	150.2	149	220	218.2	28	48342	693.77
5	1100	121.6	137.77	183.1	174	265	259.7	41.9	60187	1029.22
6	1250	125	150	225	210	280	315	54.6	68772	1367.519

Table 6
CEED solution for 6 unit system using PSO with wind integration

S.No.	*Load*	P_W *(MW)*	*P1 (MW)*	*P2 (MW)*	*P3 (MW)*	*P4 (MW)*	*P5 (MW)*	*P6 (MW)*	*PL (MW)*	*Fuel cost (Rs/Hr)*	*Emission (Kg/Hr)*
1	300	94.02	10	10	35	35	130	125	4.9	20365	199.576
2	500	94.02	11.69	10	67.13	68.5	130	125	6.37	23232	210.587
3	700	94.02	53.77	51.556	111.2	111	166	125	12.5	32892	349.504
4	900	94.02	78.44	81.492	135.8	135	200	197.9	22.5	43136	564.096
5	1100	94.02	108	117.64	166.6	164	243	241.1	35	54467	861.609
6	1250	94.02	123.7	150	191.4	185	272	279.8	46.3	63549	1141.471

6. CONCLUSIONS

It is recognized that the optimal combined economic emission dispatch (CEED) of thermal systems results in reduction of cost and emission. CEED is the problem of determining the schedule of generating units subject to device and operating constraints. The formulation of Combined Economic Emission Dispatch (CEED) has been discussed and the solution is obtained by Particle Swarm Optimization method (PSO). The effectiveness of these algorithms has been tested on systems comprising three units and six units (both with and without wind) and compared for total fuel cost.

The price penalty factor for solving the CEED problem has been demonstrated on the IEEE 30 bus test system in order to obtain the exact total operating cost and emission. The better computation efficiency and convergence property of the proposed PSO approach shows that it can be applied to a wide range of optimization problems.

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