A Novel Combined Economic and Emission Dispatch Control by Hybrid Particle Swarm Optimization Technique

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Received: January 2010 Revised: March 2010 Accepted: May 2010

ABSTRACT:
The problem of Economic Dispatch (ED) in electric power systems is to schedule the power output for each committed generator unit such that the operating cost is minimized and simultaneously, the customer load demand is matched and the generator operating limits are met. Nowadays with increasing awareness of environmental pollution caused by burning of fossil fuels, emission of pollutants is also a criterion for economic dispatch of the plants. The environmental objective of generation dispatch is to minimize the total environmental cost or the total pollutant emission. This paper presents an efficient and simple approach for solving the emission constrained economic dispatch problem using the proposed Hybrid Particle Swarm Optimization Technique (HPSO). The convergence and usefulness of the proposed HPSO is demonstrated through its application to a test system. The computational results reveal that the proposed algorithm has an excellent convergence characteristic and has the potential to apply to other power system problems.

KEYWORDS: Economic Dispatch, Emission Constraints, Hybrid Particle Swarm Optimization.

1. INTRODUCTION

The electrical energy supply system faces its main problem with efficiency on the generator, transmission, and distribution system or combination of these three matters. Problem solving efforts are concentrated on minimizing

Operational cost of fuel consumption which has become the objective function and other requirements as the constraints [1]. Another problem faced by electricity nowadays is the pollution which comes from fuel consumption needs as its primary energy source. Diversification of various energy sources has been applied, for example, the use of coal as fuel in power plants [6].this had enabled us to produce electrical energy with relatively low cost , though the impact of pollution caused by burning coal should be monitored. The use of coal as a fuel can cause pollutants to pollute the air with Carbon diOxide (CO_2), Sulphur diOxide (SO_2) and oxides of Nitrogen (NO_X). These pollutants are able to cause acid rain that is responsible for damaging forest and plantation. It leads to greenhouse effect which causes global temperature rise on the surface of the earth and carries along other side effects. To anticipate the ECED problem, the PSO proposed algorithm contains two objective functions, i.e. economic objective function (fuel cost and transmission losses) and emission objective function.

In the past, many conventional techniques such as linear programming, dynamic programming and interior point methods often had problems of convergence and difficulties in locating the global optima. These methods rely on convexity to obtain the global optimum solution and they are forced to simplify relationships in order to ensure convexity. However, the ECED problem is in general non-convex, for example, during the valve-point loading effects of thermal generators, which results in many local minima. The advantages of PSO [7-11] are, generating high quality solutions within shorter calculation time and having more stable convergence characteristic compared to other stochastic methods like genetic algorithm, evolutionary programming, etc.

PSO based algorithms are increasingly applied for solving power system optimization problems in recent years [11-13]. Several researches led to solving the ED problem with various constrains using PSO [11-13]. The popularity of the proposed algorithm is due to their significant property of dealing with the optimization problems without any restrictions on the structure or type of the function to be optimized and due to the ease of computation. An amendment in the PSO technique is incorporated using the mutation operator of Genetic

Algorithm for obtaining a faster convergence. These improved techniques are pertinently termed as Hybrid Particle Swarm Optimization Technique (HPSO) [14].

2. FORMATION OF EMISSION CONSTRAINED ECONOMIC DISPATCH PROBLEM

The classical ECED problem is to find the optimum combination of generations to the available units to minimize the total cost of generation and emission level simultaneously, subject to the system constraints. The cost of generation *F (P)* can be expressed as

$$F(P) = \sum_{i=1}^{NG} (a_i P_i^2 + b_i P_i + c_i) \quad \$/h \tag{1}$$

Where

a_i, b_i, c_i Fuel cost coefficients of i^{th} unit.

P_i Active power generation of i^{th} unit.

NG Number of committed generating units.

The combustion of fuel used in fossil based generating units, gives rise to four basic forms (SO_x, NO_x, CO_2 and particulates) of pollutant. In the present work, the total pollution level *E(P)* is expressed as a single pollution criterion as follows

$$E(P) = \sum_{i=1}^{NG} a_i^e P_i^2 + b_i^e P_i + c_i^e \quad kg/h \tag{2}$$

Where

a_i^e, b_i^e, c_i^e Emission coefficients of i^{th} unit.

The fuel cost F_T for combined economic and emission dispatch can be represented as

$$\min F_T = \sum_{i=1}^{NG} (a_i P_i^2 + b_i P_i + c_i) + h \sum_{i=1}^{NG} a_i^e P_i^2 + b_i^e P_i + c_i^e \quad \$/h \tag{3}$$

The ECED problem (3) is subject to the following practical constraints:

(i) Power Balance Constraint (*PBC*) ,

$$\sum_{i=1}^{NG} P_i - P_D - P_L = 0 \tag{4}$$

where,

P_D Total load in the system.

P_L Transmission loss.

Transmission loss is expressed as

$$P_L = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_i B_{ij} P_j \tag{5}$$

Where

B Loss coefficient.

(ii) Generation active power limits,

$$P_{i,\min} \le P_i \le P_{i,\max} \tag{6}$$

Where

$P_{i,\min}$ Minimum power output of i^{th} unit.

$P_{i,\max}$ Maximum power output of i^{th} unit

To perform combined economic and emission dispatch, a single objective function is preferred. To do so, the emission costs are blended with the fuel costs by the use of a price penalty factor, *h* expressed in *$*/kg. And the step to calculate the price penalty factor (*h*) is as follows,

Practical way of determining, *h is* presented here by assuming a system load of $P_D{}'$ MW.

(i) Evaluate the average cost of each generator at its maximum output, that is

(ii)

$$F(P_{i,\max}) / P_{i,\max} = (a_i P_{i,\max}^2 + b_i P_{i,\max} + c_i) / P_{i,\max}$$

(ii) Evaluate average emission of each generator at its maximum output

$$E(P_{i,\max}) / P_{i,\max} = (a_i^e P_{i,\max}^2 + b_i^e P_{i,\max} + c_i^e) / P_{i,\max}$$

(iii) Divide average cost of each generator by its average emission gives the value of h_i

$$h_i = (F_i(P_{i,\max}) / P_{i,\max}) / (E_i(P_{i,\max}) / P_{i,\max})$$

(iv) Arrange h_i (*i* =1, 2, . . ., *NG*) in ascending order.

(v) Add the maximum capacity of each unit, ($P_{i\ max}$) one at a time, starting from the smallest h_i unit, until

$$\sum_{i=1}^{NG} P_{i\ \max} \ge P_D{}'$$

(vi) At this stage, h_i associated with the last unit in the process is the price penalty factor. However, the dispatch strategy has been made simpler and similar to economic dispatch by replacing the fuel cost coefficients in the economic dispatch algorithm by the

blended cost coefficients.
$a_i^b = a_i + h\, a_i^e$, $b_i^b = b_i + h\, b_i^e$, $c_i^b = c_i + h\, c_i^e$

where

a_i^b, b_i^b, c_i^b Blended cost coefficients.

After the replacement of the fuel cost coefficients by the blended cost coefficients, economic dispatch was performed, which gives the solution for combined economic and emission dispatch.

3. PARTICLE SWARM OPTIMIZATION BASED ECED

Like evolutionary algorithms, PSO technique conducts searching using a population of particles, corresponding to individuals. Each particle represents a candidate solution to the problem at hand. In a PSO system, particles change their positions by flying around in a multi-dimensional search space until a relatively unchanging position has been encountered, or until computational limitations are exceeded. Unlike GA and other heuristic algorithms, PSO has the flexibility to control the balance between the global and local exploration of the search space. This unique feature of PSO overcomes the premature convergence problem and enhances the search capability.

3.1. Particle Swarm Optimization

The PSO method was introduced in 1995 by Kennedy and Eberhart [7]. The method is motivated by social behavior of organisms such as fish schooling and bird flocking. PSO provides a population-based search procedure. Here individuals called as particles change their positions with time. These particles fly around experience, and the experience of neighboring particles. Thus each particle makes use of the best position encountered by itself and its neighbours. The direction of the particle is given by the set of particles neighbouring the particle and its past experience. Let x and v denote the particle position and its corresponding velocity in the search space. *pbest* is the best previous position of the particle and *gbest* is the best particle among all the particles in the group. The velocity and position for each element in the particle at *(t+1)*th iteration is calculated by using the following equations.

$$v_i^{t+1} = k * \begin{pmatrix} w * v_i^t + \varphi_1.rand\left(pbest - x_i^t\right) + \\ \varphi_2.rand\left(gbest - x_i^t\right) \end{pmatrix} \quad (7)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (8)$$

where x_i and v_i are the current position and velocity of the i^{th} particle, w is the inertia weight factor, φ_1 and φ_2 are acceleration constants, $rand()$ is the function that generates uniform random number in the range [0,1] , and k is the constriction factor introduced by Eberhart and Shi to avoid the swarm from premature convergence and to ensure stability of the system. Mathematically, k can be determined as follows

$$k = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|} \quad (9)$$

where $\varphi = \varphi_1 + \varphi_2$ and $\varphi > 4$.

The selection of w provides a balance between global and local explorations. In general, the inertia weight w is set as

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{t_{\max}} \times t \quad (10)$$

Where $t_{\max}$ is the maximum number of iterations or generations and $w_{\max}$ and $w_{\min}$ are the upper and lower limit of the inertia weight. The inertia weight balances global and local explorations and it decreases linearly from 0.9 to 0.4 in each run. The constants c_1 and c_2 pulls each particle toward *pbest* and *gbest* positions. $V_{\max}$ was set at 10 – 20 % of the dynamic range of variable on each dimension. The swarm evolves from iteration *t* to *t+1* by repeating the procedure as given below,

```
begin
  t -> 0                              // iteration number
      Initialize x(t)      //x(t): Swarm for iteration t
      Evaluate f_pi  //Fitness function
  While (not termination condition) do
begin
      t-> t+1
//process of PSO//
    Update velocity v_i and position of each particle x_i
    based on (7) and (8) respectively
            If  v_i > v_max
        v_i = v_max
End
            If  v_i <  v_max
        v_i = -v_max
End
  //end of the process of PSO//
      Reproduce new x(t)
      Evaluate f_pi        //fitness function
      End
```

3.2. Hybrid Particle Swarm Optimization

PSO performs well in the early iterations, but it usually presents problems reaching a near optimal solution. The behavior of the PSO in the model presents some important aspects related with the velocity update. If a particle's current position coincides with the global best position, the particle will only move away from this point if its inertia weigh (w) and velocity (v) are different from zero. If their velocities are very close to zero, then all the particles will stop moving once they catch up with the global best particle, which may lead to a premature convergence to the PSO. In fact, this does not even guarantee that the PSO has converged on a local minimum. It merely means that all the particles have converged to the best position discovered so far by the swarm. This phenomenon is known as stagnation. To prevent it, Ahmed et al have proposed to integrate the mutation of GAs into the PSO [14]. This approach allows the search to escape from local optima and search in different zones of the search space. It starts with the random choice of a particle in the swarm and moves to different positions inside the search area. Ahmed et al employed the mutation operation by the following equation:

$$mut\ (p[k]) = p\ ([k] \times -1) + \omega \qquad (11)$$

Where $p[k]$ is the random choice particle from the swarm, and ω is randomly generated value. The swarm evolves from iteration t to $t+1$ by repeating the procedure as given below,

begin
t-> 0 // iteration number
Initialize x(t) //x(t): Swarm for iteration t
Evaluate f_{pi} //Fitness function
While (not termination condition) do
begin
t-> t+1
Perform the process of PSO
Perform mutation operation
Reproduce a new x(t)
Evaluate f_{pi} // fitness function
end
end

3.3. Solution of ECED Problem Using PSO

Particle Swarm Optimization (PSO) is an effective stochastic optimization technique that has been successfully applied to a number of power engineering optimization problems. It has some advantages over Evolutionary Programming technique. The PSO technique comprises of Initialization of Population, Calculating the fitness function, swarming and updating the velocity and position by equation (7), (8) and reproducing new particle.

The various sequential steps for solving ECED problem are as follows:

(i) Initialization of parent population:- An initial parent population size N_p is generated randomly within the feasible range and the distributions of initial trial parents are uniform. The elements of each parent individuals are real power output of committed NG generating units.

$$I_{pi} = [P_1^{pi}, P_2^{pi}, ...P_{NG}^{pi}] \qquad (12)$$

Where

I_{pi} pi^{th} parent individual.

ii) The fitness function value f_{pi} of each parent individual is computed using equation (13).

$$f_{pi} = F_T^{pi} + k_1 \mid PBC^{pi} \mid + k_2 P_i^{\lim, pi} \qquad (13)$$

Where

f_{pi} Fitness function of pi^{th} parent individual.

$$P_i^{\lim, pi} = \begin{Bmatrix} P_{i,\min} - P_i^{pi}, if\ P_i^{pi} < P_{i,\min} \\ P_i^{pi} - P_{i,\max}, if\ P_i^{pi} > P_{i,\max} \\ 0 \qquad , \text{otherwise} \end{Bmatrix} \qquad (14)$$

The maximum fitness value is stored as f_{max}.

Where k_1 and k_2 are the penalty factors of constraints (4) and (5) violations respectively. The values of the penalty factors k_1 and k_2 are chosen such that if there is any constraint violation the fitness function value corresponding to that parent is ineffective. Then by updating the velocity and position of the parent individuals (real power output) by equation (7) and (8), a new parent individual is generated for the best fitness function.

4. SAMPLE SYSTEM STUDIES AND RESULTS

The proposed HPSO algorithm is tested on a 6-unit system [15]. Each generator has quadratic cost and emission functions. A total load of 900 MW is considered. The simulations were carried out on Pentium IV, 2.5 GHz processor. For the test system, the mutation scaling factor is taken as 0.25. The parameters used in the PSO approaches are as follows: $c_1 = c_2 = 2.05$, $w_{\max} = 2.0$ and $w_{\min} = 0.2$. In these case studies, the maximum number of iteration $t_{\max}$, is fixed at 25. The optimum swarm size N_p for the proposed models are 100. For each proposed models, 100 independent runs were made involving 100 different initial trial solutions. For combined economic and emission dispatch, blended cost coefficients are used.

The convergence characteristics of 6-bus test system with PSO and HPSO algorithm for combined economic and emission dispatches are shown in figure 1. The convergence characteristics are drawn by plotting the minimum fitness value from the global best across iteration index. From figure 1 it is observed that the fitness function value converges smoothly to the optimum value without any abrupt oscillations, thus ensuring convergence reliability of the proposed HPSO algorithm. It is also inferred that the HPSO has a faster convergence than PSO.

The optimum solution for combined economic and emission dispatch is given in Table 1. The results are compared against the results obtained from GA [8], EP [16] and PSO and they were in good agreement.

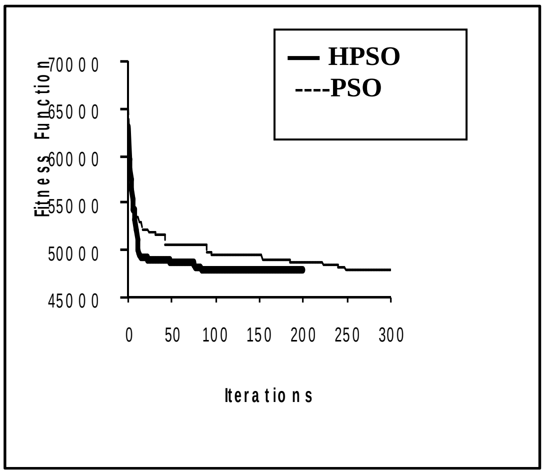

Fig. 1. Convergence characteristic of PSO and HPSO

Table 1. Optimum solution for combined economic and emission dispatch

Unit Generation (MW)	GA	EP	PSO	HPSO
P_1	68.53	68.53	68.53	68.34
P_2	89.74	89.74	89.74	89.62
P_3	147.71	147.71	147.71	146.68
P_4	178.56	178.56	178.56	180.19
P_5	245.62	245.62	245.62	245.55
P_6	206.85	206.85	206.85	206.63
Total Fuel cost ($/h)	47804.6	47804.6	47804.6	47804.5
Total emission NOx (kg/h)	844.44	844.44	844.44	843.48
Loss (MW)	37.01	37.01	37.01	37.01
No. of Iterations	280	250	200	105
CPU time (ms)	150	120	110	85

The optimum solution for economic dispatch and emission dispatch by using the proposed HPSO is given in Table II and Table III respectively. From Tables I, II and III it is interesting to note that the total fuel cost, total emission and transmission losses are in between the respective values of separate economic and emission dispatches. And also it is observed that HPSO takes less computational time than GA and EP, this shows the convergence efficiency of the proposed HPSO algorithm.

Table 2. Optimum solution for economic dispatch

Unit Generation MW	GA	EP	PSO	HPSO
P_1	55.32	55.38	55.32	55.38
P_2	52.84	52.45	52.84	52.45
P_3	203.85	206.23	203.85	206.23
P_4	146.67	146.38	146.67	146.38
P_5	291.55	290.62	291.55	290.62
P_6	185.35	184.39	185.35	184.39
Total Fuel cost ($/h)	47188.6	47188.3	47188.6	47188.3
Total emission NOx (kg/h)	857.89	857.77	857.89	857.77
Loss (MW)	35.58	35.45	35.58	35.45
No of Iterations	280	250	200	105
CPU time (ms)	150	120	110	85

Table 3. Optimum solution for emission dispatch

Unit Generation MW	GA	EP	PSO	HPSO
P_1	125.00	124.56	125.00	124.56
P_2	104.51	103.98	104.51	103.98
P_3	148.86	152.46	148.86	152.46
P_4	156.86	155.32	156.86	155.32
P_5	194.56	193.34	194.56	193.34
P_6	208.25	208.35	208.25	208.35
Total Fuel cost ($/h)	50217.7	50217.6	50217.7	50217.6
Total emission NOx (kg/h)	697.08	697.02	697.08	697.02
Loss (MW)	38.04	38.01	38.04	38.01
No. of iterations	280	250	200	105
CPU time (ms)	150	120	110	85

5. CONCLUSION

This paper presents a new method for solving the ECED problem. Economic and emission dispatch is a multi-objective problem. But the present approach makes use of only one objective function and depending upon the problem such as economic, emission or combined economic and emission dispatch, only the coefficients of the objective function has to be changed. For smooth and better convergence in PSO the mutation strategy is adapted, leading to HPSO technique. A sample system of 6-units has been tested and results are compared with those obtained from GA, EP, PSO and analytical methods. The results show that the proposed HPSO is computationally efficient approach for solving ECED problem.

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