Comparative study of the price penalty factors approaches for Bi-objective dispatch problem via PSO

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ABSTRACT

One of the main objectives of electricity dispatch centers is to schedule the operation of available generating units to meet the required load demand at minimum operating cost with minimum emission level caused by fossil-based power plants. Finding the right balance between the fuel cost and green gasemissions is referred as Combined Economic and Emission Dispatch (CEED) problem which is one of the important optimization problems related the operation modern power systems. The Particle Swarm Optimization algorithm (PSO) is a stochastic optimization technique which is inspired from the social learning of birds or fishes. It is exploited to solve CEED problem. This paper examines the impact of six penalty factors like “Min-Max”, “Max-Min”, “Min-Min”, “Max-Min”, “Average” and “Common” price penalty factors for solving CEED problem. The Price Penalty Factor for the CEED is the ratio of fuel cost to emission value. This bi-objective dispatch problem is investigated in the Real West Algeria power network consisting of 22 buses with 7 generators. Results prove capability of PSO in solving CEED problem with various penalty factors and it proves that Min-Max price penalty factor provides the best compromise solution in comparison to the other penalty factors.

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1. INTRODUCTION

Electric utility systems are interconnected to achieve high operating efficiency and to produce cheap electricity with minimum production cost, maximum reliability, and better operating conditions [1]. The optimal power flow problem (OPF) is an important tool in operation and control of large modern power systems, it was first discussed by Carpentier in 1962 [2], the main purpose of OPF is to find the optimal output power of generators to minimize the total generation cost and satisfy the equality and inequality constraints. Operating at absolute minimum cost can no longer be the only criterion for dispatching electric power due to increasing concern over the environmental issues. The generation of electricity from fossil fuel resources releases several contaminants, such as SOx, NOx and CO2 into the atmosphere [3]. In this paper the used term Economic Dispatch Problem (ED) is the short-term which refers to the determination of the optimal output of a number of electricity generation facilities.

The aim of every generating station is to produce electricity at the lowest possible fuel consumption and emission rates, but these two constraints cannot be met simultaneously. Nowadays, the demand for energy is increasing at a high pace, which makes it highly crucial to run generators at very minimal cost. This is the main goal of an Economic Dispatch Problem. With the exceptional production of carbon emissions by
thermal power plants [4], the environmental issues has become a big concern which has to be addressed to mitigate the effects of pollution and hence rectify problem of global warming. Therefore, production of electricity with an optimized cost at a lower green gas emissions acts as two vital parts of economic dispatch problem. Production at the minimum cost result in a relatively high amount of emissions. Similarly, ensuring minimum gas emissions limits the production of utilities running on fossil fuels. In order to find a right balance in the present tradeoff, this optimization problem can be modelled as a multi-objective function (Economic/Emission) which involves minimization of the cost function of producing electrical energy and minimization of the gas emission function, by satisfying the constraints of both functions.

In the modeling of the bi-objective economic dispatch problem, the present comparative study examines different types of the constraints and various types of price penalty factors. The following parameters are considered:

- Fuel cost and emission functions are modelled as second order polynomial function for both.
- The following types of price penalty factors are used for the multi-objective dispatch problem:
  - Min-Max price penalty factor
  - Max-Max price penalty factor
  - Min-Min price penalty factor
  - Max-Min price penalty factor
  - Average price penalty factor
  - Common price penalty factor

  Type of constraints to be satisfied are:
  - Load/supply balance
  - Minimum/maximum limits of the energy produced by the generators
  - Transmission line losses

In order to overcome the above illustrated drawbacks, heuristic methodologies have been under research for solving CEED problem. In the past the traditional methods used to solve this economic load dispatch problem are the Lambda iteration method, Gradient, Newton, linear programming and interior point method. Recently, meta-heuristic techniques such as Simulated Annealing, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Tabu search algorithm are used to solve this problem [5]. In this paper, the Particle Swarm Optimization based-approach is proposed to solve the CEED problem. In order to facilitate the search for the optimized solution, the price penalty factor is used to convert the bi-objective CEED problem into a single objective function. The proposed method has been examined and tested on a real grid in west Algeria which consists of a 22-bus system of 220 kV voltage level. Satisfactory simulation results show the effectiveness of the proposed algorithm.

2. MATHEMATICAAL FORMULATION OF CEED PROBLEM

The bi-objective function for CEED problem [6-12] is given as follows:

$$F_e = Min \sum_{i=1}^{nG} F_i(P_{G_i}) = Min \sum_{i=1}^{nG} (a_i P_{G_i}^2 + b_i P_{G_i} + c_i)$$

(1)

where $F_e$ is the total fuel cost of the system is, $n_G$ is the number of generators, $P_{G_i}$ is real power generation of a generator unit $i$, and $a_i, b_i$ and $c_i$ are the cost coefficients of the $i^{th}$ generating unit.

$$E_T = Min \sum_{i=1}^{nG} (a_i P_{G_i}^2 + \beta_i P_{G_i} + \gamma_i)$$

(2)

where, $E_T$ is total emission; $a_i, \beta_i, \gamma_i$ are emission coefficients of generating unit $i$ in [kg/MW\text{h}], [kg/MWh] and [kg/h] respectively. Price penalty factor $h_i$ is used to convert the bi-objective CEED optimization problem into a single objective [6-13] problem:

$$F_T = \sum_{i=1}^{nG} \left[ (a_i P_{G_i}^2 + b_i P_{G_i} + c_i) + h_i \left( (a_i P_{G_i}^2 + \beta_i P_{G_i} + \gamma_i) \right) \right]$$

(3)

where, $F_T$ is total CEED fuel cost; $h_i$ is price penalty factor.

3. PRICE PENALTY FACTORS (PPF)

The PPF [6, 11, 13-23] for CEED problem is formulated taking the ratio fuel cost and emission value of the corresponding generators as follows:
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- Min-Max price penalty factor is described as:

\[ h_i = \frac{a_i P_{Gi,\text{min}} + b_i P_{Gi,\text{min}} + c_i}{a_i P_{Gi,\text{max}} + b_i P_{Gi,\text{max}} + f_i} \]  

(4)

- Max-Max price penalty factor is described as:

\[ h_i = \frac{a_i P_{Gi,\text{max}} + b_i P_{Gi,\text{max}} + c_i}{a_i P_{Gi,\text{min}} + b_i P_{Gi,\text{min}} + f_i} \]  

(5)

- Min-Min price penalty factor is described as:

\[ h_i = \frac{a_i P_{Gi,\text{min}} + b_i P_{Gi,\text{min}} + c_i}{a_i P_{Gi,\text{max}} + b_i P_{Gi,\text{max}} + f_i} \]  

(6)

- Max-Min price penalty factor is described as:

\[ h_i = \frac{a_i P_{Gi,\text{max}} + b_i P_{Gi,\text{max}} + c_i}{a_i P_{Gi,\text{min}} + b_i P_{Gi,\text{min}} + f_i} \]  

(7)

- Average price penalty factor is formulated as:

\[ h_{\text{AVERAGE}} = \frac{\sum h_i}{4} \]  

(8)

- Common price penalty factor is formulated as:

\[ h_{\text{COMMON}} = \frac{h_{\text{AVERAGE}}}{4n} \]  

(9)

where: \( n \) is operational generating unit.

4. CONSTRAINTS

4.1. Power balance constraints [24]

Where, \( P_G \), \( P_{\text{Demand}} \) and \( P_{\text{Loss}} \) are the total generated power, load demand and transmission line loss of the system respectively. Transmission line loss constraint can be given as, [25]:

\[ P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \]  

(11)

4.2. Generator limits

The power output of each generator is restricted by minimum and maximum power limits, is given as:

\[ P_{Gi,\text{min}} \leq P_{Gi} \leq P_{Gi,\text{max}} \]  

(12)

5. PARTIAL SWARM OPTIMIZATION ALGORITHM

Particle swarm optimization PSO is a population-based optimization technique which was first introduced by Kennedy and Eberhart in 1995 [26], inspired by social behavior of bird flocking or fish schooling in search of food. The most important prominent features of PSO, compared to other existing heuristic optimization strategies such as genetic algorithm, are its easy implementation, there are few parameters to adjust and computation efficiency. In a PSO system, particles fly around in a multidimensional search space. During flight, each particle adjusts its trajectory towards its own previous best position this value is called \( P_{\text{best}} \), and towards the best previous position attained by any member of its neighborhood or

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globally, the whole swarm this value is called (Gbest) [27-32]. The two equations which are used in PSO are velocity update equation (13) and position update equations (14). These are to be modified at each time step, of PSO algorithm to converge the optimum solution.

\[ V_i(t+1) = \omega V_i(t) + c_1 r_1 [Pbest_i(t) - X_i(t)] + c_2 r_2 [Gbest(t) - X_i(t)] \]  \hspace{1cm} (13)

\[ X_i(t+1) = X_i(t) + V_i(t+1) \]  \hspace{1cm} (14)

Where, \(i\) is the particle index; \(\omega\) is the inertia coefficient; are acceleration coefficients \(0 \leq c_1 \cdot c_2 \leq 2\); \(r_1 \cdot r_2\) are random values, \(0 \leq r_1 \cdot r_2 \leq 1\) are regenerated every velocity \(c_1 \cdot c_2\) update; \(V_i\) is the particles velocity at time \(t\); \(X_i\) is the particles position at time \(t\); \(P_{best}\) is the particles individual best solution as of time \(t\); \(G_{best}\) is the swarms best solution as of time \(t\).

6. SIMULATION RESULTS AND ANALYSIS

The west algerian power network is a 22 bus system with 7 production units. This latter is considered in an attempt to solve the CEED problem using “Min-Max”, “Max-Max”, “Min-Min”, “Max-Min”, ”Average” and “Common” price penalty factors. The test system consists of 7 thermal units, 15 load buses and 31 transmission lines, 03compensator VARSTATIC SVC [3* (+40Mvar and 10Mvar)]. The total system demand is 856 MW. The data for the considering test system is shown in Table 1. The total power limits of the generators, fuel cost coefficients are also given in the Table 1. Programming of the CEED using the PSO method has been applied by using MATLAB software, tested on a CORE i5, personal computer with 2.20 GHz and 4 GO RAM. Table 2 show solution of CEED problem with different price penalty factors such as “Min-Max”, “Max-Max”, “Min-Min”, “Max-Min”, Average and Common. Table 3 compares the results obtained with all six penalty factors. As illustrated in Table 2 the results show an acceptable improvement in the fuel cost, and total fuel cost CEED of the system when using the Min-Max price penalty factor compared to other penalty factors. The emission value is less when using Max-Max price penalty factor in comparison with the other penalty factors. The Max-Min penalty price factor is better in terms of the lowest transmission loss compared to other penalty factors.

| Table 1. 22 bus system data |
|----------------------------|
| Generator Numbers | Generator limits [MW] | Fuel cost coefficients |
|                   | \(p_{min}\) [MW] | \(p_{max}\) [MW] | \(a_i\) [$/MW^2h$] | \(b_i\) [$/MWh$] | \(c_i\) [$/$] |
| 1                  | 100              | 500              | 0.007            | 7.5            | 200            |
| 2                  | 50               | 200              | 0.008            | 7              | 200            |
| 3                  | 80               | 300              | 0.0085           | 7.5            | 220            |
| 4                  | 50               | 150              | 0.009            | 7              | 200            |
| 5                  | 50               | 200              | 0.009            | 9              | 220            |
| 6                  | 50               | 120              | 0.0075           | 10             | 190            |
| 7                  | 10               | 80               | 0.009            | 6.3            | 180            |

| Table 2. Solution of CEED problem using PSO with various price penalty factors |
|-----------------------------|
| Price Penalty Factors | Data From SONELG AZ [30] | Min-Max | Max-Max | Min-Min | Max-Min | Average | Common |
| \(P_1\) [MW]             | 200                 | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 |
| \(P_2\) [MW]             | 200                 | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 |
| \(P_3\) [MW]             | 300                 | 188.3073 | 219.3888 | 224.8282 | 191.1794 | 257.3631 | 236.7597 |
| \(P_4\) [MW]             | 80                  | 130.3337 | 96.3901  | 138.6912 | 141.6869 | 56.5279  | 60.8637  |
| \(P_5\) [MW]             | 100                 | 124.7016 | 124.0204 | 65.8667  | 60.0516  | 135.4592 | 105.7322 |
| \(P_6\) [MW]             | 100                 | 88.4415  | 86.7610  | 63.0696  | 60.6996  | 73.1928  | 104.4470 |
| \(P_7\) [MW]             | 50                  | 19.5432  | 50.2276  | 27.0108  | 43.4642  | 73.6464  | 83.2097  |
| Power Loss [MW]           | 21.4                | 20.882   | 20.175   | 20.087   | 17.409   | 21.550   | 19.049   |
| Total output [MW]         | 990                 | 857.5555 | 863.4476 | 866.4007 | 856.3434 | 860.7412 | 877.0031 |
| Power demand [MW]         | 856                 | 856      | 856      | 856      | 856      | 856      | 856      |
| Generation cost[$/h]      | 9104.44             | 8892.0   | 8899.4   | 9089.8   | 8904.5   | 8999.5   | 9040     |
| Emission [Kg/h]           | *                   | 1096.1   | 1078.1   | 1228.9   | 1196.5   | 1101.4   | 1225.5   |
| Total cost[$/h]           | *                   | 10903    | 14406    | 18895    | 32386    | 40640    |
| Temps [S]                 | *                   | 0.095112 | 0.106198 | 0.080914 | 0.084423 | 0.096332 | 0.096956 |
Table 3. Comparison of simulation results obtained from “Min-Max”, “Max-Max”, “Min-Min”, “Max-Min”, “Average”, “Common” price penalty factors

| Criterion            | Min-Max price penalty factor | Max-Max price penalty factor | Min-Min price penalty factor | Max-Min price penalty factor | Average price penalty factor | Common price penalty factor |
|----------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| Power Loss [MW]      | 100%                         | 96.61%                       | 96.19%                       | 83.37%                       | 103.19%                      | 93.03%                       |
| Generation cost[$/h]| 100%                         | 100.10%                      | 102.22%                      | 100.14%                      | 100.19%                      | 100.23%                      |
| Emission [Kg/h]     | 100%                         | 98.36%                       | 112.12%                      | 109.16%                      | 100.48%                      | 103.52%                      |
| Total cost[$/h]     | 100%                         | 132.13%                      | 174.12%                      | 338.09%                      | 296.67%                      | 652.79%                      |

Figure 1 show clearly that the convergence profile obtained by PSO algorithm of functions such as CEED total cost, generation cost, emission cost and transmission loss when using Min-Max, Max-Max, Min-Min, Max-Min, average and common price penalty factors is faster and more effective, which proves that the proposed algorithm has more ability to find the optimal points in a search space compared with data provided by SONELGAZ, the company which is in charge of operating the above mentioned grid of west of Algeria [30].

From Figure 1(a), the variation of CEED fuel cost values of the bi-objective dispatch problem using Min-Max price penalty factor are the lowest compared to other penalty factors. Similarly, the variation of fuel cost values of the bi-objective dispatch problem using Min-Max price penalty factor are the lowest compared to other penalty factors, see Figure 1(b). Likewise, according to Figure 1(c) the variation of emission values of the bi-objective dispatch problem using Max-Max price penalty factor has minimum pollution control compared to other penalty factors. Finally, From Figure 1(d) the variation of power loss values of the bi-objective dispatch problem using Max-Min price penalty factor has lowest transmission power loss compared to other penalty factors.

![Figure 1](image1.png)

(a) CEED Total Cost (a) Generation Cost (b) Emission (c) Power Loss (d) Convergence curve for functions such as, (a) CEED (comparison of CEED total cost using various price penalty factors), (b) fuel cost (comparison of generation cost using various price penalty factors), (c) emission value (comparison of emission value using various price penalty factors), (d) power loss (comparison of power loss using various price penalty factors)
7. CONCLUSION

In this paper, the impact of price penalty factors on the solution of the bi-objective power system economic dispatch optimization problem is examined on electric grid of west Algeria which consists of 22-Bus system. The Particle Swarm Optimization algorithm is proposed for solving the combined economic emission dispatch problem. On the basis of results obtained some conclusions are made: the simulation results show that Min-Max price penalty factor yields a minimum generation cost for bi-objective power dispatch problem. The results show that the minimum emission values are less in Max-Max price penalty factor compared to other penalty factors. The Max-Min price penalty factor is better in terms of the lowest transmission loss compared to other penalty factors.

In Summary, it has been shown that the minimum overall cost for the bi-objective power system dispatch optimization problem can be obtained using Min-Max Price penalty factor. From Table 2 the CEED fuel cost values are significantly lower with Min-Max price penalty factor by 32.13% in comparison to the solution using Max-Max price penalty factor. The results also show that the emission values are less in Max-Max price penalty factor by 1.68% when compared to Min-Max price penalty factor.

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