Application of Particle Swarm Optimisation in solving Emission Constrained Economic Dispatch

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Abstract. Production of electricity has long been equated with emission of hazardous greenhouse gases and pollutants. One of the ways to reduce this negative impact is via emission constrained economic dispatch (ECED). The ECED is aimed to simultaneously minimize the total cost of generation and the total emission level. In order to overcome the limitations of the widely-used conventional method (CM) such as lack of flexibility and accuracy and the probability of achieving only local minima, meta-heuristic optimisers are gaining popularity. The paper presents the formulation of the ECED problem and proposes the use of Particle Swarm Optimizer (PSO) as a better alternative to the CM. The effectiveness of using PSO to solve the ECED problem as compared to CM is demonstrated and discussed.

1. Introduction
Economic dispatch is a method used to allocate loads to plants or generator units in order to operate for minimum cost while meeting power demand and various operational constraints. Normally, each generator units are arranged in a way that lowest cost generators will be used as much as possible while the generators with higher operating cost comes into production only when the demand increases and the generators with lower generation cost is not capable to handle the power generation. However, the conventional economic dispatch problem does not take into consideration the issue of thermal power stations using coal, oil and gas producing large amounts of greenhouse gases (GHG) and pollutants; altering the global climate and affecting health of living things in the process. At the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties – 15 (COP-15) in Copenhagen in 2009, Malaysia has voluntarily pledged to reduce the country’s emission intensity of GDP up to 40% by the year 2020 as compared to 2005 levels. Achieving this target is certainly a challenge that requires cooperation and commitment from everyone, including the public and private sectors, and the general public.

In order to reduce GHGs emission, [3] suggested a full range of options available to control emissions which are emission constrained in system operation, fuel switching, switching to lower sulphur coal, energy conservation that lowers SO₂ and NOx emission, purchase or sale of emission allowance, and installing power plant emission control technologies such as cleaning equipments [3]. Those options that require installation of new equipment or modification of the existing systems may involve considerable capital outlay and, hence, they are considered as long-term options. Among all those methods, emission constrained economic dispatch (ECED) is one of the most attractive and

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effective short-term options due to it not only control GHGs emission but also help in minimizing fuel cost at the same times.

Conventionally, the economic dispatch (ED) problem is solved by using Lagrange-iteration method with Lagrange multiplier. Reference [4] has shown the incorporation of emission constraint into the fitness function of the economic dispatch problem using this method. The modified objective function is then solved by using Dynamic Programming Based Hydrothermal Coordination program. The simulated result shows that only a slight increase in production cost can cause a large decrease in emission level.

However, this technique may not yield an optimal solution [5]. Besides, the linearization, assumptions and approximations that are used to limit the complexity of the economic dispatch problems causes the solution to be inaccurate [6] and the loss of accuracy by these approximations is not desired. In reality, unit incremental heat rate curves do not exhibit the monotonically increasing shape required by the classical method [7]. The application of intelligent optimizers as well as evolutionary computational techniques is suggested to be used to solve the problems.

This paper demonstrated the use of Particle Swarm Optimization (PSO) to solve the emission constrained economic dispatch (ECED) as compared the solutions of Conventional Method (CM). The method is expected to achieve more accurate results as they are non-gradient dependence. Thus, unlike conventional mathematical methods, they present a higher chance to escape local optima.

2. Formulation of the Emission Constraint Economic Dispatch Problem

2.1 Objective Function

Emission constrained economic dispatch (ECED) problem involves the simultaneous optimization of fuel cost and emission objectives which are conflicting with each other.

i. Fuel Cost

$$\min FC(P_i) = \min \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i$$

where

- $FC(P_i)$ = fuel cost of power generation by unit $i$
- $a_i, b_i, c_i$ = fuel cost coefficient of unit $i$
- $P_i$ = power generation of unit $i$

ii. Emission Cost

$$\min EC(P_i) = \min \sum_{i=1}^{n} d_i P_i^2 + e_i P_i + f_i$$

where

- $EC(P_i)$ = emission cost of power generation by unit $i$
- $d_i, e_i, f_i$ = emission coefficient of unit $i$

The two separate objective functions are combined into a single-objective function to be solved simultaneously by introducing a penalty factor to obtain the solution that gives the minimum total cost.

$$\min TC(P_i) = \sum_{i=1}^{n} FC(P_i) + h_i \left( EC(P_i) \right)$$

$$h_i = \frac{a_i P_{i\text{max}}^2 + b_i P_{i\text{max}} + c_i}{d_i P_{i\text{max}}^2 + e_i P_{i\text{max}} + f_i}$$
where

\[ TC(P_i) = \text{total cost of power generation by unit } i \]
\[ h_i = \text{penalty factor of unit } i \]
\[ P_{i\text{max}} = \text{maximum power generation by unit } i \]

2.2 Constraints

i. Power Balance Constraint

\[ \sum_{i=1}^{n} P_i = P_D \]  

(5)

where \( P_D \) = Power demand

ii. Generator Capacity Constraint

\[ P_{i\text{min}} \leq P_i \leq P_{i\text{max}} \]  

(6)

where

\( P_{i\text{min}} \) = minimum power generation allowed for unit \( i \)
\( P_{i\text{max}} \) = maximum power generation allowed for unit \( i \)

The problem is solved by using CM and PSO. The PSO algorithm used may be referred to [8].

3. Results and Discussions

In order to determine and compare the effectiveness and accuracy between the solutions of CM and PSO, a test system with a six generator units has been selected. The fuel cost coefficients \( (a_i, b_i, c_i) \), the emission coefficient \( (d_i, e_i, f_i) \), as well as the generator minimum and maximum capacity limit \( (P_{i\text{min}}, P_{i\text{max}}) \) are given in [8]. Although it is shown in Figure 1 that the total fuel cost for the solutions without emission constraint is slightly lower than the solutions with emission constraint, Figure 2 shows that the ECED formulation has significantly reduced the emission levels of the economic dispatch. These show the effectiveness of the algorithms in achieving its objective. The total generation cost and total emission level generated by the PSO as compared to the CM are presented in Table 1 and Table 2.

![Figure 1. Total fuel cost by PSO](image1)

![Figure 2. Total emission level by PSO](image2)
### Table 1. Total generation costs

| Power MW | Total Fuel Cost (FC), ($/hr) | CM       | PSO      |
|----------|-------------------------------|----------|----------|
| 500      | 27092.5                       | 27092.5  | 27091.8  |
| 600      | 31628.7                       | 31627.7  | 31628.7  |
| 700      | 36313.9                       | 36312.7  | 36313.9  |
| 800      | 41148.3                       | 41146.9  | 41148.3  |
| 900      | 46131.8                       | 46130.1  | 46131.8  |
| 1000     | 51264.5                       | 51262.5  | 51264.5  |
| 1100     | 56546.2                       | 56543.9  | 56546.2  |

### Table 2. Total emission levels

| Power MW | Total Emission Level (E), (kg/hr) | CM       | PSO      |
|----------|-----------------------------------|----------|----------|
| 500      | 261.634                           | 261.196  | 261.634  |
| 600      | 338.992                           | 338.098  | 338.992  |
| 700      | 434.38                            | 433.563  | 434.38   |
| 800      | 547.796                           | 546.748  | 547.796  |
| 900      | 679.24                            | 677.933  | 679.24   |
| 1000     | 828.72                            | 827.119  | 828.72   |
| 1100     | 996.224                           | 994.306  | 996.224  |

From the objective function of the ECED (refer equation 3), the emission and fuel costs of each generator are summed up during the evaluation of optimal solution. From Table 1, it is observed that the total generation costs achieved by using PSO are always lower than the CM. Similarly, PSO gives lower total emission level. Hence, it is proven that the PSO is more accurate and effective in solving emission constraint economic dispatch problems.

### 4. Conclusions

Emission constrained economic dispatch is an effective way to not only minimize generation cost, but also to reduce emission level of GHG. This paper has also shown that the PSO is a better technique to achieve optimal solutions compared to the conventional method employing Lagrange Multiplier. Further improvement can be done by specifying the types of GHGs when solving the problems so that the emission of certain type of GHGs which is considered to be more harmful may be specifically decreased to reduce the damage to our environment. Furthermore, consideration of extra constraints such as transmission losses, power flow and valve-point loading effect may also be considered. By taking into account more factors that can cause the increase of generation cost, more accurate solutions which provide system operator optimal decision making may be achieved.

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