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# Solving Combined Economic Emission Dispatch With Valve Point Loading Problem Using Firefly Algorithm

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## Abstract

Combined economic emission dispatch (CEED) is the generation side control and operation problem of a power system. Power system firm has to supply electric energy to its consumer in a reliable manner, in good quality and at economical price. At same time the firm has to control its emission level as low as possible for the green environment. Most of the electric power generation is by thermal power plant and its fuel is coal. This coal produces harmful gas emission such as Sulphur oxides, Nitrogen oxides, Carbon oxides and other fumes. Reduction of this emission may increase the cost of electric power generation. CEED optimization problem finds best compromise between reduction of generating cost and reduction of emission. Conventional mathematical optimization methods may settle local optimal point. Intelligent algorithms may escape from these local optimal points and discover global optimal points. Firefly intelligent algorithm is one of the latest and mimic nature fireflies social behavior. In this paper firefly intelligent algorithm is used to solve CEED. To estimate generation cost valve point loading effect is consider for more practical application. Standard IEEE 30 bus system is considered to evaluate the firefly algorithm.

**Keywords:** Economic dispatch, Emission dispatch, Valve point, Optimization, Firefly algorithm.

## Introduction

CEED is two objective problems, one is to minimize generating cost and another one is to minimize emission. These two objectives are opposite to one another, minimizing generating cost may lead to increase emission and vice versa. This two objective problem may convert into single objective problem using price penalty factor [1]. Load demand of the power system has to meet out by the committed generators at the same time generating cost has to be optimized is one objective.

Instead installing additional equipment for air purification or to change to low emission fuel, reschedule of generating pattern may reduce emission [2]. Solving two objective CEED, after converted into single objective may solved by conventional mathematical methods like linear programming (LP) but this approach may lead to inferior solution [3]. Intelligent techniques such as nature inspired techniques and parallel search techniques may lead to global optimal and pareto-optimal solutions. The following intelligent techniques are used to solve economic and emission dispatch problems in the literatures, Evolutionary Programming (EP) [1], Multi-Objective Evolutionary Algorithms (MOEA) [2]-[3], Particle Swarm Optimization (PSO) [4]-[6], [15], Genetic Algorithm (GA) [7], Differential Evolution (DE) [9]-[11], Semi-Definite Programming (SDP) [13], and Artificial Bee Colony (ABC) algorithms [14]. Probabilistic search based EP is population based intelligent technique. The three main operators of EP are initialization, mutation and crossover. It gives importance for mutation and finds better solution iteration by iteration. Main operators in EA are initialization, External set update, Fitness assignment, Selection, mutation and crossover. Biologically inspired PSO algorithm uses particles [12]. Every particle has its own position and velocity which is bounded in solution space. Among the particle global best fit particle and their won best fit of a particle is used to update velocity of all particles and finally lead to the global best solution. DE use vectors for finding global and pareto-optimal solutions. The operators used in DE are initialization, mutation, crossover and selection. The inherent property of DE is minimization of objective and suitable for all minimization problems [18]. After optimization of objective function the power quality has to be preserved for the proper operation all equipments [8]. This power quality is maintained by meeting the inequality constraints $Q_G$ of the problem [16]. In this paper another new nature inspired intelligent algorithm firefly algorithm (FA) is used to solve CEED problem. For more practical application quadratic cost function with valve point loading effect is considered.

## Firefly Algorithm

Firefly algorithm (FA) mimics firefly's intelligent technique to find optimal solution for engineering problems. For optimization flashing light is formulated based on objective function. Brightest firefly is the most optimal solution for the problem under consideration. A firefly is set of control variables of the problem considered [17]. Brightness of the firefly is calculated by evaluating the objective function to be optimized. This algorithm may used for maximization or minimization problem. FA has idealization as compared to natural firefly, they are

*A.* Firefly attracted by another firefly irrespective of sex

*B.* Firefly moves towards brightest if no brighter one then firefly moves randomly in solution space

*C.* Brightness of firefly is affected by atmospheric condition

General form FA optimization is a maximization of objective function subjected to constraints. FA moves fireflies towards global optimal solution spot through iteration by iteration. A firefly is a set of control variable and its light intensity is objective function or fitness value of the firefly. The process of FA are create or initialize fireflies, find brightness of firefly, move each firefly towards brightest one, find global brightest to give optimal solution. General form of FA optimization is maximize objective function, subjected to equality and inequality constraints as given below,

$$\text{Max. } f(x) \tag{1}$$

Subject to:

$$g(x) = 0 \tag{2}$$

$$X_{min} \leq X \leq X_{max} \tag{3}$$

Where,

$f(x)$ is objective function to maximize
$g(x)$ is equality constraint
X is a set of control variables
$X_{min}$, $X_{max}$ are minimum and maximum limits of control variables

**Encoding**

Encoding is the process of converting set of control variables into firefly for optimization. Ability of FA is to operate on floating point and mixed integer makes ease of encoding. Final iteration of FA gives global bright firefly which is the optimal solution. For the evolution and better convergence fitness function is most important as follows.

**Fitness Function**

An appropriate fitness function (brightness) is vital for evolution and convergence of FA as given in equation (1). It evaluates brightness for each firefly in the population. Objective function value for a firefly is called brightness of the firefly. FA makes a firefly to move towards brighter firefly in the population. Distance moved and brightness of each firefly is calculated and best firefly (global best) is calculated in the iteration. Improvement in solution is achieved iteration by iteration and final iteration provides global best optimal solution. The boundaries of solution space are formed by equality and inequality constraints given by equations (2) and (3).

**Attractiveness**

Firefly moves towards more attractive firefly. This attractiveness of considered firefly with others is calculated using the function. This attractiveness is decreases with increase in distance between fireflies. Main reasons for reduction in attractiveness are absorption factors in nature are implemented by using absorption coefficient. This function is monotonically decreasing function given below the equation (4).

$$\beta = \beta_0 \exp(-\gamma\, r^2) \tag{4}$$

where,

$\beta$ is attractiveness of a firefly
$\beta_0$ is initial attractiveness
$\gamma$ is absorption coefficient

r is distance between fireflies

**Distance**

Distance between fireflies i and j is calculated using Cartesian distance as given below the equation (5).

$$r_{ij} = \| x_i - x_j \| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \quad (5)$$

In 2-dimensional solution space the distance between i and j fireflies may calculated as follows the equation (6).

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (6)$$

**Movement**

Movement of $i^{th}$ firefly towards $j^{th}$ brighter firefly is based attractiveness and distance between them as given in equation (7).

$$x_i^{k+1} = x_i^k + \beta_0 * \exp(-\gamma\, r^2) * (x_j^k - x_i^k) + \alpha * \varepsilon_i^k \quad (7)$$

Where the right side first term is initial position of $i^{th}$ firefly, second term gives attractiveness towards $j^{th}$ firefly and third term introduce random movement in $i^{th}$ firefly. Initial attractiveness $\beta_0$ is taken as 1.0; absorption coefficient $\gamma$ is taken as 0.9. Randomising coefficient $\alpha$ rang in between 0 and 1, in this work it is taken as 0.2; $\varepsilon_i$ is randomization vector ranges from 0 to 0.5.

**Stopping criterion**

Fireflies moves randomly and try to attract towards brighter firefly. FA improves problems' solution iteration by iteration and the iteration has to be stopped either the problem is converged or iteration reached its maximum value. Stopping of iteration is important to provide solution for time complexity. In this research work maximum number of iterations is considered as stopping criterion.

## Ceed Problem Formulation

CEED has two objectives of generation cost and emission. Generating cost for each generator is a quadratic function and includes valve point effect [15] as given below in equation (8).

$$F(P_G) = C_t = \sum_{i=1}^{ng} \alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2 + \left|\zeta_i \sin\left[\lambda_i \left(P_{Gi}^{min} - P_{Gi}\right)\right]\right| \quad (8)$$

Gaseous emission of the committed plant is the quadratic function of real power and it is given as below in equation (9)

$$E(P_G) = \sum_{i=1}^{ng} 10^{-2} (a_i + b_i P_{Gi} + c_i P_{Gi}^2) + d_i \exp(e_i P_{Gi}) \quad (9)$$

These minimization objectives are stated as below in the equation (10).

*Objective Function*

$$\text{Min. } \{F(P_G), E(P_G)\} \quad (10)$$

*Subject To*
*Equality constraints*

$$\sum_{i=1}^{ng} P_{Gi} = P_D + P_L \quad (11)$$

$$\sum_{i=1}^{ng} Q_{Gi} = Q_D + Q_L \quad (12)$$

Equation (11) and (12) are real and reactive power balance equations.

*Inequality constraints*
Limits on control and dependent variables form inequality constraints. Limits of voltage on all buses given in equation (13). Real and reactive power generation limits given in equation (14) and (15).

$$V_{i(min)} \le V_i \le V_{i(max)} \quad \text{for i=1 to Nbus} \quad (13)$$

$$P_{Gi(\min)} \le P_{Gi} \le P_{Gi(\max)} \quad \text{for i=1 to ng} \quad (14)$$

$$Q_{Gi(\min)} \le Q_{Gi} \le Q_{Gi(\max)} \quad \text{for i=1 to ng} \quad (15)$$

*Where,*
$C_t$ = Total generation cost in $/hour
$E(P_G)$ = Total emission in ton/hour
$F(P_G)$ = CEED cost in $/hour
$\alpha, \beta, \gamma, \zeta, \lambda$ = Cost coefficients
a, b, c, d, e = Emission coefficients
$P_{Gi}$, $Q_{Gi}$ = Active and Reactive power of $i^{th}$ generator
$P_D$, $Q_D$ = Active and Reactive demand
$P_L$, $Q_L$ = Active and Reactive loss
$V_i$ = Voltage at $i^{th}$ bus
Nbus = Number of buses
ng = Number of generators

## Firefly Algorithm For Solving CEED

Control variables $P_G$ (real power generation), $V_G$ (generator bus voltage), and T (transformer tap position) are forms a firefly. In this paper IEEE 30 bus is considered, it has 6 generators including slack generator and 4 transformers. Hence in this algorithm implementation *encoding:* 5-$P_G$, 6-$V_G$, and 4-T control variables are taken as one firefly. Population of 20 such fireflies are considered in this work. *Fitness Function:* light intensity of the firefly is the fitness of the firefly. In CEED fitness functions are generating cost and emission. CEED problem is a minimization problem whereas FA is maximization algorithm. To convert the maximization into minimization algorithm, the objective values of CEED is subtracted from very big positive number to find light intensity of the firefly. *Attractiveness:* individual firefly search brighter firefly and calculate the attractive force between them using the equation (4). This attractiveness is depends on distance among the fireflies and absorption coefficient. *Distance:* distance between two attracted fireflies is calculated using the equation (5). *Movement:* after calculating attractiveness firefly moves towards brighter firefly using equation (7). This process updates control variable values & drives towards global value. *Stopping criterion:* maximum number of 200 iterations is taken as stopping criterion. The cost and emission co-efficient for IEEE 30 bus system is given table 1 and table 2.

**Table 1:** Generator limits and cost coefficients

| Gen. No | P Limit (MW) | | Q Limit (Mvar) | | Cost Coefficients | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Min* | *Max* | *Min* | *Max* | $\alpha$ | $\beta$ | $\gamma$ | $\zeta$ | $\lambda$ |
| 1 | 5 | 50 | -40 | 50 | 10 | 200 | 100 | 15 | 6.283 |
| 2 | 5 | 60 | -40 | 50 | 10 | 150 | 120 | 10 | 8.976 |
| 3 | 5 | 100 | -40 | 40 | 20 | 180 | 40 | 10 | 14.784 |
| 4 | 5 | 120 | -10 | 40 | 10 | 100 | 60 | 5 | 20.944 |
| 5 | 5 | 100 | -6 | 24 | 20 | 180 | 40 | 5 | 25.133 |
| 6 | 5 | 60 | -6 | 24 | 10 | 150 | 100 | 5 | 18.480 |

**Table 2:** Generator emission coefficients

| Gen. No | Emission Coefficients | | | | |
|---|---|---|---|---|---|
| | a | b | c | d | e |
| 1 | 4.091 | -5.554 | 6.490 | 2e-4 | 2.857 |
| 2 | 2.543 | -6.047 | 5.638 | 5e-4 | 3.333 |
| 3 | 4.258 | -5.094 | 4.586 | 1e-6 | 8.000 |
| 4 | 5.426 | -3.550 | 3.380 | 2e-3 | 2.000 |
| 5 | 4.258 | -5.094 | 4.586 | 1e-6 | 8.000 |
| 6 | 6.131 | -5.555 | 5.151 | 1e-5 | 6.667 |

## Result and Discussion

Control variable $P_G$ changes cost and emission value as given equations (8) and (9). Rescheduling of these 6 generators' real power generation gives optimal generating cost and emission. FA algorithm works well for single and multi objective function. In this work, CEED viewed as single objective of minimizing generating cost and emission, after that it viewed as two objective of simultaneous minimization both generating cost and emission. Table 3 compares FA solution.

**Table 3**. Generating cost minimization

| Gen. (MW) | PSO [4] | DE [11] | FA |
|---|---|---|---|
| $P_{G1}$ | 9.9441 | 6.78048 | 1.70697 |
| $P_{G2}$ | 36.248 | 37.7514 | 44.9543 |
| $P_{G3}$ | 48.349 | 47.857 | 53.7473 |
| $P_{G4}$ | 87.359 | 87.359 | 95.0135 |
| $P_{G5}$ | 66.428 | 67.3348 | 50.0205 |
| $P_{G6}$ | 39.004 | 39.004 | 40.9986 |
| Fuel Cost $/hr | **626.96** | **618.675** | **612.658** |
| Emission ton/hr | 0.2149 | 0.216257 | 0.26846 |

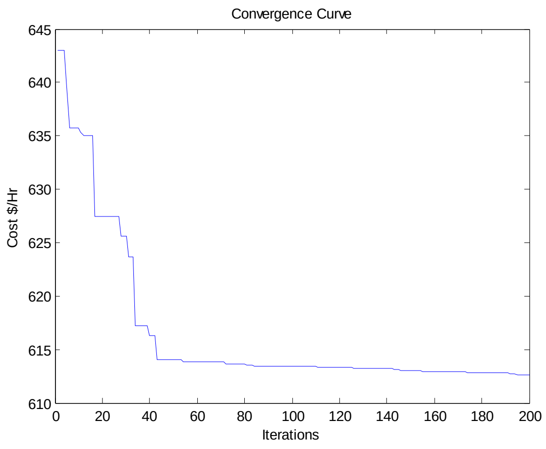


**Figure 1:** Generating cost convergence curve

FA search solution for 200 iterations and the convergence curve is shown in fig. 1. This algorithm find minimum generating cost of 612.658 $/hr.

**Table 4:** Emission minimization

| Gen. (MW) | PSO [4] | DE [11] | FA |
|---|---|---|---|
| $P_{G1}$ | 37.883 | 34.9200 | 41.3414 |
| $P_{G2}$ | 39.323 | 41.6496 | 46.6315 |
| $P_{G3}$ | 49.948 | 49.9480 | 54.4224 |
| $P_{G4}$ | 53.439 | 53.4390 | 39.4700 |
| $P_{G5}$ | 57.341 | 57.3410 | 54.9226 |
| $P_{G6}$ | 48.651 | 48.6510 | 51.6799 |
| Fuel Cost $/hr | 659.434 | 659.061 | 682.795 |
| Emission ton/hr | **0.19667** | **0.19667** | **0.19517** |

Table 4 compares FA solution with other literatures. From the table 4, FA gave minimum emission of 0.19517 ton/hr as compared to other algorithm.

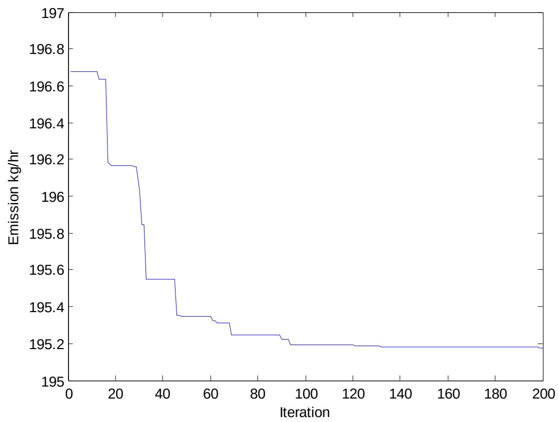


**Figure 2:** Emission convergence curve

Convergence curve of emission optimization is shown fig. 2. The maximum 200 iterations are considered as convergence criterion and depicted in fig 2. In convergence curve y-axis given in kg/hr, to convert it into ton/hr one has to divide it by 1000.

**Table 5**. CEED minimization

| Gen. (MW) | PSO [4] | DE [11] | FA |
|---|---|---|---|
| $P_{G1}$ | 14.089 | 11.6112 | 23.1363 |
| $P_{G2}$ | 34.415 | 40.4298 | 32.4303 |
| $P_{G3}$ | 67.558 | 47.4897 | 50.2470 |
| $P_{G4}$ | 83.971 | 80.1988 | 78.2441 |
| $P_{G5}$ | 49.043 | 67.5565 | 50.5606 |
| $P_{G6}$ | 39.797 | 39.004 | 51.5475 |
| Fuel Cost $/hr | **639.6507** | **618.437** | **613.539** |
| Emission ton/hr | **0.21205** | **0.21092** | **0.20578** |

Two objectives of CEED is solved simultaneously and given in table 5. From the table, FA gives optimal generating cost of 613.539 $/hr at optimal emission of 0.20578 ton/hr. This CEED result for the valve point loading is low as compared to other algorithms in the literature.

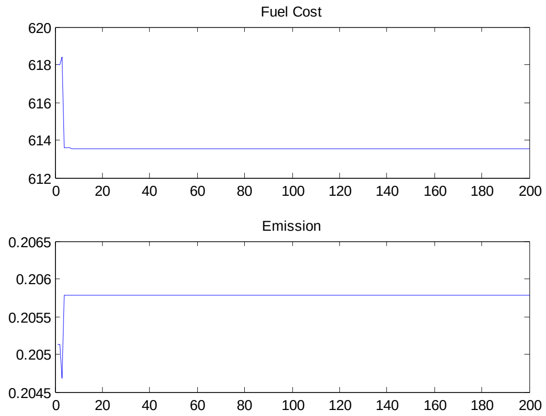


**Figure 3:** CEED convergence curve

Fig. 3, shows CEED convergence curve. It has 2 convergences one corresponds to generating cost and another one is for emission. In this convergence curve x-axis is number of iterations and y-axis of first curve is cost in $/hr, y-axis of second curve is emission ton/hr.

## Conclusion

Two objectives CEED problem is solved by the intelligent FA. The two objectives of generating cost and emission minimization are opposite to one another. The optimal point of compromised generating pattern of real power generation of IEEE 30 bus system is obtained. FA algorithm mimics social behavior of fireflies and finds global optimal value. FA superior in solving multi objective problem as compared to conventional and other nature inspired algorithms. FA solves CEED as single objectives and two objective and solutions are compared with earlier literatures. These single and two objective solutions are helpful for the decision making management system for the profit of the firm and to ensure less pollution of atmospheric air. The future work may extend to dynamic load condition of the power system. Line flow constraints may add to the CEED problem for more practical application.

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