

## An improved flower pollination solution for economic dispatch with valve point effect

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### ABSTRACT

The economic dispatch (ED) is used to find the best optimal output of power generation at the lowest operating cost of each generator, to fulfill the requirements of the consumer. To get a practical solution, several constraints have to be considered, like transmission losses, the valve point effect, prohibited operating region, and emissions. In this research, the valve point effect is to be considered which increases the complexity of the problem due to its ripple effect on the fuel cost curve. Economic load dispatch problems are well-known optimization problems. Many classical and meta-heuristic techniques have been used to get better solutions. However, there is still room for improvement to get an optimal solution for the economic dispatch problem. In this paper, an improved flower pollination algorithm with dynamic switch probability and crossover operator is proposed to solve these complex optimization problems. The performance of our proposed technique is analyzed against fast evolutionary programming (FEP), modified fast evolutionary programming (MFEP), improved fast evolutionary programming (IFEP), artificial bee colony algorithm (ABC), modified particle swarm optimization (MPSO), and standard flower pollination algorithm (FPA) using three generator units and thirteen thermal power generation units, by including the effects of valve point loading unit and without adding it. The proposed technique has outperformed other methods in terms of the lowest operating fuel cost.

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## 1. INTRODUCTION

The Statistical survey of world energy shows that more than 60% of the total electricity is produced by thermal power generation [1]. In this modern era, the usage of technology is increasing tremendously. Moreover, electricity demand is also growing exponentially. Therefore, to overcome this gap, different means of power generation like hydropower, solar power, wind power, atomic power, and thermal power are adapted to provide an adequate balance between supply and demand. However, thermal power generation still plays a vital role to fulfill the requirement, and it is also feasible to install in a multi-environment. Fuels like natural gas, fossil, and coal are used to produce steam to run turbines for power generation. The valve controls the steam entering the turbine by using different nozzle groups (several valves are opened) to achieve the best efficiency at the given output. That is why the valve point loading effect is considered to control the fuel consumption in power generation. It is a non-linear complex objective function that contains

many constraints such as cost coefficients with a sinusoidal function. In the last thirty years, many techniques have been established to minimize the cost of power generation by optimal scheduling of the generators within its limits.

Some well-known conventional techniques like lambda iteration [2], quadratic programming [3], and other gradient methods are used to solve the nonlinear economic dispatch (ED) problems. These methods require smooth, incremental cost, but practically, the input and output of the generators are always piece-wise nonlinear because each generator has its non-smooth cost curve, as shown in Figure 1. Therefore, in solving such non-convex problems, some derivative techniques have dimensionality issues and complications with time management. Since the meta-heuristic algorithms are population-based, using many solution candidates to estimate the best solution, they hold an advantage in getting optimal solutions over classical methods that use single solution techniques. In the literature, many bio-inspired and evolutionary techniques have been applied to solve economic dispatch (ED) problems, such as genetic algorithm (GA) [4] and harmony search algorithms [5], [6], that are used with valve point loading effect. The modified Tabu Search (MTS) algorithm was applied on ED non-smooth function with multiple minima [7] and particle swarm optimization (PSO) and modified particle swarm optimization [8] were also used to improve the results. The flower pollination algorithm [9] and its modified version have been implemented to solve the combined economic load dispatch problems [10]. Furthermore, some hybrid techniques have been introduced to address the complex economic dispatch (ED) problems [1], [11]. The flower pollination algorithm has been applied in the field of power distribution to analyse the optimality of capacitors in case of placement (allocation) and sizing [12]. On the other hand, it is also used to optimize the parameters of static VAR compensators for multi-machine power systems [13].

In this paper, an improved flower pollination algorithm with dynamic switch probability and cross over operator (IFPDS) is proposed to solve the ED problems including the valve point load effect. This method is easy to implement due to its fewer parameters, excellent ability to search, and effective convergence rate. The performance of the proposed algorithm in terms of the optimal solution has been compared with artificial bee colony (ABC) [14], standard flower pollination algorithm (FPA), and other discussed algorithms. This paper has divided into main five parts. In the second section, the economic dispatch problem is explained with the valve point effect and the third part is consisting of the proposed methodology. In the fourth section, the results are discussed with graphs. In the end, the paper is concluded with its future work.

## 2. PROBLEM FORMULATION OF ED

The economic dispatch is used to determine the operating fuel cost of every generator at its optimal power generation. The Economic dispatch problems are complex optimization problems with generic objective function:

$$\text{in } \sum_{i=1}^n F_{c_i} P_i \quad (1)$$

where  $F_{c_i}$ , represents the fuel cost of the given generator 'i' to produce power  $P_i$ .

The equality and inequality constraints are:

$$P_d = \sum_{i=1}^n P_i - P_l \quad (2)$$

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad (3)$$

where,  $P_d$  is the power of demand for the system and  $P_l$  represents the power transmission losses. In the inequality constraint power capacity of each generator is lemmatized with minimum power  $P_i^{\min}$  and maximum power  $P_i^{\max}$ .

The quadratic function of fuel cost without valve point loading effect is given by;

$$f(P_i) = a_i P_i^2 + b_i P_i + c_i \quad (4)$$

In this case, the thermal power generation is considered that has multi-valves point steam turbines. These turbines have a different input-output convex curve at each steam valve point results in a ripple in Figure 1 [4], [15]. Therefore, the problem is composed of a combination of quadratic function and superposition of sinusoidal function which contains multiple optima. The non-smooth cost function with valve point loading effect can be represented as:

$$F_t = a_i P_i^2 + b_i P_i + c_i + \left| e_i * \sin \left( f_i * (P_i^{\min} - P_i) \right) \right| \tag{5}$$

where,  $a_i$ ,  $b_i$  and  $c_i$  are the cost co-efficient of each generator and  $e_i$ ,  $f_i$  are the coefficient of the valve point effect for each turbine [16], [17].

When the sinusoidal function is added to the quadratic function of the fuel cost of the generator then the ripple effect of the valve point loading effect makes the cost function more complex as in Figure 1. In solving this complicated problem, stochastic techniques are useful to get the optimal solution.

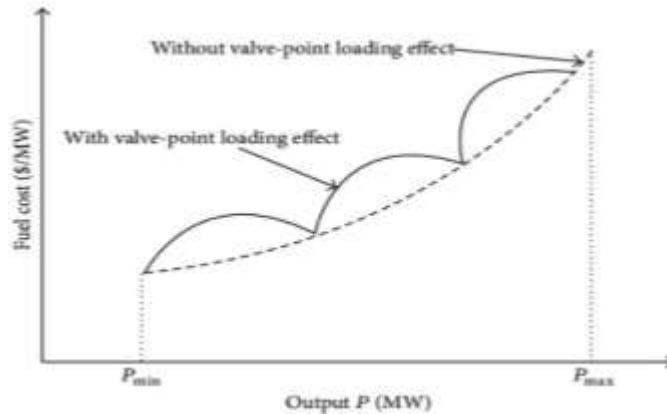


Figure 1. Valve point loading effect and the dotted line represents the quadratic cost

### 3. THE PROPOSED METHOD

The standard flower pollination algorithm (FPA) was introduced by Xing-She Yang [18]. It is a meta-heuristic, nature-inspired, and stochastic technique. The author learns the pollination behavior of the flowers to pollinate for its survival. Some flowers only attract those insects that help in the pollination process. These insects play the primary role as pollinators in global pollination. The main focus was to address the complex problems which were not tackled adequately by conventional methods. There are mainly two types of pollination:

- Biotic: it is long distance, cross-pollination which needs some pollinator to perform, like birds, bees, insects. So, for long-distance, he used levy's flight that behaves like a global search. It covers 90% of pollination.
- Abiotic: it occurs within the flower means self-pollination or local pollination, which no need for pollinators. It is only 10% of pollination.

Other characteristics of the pollination process like flower constancy that can be conceived as the reproduction probability are directly proportional to the similarity of two flowers involved and switch probability  $p \in [0,1]$  that controls both local pollination and global pollination. Global pollination is ensured through insects that are the fittest reproduction. If it is represented by “ $g^*$ ” then the relation of global pollination:

$$x_i^{t+1} = x_i^t + \gamma L(\lambda) (x_i^t - g^*) \tag{6}$$

In (6) ' $x_i^t$ ' represents the solution vector at iteration  $t$ , and  $g^*$  is the current best solution among all iterations. Here ' $\gamma$ ' is the scaling factor to control the step size [19]. In (7) where ' $L(\lambda)$ ' is the controlling parameter that corresponds to the strength of pollination and uses levy's flight 'L' (which is step size) for long random walk  $L > 0$

$$L \sim \left[ \lambda \Gamma(\lambda) \frac{\sin(\frac{\lambda\pi}{2})}{\pi s(\lambda+1)} \right] \quad s \gg s_0 > 0 \tag{7}$$

where  $\Gamma(\lambda)$  is the Gamma function[20].

The local pollination is expressed in (3).

$$x_i^{t+1} = x_i^t + \epsilon (x_j^t - x_k^t) \tag{8}$$

In (8) where  $x_j$  and  $x_k$  are the two random pollens which are selected from different flowers of the same species of the plant. That will essentially mimic the flower constancy in a restricted neighborhood. Mathematically, if  $x_j^t$  and  $x_k^t$  come from the same species or selected from the same population that equivalently becomes a local random walk while  $\epsilon$  is randomly selected from a uniform distribution and to avoid immature convergence and to increase its optimality  $\epsilon$  is replaced with  $\beta \in \{0.1, 0.5\}$  [21], [22] and the selection criteria of pollens is defined

$$x_i^{t+1} = x_i^t + \beta(x_j^t - x_k^t) \tag{9}$$

where  $x_j$  and  $x_k$  are different pollens using selection criteria.

The proposed technique has a novelty to handle multi-constraints optimization problems. Due to the fewer number of parameters, it is so efficient and easy to implement. Figure 2 shows the flow chart of the improved flower pollination algorithm (IFPDS). The improved flower pollination algorithm using dynamic switch probability and crossover operator (IFPDS) is applied to solve the complex economic load dispatch optimization problem which can address the immature convergence problem by introducing the crossover operator to increase the diversity of the population in the local search process.

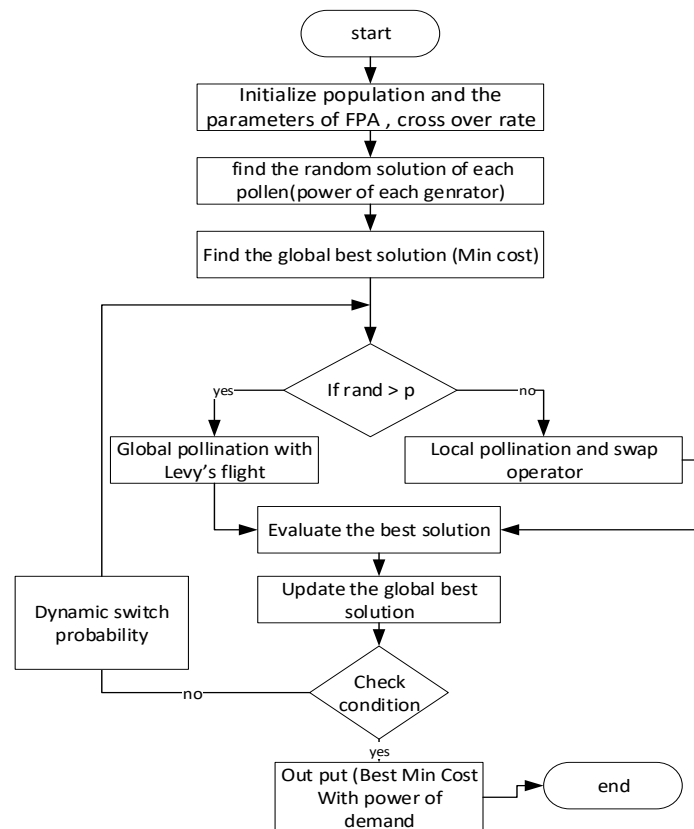


Figure 2. Flow chart Improved flower pollination algorithm with dynamic switch probability and crossover operator

The Crossover operator is explained in the following equation.

$$S_i^{t+1} = \begin{cases} y_{i,k} & \text{rand}_{i,k} [0, 1] < C_r \\ s_{i,k}^t & \text{else} \end{cases} \quad i=1,2,3,\dots,n \tag{10}$$

$k = 1, 2, 3, \dots, d$

In (10),  $s_i^k$  is the  $k^{\text{th}}$  dimension of solution vector ‘i’ and  $C_r$ , is the crossover rate set 0.3 in this algorithm to diversify the population in local optimum to avoid the immature convergence [23], [24].

On the other hand, the fixed switch probability ( $p = 0.8$ ) is used in the standard flower pollination algorithm, which creates biasedness between exploration and exploitation. The proposed approach will use dynamic switch probability to increase the searchability by the balance between exploration and exploitation of the algorithm. The Dynamic switch probability has been represented by the given (11), [25].

$$P = 0.6 + 0.2(\text{Max}_{\text{iter}} - t)/\text{Max}_{\text{iter}} \quad (11)$$

In (11),  $\text{Max}_{\text{iter}}$  is the total number of iterations and 't' is represents the current iteration.

### 3.1. The pseudo-code of the proposed algorithm

The pseudo-code of the proposed algorithm starts with the initialization of population, cross-over rate, and switch probability. After that global and local pollination will occur. In local pollination, the swap operator is introduced. In the end, the best solution is updated then dynamic switch probability is used for the next iteration.

```

1. Begin
2. Objective function minor max  $f(x)$  with dimension  $d$ ,  $x = (x_1, x_2, x_3, \dots, x_d)$ 
3. Initialize the population of (size) 'n' flowers with its random solutions and
   Define crossover rate
4. Find the global best solution  $g^*$  from the initial random solutions
5. Define (select) the switch probability  $p \in [0,1]$ 
6. While (t < Max-Iterations)
7.   For i = 1: n (total number of
8.     solutions)
9.     if rand < p
10.      Draw 'd' dimensional step
11.      vector L, which obey the
12.      Levy's distribution  $S_i^{t+1} = x_i^t + \gamma L(\lambda)(x_i^t - g^*)$ 
13.      Global pollination is used to
14.      get new solution  $S_i^{t+1}$ 
15.     else
16.      Local pollination,  $S_i^{t+1} = x_i^t + \beta(x_j^t - x_k^t)$  Local
17.      search processed to find a
18.      Solution vector and
19.      apply cross over
20.      operator then find
21.      the solution  $S_i^{t+1}$ 
22.     end if
23.   Evaluate the new fitness  $S_i^{t+1}$ 
24.   using a cost function
25.   if fitness ( $S_i^{t+1}$ ) < fitness( $S_i^t$ )
26.     (for min function)
27.     update flower  $S_i^t$ 
28.   end if
29.   Apply the dynamic switch probability  $P = 0.6 + 0.2(\text{Max}_{\text{iter}} - t)/\text{Max}_{\text{iter}}$ 
30. end for
31. end while
32. Output the best (Min or Max)

```

## 4. RESULTS WITH ANALYSIS

The performance of the proposed method has been evaluated by using two types of case studies in the economic dispatch problem, first one three thermal power generators, and the second thirteen power generators system. The statistical results of IFPDS have been compared with meta-heuristic algorithms FPA, ABC, and MPSO [8].

### 4.1. Case study I: Three generators (including valve point effect)

The data given in Table 2 [8] of three thermal generators system for economic dispatch with non-convex cost function including valve point effect and the demand for power generation is 850 MW/h. The sinusoidal objective function with valve point effect in (5) is considered to minimize the power generation cost. The IFPDS, SFPA, and ABC algorithms are applied to find the minimum fuel cost under the limited constraints. Each algorithm has run thirty times independently to analyze the performance. The statistical analysis is given in Table 3 by obtaining thirty independent runs of each algorithm. In this table minimum cost, maximum cost, mean cost, and standard deviation are calculated to compare the performance of all algorithms.

In Table 3 the performance of SFPA, ABC, and MPSO algorithm (where genetic algorithm (GA), evolutionary programming (EP), and improved evolutionary programming (IEP) have been already evaluated in [8]) are compared with the proposed algorithm to represent the efficiency of the nature-inspired algorithm and different evolutionary algorithms. The statistical analysis of all algorithms proves that the proposed IFPDS algorithm has outperformed than other algorithms in getting the minimum cost of thermal power generation to fulfill the demand. In Figure 3, the graphs of meta-heuristic algorithms represent the convergence of each algorithm and the red line represents the convergence rate of the proposed algorithm. The edges of the graphs indicate the superiority of the proposed algorithm.

Table 2. Data for three generators with valve point effect

Generator	P min	P max	A	B	c	e	F
1	100	600	0.001582	7.92	561	300	0.0315
2	50	200	0.00482	7.97	78	150	0.063
3	100	400	0.00194	7.86	310	200	0.042

Table 3. Statistical results of algorithms with valve point effect

Algorithm	Min Cost	Max -Cost	Mean Cost	Standard dev.
IFPDSO	8204.31	8233.98	8215.556	9.006109
MPSO[8]	8234.07	//	//	//
FPA	8206.37	8339.32	8229.182	25.79669
ABC	8210.83	8329.64	8271.365	30.47666

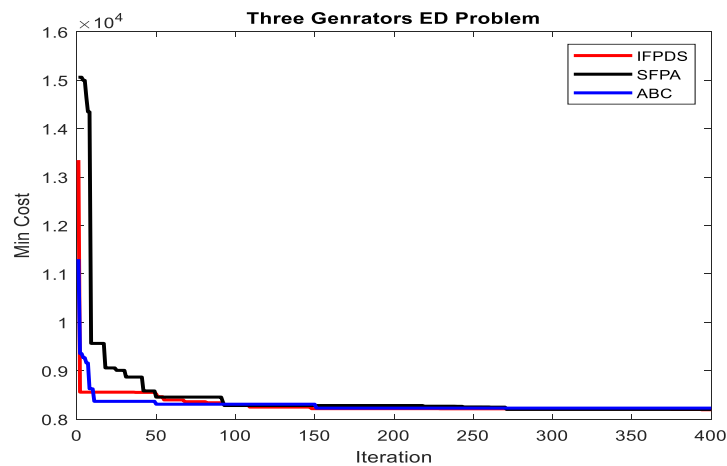


Figure 3. Minimum cost of fuel for three generators

**4.2. Case study I: Three generators (without valve point effect)**

Table 4, represents the power generation of each generator to generate the electricity of demand 850 MW/h with its minimum fuel cost using quadratic cost function without a valve point loading effect. In this case study, it is clear from the results that improved flower pollination with switch probability and crossover operator algorithm (IFPDS) has performed better than the standard flower pollination algorithm (FPA) and artificial bee colony algorithm (ABC).

Table 4. Minimum fuel cost with its generations without valve point effect

Algorithm	P 1	P 2	P3	Minimum Cost
IFPDS	391.1858	124.2041	334.6101	8197.4442
FPA	349.634	123.3567	332.01	8197.577
ABC	390.5147	123.1905	336.294	8199.9336

**4.3. Case study II: Thirteen generators (including valve point effect)**

In this case study, thirteen thermal power generators are considered to increase the complexity of objective function with the valve point effect. Table 5 represents the data of fuel cost coefficients thirteen

generators with a valve point loading effect. The algorithms such as ABC, SFPA, and IFPDS have been applied to minimize the cost of fuel to meet the demand (1800MW/h) of thermal power generation. All algorithms have been run for thirty times independently. The results of each algorithm are shown in Table 6. It is evident from the analysis of the output data that the proposed IFPDS algorithm has performed better than the ABC and FPA concerning the average fuel cost of power generation. Demand = 1800MW

In Figure 4, the graphs of nature-inspired stochastic algorithms have been plotted to compare the convergence rate of the proposed algorithm (IFPDS) with other algorithms. The red line in the graph represents the output of the proposed IFPDS algorithm which shows the best performance in case of lower cost among the algorithms such as ABC and FPA.

Table 5. Data for fuel cost co-efficient of thirteen generators

Generator	P min	P max	A	b	c	E	F
1	0	680	0.00028	8.1	550	300	0.035
2	0	360	0.00056	8.1	309	200	0.42
3	0	360	0.00056	8.1	307	200	0.42
4	60	180	0.00324	7.74	240	150	0.036
5	60	180	0.00324	7.74	240	150	0.036
6	60	180	0.00324	7.74	240	150	0.036
7	60	180	0.00324	7.74	240	150	0.036
8	60	180	0.00324	7.74	240	150	0.036
9	60	180	0.00324	7.74	240	150	0.036
10	40	120	0.00284	8.6	126	100	0.084
11	40	120	0.00284	8.6	126	100	0.084
12	55	120	0.00284	8.6	126	100	0.084
13	55	120	0.00284	8.6	126	100	0.084

Table 6. Statistical analysis of all algorithms (with valve point effect)

Algorithm	Min- Cost	Max -Cost	Mean- Cost	Standard deviation
IFPDSO	17996.45	18145.56	18097.2	29.8408
FPA	18103.54	18194.08	18121.53	39.44098
ABC	18110.87	18623.39	18406.12	128.8278

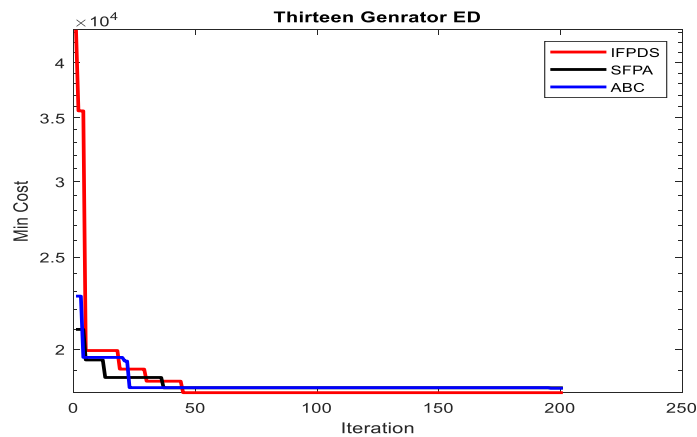


Figure 4. Minimum cost of fuel for thirteen generators

**4.4. Case study II: Thirteen generators (without valve point effect)**

Table 7, represents the power generation of each generator to generate the electricity of demand 1800 MW/h with its minimum fuel cost using quadratic cost function without a valve point loading effect. In this case, study results show that the improved flower pollination with switch probability and crossover operator algorithm (IFPDS) has outperformed better than the standard flower pollination algorithm (SFPA) and artificial bee colony algorithm (ABC), in achieving the lowest fuel cost.

Table 7. Minimum fuel Cost with its generations without valve point effect

Algo	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P 10	P 11	P 12	P 13	Minimum Cost
IFPDS	498.2	247.4	281.5	112.6	124.5	76.5	74.7	101.2	69.5	40	44.4	57.5	72.1	17961.91
FPA	542.7	154.5	342.6	95.7	72.1	76.1	12.6	292.5	96.5	47.3	58.9	59.2	58.9	8197.57
ABC	482.7	254.5	190.5	136.5	108.6	60	81.8	123.3	132.6	45.4	40	88.7	55	8199.93

## 5. CONCLUSION

The proposed algorithm IFPDS has been applied to solve economic dispatch (ED) problems using non-smooth fuel cost, with and without valve point effect. The simulation results are tabulated for comparison. It is evident from the results that the proposed IFPDS has minimized the cost of fuel better than the other mentioned algorithms. The convergence ability has been observed by comparing graphical results with other nature-inspired meta-heuristic techniques. The overall performance of the proposed IFPDS indicates that in the future, this method will be an important tool to solve the complex optimization problems of the multi-machine system, distribution system, and power generation systems, including transmission line losses to minimize the expense of power generation and emission cost to clean the environment.

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