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Application of artificial intelligence technique to economic load dispatch of thermal power generation unit

Pragya Nema[1], Shraddha Gajbhiye[2]

[1]Engg Department, LNCT, Indore, India
[2] Electrical Engg Department, SVITS, Indore, India

Email address:
dr.pragyanema@ymail.com (P. Nema), shraddhagajbhiye@gmail.com (S. Gajbhiye)

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Abstract: Economic Dispatch(ED) is one of the main problem of power system operation and control which determines the optimal real power settings of generating units with an objective of minimizing the total fuel cost, subjected to limits on generator real power output & transmission losses. In all practical cases, the fuel cost of generator can be represented as a quadratic function of real power generation. This paper describe and Introduce a new nature Inspired Artificial Intelligence method called Firefly Algorithm(FA). The Firefly Algorithm is a stochastic Meta heuristic approach based on the idealized behavior of the flashing characteristics of fireflies. The aim is to minimize the generating unit's combined fuel cost having quadratic cost characteristics subjected to limits on generator real power output & transmission losses. This paper presents an application of the FA to ED with valve point loading for different Test Case system. The obtained solution quality and computation efficiency is compared to another artificial intelligence technique, called Genetic algorithm (GA) . The simulation results show that the proposed algorithm outperforms previous artificial intelligence method.

Keywords: Economic Dispatch, Firefly Algorithm, Genetic Algorithm

1. Introduction

Knowledge-based or Artificial Intelligence techniques are used increasingly as alternatives to more classical techniques to model environmental systems. Artificial Intelligence (AI) could be defined as the ability of computer software and hardware to do those things that we, as humans, recognize as intelligent behavior. Traditionally those things include such activities as[1]:

Finding "good" material after having been provided only limited direction, especially from a large quantity of available data.

Surmounting constraints: finding ways that something will fit into a confined space, taking apart or building a complex object, or moving through a difficult maze.

Recognizing patterns: finding items with similar characteristics, or identifying an entity when not all its characteristics are stated or available.

Making logical inferences: drawing conclusions based upon understood reasoning methods such as deduction and induction.

All metaheuristic algorithms use certain tradeoff a randomization and local search [2], [3], [4]. Most stochastic algorithms can be considered as metaheuristic and good examples are Genetic Algorithm (GA) [5], [6]. Many modern metaheuristic algorithms were developed based on the swarm intelligence in nature like PSO [7].

A new algorithm that belongs in the category of nature inspired algorithms is the firefly algorithm, which was developed by Dr. Xin-She Yang at Cambridge University in 2007, shows its superiority over some traditional algorithms [5], [8]. Firefly algorithm is based on the flashing light of fireflies. Although the real purpose and the details of this complex biochemical process of producing this flashing light is still a debating issue in the scientific community, many researchers believe that it helps fireflies for finding mates, protecting themselves from their predators and attracting their potential prey[9-12]. In the firefly algorithm, the objective function of a given problem is associated with flashing light or light intensity which helps the swarm of fireflies to move to brighter and more attractive locations in order to obtain efficient optimal solutions.

In this research paper, the firefly algorithm is used to solve the economic load dispatch with valve point loading problem. This problem constitutes one of the key problems in power system operation and planning in which a direct solution cannot be found and therefore metaheuristic approaches, such as the firefly algorithm, have to be used to find the optimal solutions.

For the efficiency and validation of this algorithm, hear using, as an example, two case study system of 3 generators and 6 generators, and compare the solutions obtained with the ones obtained by alternative optimization techniques that have been successfully applied by many researchers in order to solve these types of problems, such as the Genetic algorithm[6][7].

2. Economic Dispatch Problem

The classical Economic Dispatch(ED) problem is an optimization problem that determines the power output of each online generator that will result in a least cost system operating state. The objective of the economic load dispatch is to minimize the total cost of each online generator .This power allocation is done considering system balance between generation and loads, and feasible regions of operation for each generating unit. The basic economic dispatch problem can be described by the following points:

a) The Fuel Cost Objective

The aim is to minimize the total fuel cost (operating cost) of all committed plants can be stated as follows:

Minimize

$$f_1(x) = \sum_{i=1}^{n} C_i(P_i) \tag{1}$$

where C_i (P_i) is the fuel cost equation of the 'ith plant. It is the variation of fuel cost in rupee with generated Power (MW).

$$C_i(P_i) = a_i P_i^2 + b_i P_i + c_i \tag{2}$$

where n is the number of units power generators of a power plant, C_i is the fuel cost of the ith generator, P_i is the out power of generator i and a_i, b_i and c_i are the fuel cost coefficients of the ith generator. Normally, the fuel cost equation $f_1(x)$ is expressed as continuous quadratic (higher order) equation, as here, but sometimes it can be expressed in linear form, when the coefficient c_i is equal to zero. However, in both cases, the equation expresses the variation of fuel cost ($ or Rs) with generated power or time (MW or hr).

b) The Necessary Constraints of the Problem

The total power generation must satisfy the total required demand (power balance) and transmission losses. This can be formulated as follows:

$$\sum_{i=1}^{n} P_{Gi} = D + P_{loss} \tag{3}$$

where D is the real total load demand of the system, P_{Gi} is the ith generator's power, and P_{loss} is the transmission losses. These can be determined from either the load/power flow or the matrix B_{ij} of coefficients. In this paper, only the B_{ij} coefficients are considered

$$P_{loss} = \sum_{i=1}^{n} \sum_{j=1}^{n} B_{ij} P_i P_j \tag{4}$$

where, B_{ij} are the elements of the loss coefficient matrix B and P_i and P_j are the out powers of the ith and jth generator; respectively. In this paper, the MW as the only unit of measurement of the power balance constrain is use.

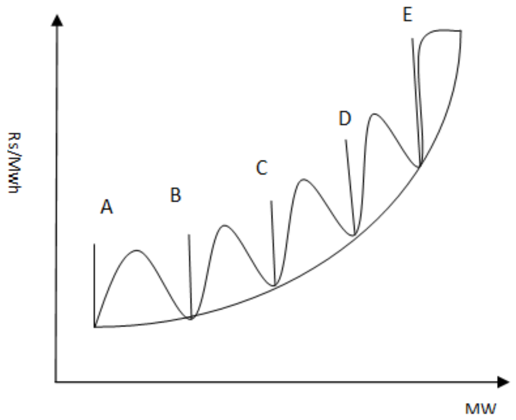
Apart from the total demand and transmission loss constrain, there is also the generator capacity constrain in which the power limits of each generator are formulated in order to have a stable operation of a plant. The upper and lower limits are defined as follows:

$$P_{Gi}^{MIN} \le P_{Gi} \le P_{Gi}^{MAX} \text{ , for i = 1.......n}$$

where P_{Gi}^{MIN} and P_{Gi}^{MAX} are the lower and upper limit of the ith generator's out power P_{Gi}, respectively. The power load of each generator unit is measured in MW.

3. Economic Dispatch with Valve Point Loading

The Input-output characteristic (or cost function) of a generator are approximated using quadratic or piecewise quadratic function, under the assumption that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. However, real input-output characteristics display higher order non linearities and discontinuities due to valve-point loading in fossil fuel burning plants. The valve-point loading effect has been modeled in as a recurring rectified sinusoidal function as shown in Fig:1.



A: Primary valve, B: Secondary valve, C: Tertiary valve, D: Quaternary valve, E: Quinary valve

Fig. 1. *Operating cost characteristics with valve point loading.*

The generating units with multivalve steam turbines exhibits a greater variation in the fuel cost functions. The valve point effects introduce ripple in the heat rate curves. Mathematically ELD problem considering valve point loading is defined as:

$$C_i\left(P_i\right)=\sum_{i=1}^{NG}\left(a_iP_i^2+b_iP_i+c_i+\left|d_i*sin\left\{e_i*\left(P_i^{min}-P_i\right)\right\}\right|\right) \quad (5)$$

where, a_i,b_i,c_i,d_i,e_i are cost coefficients of the i^{th} unit.

Subject to:- (i) The energy balance equation

$$\sum_{i=1}^{NG}P_i=P_D+P_L$$

(ii) the inequality constraints

$$P_i^{\min}\le P_i\le P_i^{\max} \quad \text{(i=1,2……NG)}$$

4. The Genetic Algorithm

Genetic algorithms were formally introduced in the United States in the 1970s by John Holland at University of Michigan. Genetic algorithm is based on the mechanics of natural selection and natural genetics [7].Its fundamental principle is that *the fittest member of* population *has the highest probability for survival.* The genetic algorithm, works only with objective function information in a search for an optimal parameter set. In particular, genetic algorithms work very well on mixed (continuous and discrete), combinatorial problems. They are less susceptible to getting 'stuck' at local optima than gradient search methods. But they tend to be computationally expensive. To use a genetic algorithm, it must represent a solution to your problem as a genome (or chromosome)[6] The genetic algorithm then creates a population of solutions and applies genetic operators such as mutation and crossover to evolve the solutions in order to find the best one(s) which is shown in Fig:2, as no of iteration increased the value of fitness function(objective function) improves.

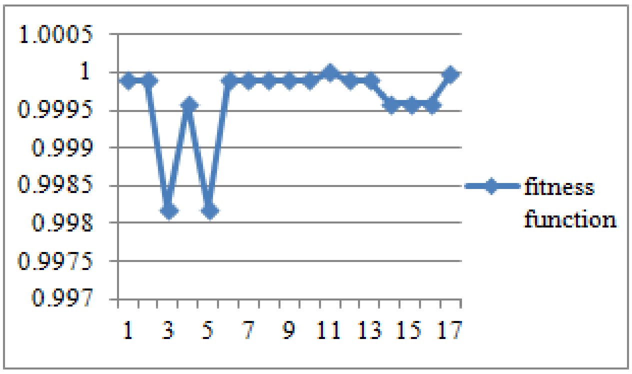


Fig. 2. *fitness function of GA Versus no of iterations.*

5. Proposed Method: The Firefly Algorithm

5.1. Description

This algorithm (FA) is based on the social (flashing) behavior of fireflies, or lighting bugs [3][11]. It was developed by Dr. Xin-She Yang at Cambridge University in 2007, and it is based on the swarm behavior such as fish, insects, or bird schooling in nature. Although the firefly algorithm has many similarities with other algorithms which are based on the swarm intelligence, such as the Particle Swarm Optimization (PSO), Artificial Bee Colony optimization (ABC), and Bacterial

Foraging (BFA) algorithms, it is indubitably much simpler both in concept and implementation[13][4][11].Moreover, according to recent bibliography, the algorithm is very efficient and can perform better than other conventional algorithms, such as genetic algorithms, for solving many optimization problems; a fact that has been justified in a recent research, where the statistical performance of the firefly algorithm was measured against other well-known optimization algorithms using various standard stochastic test functions [4][11].The main advantage of FA is that it uses mainly real random numbers, and it is based on the global communication among the swarming particles (i.e., the fireflies).

The firefly algorithm has three idealized rules which are based on some of the major flashing characteristics of real fireflies [3][8].

These are the following:

1) all fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex.
2) The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not a brighter or more attractive firefly than a particular one, it will then move randomly.
3) The brightness or light intensity of a firefly is determined by the value of
4) the objective function of a given problem. For maximization problems, the light intensity is proportional to the value of the objective function.

5.2. Attractiveness

In the firefly algorithm, the form of attractiveness function of a firefly is the following monotonically decreasing function [3][4][8][11]:

$$\beta(r)=\beta_o*\exp(-\gamma r^m) \quad m\ge 1, \qquad (6)$$

where, r is the distance between any two fireflies,

β_0 is the initial attractiveness at r =0, and

γ is an absorption coefficient which controls the decrease of the light intensity.

5.3. Distance

The distance between any two fireflies i and j, at positions x_i and x_j , respectively, can be defined as a Cartesian or Euclidean distance as follows [3][4][11]:

$$r_{ij} = \left\| x_i - x_j \right\| \quad (7)$$

$$r_{ij} = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \quad (8)$$

where $x_{i,k}$ is the k^{th} component of the spatial coordinate x_i of the i^{th} firefly and d is the number of dimensions , for d =2,

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (9)$$

5.4. Movement

The movement of a firefly i which is attracted by a more attractive (i.e., brighter) firefly j is given by the following equation [5][8][11]:

$$x_i = x_i + \beta_o * \exp(-\gamma r_{ij}^{\ 2}) * (x_j - x_i) + \alpha * (rand - 0.5)$$

where the first term is the current position of a firefly, the second term is used for considering a firefly's attractiveness to light intensity seen by adjacent fireflies, and the third term is used for the random movement of a firefly in case there are not any brighter ones. The α is a coefficient of randomization parameter, while rand is a random number generator uniformly distributed in the space [0,1]. Hear β_0 = 1.0, α =[0, 1] and the attractiveness or absorption coefficient γ =1.0, which guarantees a quick convergence of the algorithm to the optimal solution.

The basic steps of the FA can be summarized as the pseudo code for Firefly Algorithm as follows.

Pseudocode for proposed Firefly algorithm:

Input: $\alpha, \gamma, \beta_0, n$, Maximum Generation, *B*, cost- coefficients

Output: P_{Gi} for i = 1, . . . 6, $f(X)$, $f_1(X)$, $f_2(X)$

Begin of algorithm:

Define the objective function: max $-f(P_{Gi})$, with i = 1, . . . , no of generators.

Generate initial population of fireflies n = 1, . . . , 12 (generate n =12 initial solutions)

Light Intensity of firefly n is determined by objective function, $In = f(P_{Gi})$

Define α = 0.2, β_0 =1.0 and γ =1.0 %necessary algorithm's parameters

While ($t \leq$ MaxGeneration =50)

For i = 1 : 12 (for all fireflies (solutions))

For j = 1 : 12 (for all fireflies (solutions))

If ($I_i < I_j$)

Then move firefly i towards firefly j (move towards brighter one)

Attractiveness varies with distance r_{ij} via $\exp(-\gamma r_{ij})$

Generate and evaluate new solutions and update Light Intensity

End for j loop

End for i loop

Check the ranges of the given solutions and update them as appropriate

Rank the fireflies, find and display the current best %max solution for each iteration

End of while loop

% Post-process results and visualization

Find the firefly with the highest Light Intensity among all fireflies %optimal solution

End of algorithm

As shown in Fig:3 as no of iteration increased the value of light intensity(objective function) improves.

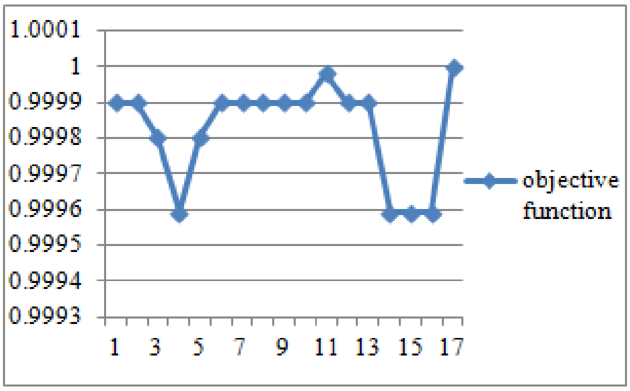


Fig. 3. *fitness function of FA Versus no of iterations.*

6. Simulation Results and Discussion

To solve the ED problem with valve point loading, this paper implement the FA in MATLAB 2008 and it was run on a portable computer with an Intel Core2 Duo (1.8GHz) processor, 2GB RAM memory and MS Windows 7 as an operating system. Mathematical calculations and comparisons can be done very quickly and effectively with MATLAB and that is the reason that the proposed Firefly algorithm was implemented in MATLAB programming environment. In this proposed method, each firefly represent and associate with a valid power output (i.e., potential solution) encoded as a real number for each power generator unit, while the fuel cost objective i.e., the objective function of the problem is associated and represented by the light intensity of the fireflies. In this simulation, the values of the control parameters are: α = 0.2, γ =1.0, β_0 = 1.0 and n =12, and the maximum generation of fireflies (iterations) is 10. The values of the fuel cost, the power limits of each generator, the power loss coefficients, and the total power load demand are supplied as inputs to the firefly algorithm. The power output of each generator, the total system power, the fuel cost with transmission losses are considered as outputs of the proposed Firefly algorithm. Initially, the objective function of the given problem is formulated and it is associated with the light intensity of the swarm of the fireflies.

The FA has been proposed for two case studies (3 and 6 generators) systems. In this system GA & FA Algorithms were used in ED with valve point loading. In table 2, results obtained from proposed FA method has been compared with other method. According to the result obtained using the FA for ED is more advantageous then Genetic Algorithm.

6.1. Case Study I: Three-Unit System

This case study consists of three thermal units.

The Input and cost coefficients are shown in Tables 1 . In this case, the load demand expected to be determined is PD = 850 MW.

6.2. Case Study II: Six-Unit System

Table 1. *Data for the three thermal units of generating unit capacity and coefficients.*

Unit	P_i^{min}	P_i^{max}	a	b	c	d	e
1	100	600	0.0016	7.92	561	300	0.032
2	50	200	0.0048	7.92	78	150	0.063
3	100	400	0.0019	7.85	310	200	0.042

Table 2. *Data for the six thermal units of generating unit capacity and coefficients.*

Unit	P_i^{min}	P_i^{max}	a	b	c	d	e
1	100	500	0.0070	7.0	240	300	0.035
2	50	200	0.0095	10.0	200	200	0.042
3	80	300	0.0090	8.5	220	200	0.042
4	50	150	0.0090	11.0	200	150	0.063
5	50	200	0.0080	10.5	220	150	0.063
6	50	120	0.0075	12.0	190	150	0.063

This case study consists of six thermal units.

The Input and cost coefficients are shown in Tables 2. In this case, the load demand expected to be determined is PD = 1263 MW.

Table 3. *Comparison table showing simulation results of various algorithms for three-unit system.*

	FA(Proposed Algorithm)	GA
PG1(MW)	297.25	297.27
PG2(MW)	186.25	186.32
PG3(MW)	367.56	367.63
Total power	851.09	851.22
Fuel cost(INR.)	8543.5	8543.9
Ploss(MW)	1.2001	1.2005

Table 4. *Comparison table showing simulation results of various algorithms for six-unit system.*

	FA(Proposed Algorithm)	GA
PG1(MW)	473.27	485.56
PG2(MW)	145.19	181.09
PG3(MW)	295.29	244.61
PG4(MW)	96.356	77.126
PG5(MW)	164.98	196.72
PG6(MW)	93.342	92.451
Total power	1268.4	1277.5
Fuel cost(INR.)	16200	16251
Ploss(MW)	13.731	14.569

7. Conclusion

The proposed FA to solve Economic Dispatch of generation with valve point loading by considering the practical constraints has been presented in this paper. The feasibility of the proposed method for solving the non-smooth economic dispatch problem is demonstrated using three and six units test system. Algorithm for economic dispatch with valve point loading, is developed for FA and GA in MATLAB. From the comparison Fig 4 and Fig 5, it is observed that the proposed algorithm exhibits a comparative performance with respect to other population based technique(GA). It is clear from the results that Firefly algorithm is capable of obtaining higher quality solution with better computation efficiency and stable convergence characteristic. The effectiveness of FA was demonstrated and tested. From the simulations, it can be seen that FA gave the best result of total cost minimization and reduced fuel cost and Power loss compared to the other method.

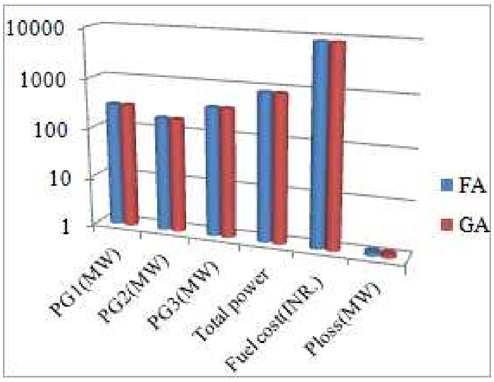


Fig. 4. *Comparison graph showing simulation results of various algorithms for three-unit system.*

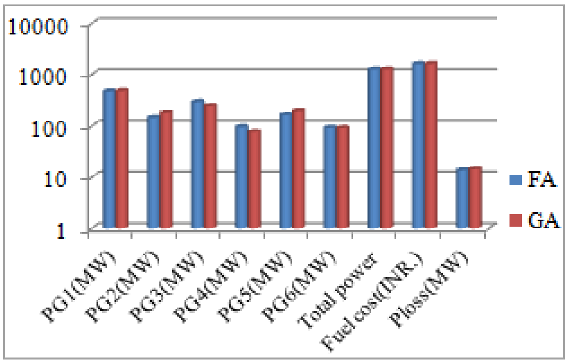


Fig. 5. *Comparison graph showing simulation results of various algorithms for six-unit system.*

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