An Efficient Firefly Algorithm to Solve Economic Dispatch Problems

R.Subramanian, K.Thanushkodi

Abstract -The Economic Dispatch(ED) problems are the major consideration in electric power generation systems in order to reduce the fuel cost their by reducing the total cost for the generation of electric power. This paper presents an Efficient and Reliable Firefly Algorithm (FA), for solving ED Problem. The main objective is to minimize the total fuel cost of the generating units having quadratic cost characteristics subjected to limits on generator true power output & transmission losses. The FA is a stochastic Meta heuristic approach based on the idealized behaviour of the flashing characteristics of fireflies. This paper presents an application of the FA to ED for different Test Case system. ED is applied and compared its solution quality and computation efficiency to Simulated Annealing (SA), Genetic algorithm (GA), Differential Evolution (DE), Particle swarm optimization (PSO), Artificial Bee Colony optimization (ABC), and Biogeography-Based Optimization (BBO) optimization techniques. The simulation results show that the proposed algorithm outperforms previous optimization methods.

Keywords: Artificial Bee Colony optimization, Biogeography-Based Optimization, Economic dispatch, Firefly Algorithm, Genetic algorithm, and Particle swarm optimization.

I. INTRODUCTION

Electrical power industry restructuring has created highly vibrant and competitive market that altered many aspects of the power industry. In this changed scenario, scarcity of energy resources, increasing power generation cost, environment concern, ever growing demand for electrical energy necessitate optimal economic dispatch. Economic Dispatch (ED)[1], is one of the important optimization problems in power systems that have the objective of dividing the power demand among the online generators economically while satisfying various constraints. Since the cost of the power generation is exorbitant, an optimum dispatch saves a considerable amount of money. Optimal generation dispatch is one of the most important problems in power system engineering, being a technique commonly used by operators in every day system operation. Optimal generation seeks to allocate the real and reactive power throughout power system obtaining optimal operating state that reduces cost and improves overall system efficiency. The economic dispatch problem reduces the system cost by allocating the real power among online generating units. In the economic dispatch problem the classical formulation presents deficiencies due to simplicity of models. Here, the power system modelled through the power balance equation and generators are modelled with smooth quadratic cost functions and generator output constraints.

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To improve power system studies, new models are continuously being developed that result in a more efficient system operation. Cost functions that consider valve point loadings, fuel switching, and prohibited operating zones as well as constraints that provide more accurate representation of system such as: emission, ramp rate limits, line flow limits, spinning reserve requirement and system voltage profile. The improved models generally increase the level of complexity of the optimization problem due to the non-linearity associated with them.

Traditional algorithms like lambda iteration, base point participation factor, gradient method, and Newton method can solve the ED problems effectively if and only if the fuel-cost curves of the generating units are piece-wise linear and monotonically increasing. The basic ED considers the power balance constraint apart from the generating capacity limits. However, a practical ED must take ramp rate limits, prohibited operating zones, valve point effects, and multi fuel options into consideration to provide the completeness for the ED formulation. The resulting ED is a non-convex optimization problem, which is a challenging one and cannot be solved by the traditional methods. Practical ED problems have nonlinear, non-convex type objective function with intense equality and inequality constraints. Recent advances in computation and the search for better results of complex optimization problems have fomented the development of techniques known as Evolutionary Algorithms. Evolutionary Algorithms are stochastic based optimization techniques that search for the solution of problems using a simplified model of the evolutionary process. These algorithms provide an alternative for obtaining global optimal solutions, especially in the presence of non-continuous, non-convex, highly solution spaces. These algorithms are population based techniques which explore the solution space randomly by using several candidate solutions instead of the single solution estimate used by many classical techniques. The success of evolutionary algorithms lies in the capability of finding solutions with random exploration of the feasible region rather than exploring the complete region. This result in a faster optimization process with lesser computational resources while maintaining the capability of finding global optima.The conventional optimization methods are not able to solve such problems due to local optimum solution convergence. Meta-heuristic optimization techniques especially Genetic Algorithms (GA) [3], Particle Swarm Optimization (PSO) [9], and Differential Evaluation (DE) [14], gained an incredible recognition as the solution algorithm for such type of ED problems in last decade.

II. ECONOMIC DISPATCH PROBLEM

The classical 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 classical economic dispatch is to minimize the total system cost where the total system cost is a function composed by the sum of the cost functions 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 objective of the classical economic dispatch is to minimize the total fuel cost by adjusting the power output of each of the generators connected to the grid. The total fuel cost is modelled as the sum of the cost function of each generator.

The basic economic dispatch problem can be described mathematically as a minimization of problem.

$$\text{Minimize Ft} = \sum_{i=1}^{n} F_i(P_i) \qquad \ldots(1)$$

Where F_i (P_i) is the fuel cost equation of the 'i'th plant. It is the variation of fuel cost in \$ with generated Power (MW).

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \qquad \ldots.(2)$$

The total fuel cost is to be minimized subject to the following constraints.

$$\sum_{i=1}^{n} P_i = P_d + P_l \qquad \ldots\ldots(3)$$

$$P_l = \sum_{i}^{n}\sum_{j}^{j} P_i B_{ij} P_j \qquad \ldots.(4)$$

$$P_i^{min} \le P_i \le P_i^{max} \qquad \ldots..(5)$$

Where

a_i, b_i, c_i : fuel cost coefficient of ith generator, \$/MW²h, \$/MW h, \$/h

$F_i(P_i)$: fuel cost of ith generator, \$/h

Ft ; total fuel cost, \$/h

n : number of generators

$P_{i\,max}$: maximum generation limit of ith generator, MW

$P_{i\,min}$: minimum generation limit of ith generator, MW

P_L : total system transmission loss, MW

P_d : system power demand, MW

III. THE FIREFLY ALGORITHM

The Firefly Algorithm (FA) is a Meta heuristic, nature-inspired, optimization algorithm which is based on the social flashing behavior of fireflies, or lighting bugs, in the summer sky in the tropical temperature regions. 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. In particular, although the firefly algorithm has many similarities with other algorithms which are based on the so-called swarm intelligence, such as the famous Particle Swarm Optimization (PSO) [9], and Artificial Bee Colony optimization (ABC) [15], algorithms it is indeed much simpler both in concept and implementation. Its main advantage is the fact that it uses mainly real random numbers, and it is based on the global communication among the swarming particles [i.e., the fireflies], and as a result, it seems more effective in optimization such as the ED problem in our case.

The FA has three particular idealized rules. They are

- All fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex.
- 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.
- The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. For maximization problems, the light intensity is proportional to the value of the objective function.

A. Algorithm

Step1: Read the system data such as cost coefficients, minimum and maximum power limits of all generator units, power demand and B-coefficients.

Step2: Initialize the parameters and constants of Firefly Algorithm. They are ***noff***, **α_{max}, α_{min}, β_0, γ_{min}, γ_{max} and *itermax*** (maximum number of iterations).

Step3: Generate ***noff*** number of fireflies (xi) randomly between λ_{min} and λ_{max}.

Step4: Set iteration count to 1.

Step5: Calculate the fitness values corresponding to ***noff*** number of fireflies.

Step6: Obtain the best fitness value ***GbestFV*** by comparing all the fitness values and also obtain the best firefly values ***GbestFF corresponding*** to the best fitness value ***GbestFV***.

Step7: Determine alpha (***α***) value of current iteration using the following equation: ***α (iter)*** = αmax - ((αmax - αmin) (current Iteration number)/ ***itermax***)

Step8: Determine the r_{ij} values of each firefly using the following equation: r_{ij}= ***GbestFV*** -**FV** r_{ij} is obtained by finding the difference between the best fitness value ***GbestFV*** (***GbestFV*** is the best fitness value i.e., jth firefly) and fitness value **FV** of the ith firefly.

Step9: New xi values are calculated for all the fireflies using the following equation:

$$xi_{new} = xi_{old} + \beta_0 * \exp(-\gamma\, r_{ij}^2 * (x_j - x_i) + \alpha\,(iter) * (rand - \tfrac{1}{2}) \qquad \ldots..(6)$$

In equation (6), β0 is the initial attractiveness γ is the absorption co-efficient rij is the difference between the best fitness value ***GbestFV*** and fitness value **FV** of the ith firefly. ***α (iter)*** is the randomization parameter (In this present work, ***α (iter)*** is set to 0.2) rand is the random number between 0 and 1.In this present work, x → λ

Step10: Iteration count is incremented and if iteration count is not reached maximum then go to step 5

Step11: ***GbestFF*** gives the optimal solution of the Economic Load Dispatch problem and the results are printed.

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

B. Pseudo code:

Objective function f(x), x = (x1,…,xd)T
Generate initial population of fireflies xi (i=1.., n)
Light intensity Ii at xi is determined by f(xi)
Define light absorption coefficient γ

while (t < *MaxGeneration*)
for i = 1*: n all n fireflies*
for j = 1*: i all n fireflies* if (*Ij* > *Ii*), *More firefly i towards j in d-dimension;* end if
Attractiveness varies with distance r via exp [-γr]
Evaluate new solutions and update light intensity
end for *j*
end for *i*
Rank the fireflies and find the current best
end while
Post process results and visualization

IV. SIMULATION RESULTS AND DISCUSSION

To solve the ED problem, we have implemented the FA in MATLAB and it was run on a computer with an Intel Core2 Duo (1.8GHz) processor, 3GB RAM memory and MS Windows XP as an operating system. Mathematical calculations and comparisons can be done very quickly and effectively with Mat lab and that is the reason that the proposed Firefly algorithm was implemented in Matlab programming environment. Since the performance of the proposed algorithm sometimes depends on input parameters, they should be carefully chosen. After several runs, the following input control parameters are found to be best for optimal performance of the proposed algorithm.

In this proposed method, we represent and associate each firefly 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 50. 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/without 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 IEEE - 30 Bus with six generator test system in the references. This power system is connected through 41 transmission lines and the demand 1263MW. The input and the cost coefficient of IEEE - 30 Bus with six generator test system are given in table 1. In this system SA, GA, PSO, DE, ABC, BBO & FA Algorithms were used in ED. In table 2, results obtained from proposed FA method has been compared with other methods. According to the result obtained using the FA for ED is more advantageous then other Algorithms. Power System with six generator test system, if ED is realized by using the FA and the total line loss is decreased.

Table 1: Generating unit capacity and coefficients

Unit	P_{min}	P_{max}	a_i	b_i	c_i
1	100	500	240	7.0	0.0070
2	50	200	200	10.0	0.0095
3	80	300	220	8.5	0.0090
4	50	150	200	11.0	0.0090
5	50	200	220	10.5	0.0080
6	50	120	190	12.0	0.0075

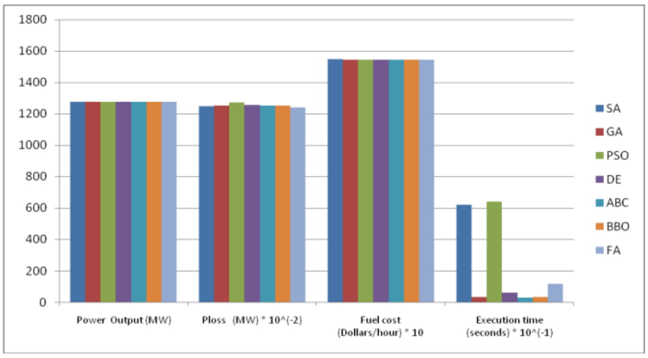

Fig-1 Comparison chart showing the power output, power loss fuel cost and execution time with various algorithms.

Table 2: Comparison table showing simulation results of various algorithms

Sl.No	Description	SA	GA	PSO	DE	ABC	BBO	FA
1.	P_1 (MW)	447.08	451.97	447.50	400.00	438.65	447.39	445.08
2.	P_2 (MW)	173.18	173.16	170.52	186.55	167.90	173.24	173.08
3.	P_3 (MW)	263.92	261.16	261.90	289.00	262.82	263.32	264.42
4.	P_4 (MW)	139.06	136.85	116.91	150.00	136.77	138.00	139.59
5.	P_5 (MW)	165.58	166.70	190.41	200.00	171.76	165.41	166.02
6.	P_6 (MW)	86.63	85.68	88.49	50.00	97.67	87.80	87.21
7.	Power Output (MW)	1275.47	1275.52	1275.73	1275.55	1275.57	1275.50	1275.40
8.	P_{loss} (MW)	12.47	12.52	12.73	12.55	12.52	12.50	12.40
9.	Fuel cost ($/hour)	15466.00	15458.00	15456.56	15452.00	15445.90	15443.09	15443.00
10.	Execution time(seconds)	62.02	3.18	64.09	6.20	2.82	3.02	11.52

V. CONCLUSION

The proposed FA to solve ED problem by considering the practical constraints has been presented in this paper. From the comparison table it is observed that the proposed algorithm exhibits a comparative performance with respect to other population based techniques. It is clear from the results that Biogeography Based Optimization 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 compared to the other methods. In future, the proposed FA can be used to solve ED with considering the valve point effects, which is still in the progress of the research work.

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