TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 2773 - 2777

Economic Dispatch of Thermal Units: A Comparison of PSO and JAYA Algorithms

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Article Info
Volume 82
Page Number: 2773 - 2777
Publication Issue:
January-February 2020

Article History
***Article Received**: 14 March 2019*
***Revised**: 27 May 2019*
***Accepted**: 16 October 2019*
***Publication**: 18 January 2020*

Abstract:
Economic load dispatch (ELD) problem becomes highly complex combinatorial exercise on account of satisfying various operational constraints pertaining to generator and transmission network. The introduction of non-convexity and discreteness in the fuel cost function owing to generator constraints has shifted the focus of researchers towards metaheuristic techniques while solving ELD problem. Metaheuristic techniques, however, usually suffer from hectic tuning of control parameters. Recently, JAYA algorithm is developed which is being free from control parameters. JAYA algorithm is derived from particle swarm optimization (PSO) which needs parameter tuning. Therefore, this paper presents a comparative study about PSO and JAYA algorithm when applied to solve multi-constrained hard combinatorial ELD problem. PSO and JAYA algorithms are investigated on a well-known large-scale optimization ELD problem of 40 generator test generating system. The results of study are presented.

Keywords:*Economic load dispatch, fuel cost minimization, JAYA algorithm, particle swarm optimization (PSO)*

I. INTRODUCTION

The economic operation of power system is one of the most important problem in the area of electrical engineering. The scarcity of available resources, mainly conventional fuels, ever increasing energy generation costs, increasing demand for electric power and the global warming of the earth's surface are some concerns for environment. The classical Economic Load Dispatch problem is generally formulated as an optimization problem where the objective is to minimize the total fuel cost with some inequality and equality constraints. Generally the fuel cost function is represented by a simple quadratic cost equation of the generators bundled with generators non-linear characteristics. Also, a set of inequality and equality constraints are also taken along with other equations for the function to be minimized [1]. There are various constraints in these optimization problems. Solution of mathematical equations with constraints need additional efforts. Some of the constraints are discussed here. Prohibited Operating Zones (POZs), ramp rate limits and valve-point loading effects etc. introduce discontinuities and non-linearity. The classical ELD methods are unable to handle such complex combinatorial problems. The modern meta-heuristic techniques have shown potential to handle such type of complex problems. These are Genetic Algorithm [2,3], Differential Evolution (DE), Particle Swarm Optimization [8], Ant Colony Optimization, Biogeography-Based Optimization (BBO), JAYA etc.

The GA has parallel search capabilities, which replicate natural genetic operations. But, the GA has slow execution speeds and it cannot assure constant optimization response times [2, 3].The Differential Evolution (DE) [4] is incapable of exploring the search space satisfactorily. The results move rapidly towards the optimum in the beginning but at the later period, when fine tuning is required, it fails to give better performance. Biogeography-Based Optimization (BBO) does not have significant search capability but has good exploitation capability in global optimization problem. Computational

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problems are solved using Ant Colony Optimization (ACO) [5] for finding good paths through graphs.

PSO is a meta-heuristic search method by which diverse engineering optimization problems are solved. It has the potential to find global optimization results. It works well with the discontinuous cost functions irrespective of the shape of the function [8]. Because of its simplicity, robustness and its convergence speed particle swam optimization is popular technique [8]. However, its performance is degraded when the tuning of the control parameters is not perfect. PSO is computationally demanding.

JAYA is relatively new algorithm developed by R Venkata Rao, 2015 [7]. It is parameter-less optimization algorithm and requires only general governing parameters such as population size and number of generations. Unconstrained and constrained optimization problems can be attempted by this method. The JAYA algorithm has not been fully explored [7]. This paper attempts to reinvestigate and to analyze the applicability of PSO and JAYA optimization algorithm for economic dispatch problems of thermal generating units under different operating conditions. Comparison of the two techniques has also been carried out on a well-known large-scale 40 generator test generating system to solve ELD problem. The results of comparison with recently established techniques are presented.

II. PSO AND JAYA ALGORITHMS

PSO is a swarm intelligence based mathematical optimization method which was introduced by Kennedy *et.al*. in 1995 [6]. The algorithm is initialized by selecting a random number tentative solution. In the area of problem search we find the solutions and called them particles. The single control equation of PSO provides movement of particles in N-dimensional search space which is being governed using inertia weight w_i that remains at constant positive number less than one during *i*th iteration and the acceleration constants c_1 and c_2, each usually has a value of 2 for the entire trial run. The control equation shown by (1) provides velocity control of particles using inertia constant, best experience of particle itself $X_{j,\text{pbest},I}$ which provides cognitive component and the best experience of the swarm $X_{j,\text{gbest},i}$ that provides social component.

$$X`_{j,k,i} = wiX_{j,k,i} + c_1 r_{1,j,i}(X_{j,\text{pbest},i} - \text{abs}(X_{j,k,i})) + c_2 r_{2,j,i}(X_{j,\text{gbest},i} - \text{abs}(X_{j,k,i})) \quad (1)$$

The algorithm runs for predefined iterations and the best solution obtained after the trial run declared as an optimal solution. For further details, Ref. [6] may be referred.

JAYA algorithm is a newly established metaheuristic optimization technique based on swarm intelligence. It is proposed by R. Venkata Rao [7] in 2016. The algorithm is fundamentally derived from PSO as can be seen from its flowchart shown in Fig. 1. Like PSO, JAYA algorithm is also governed by single control equation as given by (2). It can be observed by comparing (1) with (2) that the structure of control equation of JAYA algorithm is quite analogous to that of PSO.

$$X`_{j,k,i} = X_{j,k,i} + r_{1,j,i}(X_{j,\text{pbest},i} - \text{abs}(X_{j,k,i})) - r_{2,j,i}(X_{j,\text{worst},i} - \text{abs}(X_{j,k,i})) \quad (2)$$

However, the control equations are different on the following grounds

1. JAYA algorithm is free from control parameters, i.e. w_i, $c_1$and c_2
2. The method to mimic the social behavior is different in both the algorithms. PSO considers best experience of the swarm whereas JAYA considers worst experience of the group.
3. JAYA algorithm subtracts social and cognitive components but these components are added in particle swam optimization.

The above mentioned three fundamental differences in the control equation of these algorithms introduce marked difference in their exploration and exploitation potentials.

III. PROBLEM FORMULATION

The ED is one of the important issues in modern power system which determines optimal power

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dispatches of thermal generators to minimize fuel cost for the given load demand. ELD problem is formulated to minimize fuel cost of committed thermal generators while satisfying several equality and inequality constraints. The objective of ELD problem is to

$$Min\ F(P_{Gi}) = \sum_{i=1}^{N_G} a_i + b_i P_{Gi} + c_i P_{Gi}^2 + Mod\left(e_i \sin\left(f_i\left(P_{Gi}^{\min} - P_{Gi}\right)\right)\right) \quad (3)$$

Where cost coefficient are a_i,b_i,c_i and coefficient of valve point effect are e_i and f_i of the respective i^{th} generator.NG is the number of total generators and P_{Gi} is active power. Constraints considered are as follows:

1. Power balance constraint

$$\sum_{i=1}^{N_G} P_{Gi} = P_D \quad (4)$$

2. Generator constraints

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad (5)$$

In addition, the generator constraints pertaining to ramp rates and restricted operating area are also considered. The line losses are ignored.

IV. SIMULATION RESULTS

The proposed algorithm is tested on 40 generator test system which has been taken from [7]. The optimized parameters of PSO are taken from [8] as shown in Table I. The table presents that particle size NP and maximum iterations itrmax of PSO set for this system. JAYA algorithm also runs with the same NP and itrmax. PSO has been developed using the MATLAB. JAYA algorithm is developed by the help of MATLAB and we have used personal computer of specifications Intel i5, frequency of 3.2 GHz, RAM size of 4GB and all other termination criterion of maximum iteration count on both the PSO and JAYA were taken identical. Comparison results are presented which were obtained after 100 independent trials. The statistical analysis of 100 collected data solutions established using PSO and JAYA algorithms is described in Table II. The table compares best, mean and drub fuel cost of sampled results. Fuel cost should be minimum for these type of optimization problem. The table shows that JAYA algorithm is quite better than PSO. Comparison results are also presented for other algorithms, namely fuzzy adaptive PSO (FAPSO), new adaptive PSO (NAPSO) and Cuckoo Search Algorithm (CSA) and compared with JAYA. It is clear noticeable from the above table that JAYA algorithm yield comparable out comes with these techniques. However, mean CPU time of JAYA and PSO algorithms is found to be least than other algorithms. Thus JAYA algorithm is found to be efficient than PSO with the same computational burden.

Table I Optimum parameters used for PSO

c_1	c_2	w_{min}	w_{max}	N_P	itr_{max}
1.4	2.0	0.1	1.0	100	2500

Table II Comparison of PSO and JAYA algorithms

	Fuel cost ($/hr)			
Method	Best	Mean	Worst	Execution time(s)
PSO	124870.35	125160.72	126344.55	8.4
FAPSO[19]	122261.37	122471.08	122597.52	19.6
CSA[20]	121487.77	121611.32	122162.93	14.7
JAYA	121487.77	121498.32	121643.23	8.4
NAPSO[19]	121491.07	121491.28	122491.53	12.7

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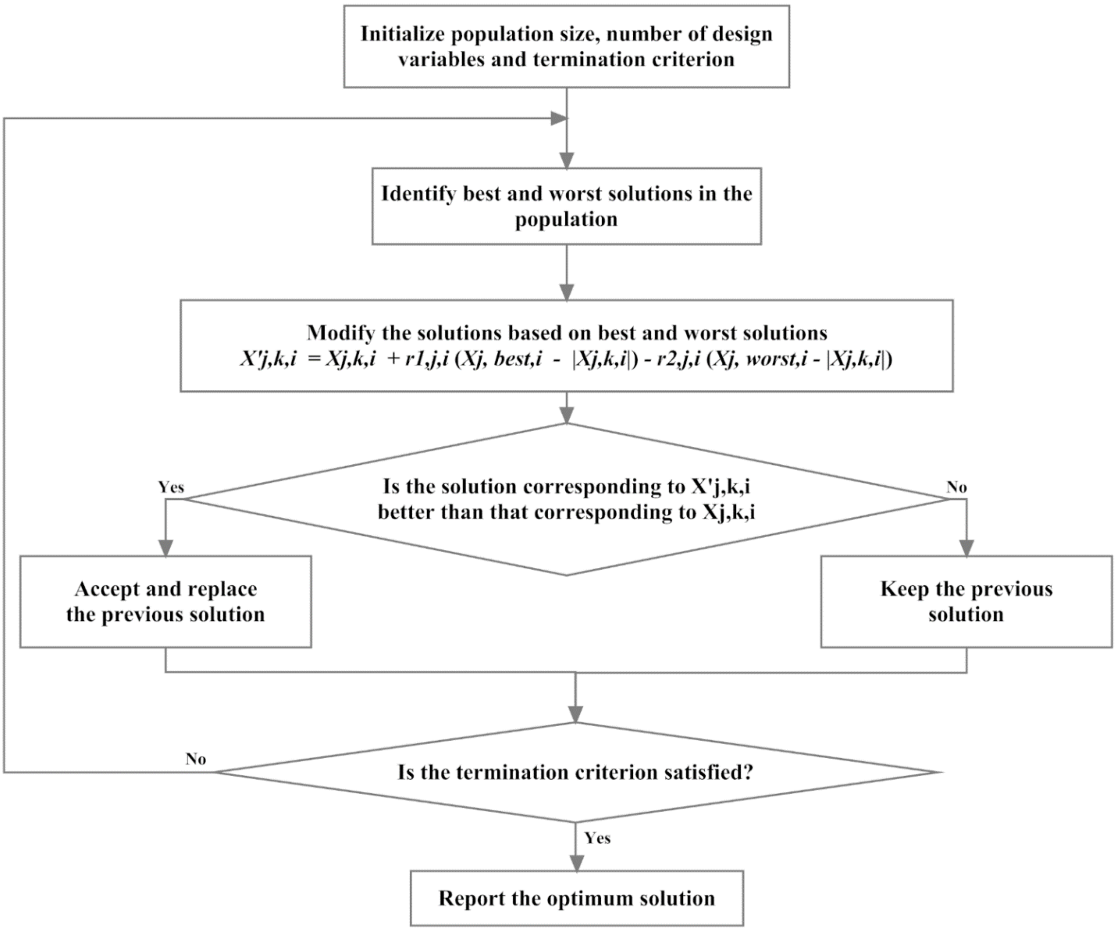

Fig. 1 Flowchart of JAYA algorithm

V. DISCUSSION

PSO and JAYA algorithms have similar ideology except the nature and modeling of social behavior of swarm. This makes fundamental difference in the philosophy of these two powerful swarm intelligence techniques. In PSO, particles follow the leader whereas individuals behave in an opposite way from the worst individual in JAYA algorithm. This makes difference in the exploration potential of these two algorithms. While algorithms are passing through anaphase, the mean distance from the best particle diminishes in PSO whereas it increased in JAYA. Therefore, social behavior becomes ineffective in PSO, but not in case of JAYA algorithm. This improved exploitation of search space avoids local trapping in JAYA which is quite prominent in PSO. Therefore, JAYA algorithm performs better than PSO, specifically for large-scale optimization.

VI. CONCLUSION

JAYA algorithm is also derive from PSO. JAYA is a recent algorithm which has proved its effectiveness for solving optimization techniques. This paper has presented a comparison of performance of these two optimization techniques while solving hard combinatorial ELD problem of power system. The algorithms are applied to large-scale 40 generator test system. The statistical analysis of 100 sample results shows that PSO is usually trapped in local minima whereas JAYA algorithm has capability to pull out of the hat. We conclude that the recently established JAYA algorithm is better than other metaheuristic techniques. Hence, we conclude that JAYA is a better tool to solve optimization problem of large size. It was also found to be computationally less burdensome. The algorithm is free from hectic parameter tuning makes it a class apart over other metaheuristics.

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