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DPD: An intelligent parallel hybrid algorithm for economic load dispatch problems with various practical constraints

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ABSTRACT

The Economic Load Dispatch (ELD) problem has attracted much attention in the field of electric power system. This paper proposes a novel parallel hybrid optimization methodology aimed at solving ELD problem with various generator constraints. The proposed approach combines the Differential Evolution (DE) and Particle Swarm Optimization (PSO). Initially the whole population (in increasing order of fitness) is divided into three groups - Inferior Group, Mid Group and Superior Group. DE is employed in the inferior and superior groups, whereas PSO is used in the mid-group. The proposed method is called DPD as it uses DE-PSO-DE on a population in parallel manner. Two strategies namely *Elitism* (to retain the best obtained values so far) and *Non-redundant search* (to improve the solution quality) have been employed in DPD cycle. Moreover, the suitable mutation strategy for both DEs used in DPD is investigated over a set of 8 popular mutation strategies. Combination of 8 mutation strategies generated 64 different variants of DPD. Top 4 DPDs are investigated through IEEE CEC 2006 functions. Based on the performance analysis, best DPD is reported and further used in solving four different typical test systems of ELD problem. Numerical and graphical results indicate the efficiency, convergence characteristic and robustness of proposed DPD.

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1. Introduction

Nowadays, with an increase in the need for electrical energy, ELD problem has become one of the most important issues in the power systems. However, considering ramp rate limits, valve point effects, prohibited operating zones, transmission losses, multi-fuels and spinning reserve in ELD makes it a non-convex optimization problem, which is a challenging one. In the past decades, many traditional methods such as gradient method, lambda iteration, base point participation, Newton methods and dynamic programming have been proposed to solve the ELD problem. These methods are unable to solve non-convex optimization problem (Wood & Wollenberg, 1996), due to computationally extensive, and suffers from 'curse of dimensionality' when involves with high number of variables (Shoults, Venkatesh, Helmick, Ward, & Lollar, 1986).

In the recent past, Evolutionary Algorithms (EAs) are proven to be very effective in solving ELD problem and provide a fast, reasonable nearly optimal solution. However, all those methods often provide fast and reasonable solutions but do not guarantee in obtaining the global optimal solutions. Moreover, according to 'No Free Lunch Theorem (Wolpert & Macready, 1997)', no single optimization method exist which is able to solve all global optimization problems, consistently. Among the members of the EAs family, Differential Evolution (DE) (Storn & Price, 1997) and Particle Swarm Optimization (PSO) (Kennedy & Eberhart, 1995) is a most powerful, robust and reliable techniques. However, the premature convergence of DE and PSO methods, when applied to solve the ELD problem, may trap into the local optimum, which may reduce their optimization ability.

Recently, hybrid algorithms are growing area of interest since their solution quality can be made better than the algorithms that form them by combining their desirable features. In fact, the hybrid techniques, being powerful, yields promising results in solving specific problems. Moreover, a vast number of DE and PSO hybrid methods (Das, Abraham, & Konar, 2008, Zhang, Ning, Lu, Ouyang, & Ding, 2009; Liu, Cai, & Wang, 2010; Parouha & Das, 2016; Sayah & Hamouda, 2013; Seyedmahmoudian et al., 2015; Thangaraj, Pant, Abraham, & Bouvry, 2011; Vasundhara, Kar, & Ghoshal, 2014; Wang, Yang, & Zhao, 2010; Xin, Chen, Zhang, Fang, & Peng, 2012; Zuo & Xiao, 2014) have emerged with diverse design ideas from many researchers. As a result both DE and PSO are capable to dominating the shortcoming of the each other and

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add the robustness in the resultant hybrid algorithm. All in all hybridization of DE and PSO (Das et al., 2008; Xin et al., 2012) is to take advantage of both algorithms for providing better solution. In such hybridizations, DE and PSO are used in the alternative generations during simulation. However, there has been a continuous modification in the operators and/or the way of applying them. Even, hybrid methods still have drawbacks such as choosing suitable parameter value and slow convergence to the final result for the large amount of procedural iterations when applied for complex optimization problems.

Moreover, parallelization is one of the best approaches that can be used to enhance the performance of EAs. Many parallel EAs (Asadzadeh, 2016; Elsayed, Sarker, & Essam, 2011; Han, Liao, Chang, & Lin, 2013; Kordestani, Rezvanian, & Meybodi, 2014; Kurdi, 2015; Li, Bi, Zhu, Yuana, & Zhang, 2016; Wang, Yang, & Zhao, 2010; Yadav & Deep 2014; Zhang, Cheng, Gheorghe, & Meng 2013) have been proposed and successfully applied in typical optimization problems. Hence, the parallel employment of EAs is more preferred over the sequential one (Das et al., 2008, Xin et al., 2012). The results reported in parallel approaches were promising and encouraging for further research in this direction.

To overcome premature convergence and to speed up the searching process, a novel parallel hybrid algorithm that integrates the DE and PSO is proposed to take advantage of them. The process of hybridization is being emphasized over a population in 'tri-population' environment and named as DE-PSO-DE (DPD). The proposed approach combines differential information obtained by DE with the memory information extracted by PSO to create the promising solution. Therefore, the proposed algorithm's possibility of finding global optimal point and the convergence speed is improved. The proposed approach has been tested on IEEE CEC 2006 with four different typical test systems on ELD problem. Moreover, the obtained results have been compared with some of the most recent expert and intelligent EAs. The obtained results show that the proposed method is efficient, robust and has potential for solving ELD problems.

The reminder of this paper is organized as follows: Section 2 presents the general formulation of the ELD problem. Section 3 provides an overview on DE and PSO. Section 4 presents constrained handling technique. The proposed algorithm is described along with the selection of best suit mutation operators for DEs employed in the proposed algorithm, in Section 5. Section 6 includes comparison of DPD with latest existing algorithms for constrained functions. Implementation of DPD on ELD problem with four different Test Systems presented in Section 7. Finally, conclusion of the present work and future research directions is drawn in Section 8.

2. Economic load dispatch problem

The objective of the ELD problem is to determine the optimal output power of a scheduled generator that minimizes the total generation cost (Fc) given as follows.

$$\text{minimize } F_c = \sum_{i=1}^{N} F_i(P_i) \tag{1}$$

Where, traditionally the fuel cost of the generating units is represented in smooth quadratic polynomial function as follows:

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

where F_i- fuel cost function of the ith generator ($/h), N - number of online generating units, P_i - power of generator i and $a_{i,}$ b_i and c_i - cost coefficients of a generator i.

When valve point effect is considered, generation cost function in (2) is added with rectified sinusoidal function to obtain an accurate ELD modeling. Therefore, (2) can be modified as follows.

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_i sin(f_i(P_i^{min} - P_i)) \right| \tag{3}$$

where e_i and f_i - coefficients of generator i reflecting valve point effects and $P_i{}^{min}$ - minimum generation limit of unit i.

In many practical situations, there are some generating units supplied with multiple fuels. Modeling multi-fuel effect makes the ELD problem non-smooth and more complicated. The cost function of a unit with multiple fuels is a superposition of this piecewise quadratic function as follows:

$$F_i(P_i) = a_{ij} P_i^2 + b_{ij} P_i + c_{ij} + \left| e_{ij} sin(f_{ij}(P_i^{min} - P_i)) \right|$$
$$\text{if } P_{i,j}^{min} \le P_i \le P_{i,j}^{max},\ j = 1, \ldots\ldots, nf \tag{4}$$

where i – index of unit; j – index of fuel type; a_{ij}, b_{ij}, c_{ij}, e_{ij} and f_{ij} – Cost coefficients of the unit i for fuel type j; $P_{i,j}^{min}$ and $P_{i,j}^{max}$ - minimum and maximum power output of unit i with fuel option j respectively and nf - number of fuel types for each unit.

2.1. Problem constraints

The equality and inequality constraints that must be satisfied during the ELD optimization process are given as follows:

2.1.1. Power balance constraint

The total power generated should be equal to total power demand and transmission loss as follows:

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

whereP_D - Total real power demand, P_L - Total transmission loss

The transmission loss can be calculated by using B coefficient approach as follows:

$$\sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} = P_L$$

where, B_{ij} - ijth element of loss coefficient symmetric matrix B, B_{0i} - ith element of the loss coefficient vector, B_{00} - loss coefficient constant.

2.1.2. Generator constraints

Each unit has a generation range which is represented as follows, $P_i^{min} \le P \le P_i^{max}$; where $P_i{}^{min}$ and $P_i{}^{max}$ are the minimum and maximum limits of real power output for unit i.

2.1.3. Ramp rate limits

The effective generator limit with the presence ramp rate limits can be written as follows:

$$\max(P_i^{min}, P_i^0 - DR_i) \le P_i \le \min(P_i^{max}, P_i^0 + UR_i)$$

where P_i - current real output power of ith generator (MW), P^0 - previous real output power of ith generator (MW), DR_i - upper ramp rate limits of ith generator (MW/time period), UR_i - lower ramp rate limits of ith generator (MW/time period)

2.1.4. Prohibited operating zones

A generation unit with prohibited operating zones (POZs) has discontinuous fuel cost characteristics. The concept of POZs is considered as the following constraint in the ELD:

$$\begin{cases} P_i^{min} \le P_i \le P_{i,1}^{L} \\ P_{i,k-1}^{U} \le P_i \le P_{i,k}^{L} \quad k = 2, 3, \ldots\ldots, nz \\ P_{i,nz}^{U} \le P_i \le P_i^{max} \end{cases}$$

where $P_{i,k}^{L}$ and $P_{i,k}^{U}$ are the lower and upper limits of POZ of generator i in (MW) respectively and nz is the number of POZs of ith generator.

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