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A novel hybrid optimizer for solving Economic Load Dispatch problem

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ABSTRACT

Economic Load Dispatch (ELD) is one of the major concerns to show the potential and effectiveness of an optimization algorithm. In this context, a novel hybrid algorithm of Differential Evolution (DE) and Particle Swarm Optimization (PSO) proposed. It is based on 'tri-population' environment. 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 abbreviated as DPD because it uses DE–PSO–DE on a population. 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. Many mutation strategies of DE have emerged in the last couple of years. However, its actual ability has not been well studied yet because every mutation strategy has its own pros and cons. Therefore suitable mutation strategy for both DEs used in DPD is investigated over a set of 8 popular mutation strategies. Combination of 8 mutation strategies is generated 64 different variants of DPD. Top 4 DPDs are investigated through CEC 2006 functions out of 64 different variants of DPDs. Based on the 'performance' analysis best DPD is reported using CEC 2006 and 5 Engineering Design Problems. Further best DPD is considered for solving ELD problem. Results reveal that the superiority of the proposed DPD.

Introduction

Economic Load Dispatch (ELD) problem is one of the important problems in the operation of 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 and cannot be solved by traditional methods. There are many studies on solving ELD problem using evolutionary algorithms (EAs). In recent years, Differential Evolution (DE) [1] and Particle Swarm Optimization (PSO) [2] is an efficient variant of EAs for solving ELD problem. Because of the individual shortcomings of each of DE and PSO, the solution leads to a premature convergence or getting stack in some local optima. These EAs do not always guarantee discovering the globally optimal solution in a finite time, they often provide a fast and reasonable solution (sub-optimal, nearly global optimal). Unfortunately, according to 'No Free Lunch Theorem [3]', no single optimization method exist which is able to solve all global optimization problems, consistently. Therefore number of attempts to solve optimization problems, while hybrid algorithms have shown outstanding reliability and efficiency to solve these problems. In fact, the hybrid techniques, being powerful, yields promising results in solving specific problems.

The first hybridized algorithm between DE and PSO was reported by Hendtlass [4] and successfully applied in unconstrained global optimization problem. Later, many hybrids of DE and PSO [5–23] have been emerged with diverse design ideas. These approach moves around the enhancement of capabilities of DE and PSO in various aspects and successfully applied to solve global optimization problems with its applications such as, Image Processing [6], Engineering Design Problems [11–13], Data Clustering [14], Optimal Well Placement Problem [15], and Economic Load Dispatch (ELD) problem [19–23]. In such hybridizations, DE and PSO are used in the alternative generations during simulation. Similarly, DE/PSO have been hybridized with other heuristic techniques [24–29] and successfully applied to solve ELD problem. All in all hybridization of DE and PSO [30–32] is to take advantage of both algorithms for providing better solution, simultaneously. However, there has been a continuous modification in the operators and/or the way of applying them.

In recent years, parallel employment of DE and PSO is preferred over the sequential one. Here parallel means, DE and PSO are used simultaneously on different part of the same population.

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Kordestani et al. [33] presented a bi-population based hybrid approach (CDEPSO) for dynamic optimization problems. In this paper, the first population uses CDE (Crowding-based DE) and the second population uses PSO. The first population is responsible for locating multiple promising areas of the search space and preserving a certain level of diversity throughout the run. The second population is exploiting to useful information in the vicinity of the best position found by the first population. Elsayed et al. [34] presented two methods (i) Self-Adaptive Multi-Operator Genetic Algorithm (SAMO-GA) and (ii) Self-Adaptive Multi-Operator Differential Evolution (SAMO-DE). Both methods start with a random initial population which is divided into four subpopulations of equal size and applied to solve constrained benchmark functions. Authors conclude that the concept of population breakup mechanism retains stronger diversity and the performance of SAMO-DE is better than SAMO-GA. Zhang et al. [35] presents a hybrid approach (DETPS) based on a tissue P system and DE. In DETPS, initial population divided into five groups. Each Five groups of individuals are put inside five cells of tissue P systems respectively with specify five variants of DE. The uses of five variants of DE in five cells of tissue P system produce good balance between exploration and exploitation. DETPS is successfully applied to solve constrained optimization problems. Yadav and Deep [36] proposed a new co-swarm PSO (CSHPSO) for constrained optimization problems. It is formed by hybridizing the shrinking hyper-sphere PSO (SHPSO) with the DE approach. Initially, the total swarm is subdivided into two sub-swarms. The first sub-swarm uses SHPSO and second sub-swarm uses DE. CSHPSO is successfully applied on constrained benchmark and power system optimization problem. Cagnina et al. [37,38] proposed a dual population based technique which is able to overcome premature convergence. In order to maintain a good balance between local and global search ability, Han et al. [39], proposed a dynamic group-based DE using a self-adaptive (1/5th rule) strategy. It is based on partitioning the population into two parts in order to apply two different mutation strategies of DE. Authors claimed that it has both exploitation and exploration abilities. Wang et al. [40] proposed a hybrid technique with a tri-break-up population based mechanism. It maintains three subpopulations to use classical PSO and two DE variants, respectively. The three subpopulations share the global best solution during simulation.

Based on the earlier work and inspired by the recent works on subpopulation concept, a further study is being carried out in this paper to improve the robustness of the hybridization of DE and PSO in a different fashion. In this present study, the process of hybridization is being emphasized over a population in 'tri-population' environment. The novel hybrid algorithm thus proposed is named as DE–PSO–DE (called DPD) for Economic Load Dispatch problem.

The reminder of this paper is organized as follows: Section 'Economic Load Dispatch (ELD) problem' presents the general formulation of the ELD problem. Section 'Brief on DE and PSO' present brief reviews of DE and PSO. Section 'Constraint handling method' presents constraint handling method used in this present study. The proposed algorithm is described along with the selection of best suit mutation operators for DEs employed in the proposed algorithm, in Section 'Proposed DPD and the selection of DE-mutation-strategies'. Section 'Illustrate the efficiency of DPD with latest existing algorithms' includes comparison of DPD with latest existing algorithms for CEC 2006 constrained benchmark functions and engineering design problems. Implementation of DPD for ELD problem presented in Section 'Impleme ntation of DPD for ELD problem'. Finally, conclusion is drawn in Section 'Conclusion'.

Economic Load Dispatch (ELD) problem

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

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

where traditionally, the fuel cost of the generating units is represented in smooth quadratic polynomial function [23] given by

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

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:

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

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:

$$F_i(P_i) = a_{ij} P_i^2 + b_{ij} P_i + c_{ij} + \left| e_{ij} sin\left(f_{ij}\left(P_i^{min} - P_i\right)\right)\right| \tag{4}$$

$$\text{if} \quad P_{i,j}^{min} \leqslant P_i \leqslant P_{i,j}^{max}, \quad j = 1, \ldots\ldots, nf$$

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.

Problem constraints

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

Power balance constraint

The total power generated should be equal to total power demand and transmission loss,

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

where P_D – total real power demand and P_L – total transmission loss

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

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

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

Generator constraints

Each unit has a generation range which is represented as

$$P_i^{min} \leqslant P_i \leqslant P_i^{max}$$