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A new rooted tree optimization algorithm for economic dispatch with valve-point effect

Yacine Labbi [a,b,*], Djilani Ben Attous [a], Hossam A. Gabbar [b], Belkacem Mahdad [c], Aboelsood Zidan [b]

[a] University of El-Oued, Department of Electrical Engineering, El-Oued, Algeria
[b] Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, UOIT, ON, Canada
[c] Department of Electrical Engineering, University of Biskra, Biskra, Algeria

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ABSTRACT

This work proposes a new optimization method called root tree optimization algorithm (RTO). The robustness and efficiency of the proposed RTO algorithm is validated on a 23 standard benchmark nonlinear functions and compared with well-known methods by addressing the same problem. Simulation results show effectiveness of the proposed RTO algorithm in term of solution quality and convergence characteristics. In order to evaluate the effectiveness of the proposed method, 3-unit, 30 Bus IEEE, 13-unit and 15-units are used as case studies with incremental fuel cost functions. The constraints include ramp rate limits, prohibited operating zones and the valve point effect. These constraints make the economic dispatch (ED) problem a non-convex minimization problem with constraints. Simulation results obtained by the proposed algorithm are compared with the results obtained using other methods available in the literature. Based on the numerical results, the proposed RTO algorithm is able to provide better solutions than other reported techniques in terms of fuel cost and robustness.

1. Introduction

Economic dispatch (ED) is one of the essential operational planning problems in power engineering [1]. ED aims to schedule the committed generating units' outputs in order to meet the load demand at minimum operating cost while satisfying system constraints [2–4]. In the past twenty years, many researchers have been used heuristic optimization and conventional mathematical techniques to solve ED problem in power systems [5–15]. Artificial intelligence started to be oriented to the simulation of nature (e.g., to the way how the human brain functions and the human operations thinking). Consequently, a new branch of artificial intelligence has emerged which studies and designs intelligent implements in order to adapt intelligently with their environment and to show a cognitive behavior. Thus, a decision can be taken through the recuperation of the acquired information. This intelligence considers the human beings as an example of these implements. The arithmetic intelligence includes the evaluating computing, fuzzy computing and the neural computing [16,17].

By the beginning of ninetieth, researches started to simulate other creatures with limited capacities such as pants, birds, and fishes that show a clever social behavior. In 1990, Dorigo suggested an algorithm of ant colony optimization (ACO) which simulates the ants settlements [18]. In 1995, Kennedy and Eberhart suggested an algorithm of practical swarm optimization (PSO) that depends totally on the simulation of birds swarms [19]. PSO and ACO were a starting point for a new branch of the swarm intelligence (SI). The most important characteristics of these new branches are their dependence on digital treatment as they are not based on mathematical knowledge. They are considered as complex algorithms composed of specific steps with known start and end points which lead to problem solving. Even with the great enhancement of computing capacities, still there are challenging problems. Fortunately, many sensitive research algorithms are developed to find suitable solutions for those problems at a reasonable time. They are developed according to the evolution of physiology and biology. Examples are genetic algorithm (GA) and simulated annealing (SA), these techniques are used to solve many problems widely [20–22].

This work proposes a new algorithm that is called rooted tree optimization (RTO) as its concept is extracted from the movement of plant roots while looking for the nearest place of water. RTO algorithm mimics the behavior of desert plants where the water resources are lacked. If vegetal/biologists scientists allow, we can say that a desert plant roots smell the places of water (intuitive behavior) around it, where these places present the optimal solution. To determine water places, a group of roots which oriented

* Corresponding author at: University of El-Oued, Department of Electrical Engineering, P.O. Box 789, 39000, El-Oued, Algeria.
E-mail addresses: yacine-labbi@univ-eloued.dz, yacinelabbi@gmail.com (Y. Labbi).

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by a special conducting are used. Therefore, this work attempts to introduce an algorithm (RTO) based on that intuitive behavior which leads to water locations and has an oriented movement while looking for the best solution.

RTO starts its search with a random set of solutions (group of roots). Each population member is evaluated based on a given objective function and assigned with its fitness value. Best candidate solutions are forwarded for the next generation/iteration while others are discarded and compensated by new set of random solutions in each generation. Far solutions from water places are omitted and replaced by new roots oriented randomly (they can be replaced by roots closer to the best root of the previous generation). The stopping criterion is the completion of a maximum number of cycles or generations. At the end of the cycles, the solution with the best fitness will be the desired solution.

The main aim of this study is to present the use of the RTO algorithm to the subject of ED in power systems. Thus, the RTO algorithm has been proposed and applied to solve the ED problem for 3, 6, 13 and 15-units test systems. Furthermore, the valve-point effect, the prohibited operating zones, ramp rate limits constraints, and transmission network losses have been considered. The results obtained with the proposed RTO algorithm were analyzed and compared other with optimization results reported in literature. The reminder of this paper is organized as follows: Section 2 presents the mathematical formulation of ED problem considering various constraints. RTO concept and its application is explained in Section 3. The parameter settings for the test system to evaluate the performance of RTO and the results are discussed in Sections 4 and 5. The conclusion is drawn in Section 6.

2. Formulation of ED problem

ED problem is an optimization problem to determine the schedule of real power outputs of generating units subjected to the real power balance with load demand as well as limits on generators' outputs. The mathematical formulation of the problem can be defined as follows:

$$\min\ F = \sum_{i=1}^{N} F_i(P_i) \tag{1}$$

where F_i is the total fuel cost of the generator units, which is defined by:

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

where $a_i,\ b_i$ and c_i are cost coefficients of generator i and P_i is subject to power balance constraints:

$$\sum_{i=1}^{N} P_i - P_D - P_L = 0 \tag{3}$$

where P_D is the system load demand and P_L is the transmission network loss. The transmission loss may be expressed using β-coefficients as

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i \cdot \beta_{ij} \cdot P_j + \sum_{i=1}^{N} \beta_{oi} \cdot P_i + \beta_{oo} MW \tag{4}$$

where β_{ij}, β_{oi}, β_{oo} are the elements of loss coefficient, the output of each generator must be within its limits:

$$P_i^{\min} \leqslant P_i \leqslant P_i^{\max} \quad \forall i = 1, 2, 3, \ldots, N \tag{5}$$

2.1. ED with valve-point loading effects

The inclusion of valve-point loading effect makes the modeling of the incremental fuel cost function of generators more practical. It increases the non-linearity as well as the number of local optima in the solution space. The incremental fuel cost function of the generating units with valve-point loadings are represented [2,7,8] as follows:

$$\tilde{F}_i(P_i) = F_i(P_i) + \left| e_i \times \sin(f_i \times (P_i^{\min} - P_i)) \right| \tag{6}$$

$$\tilde{F}_i(P_i) = a_i \times P_i^2 + a_i \times P_i + c_i + \left| e_i \times \sin(f_i \times (P_i^{\min} - P_i)) \right| \tag{7}$$

where e_i and f_i are constants of the valve-point effect of generators. Therefore, the total fuel cost to be minimized is represented in Eq. (7) [11]:

$$\min\ F = \sum_{i=1}^{N} \tilde{F}_i(P_i) \tag{8}$$

where $\tilde{F}_i$ is the cost function of ith generator in (\$/h).

2.2. ED with prohibited operating zones and ramp rate limits constraints

Here the objective function is to be minimized subject to the following constraints.

- *Real Power Balance Constraint/Generator Capacity Constraints:* The real power balance constraint remains the same as in (3). Also, the output of each generator must be within its limits as given in (5).
- *Ramp Rate Limit Constraints:* The power generated, $P_{i,(t-1)}$, by the ith generator in certain interval may not exceed that of previous interval by $P_{i,(t-1)}$ more than a certain amount UR_i, the up-ramp limit and neither may it be less than that of the previous interval by more than some amount DR_i the down-ramp limit of the generator. These give rise to the following constraints.
  Generating unit ramp-rate limits:
  $$\begin{aligned} P_{i,t} - P_{i,(t-1)} &\leqslant UR_i, \quad i = 1, 2, \ldots, N \\ P_{i,(t-1)} - P_{i,t} &\leqslant DR_i, \quad i = 1, 2, \ldots, N \end{aligned} \tag{9}$$
  where UR_i and DR_i are ramp-up and ramp-down rate limits of ith unit, respectively and are expressed in MW/h.
- *Prohibited operating zones constraint:* In practical operations, generated output P_i of unit i must avoid operations in prohibited zones. The feasible operating zones of unit i can be described as
  $$\begin{aligned} &P_{\min,i} \leqslant P_i \leqslant P_{i,l}^{L} \text{ or} \\ &P_{i,k-1}^{U} \leqslant P_i \leqslant P_{i,k}^{L}\ k = 2, \ldots, n_i \text{ or} \\ &P_{i,n_i}^{U} \leqslant P_i \leqslant P_{\max,i} \end{aligned} \tag{10}$$
  where n_i is the number of prohibited zones for unit i, k index of prohibited zones of a unit and $P_{i,k-1}^{U/L}$ are the lower/upper bounds of the kth prohibited zones of unit i.

3. Rooted tree optimization algorithm (RTO)

3.1. Roots look for water

One root has limited capacity, but a group of roots can find together the best place to get water, and the majority of them are located around this place or around the way that links the plant with the resource of water. To create the algorithm, a hypothetical behavior has been added which is the way how roots decide together to choose their orientation according to the wetness degree where the root head is located. These roots move randomly