Energy Conversion and Management 52 (2011) 2854–2860

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

An effortless hybrid method to solve economic load dispatch problem in power systems

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ARTICLE INFO

Article history:
Received 28 April 2010
Accepted 28 February 2011
Available online 4 May 2011

Keywords:
Economic dispatch
Prohibited operating zones
Ramp rate limits
Network loss

ABSTRACT

This paper proposes a new approach and coding scheme for solving economic dispatch problems (ED) in power systems through an effortless hybrid method (EHM). This novel coding scheme can effectively prevent futile searching and also prevents obtaining infeasible solutions through the application of stochastic search methods, consequently dramatically improves search efficiency and solution quality. The dominant constraint of an economic dispatch problem is power balance. The operational constraints, such as generation limitations, ramp rate limits, prohibited operating zones (POZ), network loss are considered for practical operation. Firstly, in the EHM procedure, the output of generator is obtained with a lambda iteration method and without considering POZ and later in a genetic based algorithm this constraint is satisfied. To demonstrate its efficiency, feasibility and fastness, the EHM algorithm was applied to solve constrained ED problems of power systems with 6 and 15 units. The simulation results obtained from the EHM were compared to those achieved from previous literature in terms of solution quality and computational efficiency. Results reveal that the superiority of this method in both aspects of financial and CPU time.

1. Introduction

According to fast growing power demand associated with the fuel cost increase, economic load dispatch (ED) has been become a crucial issue in power system operation. The main objective of ED is to determine the scheduling of all online units with minimum total operating cost over an appropriate period (usually 1 h) which is subject to load demand and operational constraints. As ED is used in real-time energy management such as unit commitment [1], it has been seen as the kernel of a power system. With such importance schemes in ED, it has received an increasing attention. The ED basically considers the power balance constraint besides the generating capacity limits. However, in a practical ED, ramp rate limits as well as prohibited operating zones, valve-point effects, and multi-fuel options must taken into account. The resulting ED is a non-convex, nonlinear problem which finding an optimal solution for it is very hard and complicated. A typical thermal unit may have a POZ due to steam valve operation or a vibration in a shaft bearing, which may yield to a discontinues input–output performance curve sections [2]. Moreover, in practical operations each unit has a change restriction in generation output called ramp rate limit.

In the previous literatures various mathematical programming and optimization techniques have been used. Classical methods are based on the assumption that the incremental cost of generator monotonically increases [3]. These classical methods include the base point and participation factor, gradient method (GM), lambda iteration (Li), and the Newton–Raphson method (NR) [4–8]. Some other traditional mathematical optimization techniques include linear programming (LP) [9], nonlinear programming (NLP) [10], Lagrangian relaxation (LR) [11], quadratic programming (QP) [12], and dynamic programming (DP) [13]. Nonlinear feature of generators in practical aspects is the main reason that generally a classical optimization technique may not be able to find a solution with a significant computational time for medium or large-scale ED problem and on the other hand these techniques may further being restricted by their lack of robustness and efficiency in a number of practical limitations. Accordingly, these limitations are redounded to introduce the heuristic optimization methods [14]. With the emergence of metaheuristic and evolutionary algorithm in modern optimization technique, the following methods have been used to solve the ED problem including simulated annealing (SA) [15], genetic algorithm (GA) [16,17], evolutionary programming (EP) [18,19], particle swarm optimization (PSO) [20,21], Tabu search (TS) [22], and differential evolution (DE) [23]. The hybrid methods are also applied to handle more

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doi:10.1016/j.enconman.2011.02.018

complicated constraints, and are claimed to have a better performance. In one hand, evolutionary algorithms may seem simple but their solution might be suboptimal and on the other hand, they might be complicated with more accurate results. Hybrid methods including fuzzy adaptive PSO algorithm with Nelder–Mead simplex search (FAPSO–NM) [3], hybrid PSO and sequential quadratic programming (PSO–SQP) [24], hybrid EP and sequential quadratic programming (EP–SQP) [25], and hybrid DE and sequential quadratic programming (DE–SQP) [26].

In this paper a hybrid method is used to determine generators' output economically, where a GA as a heuristic technique has been combined with a lambda iteration method. Exactly a two step approach is used to determine the optimal output of generators having prohibited zones. In the first step, it determines the optimum dispatch without considering prohibited operating zones. If all the units are within allowable limits, the optimal dispatch is obtained and this is the final result. If any or all of the units are caught within prohibited zones, GA will check the status of units in order to receive an optimal solution in the second step where the power outputs are out of the prohibited zones and within the legal range. Firstly, the outputs of such generators are set to upper or lower limits of prohibited zones, then an ED determines the optimal output of generators once more when those statuses that are feasible are selected, therefore, this approach will be continued till it becomes optimum and gives a feasible solution. Results show that this method is faster and more efficient than other studies.

The present paper is organized as follows: Section 2 formulates the ED problem. The methodology used is explained in detail in Section 3. Case studies with various number of generator units are presented in Sections 4 and 5 concludes the paper.

2. Problem formulation

The objective of ED as the kernel of power system is to minimize the total operating costs of a power system over an appropriate period (usually 1 h which is subject to satisfy various constraints. ED is a nonlinear optimization problem containing hard (equality) and soft (inequality) constraints. Practical constraints of generators include ramp rate limits, maximum and minimum limits, and prohibited operating zones. The cost function of generating units and the major component of the operating costs for thermal units are generally given in a quadratic polynomial as it is shown in Eq. (1). Operating cost coefficients can be given or estimated using bidding strategies

$$Min\ F = \sum_{i=1}^{N} F_i(P_i) = \sum_{i=1}^{N} a_i + b_i P_i + c_i P_i^2 \tag{1}$$

where F is the system overall cost function in quadratic form, N the number of generators, P_i the power generation of unit i and a_i, b_i and c_i are the fuel-cost coefficients of generator i. The minimization of the objective function is subject to a number of system and unit constraints such as: power balance, spinning reserve capacity of generating units, prohibited operating zones, minimum up/down time limit as well as spinning reserve requirement. Initial conditions are needed to be considered in ED problem.

2.1. Power balance

The real power generated must be sufficient enough to meet the load demand and network loss which is an equality constraint. In others words, this constraint has a main role to appease customers

$$\sum_{i=1}^{N} P_i = P_D + P_L \tag{2}$$

where P_D is total power system demand, P_L the total system transmission losses. B coefficient method is commonly used to get the network loss as it is shown in the following:

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \tag{3}$$

where is the ijth element of the loss coefficient matrix, P_i and P_j are the active power generation of generator i and j respectively, B_{0i} the ith element of the loss coefficient vector, and B_{00} is the loss coefficient constant.

2.2. Real power output of generator

$$P_i^{\min} \leqslant P_i \leqslant P_i^{\max} \tag{4}$$

where $P_i^{\min}$ and P_i^{max} are the minimum and maximum generation limit (MW) of ith generator respectively.

2.3. Ramp rate limits

The operating range of units is restricted by their ramp rate limits during each dispatch period. Consequently the power output of a practical generator cannot be varied instantaneously beyond the range as it is shown in the following:

$$P_i - P_i^o \leqslant DR_i,\ if\ generation\ decrease \tag{5}$$

$$P_i^o - P_i \leqslant UR_i,\ if\ generation\ increase \tag{6}$$

where P_i^o is the previous operating point of generator i, DR_i and UR_i are the down and up rate limits of the generator i. From Eqs. (4)–(6) the output power can be obtained as follows

$$\max(P_i^{\min}, P_i^o - DR_i) \leqslant P_i \leqslant \min(P_i^{\max}, P_i^o + UR_i) \tag{7}$$

2.4. Prohibited operating zone and generation limits

A typical thermal unit can have a discontinued fuel cost characteristic when it contains a prohibited operating zone. Prohibited zones are either because of vibrations in the shaft bearing caused by a steam valve or due to the associated auxiliary equipment such as boiler or feed pumps. In practical operation, adjusting the power output of a unit must be out of prohibited zones. The feasible operating zones of a unit can be described as follows:

$$\begin{array}{l} P_i^{\min} \leqslant P_i \leqslant P_{i,1}^l \\ P_{i,k-1}^u \leqslant P_i \leqslant P_{i,k}^l\ , \quad k = 2, \ldots, pz_i \\ P_{i,pz_i}^u \leqslant P_i \leqslant P_i^{\max} \end{array} \tag{8}$$

where $P_{i,k}^l$ and $P_{i,k}^u$ are the lower and upper bounds of the kth prohibited zone of unit i, respectively, k is the index of prohibited zones (pz_i).

3. Proposed approach

The proposed approach consists of two main efforts (E1 and E2) and the various steps involved in the proposed approach are as follows via a simple example:

Example 1. A 4-unit system: the load demand in the scheduling hour is set at 170 MW. Data for this example are given in Table 1.

This example tries to explain the proposed approach, where the mentioned data is not real and the objective is to consider different statuses that may happen in a real dispatch. At each step, outputs will be different to explain that step.