Electrical Power and Energy Systems 69 (2015) 18–26

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

A hybrid genetic algorithm and bacterial foraging approach for dynamic economic dispatch problem

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ARTICLE INFO

Article history:
Received 24 March 2014
Received in revised form 6 December 2014
Accepted 31 December 2014
Available online 17 January 2015

Keywords:
Dynamic economic dispatch
Hybrid genetic algorithm and bacterial foraging approach
Valve-point effects
Transmission losses
Ramp-rate constraints

ABSTRACT

Dynamic economic dispatch (DED) is one of the most significant non-linear complicated problems showing non-convex characteristic in power systems. This is due to the effect of valve-points in the generating units' cost functions, the ramp-rate limits and transmission losses. Hence, proposing an effective solution method for this optimization problem is of great interest. The original bacterial foraging (BF) optimization algorithm suffers from poor convergence characteristics for larger constrained problems. To overcome this drawback, a hybrid genetic algorithm and bacterial foraging (HGABF) approach is presented in this paper to solve the dynamic economic dispatch problem considering valve-point effects, ramp-rate limits and transmission losses. The HGABF approach can be derived by integrating BF algorithm and genetic algorithm (GA), so that the BF's drawback can be treated before employing it to solve the complex and high dimensioned search space of the DED problem. To illustrate the effectiveness of the HGABF approach, several test systems with different numbers of generating units are used. The results of HGABF approach are compared with those obtained by other published methods employing same test systems. These results show the effectiveness and the superiority of the introduced method over other published methods.

Introduction

The optimal operation of electrical power systems should be characterized by high degree of economy, reliability and security. The economic dispatch (ED) represents one of the basic functions of power system operation, especially with the increase in cost of different fuel types [1]. The main target of ED of electric power generation is to schedule the outputs of committed generating unit and to meet the load demand at a certain time at minimum operating cost while satisfying load balance and other system constraints [2]. Therefore, the ED problem is considered as a large-scale highly constrained nonlinear optimization problem [3].

In general, economic dispatch of a power system can be categorized into static economic dispatch (SED) and dynamic economic dispatch (DED). The former one optimizes the total fuel cost in general in a specified time. The SED does not take into account the fundamental relation of systems between the different operating times. While, the DED takes into account the connection of different operating times by considering ramp-rate constraints [4].

DED is one of the major optimization issues in power system operations which used to obtain the optimal operation schedule of the committed units over a certain period of time among available generators in the best economical manner, while all physical and operational constraints are satisfied. Considering the dynamic constraints, such as ramp-rate limits, the DED shows non-convex characteristics which makes it more complicated [5,6].

Obtaining the global optimum or better local optimum for non-convex DED problems is a great challenge. Therefore, different methods are proposed in the literature to solve the DED problem. These methods can be classified into two categories of classical optimization methods and artificial intelligence based methods. The classical optimization methods such as Lagrangian relaxation (LR) [7] and dynamic programming (DP) [8], suffer from curse of the dimensionality in the case of large scale power systems and fail to lead to optimal solutions because of nonlinear and non-convex characteristics of the DED problem.

Over the past few years, optimization methods based on artificial intelligence are used to solve the DED problem. These methods, which have capability of modelling more realistic objective function and constraints, have shown better performance in solving the DED problem in comparison with classical optimization methods. Examples of some of well-known artificial intelligence based

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http://dx.doi.org/10.1016/j.ijepes.2014.12.091

methods are: differential evolution (DE) [9], particle swarm optimization (PSO) [10,11] and artificial immune system (AIS) [12]. Although these methods impose no restriction on the problem formulation, these methods do not guarantee to find the global solution [13].

Recently, hybrid methods are found to be more effective in solving complex optimization problems such as the DED problem [14]. The hybrid methods have some merits. They reduce the search space. In addition, they have better quality of solutions for small and large scale problems. Moreover, they give solution in an acceptable computation time. Finally, they can accommodate more constraints. Hybrid evolutionary programming and sequential quadratic programming (EP-SQP) are proposed to solve DED problem in [15]. While evolutionary programming (EP) and PSO were combined with SQP in [16] as a two-phase optimizer to solve the dynamic economic dispatch problem of generating units considering the valve-point effects. Chakraborty et al. [17] presented a solution strategy to solve DED problem in an efficient way while considering several aspects of DED. This strategy employs a hybrid mechanism involving a quantum mechanics inspired PSO. A novel heuristic algorithm to solve the non-convex DED problem is proposed in [4] by employing a hybrid immune-genetic algorithm. Niknam and Golestaneh [13] proposed an enhanced bee swarm optimization method to solve the dynamic economic dispatch problem of thermal units.

GA is based on the process of the evolution of biological organisms. Recognized as a powerful global search technique, genetic algorithms have been applied to a wide variety of problems with success [18]. The disadvantage of GA based approaches is that they show a very fast initial convergence, followed by progressive slower improvements. If the fitness of all the models is similar, the convergence may be slow. In addition, good models are sometimes better than the rest of the population and result in the premature convergence to local minima [18].

Bacteria foraging (BF) algorithm which proposed by Passino [19] is a new comer to the family of nature-inspired optimization algorithms. BF has been widely used as a global optimization algorithm for distributed optimization and control. BF which inspired by the social foraging behavior of *Escherichia coli* (*E.coli*) has already drawn the attention of researchers because of its efficiency in solving real world optimization problems [20]. The underlying biology behind the foraging strategy of *E.coli* is emulated in an extraordinary manner and used as a simple optimization algorithm. The original BF suffers from poor convergence characteristics for larger constrained problems. Hence, in order to use it to solve the complex and high dimensioned search space of the DED problem, this drawback should be treated first [21].

In this paper, a hybrid genetic algorithm and bacterial foraging approach (HGABF) is introduced to solve the non-convex DED problem considering ramp-rate limits, valve-point effects, and transmission losses. The HGABF approach use the same operators as GA and BF, respectively, though they require expression trees for gene representation. By using HGABF method, the global optimization capability can be improved and the delay in reaching the global solution can be reduced. The presented method is evaluated using different standard test systems and compared with some published methods employing the same data. The contributions of this paper are: to introduce a hybrid algorithm using GA and BF algorithm, to apply the introduced method to solve the non-convex DED problem considering ramp-rate limits, valve-point effects, and transmission losses and to improve the economic dispatch problem solution in comparison with the results obtained with other published methods. Although this paper focuses on DED problem, the introduced HGABF method may be used as a promising generic optimization tool for various optimization problems in industrial fields.

The paper is organized as follows: Section 'Dynamic economic dispatch (DED) problem formulation' gives the mathematical formulation of the DED problem. Section 'Overview of genetic and bacterial foraging algorithms' gives a brief overview of GA and BF algorithm. The HGABF method is described in Section 'Hybrid genetic and bacterial foraging algorithm (HGABF)'. Experimental results and comparisons with other methods are presented in Section 'Case studies and numerical results'. Finally, Section 'Conclusion' concludes the work.

Dynamic economic dispatch (DED) problem formulation

Objective function

The objective function of the DED problem is to minimize the total production cost over the operating horizon, expressed as:

$$\min C = \sum_{t=1}^{T}\sum_{i=1}^{N} C_{i,t}(P_{i,t}) \tag{1}$$

where C is the total production cost over the whole dispatch period, $C_{i,t}$ is the production cost of generator i at time t, $P_{i,t}$ is the power output of generator i at time t, N is the number of generators and T is the total number of hours in the operating horizon. By considering valve-point effects, the production cost of the generation unit can be defined as:

$$C_{i,t}(P_{i,t}) = a_i + b_i P_{i,t} + c_i P_{i,t}^2 + |e_i \times \sin(h_i(P_i^{min} - P_{i,t}))| \tag{2}$$

where a_i, b_i and c_i are the fuel cost coefficients of generator i, e_i, h_i are the valve-point coefficients of generator i and P_i^{min} is the minimum capacity limit of generator i. It should be noted that the added sinusoidal term in (2) reflects the valve-point effects. Therefore, the DED problem will be non-convex and non-differentiable considering valve-point effects [4].

Constraint

The DED optimization problem is subject to the following constraints:

- Real power balance: The total power generated must supply the total load demand and the transmission losses.

$$\sum P_{i,t} - P_{D,t} - P_{loss,t} = 0 \tag{3}$$

where $P_{D,t}$ and $P_{loss,t}$ are total load demand of the system and total transmission loss at time t, respectively. System loss is a function of units power production and can be calculated using the results of load flow problem [22] or Kron's loss formula known as B-matrix coefficients [23]. In this paper, the B-matrix coefficients method is used to calculate system loss as follows:

$$P_{loss,t} = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{i,t} B_{ij} P_{j,t} + \sum_{i=1}^{N} B_{i0} P_{i,t} + B_{00} \tag{4}$$

where B_{ij} is the loss coefficient relating the productions of units i and j, B_{i0} is the loss coefficient associated with the production of unit i and B_{00} is the loss coefficient parameter.

- Maximum and minimum limits of power generation: The power generated by each generator is constrained between its minimum and maximum limits as following,

$$P_i^{min} \leqslant P_{i,t} \leqslant P_i^{max} \tag{5}$$