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Hybridization of bee colony optimization and sequential quadratic programming for dynamic economic dispatch

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ABSTRACT

Dynamic economic dispatch deals with the scheduling of online generator outputs with predicted load demands over a certain period of time so as to operate an electric power system most economically. This paper proposes a hybrid methodology integrating bee colony optimization with sequential quadratic programming for solving dynamic economic dispatch problem of generating units considering valve-point effects. This hybrid method incorporates bee colony optimization as a base level search which can give a good direction to the optimal region and sequential quadratic programming as a local search procedure which is used to fine tune that region for achieving the final solution. Numerical results of a ten-unit system have been presented to demonstrate the performance and applicability of the proposed method. The results obtained from the proposed method are compared with those obtained from hybrid of particle swarm optimization and sequential quadratic programming and hybrid of evolutionary programming and sequential quadratic programming.

1. Introduction

Static economic dispatch (SED) allocates the load demand for a given interval of time among the committed generating units economically while satisfying various constraints. Dynamic economic dispatch (DED) which is an extension of static economic dispatch, determines the optimal sharing of time varying load demand among the committed units. Power plant operators try to keep gradients for temperature and pressure inside the boiler and turbine within safe limits to avoid shortening the life of the equipments. This mechanical constraint imposes limit on the rate of increase or decrease of the electrical power output. This limit is called ramp rate limit which differentiates DED from SED problem. Thus, in DED the dispatch decision at one time period affects those at later time periods. DED is the most accurate formulation of the economic dispatch problem but it is the most difficult to solve because of its large dimensionality. As competition is increasingly introduced into the wholesale generation markets, there is a need to understand the incremental cost burden imposed on the system operation by the generator ramping rate limitations.

Since the DED was introduced, several classical methods [1–6] have been employed for solving this problem. However, all of these methods may not be able to find an optimal solution and usually stuck at a local optimum solution. Classical calculus-based methods address DED problem with convex cost function. But in reality large steam turbines have a number of steam admission valves, which contribute nonconvexity in the fuel cost function of the generating units. Dynamic programming (DP) can solve such type of problems but it suffers from the curse of dimensionality.

Recently, stochastic search algorithms [7–11] such as simulated annealing (SA), Genetic algorithm (GA), evolutionary programming (EP), particle swarm optimization (PSO) and differential evolution (DE) have been successfully used to solve power system optimization problems due to their ability to find the near global solution of a nonconvex optimization problem. These methods use probabilistic rules and have a large possibility to explore the search space freely. These methods do not always provide global optimum solution but they often provide a fast and reasonable solution.

Swarm intelligence [12–14], a branch of natural inspired algorithms, focuses on the behavior of insect in order to develop some meta-heuristics algorithms. Bee colony optimization (BCO) algorithm [15] is a new member of swarm intelligence and it mimics the food foraging behavior of honey bees. This algorithm is simple, robust and capable to solve difficult combinatorial optimization problems.

Hybrid methods [16–18] combining probabilistic methods and deterministic methods are found to be very effective for solving DED problems. In hybrid methods, probabilistic method is used as a base level search which gives a good direction to the optimal global region and deterministic method is used to fine tune that region to get the final solution.

In this paper a hybrid method which integrates bee colony optimization (BCO) and sequential quadratic programming (SQP) is proposed for solving DED problem. The proposed hybrid method

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Nomenclature

P_{it} real power output of ith unit during time interval t
$P_i^{\min}, P_i^{\max}$ lower and upper generation limits of ith unit
P_{Dt} load demand at the time interval t
a_i, b_i, c_i, d_i, e_i cost coefficients of ith unit
$F_{it}(P_{it})$ cost of producing real power output P_{it} at time t
UR_i, DR_i ramp-up and ramp-down rate limits of the ith generator
N number of generating units
T number of intervals in the scheduled horizon

uses the property of BCO which can give a good solution even when the problem has many local optimum solution at the beginning and SQP which has local search property is used to obtain the final solution. BCO-SQP method is divided into two parts. In the first part BCO is employed to obtain near global solution. In the second part SQP is employed to find the optimum solution. In order to show the effectiveness of the proposed hybrid method a 10-unit test system with nonsmooth fuel cost function is used in this paper. The results of the proposed hybrid BCO-SQP method are compared with those obtained from hybrid of particle swarm optimization and sequential quadratic programming (PSO-SQP) and hybrid of evolutionary programming and sequential quadratic programming (EP-SQP).

2. Problem formulation

Normally, the DED problem minimizes the following total production cost of committed units:

$$F = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{it}(P_{it}) \tag{1}$$

The fuel cost function of each unit considering valve-point effect [8] can be expressed as

$$F_{it}(P_{it}) = a_i + b_i P_{it} + c_i P_{it}^2 + \left| d_i \sin\left(e_i\left(P_i^{\min} - P_{it}\right)\right)\right| \tag{2}$$

Subject to the following equality and inequality constraints for the tth interval in the scheduled horizon

(i) Real power balance

$$\sum_{i=1}^{N} P_{it} - P_{Dt} = 0 \quad t \in T \tag{3}$$

(ii) Real power operating limits

$$P_i^{\min} \leqslant P_{it} \leqslant P_i^{\max} \quad i \in N,\ t \in T \tag{4}$$

(iii) Generator ramp rate limits

$$\begin{aligned} P_{it} - P_{i(t-1)} &\leqslant UR_i, \quad i \in N,\ t \in T \\ P_{i(t-1)} - P_{it} &\leqslant DR_i, \quad i \in N,\ t \in T \end{aligned} \tag{5}$$

3. The bee colony optimization

Social insects have lived on earth for million of years, building nests, organizing production and procuring food. The colonies of social insects are very flexible and can adapt well to the changing environment. This flexibility allows the colony of social insects to be robust and maintain its life in spite of considerable disturbances. The dynamics of the social insect population is a result of the different actions and interactions of individual insects with each other as well as with their environment. The interactions are executed via multitude of various chemical and/or physical signals. The final product of different actions and interactions represents social insect colony behavior. The examples of interaction between individual insects in the colony of social insects are bee dancing during the food procurement and performance of specific acts which signal the other insects to start performing the same action. These communication systems between individual insects contribute to the formation of swarm intelligence.

A colony of honey bees can extend itself over long distances and in multiple directions simultaneously to exploit a large number of food sources. A colony prospers by deploying its foragers to good fields. In principle, flower patches with plentiful amounts of nectar can be collected with less effort and should be visited by more bees whereas patches with less nectar should receive fewer bees. The foraging process begins in a colony by scout bees that are sent to search for promising flower patches. Scout bees move randomly from one patch to another. When they return to the hive, those scout bees that found a patch which is rated above a certain quality threshold deposit their nectar and go to the dance floor to perform a dance known as waggle dance. This dance is essential for colony communication and contains three pieces of information regarding a flower patch: the direction in which it will be found, its distance from the hive and its quality rating. This information helps the colony to send it bees to flower patches precisely. After waggle dancing on the dance floor, the dancer goes back to the flower patch with follower bees that are waiting inside the hive. More follower bees are sent to more promising patches. This allows the colony to gather food quickly and efficiently. While harvesting from a patch, the bees monitor its food level. If the patch is still good enough as a food source, then it will be advertised in the waggle dance and more bees will be recruited to that source.

Bee colony optimization (BCO) algorithm is proposed by Karaboga for numerical optimization in 2005. This algorithm mimics the food foraging behavior of honey bees. In BCO algorithm, the colony of bees consists of two groups, scout and employed bees. The scout bees seek a new food source and the employed bees look for a food source within the neighborhood of the food source in their memories. Both scout and employed bees share their information with other bees within the hive.

4. Sequential quadratic programming

Sequential quadratic programming (SQP) [19] is widely used to solve practical optimization problems. It outperforms every other nonlinear programming method in terms of efficiency, accuracy and percentage of successful solutions. The method closely mimics Newton's method for constrained optimization just as is done for unconstrained optimization. At each major iteration, an approximation is made of the Hessian of the Lagrange function using Broyden–Fletcher–Goldfarb–Shanno (BFGS) quasi-Newton updating method. This is then used to generate a quadratic programming sub-problem whose solution is used to form a search direction for a line search procedure.

As the objective function to be minimized is nonconvex, SQP requires a local minimum for an initial solution. In this paper, SQP is used as a local optimizer for fine-tunning the better region