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Artificial bee colony optimization for multi-area economic dispatch

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ABSTRACT

This paper presents artificial bee colony optimization for solving multi-area economic dispatch (MAED) problem with tie line constraints considering transmission losses, multiple fuels, valve-point loading and prohibited operating zones. Artificial bee colony optimization is a swarm-based algorithm inspired by the food foraging behavior of honey bees. The effectiveness of the proposed algorithm has been verified on three different test systems, both small and large, involving varying degree of complexity. Compared with differential evolution, evolutionary programming and real coded genetic algorithm, considering the quality of the solution obtained, the proposed algorithm seems to be a promising alternative approach for solving the MAED problems in practical power system.

1. Introduction

Economic dispatch (ED) [1] is one of the important optimization problems in power system operation. ED allocates the load demand among the committed generators most economically while satisfying the physical and operational constraints in a single area. Generally, the generators are divided into several generation areas interconnected by tie-lines. Multi-area economic dispatch (MAED) is an extension of economic dispatch. MAED determines the generation level and interchange power between areas such that total fuel cost in all areas is minimized while satisfying power balance constraints, generating limits constraints and tie-line capacity constraints.

The economic dispatch problem is frequently solved without considering transmission constraints. However, some researchers have taken transmission capacity constraints into account. Shoults et al. [2] solved economic dispatch problem considering import and export constraints between areas. This study provides a complete formulation of multi-area generation scheduling, and a framework for multi-area studies. Romano et al. [3] presented the Dantzig–Wolfe decomposition principle to the constrained economic dispatch of multi-area systems. Doty and McEntire [4] solved a multi-area economic dispatch problem by using spatial dynamic programming and the result obtained was a global optimum. An application of linear programming to transmission constrained production cost analysis was proposed in Ref. [5]. Helmick and Shoults [6] solved multi-area economic dispatch with area control error. Ouyang and Shahidehpour [7] proposed heuristic multi-area unit commitment with economic dispatch. Wang and Shahidehpour [8] proposed a decomposition approach for solving multi-area generation scheduling with tie-line constraints using expert systems. Network flow models for solving the multi-area economic dispatch problem with transmission constraints have been proposed by Streiffert [9]. An algorithm for multi-area economic dispatch and calculation of short range margin cost based prices has been presented by Wernerus and Soder [10], where the multi-area economic dispatch problem was solved via Newton–Raphson's method. Yalcinoz and Short [11] solved multi-area economic dispatch problems by using Hopfield neural network approach. Jayabarathi et al. [12] solved multi-area economic dispatch problems with tie line constraints using evolutionary programming. The direct search method for solving economic dispatch problem considering transmission capacity constraints was presented in Ref. [13]. Manoharan et al. [14] explored the performance of the various evolutionary algorithms on multi-area economic dispatch (MAED) problems.

Here, evolutionary algorithms such as the Real-coded Genetic Algorithm (RCGA), Particle Swarm Optimization (PSO), Differential Evolution (DE) and Covariance Matrix Adapted Evolution Strategy (CMAES) are considered. Multi-area economic environmental dispatch (MAEED) problem is proposed in [15]. Here, MAEED problem is handled by an improved multi-objective particle swarm optimization (MOPSO) algorithm for searching out the Pareto-optimal solutions. Sharma et al. [16] have presented a close comparison of classic PSO and DE strategies and their variants for solving the reserve constrained multi-area economic dispatch problem with power balance constraint, upper/lower generation limits, ramp rate limits, transmission constraints and other practical constraints. In [17] a discussion of "Reserve constrained multi-area economic dispatch employing differential evolution with time-varying mutation" has been presented.

Swarm intelligence [18–20], a branch of natural inspired algorithms, focuses on the behavior of insect in order to develop some

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meta-heuristics algorithms. Artificial bee colony optimization (ABCO) algorithm [21] 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.

In this paper, ABCO has been applied to solve MAED problem. Here, three types of MAED problems have been considered. These are (A) multi area economic dispatch with quadratic cost function, prohibited operating zones and transmission losses (MAEDQCPOZTL), (B) multi area economic dispatch with valve point loading (MAEDVPL), (C) multi area economic dispatch with valve point loading multiple fuel sources and transmission losses (MAEDVPLMFTL).

The proposed ABCO approach has been validated by applying it to three different test systems. The performance of the proposed ABCO in terms of solution quality has been compared with differential evolution (DE), evolutionary programming (EP) and real coded genetic algorithm (RCGA).

2. Problem formulation

The objective of MAED is to minimize the total production cost of supplying loads to all areas while satisfying power balance constraints, generating limits constraints and tie-line capacity constraints.

Three different types of MAED problems have been considered.

2.1. Multi area economic dispatch with quadratic cost function, prohibited operating zones and transmission losses (MAEDQCPOZTL)

The objective function F_t, total cost of committed generators of all areas, of MAED problem may be written as

$$F_t = \sum_{i=1}^{N}\sum_{j=1}^{M_i} F_{ij}(P_{ij}) = \sum_{i=1}^{N}\sum_{j=1}^{M_i} a_{ij} + b_{ij}P_{ij} + c_{ij}P_{ij}^2 \tag{1}$$

where $F_{ij}(P_{ij})$ is the cost function of jth generator in area i and is usually expressed as a quadratic polynomial; a_{ij}, b_{ij} and c_{ij} are the cost coefficients of jth generator in area i; N is the number of areas, M_i is the number of committed generators in area i; P_{ij} is the real power output of jth generator in area i. The MAED problem minimizes F_t subject to the following constraints.

2.1.1. Real power balance constraint

$$\sum_{j=1}^{M_i} P_{ij} = P_{Di} + P_{Li} + \sum_{k,k\neq i} T_{ik} \quad i \in N \tag{2}$$

The transmission loss P_{Li} of area i may be expressed by using B-coefficients as

$$P_{Li} = \sum_{l=1}^{M_i}\sum_{j=1}^{M_i} P_{ij}B_{ilj}P_{il} + \sum_{j=1}^{M_i} B_{0ij}P_{ij} + B_{00i} \tag{3}$$

where P_{Di} real power demand of area i; T_{ik} is the tie line real power transfer from area i to area k. T_{ik} is positive when power flows from area i to area k and T_{ik} is negative when power flows from area k to area i.

2.1.2. Tie line capacity constraints

The tie line real power transfer T_{ik} from area i to area k should not exceed the tie line transfer capacity for security consideration.

$$-T_{ik}^{\max} \leqslant T_{ik} \leqslant T_{ik}^{\max} \tag{4}$$

where $T_{ik}^{\max}$ is the power flow limit from area i to area k and -$T_{ik}^{\max}$ is the power flow limit from area k to area i.

2.1.3. Real power generation capacity constraints

The real power generated by each generator should be within its lower limit $P_{ij}^{\min}$ and upper limit $P_{ij}^{\max}$, so that

$$P_{ij}^{\min} \leqslant P_{ij} \leqslant P_{ij}^{\max} \quad i \in N \quad \text{and} \quad j \in M_i \tag{5}$$

2.1.4. Prohibited operating zone

The prohibited operating zones are the range of power output of a generator where the operation causes undue vibration of the turbine shaft bearing caused by opening or closing of the steam valve. This undue vibration might cause damage to the shaft and bearings. Normally operation is avoided in such regions. The feasible operating zones of unit can be described as follows:

$$\begin{aligned} &P_{ij}^{\min} \leqslant P_{ij} \leqslant P_{ij,1}^{l} \\ &P_{ij,m-1}^{u} \leqslant P_{ij} \leqslant P_{ij,m}^{l}; \quad m = 2,3,\ldots,n_{ij} \\ &P_{ij,n_{ij}}^{u} \leqslant P_{ij} \leqslant P_{ij}^{\max} \end{aligned} \tag{6}$$

where m represents the number of prohibited operating zones of j the generator in area i. $P_{ij,m-1}^{u}$ is the upper limit of $(m-1)$th prohibited operating zone of j the generator in area i. $P_{ij,m}^{l}$ is the lower limit of m th prohibited operating zone of j the generator in area i. Total number of prohibited operating zone of j the generator in area i is n_{ij}.

2.2. Multi area economic dispatch with valve point loading (MAEDVPL)

The generator cost function is obtained from data points taken during "heat run" tests, when input and output data are measured as the unit is slowly varied through its operating region. Wire drawing effects, occurring as each steam admission valve in a turbine starts to open, produce a rippling effect on the unit curve. To model the effect of valve-points, a recurring rectified sinusoid contribution is added to the quadratic function [22]. The fuel cost function considering valve-point loading of the generator is given as

$$\begin{aligned} F_t &= \sum_{i=1}^{N}\sum_{j=1}^{M_i} F_{ij}(P_{ij}) \\ &= \sum_{i=1}^{N}\sum_{j=1}^{M_i} a_{ij} + b_{ij}P_{ij} + c_{ij}P_{ij}^2 + \left| d_{ij} \times \sin\left\{ e_{ij} \times \left(P_{ij}^{\min} - P_{ij} \right) \right\} \right| \end{aligned} \tag{7}$$

where d_{ij} and e_{ij} are cost coefficients of i th generator in area i due to valve-point effect. The objective of MAEDVPL is to minimize F_t subject to the constraints given in (2), (4), and (5). Here transmission loss (P_L) is not considered.

2.3. Multi area economic dispatch with valve point loading multiple fuel sources and transmission losses (MAEDVPLMFTL)

Since generators are practically supplied with multi-fuel sources [25], each generator should be represented with several piecewise quadratic functions superimposed sine terms reflecting the effect of fuel type changes and the generator must identify the most economical fuel to burn. The fuel cost function of the ith generator with N_F fuel types considering valve-point loading is expressed as

$$F_{ij}(P_{ij}) = a_{ijm} + b_{ijm}P_{ij} + c_{ijm}P_{ij}^2 + \left| d_{ijm} \times \sin\left\{ e_{ijm} \times \left(P_{ijm}^{\min} - P_{ij} \right) \right\} \right| \tag{8}$$

if $P_{ijm}^{\min} \leqslant P_{ij} \leqslant P_{ijm}^{\max}$ for fuel type m and m = 1, 2, ..., N_F.