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Flower pollination algorithm to solve combined economic and emission dispatch problems

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ABSTRACT

Economic Load Dispatch (ELD) is the process of allocating the required load between the available generation units such that the cost of operation is minimized. The ELD problem is formulated as a nonlinear constrained optimization problem with both equality and inequality constraints. The dual-objective Combined Economic Emission Dispatch (CEED) problem is considering the environmental impacts that accumulated from emission of gaseous pollutants of fossil-fuelled power plants. In this paper, an implementation of Flower Pollination Algorithm (FPA) to solve ELD and CEED problems in power systems is discussed. Results obtained by the proposed FPA are compared with other optimization algorithms for various power systems. The results introduced in this paper show that the proposed FPA outlasts other techniques even for large scale power system considering valve point effect in terms of total cost and computational time.

1. Introduction

Economic Dispatch (ED) problem has become a crucial task in the operation and planning of power system [1]. It is very complex to solve because of a nonlinear objective function and a large number of constraints. ED in power system deals with the determination of optimum generation schedule of available generators so that the total cost of generation is minimized within the system constraints [2,3]. Well known long-established techniques such as gradient method [4], lambda iteration method [5,6], linear programming [7], quadratic programming [8], Lagrangian multiplier method [9], and classical technique based on co-ordination equations [10] are applied to solve ELD problems. These conventional methods cannot perform satisfactorily for solving such problems as they are sensitive to initial estimates and converge into local optimal solution in addition to its computational complexity.

During the last decades many researches and techniques had dealt with ELD problems. Fuzzy Logic Control (FLC) has attracted the attention in control applications. In contrast with the conventional techniques, FLC formulates the control action in terms of linguistic rules drawn from the behavior of a human operator rather than in terms of an algorithm synthesized from a model of the system [11–14]. However, it requests more fine tuning and simulation before operational. Another technique like Artificial Neural Network (ANN)

Abbreviations: ELD, economic load dispatch; CEED, combined economic emission dispatch; FPA, flower pollination algorithm; ED, economic dispatch; FLC, fuzzy logic control; ANN, artificial neural network; EA, evolutionary algorithm; GA, genetic algorithm; SA, simulated annealing; EP, evolutionary programming; TS, Tabu search; PSO, particle swarm optimization; GSA, gravitational search algorithm; ABC, artificial bee colony; QP, quadratic programming; DE, differential evolution; PPSO, personal best-oriented PSO; APPSO, adaptive personal-best oriented PSO; MPSO, modified particle swarm optimization; ARCGA, adaptive real coded GA; TSAGA, Taguchi self-adaptive real-coded genetic algorithm; CCPSO, PSO with both chaotic sequences and crossover operation; CDE_SQP, combining of chaotic DE and quadratic programming; EDA/DE, estimation of distribution and differential evolution cooperation; SOMA, self-organizing migrating strategy; CSOMA, cultural self-organizing migrating strategy; DE/BBO, combination of differential evolution and biogeography-based optimization; DHS, differential harmony search; BBO, biogeography based optimization; PSO–SQP, integrating PSO with the sequential quadratic programming; GA–PS–SQP, hybrid algorithm consisting of GA, pattern search (PS) and SQP; CPSO, chaotic particle swarm optimization; CPSO–SQP, hybrid algorithm consisting of CPSO and SQP; NPSO_LRS, new PSO with local random search; CDEMD, cultural DE based on measure of population's diversity; HMAPSO, hybrid multi agent based PSO; FAPSO-NM, fuzzy adaptive PSO algorithm with Nelder–Mead; ICA-PSO, improved coordinated aggregation-based PSO; MODE, multiobjective differential evolution; NSGA-II, non-dominated sorting genetic algorithm-II; PDE, Pareto differential evolution; SPEA-2, strength Pareto evolutionary algorithm 2; ABC_PSO, ABC and PSO; EMOCA, enhanced multi-objective cultural algorithm; MABC/D/Cat, modified artificial bee colony with disruptive cat map; MABC/D/Log, modified artificial bee colony with disruptive logistic map; CPU, computational time; NA, not available; PV, photovoltaic.

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has its own advantages and disadvantages. The characteristics of the system is enhanced by ANN, but the main problem of this technique is the long training time, the selecting number of layers and the number of neurons in each layer [6,15–17].

An alternative approach is to employ Evolutionary Algorithm (EA) techniques. Due to its ability to treat nonlinear objective functions, EA is believed to be very effective to deal with ELD problem. Among the EA techniques, Genetic Algorithm (GA) is introduced in References 18 and 19, but it requires a very long run time depending on the size of the system under study. Also, it gives rise to repeat revisiting of the same suboptimal solutions. Simulated Annealing (SA) is illustrated in References 20 and 21, but this technique might fail by getting trapped in one of the local optimal. Evolutionary Programming (EP) is discussed in Reference 22, but it has a slow convergence rate for large problem. Improved Tabu Search (TS) is introduced in Reference 23, but the efficiency of this algorithm is reduced by the use of highly epistatic objective functions and the large number of parameters to be optimized. Also, it is a time-consuming method. Ant swarm optimization is presented in Reference 24, but its theoretical analysis is difficult and probability distribution changes by iteration. Particle Swarm Optimization (PSO) is discussed in References 25–28, but it pains from the partial optimism. Moreover, the algorithm cannot work out the problems of scattering and optimization. Gravitational Search Algorithm (GSA) in illustrated in Reference 29. However, this algorithm appears to be effective for solving ELD problem, it has poor performance at the later search stage due to the lack of agents' diversity in GSA. Artificial Bee Colony (ABC) is developed in Reference 30 to solve the complex non-linear optimization problem, but it is slow to converge and the processes of the exploration and exploitation contradict with each other, so the two abilities should be well balanced for achieving good optimization performance. On the other hand, FPA has only one key parameter p (switch probability) which makes the algorithm easier to implement and faster to reach optimum solution. Moreover, this transferring switch between local and global pollination can guarantee escaping from local minimum solution. Thus, FPA is proposed in this paper to overcome the previous drawbacks. In addition, it is clear from the literature survey that the application of FPA to solve ELD and CEED problems has not been discussed. This encourages us to adopt FPA to deal with these problems.

In this paper, a new approach for solving ELD and CEED problems using FPA methodology is discussed considering the power limits of the generator. The purpose of CEED is to minimize both the operating fuel cost and emission level simultaneously while satisfying load demand and operational constraints. This multi-objective CEED problem is converted into a single objective function using a modified price penalty factor approach. FPA is investigated to determine the optimal loading of generators in power systems. Simulations results for small and large scale power system considering the valve loading effect are implemented to indicate the robustness of FPA.

The remainder of this paper is organized as follows: Section 2 provides a brief description and mathematical formulation of ELD and CEED problems. In section 3, the concept of FPA is discussed. Section 4 shows the result on three, ten and forty unit thermal test systems. Finally, the conclusion and future work of research are outlined in section 5.

2. Problem formulation

The CEED problem is to minimize two computing objective functions simultaneously, fuel cost and emission, while satisfying various equality and inequality constraints. Generally the problem is formulated as follows.

2.1. Objective function of ELD

For thermal generating units, the cost of fuel per unit power output varies significantly with the output power of the unit. Fuel costs are usually represented as a quadratic function of output power [31], as shown in equation (1).

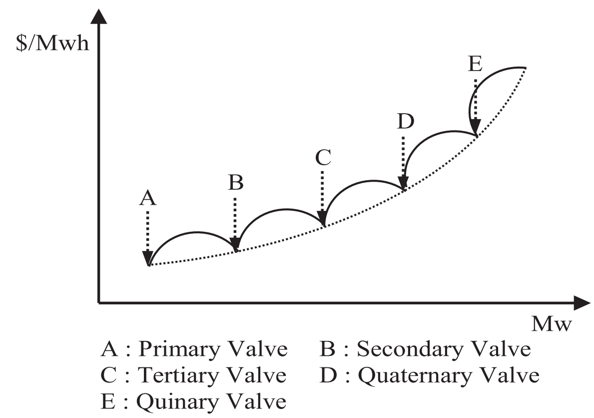

Fig. 1. Valve point effect.

$$F(P)=\gamma P^2+\beta P+\alpha \tag{1}$$

Minimize

$$F_t=\sum_{i=1}^{d}F_i(P_i)=\sum_{i=1}^{d}\left(\gamma_i P_i^2+\beta_i P_i+\alpha_i\right) \tag{2}$$

The minimization is performed subject to the equality constraint that the total generation must equal to the demand plus the loss thus:

$$\sum_{i=1}^{d}P_i=P_D+P_L \tag{3}$$

The total transmission loss using Kron's loss formula is given in equation (4)

$$P_L=\sum_{i=1}^{d}\sum_{j=1}^{d}(P_iB_{ij}P_j)+\sum_{i=1}^{d}B_{0i}P_i+B_{00} \tag{4}$$

It is assumed with little error that these coefficients are constant (as long as operation is near the value where these coefficients are computed).

Based on the maximum and minimum power limits of generators the inequality constraint is

$$P_i^{\min}\le P_i\le P_i^{\max}\quad i=1,2,\ldots\ldots,d \tag{5}$$

2.2. Effect of valve point on fuel cost objective

To be more practical, the valve point effect is taken into account in the cost function of generators. The sharp increase in losses due to the wire drawing effects which occur as each steam admission valve starts to open leads to the nonlinear rippled input output curve [32] as shown in Fig. 1. The obtained cost function based on the rippled curve is more accurate modeling. Thus, the fuel cost function of each fossil fuel generator is given as the sum of a quadratic and a sinusoidal function [33].

$$F_t=\sum_{i=1}^{d}F_i(P_i)=\sum_{i=1}^{d}\left(\gamma_iP_i^2+\beta_iP_i+\alpha_i+e_i*\sin\left(f_i*\left(P_i^{\min}-P_i\right)\right)\right) \tag{6}$$

2.3. Objective function of CEED

The atmospheric pollutants such as sulfur oxides, nitrogen oxides and carbon dioxide caused by fossil fuel fired generator can be