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Spiral Optimization Algorithm for solving Combined Economic and Emission Dispatch

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ABSTRACT

The Spiral Optimization Algorithm (SOA) is an optimization technique developed recently (2011) by K. Tamura and K. Yasuda at Tokyo Metropolitan University-Japan. SOA is a metaheuristic based on an analogy of spiral phenomena in nature and it is simple in concept, few in parameters and easy in implementation.

In this paper, SOA is proposed for solving the Combined Economic and Emission Dispatch (CEED) problem. It is aimed, in the CEED problem, that scheduling of generators should operate with both minimum fuel costs and emission levels, simultaneously, while satisfying the load demand and operational constraints. The CEED problem is formulated as a multi-objective problem by considering the fuel cost and emission objectives of generating units. The bi-objective optimization problem is converted into a single objective function using a price penalty factor. The proposed algorithm has been implemented on three test systems with 3, 6, and 40 generating units, with different constraints and various cost curve nature. In order to see the effectiveness of the proposed algorithm, its results are compared to those reported in the recent literature. Those results are quite encouraging showing the good applicability of SOA for CEED problem.

Introduction

Economic dispatch problem is one of the most important optimization problems in power system operation and forms the basis of many application programs. The main objective of economic load dispatch of electric power generation is to schedule the committed generating unit outputs to meet the load demand at minimum operating cost while satisfying all unit and system constraints. One of those constraints which are always taken into account is the environmental constraints. That is minimization of pollution emission (NO_x, CO_2, SO_x, toxic metals, etc.) in case of power plants [1,2]. Thus, we are facing with a bi-objective optimization problem to deal with.

Traditionally, electric utilities dispatch generation using minimum fuel cost as the main criterion. However the best economic dispatch does not lead to minimum emission and vice versa. The goal of emission dispatch is to determine the generation schedule that has the minimum emission cost. The two criteria are contradictory to each other and are in trade-off relationship. It therefore makes it difficult to handle such problem by conventional approaches that optimize a single objective function. One feasible approach to solve this kind of problem using conventional optimization method is to convert the bi-objective into a single objective function by giving relative weighting values. In this case the emission dispatch is added as a second objective to the economic dispatch problem which leads to Combined Economic Emission Dispatch (CEED) [3].

Environmental issues add complexity to the solution of the economic dispatch problem due to the nonlinear characteristics of the mathematical models used to represent emissions. In addition, the Economic Emission Dispatch (EED) problem can be complicated even further if nonsmooth and nonconvex fuel cost functions are used to model generators, such as valve-point loading effects. All these considerations make the EED problem a highly nonlinear and a multimodal optimization problem [4].

Several Economic Emission Dispatch (EED) strategies have appeared in the literature over the years. Lagrange relaxation method, weighted sum method, ε-constrained algorithm, Linear programming method, Goal programming technique are used to solve the EED problem [5]. But unfortunately these methods are not able to find a solution with a significant computational time for medium or large-scale ED.

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Recently, with the development of computer science and technology, evolutionary algorithms like Genetic Algorithm (GA) [6], Particle Swarm Optimization (PSO) [7], Ant Colony Optimization (ACO) [8], Firefly Optimization Technique [9] and Harmony Search (HS) [10] are used to eliminate many difficulties in the classical methods and to solve non-linear CEED problem without modifying the shape of its fuel and emission cost curves. Those evolutionary algorithms are general-purpose stochastic search methods simulating natural selection and biological evolution. They differ from other optimization methods in the fact maintaining a population of potential solutions to a problem, and not just one solution. Generally, these algorithms work as follows: a population of individuals is randomly initialized where each individual represents a potential solution to the problem. The quality of each solution is evaluated using a fitness function. A selection process is applied during each iteration in order to form a new solution population. This procedure is repeated until convergence is reached. The best solution found is expected to be a near-optimum solution [11].

Two dimensional SOA that was recently proposed by Tamura and Yasuda [12] is a multipoint metaheuristics search method for two-dimensional continuous optimization problems based on the analogy of spiral phenomena in nature. Focused spiral phenomena are approximated to logarithmic spirals which often appear in nature and the universe, such as tropical cyclones, tornadoes and galaxies (Fig. 1).

Then Tamura and Yasuda [13] proposed n-dimensional SOA using a design philosophy of 2-dimensional optimization.

The SOA has several advantages including its few control variables, local searching capability, fast results, easy using process, simple structure and introduction of both phases of diversification and intensification in the same process.

In this paper, n-dimensional SOA is applied to solve CEED problem which it is converted into mono-objective optimization problem by introducing price penalty factor.

In order to investigate the effectiveness of the n-dimensional SOA, the algorithm is simulated for the systems with 3, 6, and 40 generating units, with different constraints and various cost curve nature. Numerical results obtained by the proposed algorithm were compared with other optimization results reported in the recent literature.

CEED formulation

In the solution of the CEED problem, the point at issue is to minimize both fuel cost and emission, simultaneously, while satisfying equality and inequality constraints. Cost and emission functions, which are independent of each other, make the CEED problem bi-objective. Bi-objective problem solving can be done by two objective functions turned into a single objective function [14]. In this paper, this operation is enhanced using a price penalty factor and the CEED problem is converted into a single-objective function.

These objectives and constraints, and the formulation of the CEED problem are expressed as follows:

Classical economic dispatch problem

In power stations, every generator has its input/output curve. It has the fuel input as a function of the power output. But if the ordinates are multiplied by the cost of \$/Btu, the result gives the fuel cost per hour as a function of power output [15].

The fuel cost of generator i may be represented as a polynomial function of real power generation:

$$F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i (/\mathrm{h}) \quad i = 1, 2, \ldots, ng \tag{1}$$

where P_{Gi} is real power output, n_G is the number of generators including the slack bus, a_i, b_i and c_i are the cost coefficients of the ith unit.

The Economic Dispatch Problem can be mathematically represented as:

$$'Min\left\{F = \sum_{i=1}^{ng} F_i(P_{Gi})\right\} \tag{2}$$

F (\$/h) is the total fuel cost function for the entire power system. It is written as the sum of the fuel cost model for each generator.

Economic dispatch problem with valve point effect

Large steam turbine generators will have a number of steam admission valves that are opened in sequence to control the power output of the unit. As the unit loading increases the input to the unit increases and the incremental heat rate decreases between the opening points for any two valves. However, when a valve is first opened, the throttling losses increase rapidly and the incremental heat rate rises suddenly. This is called valve-point effect that leads to non-smooth, non-convex input–output characteristics as shown in Fig. 2 [16].

Usually, valve-point effect is modeled by adding a recurring rectified sinusoid to the basic quadratic cost curve [4,16]. Therefore, (1) can be modified as:

$$F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i + |d_i \sin(e_i(P_{Gi\min} - P_{Gi}))| (/\mathrm{h})$$
$$i = 1, 2, \ldots, ng \tag{3}$$

where d_i and e_i are the coefficients of generator i reflecting valve-point effects and P_{Gimin} is the minimum generation limit of unit i.

Emission dispatch

The emission function can be expressed as the sum of all types of emission considered, such as NO_x, SO_2, CO_2, particles and

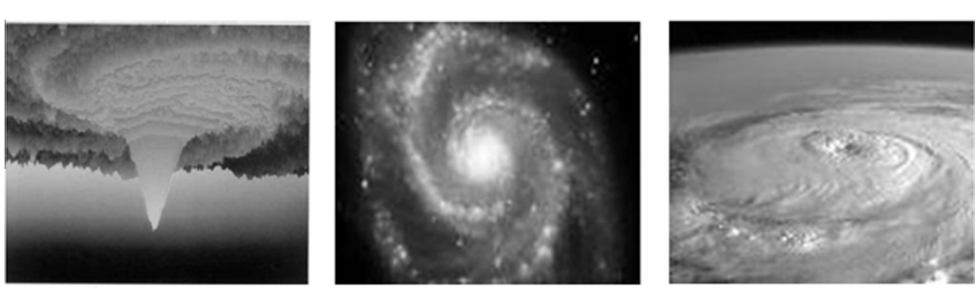

Fig. 1. Natural spiral phenomena.