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Solution of Economic Emission Load Dispatch problems of power systems by Real Coded Chemical Reaction algorithm

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ABSTRACT

This paper presents a Real Coded Chemical Reaction algorithm (RCCRO) approach to solve the Economic Emission Load Dispatch (EELD) problem of thermal generators of power systems. Emission substance like NO_X, power demand equality constraint and operating limit constraint are considered here. EELD problem has been originated as a multi-objective problem by considering both economy and emission simultaneously. Chemical Reaction Optimization (CRO) mimics the interactions of molecules in a chemical reaction to reach a low energy stable state. Basically, the CRO is designed to work in the discrete domain optimization problems. A real coded version of it, known as Real-Coded Chemical Reaction Optimization (RCCRO) is applied here to solve multi-objective EELD problems, in order to show the advantages of proposed algorithm to solve complex continuous optimization problems. Different test systems having 10, 13 and 40 generators, addressing valve-point loading and NO_X emission have been considered. The solutions obtained are quite encouraging and superior to different existing optimization techniques.

1. Introduction

Power system Economic Load Dispatch (ELD) is the most efficient, reliable and low cost operation of power system dispatching generation among the available generating units such that the cost of operation is least, subject to load demand and other operational constraints. However, since 1980s due to implementation of several pollution control acts, finding out of minimum generation cost is not only the major concern of the power generating companies. These industries are bound to consider the effect of pollutants like NO_X, SO_X, CO_X, etc. that are present in the waste matter which come out from the stack of thermal power plant. Economic Emission Dispatch (EED) has come out to minimize the emission of pollutants like NO_X, SO_X, CO_X, particulate matters, etc. from the thermal power plant. Moreover, the objective of minimum cost of generation or the objective of minimum emission may not be a desirable criterion. Therefore, the concept of Economic Emission Load Dispatch (EELD) has come into the picture to figure out both the objective of minimum cost of generation and as well as minimum emission level at the same time. In a sentence it can be said that the combination of Economic Load and Emission Dispatch problem is known as Economic Emission Load Dispatch (EELD) and it seeks a balance between cost and emission. This problem of EELD may be formulated as a multi-objective Economic Emission Load Dispatch (EELD) problem or an Emission Constrained Economic Load Dispatch problem.

Several strategies have been proposed in [1,2] and discussed to reduce the emission. One of the first approaches to solve the EED problem considering single-objective optimization was described in [3] by considering emission as a constraint. Nanda et al. treated EELD as a multiple-objective optimization problem using goal-programming techniques [4,5]. Probability security criteria approaches by considering economy, security and environment protection as objectives [6] and linear programming technique [7] were also used in multi-objective **ELD** problem. Dhillon et al. and Chang et al. used the cost of generation and emission both as a single objective in [8,9]. Abido [10–12] used non-dominated sorting genetic algorithm (NSGA) and evolutionary programming for solving multi-objective environmental and economic dispatch. The ε-constraint method was presented in [13] to use it in a non-convex optimal problem. Srinivasan et al. proposed a fuzzy optimal search technique in Multi-objective generation scheduling [14]. Huang et al. proposed a new technique fuzzy satisfaction-maximizing decision approach [15] in bi-objective power dispatch. A genetic algorithm with arithmetic crossover technique [16], the refined genetic algorithm (RGA) [17], evolutionary algorithm [18]

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based method have been also implemented for EELD problems. Multi-objective stochastic search technique was proposed in [19]. Fonseca CM [20] applied evolutionary algorithm method. In [21–23], evolutionary algorithm and PSO have been applied to solve EELD problem to provide better solution. Perez-Guerrero and Cedeno-Maldonado [24], Abou El Ela et al. [25], Basu [26] applied differential evolution and Wu et al. [27] presented a multi-objective differential evolution (MODE) algorithm method to solve **EELD**. Hota et al. [28] applied a new fuzzy based bacterial foraging algorithm (MBFA) to solve both single and multi-objective EELD problems. In 2008, Biogeography-Based Optimization (BBO) [29] has been developed by Dan Simon which has proved it's worthy to solve different optimization problems. In 2010, A. Bhattacharya et al. applied BBO successfully to solve various multi-objective EELD problems [30]. Hybrid technique of differential evolution and Biogeography-Based Optimization (DE/BBO) [31] has been adopted to solve different EELD problem in search for much improved and fast output, compared to those of BBO. Recently Rajasomashekar et al. formulated a new methodology using BBO algorithm for finding out the best compromising solution between fuel cost and NO_X emission in EELD problems [32].

Yasar and Özyön [33] applied genetic algorithm along with conic scalarization method to convert multi-objective problem into single objective problem and solved the EELD problem of power system. Same authors applied combined modified subgradient technique along with harmony search [34] to solve EELD problems. Chatterjee et al. [35] introduced an opposition based Harmony Search Algorithm to solve **EELD** problems. Güvenç et al. applied recently developed gravitational search algorithm (GSA) to solve EELD problems [36]. Shaw et al. [37] incorporated the opposition based learning scheme of [35] within gravitational search algorithm (GSA) and implemented it for solving EELD problems.

In recent times, a new optimization technique based on the concept of chemical reaction, called Chemical Reaction Optimization (CRO) has been proposed by Lam and Li [38]. In a chemical reaction, the molecules of initial reactants stay in high-energy unstable states and undergo a sequence of collisions either with walls of the container or with other molecules. The reactants pass through some energy barriers, reach in low-energy stable states and become the final products. CRO captures this phenomenon of driving high-energy molecules to stable, low energy states, through various types of on-wall or inter-molecular reactions. CRO has been proved to be a successful optimization algorithm in discrete optimization. Basically, the CRO is designed to work in the discrete domain optimization problems. In order to make this newly developed technique suitable for continuous optimization domain, Lam et al. [39] have developed a real-coded version of CRO, known as Real-Coded CRO (RCCRO). It has been observed that the performance of RCCRO is quite satisfactory when applied to solve continuous benchmark optimization problems. The improved performance of RCCRO to solve different optimization problems has motivated the present authors to implement this newly developed algorithm to solve different non-convex complex emission dispatch problems.

2. Mathematical formulation of EELD problems

The following objectives and constraints are considered for EELD problem.

2.1. Economic Load Dispatch (ELD)

The fuel cost function F_1 of **ELD** problem is presented as given below

$$F_1 = \left(\sum_{i=1}^{N} F_i(P_i)\right) = \left(\sum_{i=1}^{N} a_i + b_iP_i + c_iP_i^2 + |e_i \times Sin\{f_i \times (P_{i\min} - P_i)\}|\right) \$/\text{h}. \quad (1)$$

where $F_i(P_i)$ is the ith generator cost function for P_i output; a_i, b_i and c_i are the ith generator's cost coefficients; N is the number of generators. The objective function of (1) is minimized subject to following constraints:

2.1.1. Real power balance constraint

$$\sum_{i=1}^{N} P_i - (P_D + P_L) = 0 \quad (2)$$

The total transmission network losses P_L can be expressed using B-coefficients as given below

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_iB_{ij}P_j + \sum_{i=1}^{N} B_{0i}P_i + B_{00} \quad (3)$$

2.1.2. Generator capacity constraints

From each unit power P_i generated shall be within their lower limit $P_{i\min}$ or upper limit $P_{i\max}$. So that

$$P_{i\min} \leqslant P_i \leqslant P_{i\max} \quad (4)$$

The power level of Nth generator (i.e. Slack Generator) is given by the following equation

$$P_N = P_D + P_L - \sum_{i=1}^{(N-1)} P_i \quad (5)$$

The transmission loss P_L is a function of all the generators including that of the slack generator (Nth Generator) and it is given by

$$P_L = \sum_{i=1}^{N-1}\sum_{j=1}^{N-1} P_iB_{ij}P_j + 2P_N\left(\sum_{i=1}^{N-1} B_{Ni}P_i\right) + B_{NN}P_N^2 + \sum_{i=1}^{N-1} B_{0i}P_i + B_{0N}P_N + B_{00} \quad (6)$$

Expanding and rearranging, Eq. (5) using (6) becomes

$$B_{NN}P_N^2 + \left(2\sum_{i=1}^{N-1} B_{Ni}P_i + B_{0N} - 1\right)P_N + \left(P_D + \sum_{i=1}^{N-1}\sum_{j=1}^{N-1} P_iB_{ij}P_j + \sum_{i=1}^{N-1} B_{0i}P_i - \sum_{i=1}^{N-1} P_i + B_{00}\right) = 0 \quad (7)$$

The loading of the dependent generator called slack generator (i.e. Nth) can then be found by solving (7).

2.2. Economic Emission Dispatch (EED)

The **EED** problem for NO_X gases emission can be defined as

$$F_2 = \left(\sum_{i=1}^{N} F_{Xi}(P_i)\right) = \left(\sum_{i=1}^{N} 10^{-2}(\alpha_i + \beta_iP_i + \gamma_iP_i^2)\right) + \xi_i \exp(\lambda_iP_i) \text{ Ton/h} \quad (8)$$

where F_2 is total amount of NO_X released from the system in (kg/h or ton/h); $F_{Xi}(P_i)$ is the ith generator's emission function for P_i output; α_i, β_i, γ_i, ξ_i and λ_i are the emission coefficients of ith generator.