

Solving economic load dispatch problems in power systems using chaotic and Gaussian particle swarm optimization approaches

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Abstract

The objective of the Economic Dispatch Problems (EDPs) of electric power generation is to schedule the committed generating units outputs so as to meet the required load demand at minimum operating cost while satisfying all units and system equality and inequality constraints. Recently, global optimization approaches inspired by swarm intelligence and evolutionary computation approaches have proven to be a potential alternative for the optimization of difficult EDPs. Particle swarm optimization (PSO) is a population-based stochastic algorithm driven by the simulation of a social psychological metaphor instead of the survival of the fittest individual. Inspired by the swarm intelligence and probabilities theories, this work presents the use of combining of PSO, Gaussian probability distribution functions and/or chaotic sequences. In this context, this paper proposes improved PSO approaches for solving EDPs that takes into account non-linear generator features such as ramp-rate limits and prohibited operating zones in the power system operation. The PSO and its variants are validated for two test systems consisting of 15 and 20 thermal generation units. The proposed combined method outperforms other modern metaheuristic optimization techniques reported in the recent literature in solving for the two constrained EDPs case studies. © 2007 Elsevier Ltd. All rights reserved.

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1. Introduction

The Economic Dispatch Problems (EDPs) is to determine the optimal combination of power outputs of all generating units to minimize the total fuel cost while satisfying the load demand and operational constraints [1].

In a liberalized electricity market, the optimization of economic dispatch is of economic value to the network operator. The economic dispatch is a relevant procedure in the operation of a power system. Over the past years, many optimization methods have been proposed in the literature. A spectrum of the advances in economic dispatch is well discussed in [2–28]. When compared with the conventional (classical) techniques [4–13], modern heuristic

optimization techniques based on operational research and artificial intelligence concepts, such as evolutionary algorithms [14–19], simulated annealing [20,21], artificial neural networks [22–24], and taboo search [26,27] have been given attention by many researchers due to their ability to find an almost global optimal solution for EDPs with operating constraints.

EDPs have recently been solved by Particle Swarm Optimization (PSO) approaches [28–32]. The PSO originally developed by Eberhart and Kennedy in 1995 [33,34] is a population-based stochastic algorithm. Similarly to genetic algorithms [35], an evolutionary algorithm approach, the PSO is an evolutionary optimization tool of swarm intelligence field based on a swarm (population), where each member is seen as a particle, and each particle is a potential solution to the problem under analysis. Each particle in PSO has a randomized velocity associated to it, which moves through the space of the problem. However, unlike

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genetic algorithms, PSO does not have operators, such as crossover and mutation. PSO does not implement the survival of the fittest individuals; rather, it implements the simulation of social behavior [36]. PSO, however, allows each particle to maintain a memory of the best solution that it has found and the best solution found in the particle's neighborhood is swarm.

In PSO, a uniform probability distribution to generate random numbers into the velocity update equation is used. The use of other probability distributions may improve the ability to fine-tuning or even to escape from local optima. In the meantime, it has been proposed the use of the Gaussian [37–39], Cauchy [40], and exponential [41] probability distribution functions, and chaotic sequences [42] to generate random numbers to updating the velocity equation. All these approaches attempted to improve the performance of the standard PSO, but the amount of parameters of the algorithm to tune remained the same.

This paper proposes the Gaussian probability distribution and also chaotic sequences in PSO approaches to solve EDPs with 15 and 20 thermal units with generator constraints. Simulation results obtained through the PSO approaches are analyzed and compared with those reported in recent literature. The proposed PSO approaches of improvements in the setup of classical PSO algorithm using Gaussian and chaotic signals are powerful strategies to diversify the particle's swarm in PSO and improve the PSO's performance in preventing premature convergence to local minima.

The remaining sections of this paper are organized as follows: Section 2 describes the formulation of an EDP. Section 3 then describes the Gaussian and chaotic sequences for PSO approaches adopted here, while Section 4 details the procedure of constraint handling in PSO. Section 5 discusses the computational procedure and analyzes the PSO results when applied to case studies of EDPs with 15 and 20 thermal units. Lastly, Section 6 outlines our conclusions.

2. Formulation of an EDP with generator constraints

The EDP is to find the optimal combination of power generation that minimizes the total fuel cost while at thermal power units satisfying the total demand subjected to the operating constraints of a power system with a defined interval (typically 1 h). The essential operation constraints are the power balance constraint, where the total generated power must be equals to the load demands plus the transmission losses on the electrical network, and the power limit constraints, where individual generator units must be operated within their specified range.

In this context, for power balance, an equality constraint should be attempted. The generated power should be the same as the total load demand plus the total line losses. In this case, the active power balance is given by

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

where P_i is the power of generator i (in MW); n is the number of generators in the system; P_D is the system's total demand (in MW); P_L represents the total line losses (in MW).

Inequality constraints for each generator must be also satisfied. Generation power of each generator should be laid between maximum and minimum limits. The inequality constraint for each generator is represented by Eq. (2) given by

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad (2)$$

where $P_i^{\min}$ and $P_i^{\max}$ are the output of the minimum and maximum operation of the generating unit i (in MW), respectively. The mathematical formulation of the total fuel cost function is formulated as follows:

$$\min f = \sum_{i=1}^n F_i(P_i) \quad (3)$$

where F_i is the total fuel cost for the i th generator (in \$/h). Generally, the fuel cost of thermal generating unit is represented in polynomial function,

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \quad (4)$$

where a_i , b_i and c_i are cost coefficients of generator i . However, the Eq. (4) can be modified using a sine function to model the ripples due to valve point effect of generator. Details about the valve point effect in generators can be found in [4,5,18,28].

In this study, the ramp-rate limits, prohibited operating zone-constraints, and transmission losses are considered [14,19,30,31,43]. The constraints of EDP at specific operating interval can be represented by Eqs. (5)–(8) given by

(i) Ramp-rate limit constraints:

$$\max(P_i^{\min}, P_i^0 - DR_i) \leq P_i \leq \min(P_i^{\max}, P_i^0 + UR_i) \quad (5)$$

where $P_i(t)$ is the present output power, P_i^0 is the previous output power, UR_i is the up-ramp limit of the i th generator (in units of MW/time-period), and DR_i is the down-ramp limit of the i th generator (in units of MW/time-period).

(ii) Prohibited operating zones constraints:

$$P_i \in \begin{cases} P_i^{\min} \leq P_i \leq P_{i,1}^l \\ P_{i,k-1}^u \leq P_i \leq P_{i,k}^l, & k = 1, \dots, zo_i \\ P_{i,zo_i}^u \leq P_i \leq P_i^{\max} \end{cases} \quad (6)$$

where $P_{i,k}^l$ and $P_{i,k}^u$ are the lower and upper bounds of the k th prohibited zone of unit i , respectively; k is the index of prohibited zones (zo_i).

(iii) Line flow constraint:

$$|P_{f,j}| \leq P_{f,j}^{\max}, \quad j = 1, \dots, L \quad (7)$$

where $P_{f,j}$ is real power flow of line j and L is the number of transmission lines; and the transmission network losses, P_L , must be into account to achieve

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