Electrical Power and Energy Systems 50 (2013) 85–96

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Chaotic self-adaptive differential harmony search algorithm based dynamic economic dispatch

R. Arul [a,*], G. Ravi [b], S. Velusami [a]

[a] Department of Electrical Engineering, Annamalai University, Annamalainagar, Tamilnadu, India
[b] Department of EEE, Pondicherry Engineering College, Puducherry, India

ARTICLE INFO

Article history:
Received 19 July 2012
Received in revised form 4 February 2013
Accepted 22 February 2013
Available online 22 March 2013

Keywords:
Dynamic economic dispatch
Valve point effect
Prohibited operating zones
Ramp-rate limits
Differential harmony search algorithm
Chaotic differential harmony search algorithm

ABSTRACT

Dynamic economic dispatch (DED) is one of the main optimization problems in electrical power system operation and control. DED problem is a non-smooth and non-convex problem when valve point effect, ramp-rate limits and prohibited operating zones of generation units are taken into account. This paper proposes an efficient chaotic self-adaptive differential harmony search (CSADHS) algorithm to solve the complicated DED problem in the presence of valve point effect, ramp-rate limits and prohibited operating zones constraints. In the proposed algorithm, chaotic self-adaptive differential mutation operator is used instead of pitch adjustment operator in the harmony search (HS) algorithm, to enhance the searching performance to find the quality solution. The effectiveness of the proposed algorithm is demonstrated on 10, 15 and 30 unit systems for a period of 24 h. The simulation results obtained by the proposed algorithm are compared with the results obtained, using differential harmony search (DHS) algorithm, chaotic differential harmony search (CDHS) algorithm, and also with the results of other methods available in the literature. In terms of solution quality, the proposed algorithm is found to be better than other algorithms and in terms of speed of convergence, standard deviation of generation cost, and computational time, the proposed algorithm is better than DHS and CDHS algorithm.

1. Introduction

Dynamic economic dispatch is an extension of the conventional economic dispatch problem. It is a method to schedule the online generator outputs with the predicted load demands over a certain period of time so as to operate an electrical power system most economically [1]. The ramp-rate constraints of generators are considered as dynamic operational constraints in DED problem. Ramp-rates are the maximum rates specified at each generating unit at which the power output can be increased (ramp-up) or decreased (ramp-down) in a time interval. In practical systems, the load demand fluctuates with respect to time, so the power generation has to be altered to meet out the demand without violating the ramp-rate limits of the generating units. The input–output characteristic of thermal generators is usually approximated by quadratic functions or piecewise quadratic functions, which are unfortunately far away from the real power plant. This leads to inaccuracy in dispatch result. The modern generators are highly non-linear due to the presence of valve point effect, ramp-rate limits and prohibited operating zones. A unit with prohibited operating zones, its operating region $P_{\min}$ to $P_{\max}$ will be divided into several isolated sub-regions. These isolated sub-regions will form multiple decision spaces and result in very challenging task for determining the optimal economic dispatch. The conventional mathematical methods such as linear programming (LP), non-linear programming (NLP), quadratic programming (QP), Lagrange relaxation (LR) and dynamic programming (DP) [2] have been proposed to solve DED problems in the past decades. However, all these methods may not be able to provide the optimal solution since they usually get stuck at the local optimal solution. Recently, stochastic optimization techniques such as hybrid EP and SQP, Differential evolution (DE), Simulated annealing (SA), guided PSO, modified hybrid EP-SQP, improved PSO, hybrid DE, modified DE and hybrid swarm-intelligence based harmony search algorithm (HHS) [3] have been used to solve the DED problems without any restrictions on the shape of cost curves due to their ability in seeking the optimal solution. However choosing the control parameters for all these evolutionary algorithms is a very difficult task. In 2001, Geem et al. [4] proposed harmony search (HS) algorithm. It is a derivative-free, meta-heuristic algorithm, developed in an analogy with music improvisation process, where music players improvise the pitches of their instruments to obtain better harmony. The uniqueness of HS algorithm compared to other algorithms is that, it will generate a new harmony/solution vector, after considering all the existing solution vectors in the harmony memory (HM) matrix. These features increase the exploration power of the HS algorithm to

* Corresponding author. Tel.: +91 09865003003.
E-mail address: arulphd@yahoo.co.in (R. Arul).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.02.017

produce better solutions. The performance of HS algorithm in the complex and multi-modal fitness landscapes is not satisfactory since it gets stuck at the local optima and/or projects premature convergence. Mahdavi et al. [5] proposed an improved HS (IHS) algorithm that employs a novel method to generate new harmony vectors which in turn enhances the accuracy and speed of convergence. Mahamed and Mahdavi [6] recently tried to improve the performance of HS algorithm by incorporating some techniques from swarm intelligence. Chakraborty et al. [7] proposed differential harmony search (DHS) algorithm, where the pitch adjustment operation in the HS algorithm was replaced by the mutation operator borrowed from the differential evolution (DE) algorithm. dos Santos Coelho et al. [8] proposed chaotic differential harmony search algorithm (CDHS), where the pitch adjustment operator in the HS algorithm was modified as that of DE operator. Moreover chaotic sequences using logistic map are used to generate the values of HMCR. The term 'alpha' used in the mutation operator of CDHS algorithm is fixed as a constant throughout the optimization process. Normally, fixed value in the mutation process leads to local optima in the evolutionary algorithm. The main emphasis of this paper is to propose a new variant of HS algorithm called chaotic self-adaptive differential harmony search algorithm, which will effectively solve the DED problem considering valve point effect, ramp-rate limits and prohibited operating zones constraints. Finally, the simulation result obtained by DHS, CDHS, and the proposed CSADHS algorithm are compared with the results reported in the literature to prove the superiority of the proposed CSADHS algorithm. The solutions obtained by the proposed algorithm are found better than the results of other methods in terms of quality of solution. In terms of speed of convergence, standard deviation of generation cost, and computational time, the proposed algorithm is better than DHS and CDHS algorithm.

2. Dynamic load dispatch problem formulation

The objective function is formulated as follows:

$$\text{Minimize } F_{\text{tot}} = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{i,t}(P_{i,t}) \tag{1}$$

where $F_{i,t}(P_{i,t}) = a_i + b_i(P_{i,t}) + c_i P_{i,t}^2$ without valve point effect and $F_{i,t}(P_{i,t}) = a_i + b_i P_{i,t} + c_i P_{i,t}^2 + |e_i \sin(f_i(P_{i,\min} - P_{i,t}))|$ with valve point effect. Where F_{tot} is the total fuel cost over the whole dispatch periods, T is the total time period of dispatch, N is the number of generating units, $P_{i,t}$ is the power output of ith unit at time 't' interval. $F_{i,t}$ $(P_{i,t})$ is the fuel cost of ith unit at the output of $P_{i,t}$. a_i, b_i, c_i, e_i and f_i are the fuel cost coefficients of the ith unit with valve point effects, $P_{i,\min}$ is the minimum generation level of ith generating unit and P_i is the power output of the ith generating unit in megawatts. Minimization of DED problem is subject to the following equality and inequality constraints:

2.1. Real power balance constraint

$$\sum_{i=1}^{N} P_{i,t} - P_{D,t} - P_{L,t} = 0 \quad \text{where } i = 1,2,\ldots,N \text{ and } t = 1,2,\ldots,T \tag{2}$$

where $P_{D,t}$ is the load demand at time t, $P_{L,t}$ is the total real power transmission losses at time 't' and N is the total number of the online generators. The general formula used to calculate transmission losses using B-coefficients is given in (3).

$$P_{L,t} = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{i,t} B_{ij} P_{j,t} + \sum_{i=1}^{N} B_{0i} P_{i,t} + B_{00} \tag{3}$$

where B_{ij} is the ijth element of the loss coefficient square matrix; B_{0i} is the ith element of the loss coefficient vector; and B_{00} is the loss coefficient constant.

2.2. Real power generation limits

$$P_{i,\min} \leqslant P_{i,t} \leqslant P_{i,\max} \quad \text{for } i = 1,2,3\ldots,N \tag{4}$$

where $P_{i,\min}$, $P_{i,\max}$ are the minimum and maximum active power limits of the ith generator at time t.

2.3. Generating unit ramp-rate limits

The ramp-up and ramp-down rate limits of ith generator in MW/h are as follows:

$$P_{i,t} - P_i^{t-1} \leqslant \text{UR}_i, \quad \text{if power generation increases}$$

$$P_i^{t-1} - P_{i,t} \leqslant \text{DR}_i, \quad \text{if power generation decreases}$$

where P_i^{t-1} is the power generation of ith unit at previous hour and UR_i and DR_i are the ramp-up and ramp-down rate limits respectively. So the modified generator operating constraints after inclusion of ramp-rate limits is as follows

$$\max(P_{i,\min}, P_i^{t-1} - \text{DR}_i) \leqslant P_{i,t} \leqslant \min(P_{i,\max}, P_i^{t-1} + \text{UR}_i) \tag{5}$$

such that

$$P_{i,t\,\min} = \max(P_{i,\min}, P_i^{t-1} - \text{DR}_i) \quad \text{and}$$
$$P_{i,t\,\max} = \min(P_{i,\max}, P_i^{t-1} + \text{UR}_i) \tag{6}$$

2.4. Prohibited operating zones

A generating unit with prohibited operating zones has a discontinuous input–output power generation characteristic which gives rise to additional constraints on the unit operating range.

$$P_{i,t} = \begin{bmatrix} P_{i,\min} \leqslant P_{i,t} \leqslant P_{i,1}^{L} & \text{or} \\ P_{i,k-1}^{U} \leqslant P_{i,t} \leqslant P_{i,k}^{L} & \text{or} \\ P_{i,n_i}^{U} \leqslant P_{i,t} \leqslant P_{i,\max}, & k = 2,3,\ldots,n_i \end{bmatrix} \tag{7}$$

where n_i is the number of prohibited operating zones in the ith generating unit. k is the index of the prohibited operating zones of the ith generating unit. $P_{i,k}^{L}$ and $P_{i,k}^{U}$ are the lower and upper bounds of kth prohibited operating zones of unit i.

2.5. Fitness function in DED

The main equation to calculate the fitness function is shown in the following equation:

$$\text{FF}_{\text{tol}} = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{i,t}(P_{i,t}) + \lambda_{\text{eq}} \sum_{t=1}^{T} |P_{1,t} - P_{1,t\,\text{lim}}| + \lambda_{\text{rr}} + \sum_{t=2}^{T}\sum_{i=1}^{N} |P_{i,t} - P_{rr\_\text{lim}}| + \lambda_{poz} \sum_{t=1}^{T}\sum_{i=1}^{N} |P_{i,t\,pz\_\text{lim}}| \tag{8}$$

where $\lambda_{\text{eq}}, \lambda_{\text{rr}}$ and λ_{poz} are the penalty factors corresponding to real power limits of first unit, ramp-rate limits and prohibited operating zones. The inequality constraints limits are calculated as follows:

$$P_{1,t\,\text{lim}} = \begin{cases} P_{1,\min} & \text{if} \quad P_{i,t} < P_{1,\min} \\ P_{1,\max} & \text{if} \quad P_{i,t} > P_{1,\max} \\ P_{i,t} & \quad\quad \text{otherwise} \end{cases} \tag{9}$$