Available online at www.sciencedirect.com

SciVerse ScienceDirect

Journal of Hydro-environment Research 7 (2013) 72−80

Journal of
Hydro-environment
Research

www.elsevier.com/locate/jher

Research papers

Parameter study of differential evolution based optimal scheduling of hydrothermal systems

K.K. Mandal*, N. Chakraborty[1]

Jadavpur University, Department of Power Engineering, Sector III, Kolkata 700098, West Bengal, India

Received 9 July 2010; revised 30 March 2012; accepted 11 April 2012

Abstract

Differential evolution (DE) has been proved to be a powerful evolutionary algorithm for global optimization in many real-world problems. The performance of evolutionary algorithms is heavily dependent on the setting of control parameters. Proper selection of the control parameters is very important for the success of the algorithm. Optimal settings of control parameters of differential evolution depend on the specific problem under consideration. In this paper, a study of control parameters on differential evolution based optimal scheduling of hydrothermal systems with cascaded reservoir is conducted empirically. A multi-reservoir cascaded hydrothermal system with non-linear relationship between water discharge rate, power generation and net head is considered for the present study. The water transport delay between connected reservoirs is also taken into account. Several equality and non-equality constraints on thermal plants such as maximum and minimum generation capacity and effect of valve point loading are also considered. The results of the effect of the variations of the parameters are presented systematically and it is observed that the search algorithm may fail in finding the optimal value if the parameter selection is not done with proper attention.

Keywords: Control parameters; Differential evolution (DE); Hydrothermal scheduling; Cascaded reservoirs

---

1. Introduction

The Differential Evolution (DE) as proposed by Storn and Price (1995) is a powerful optimization technique designed for global optimization. Besides its good convergence properties, main advantage of DE lies with its conceptual simplicity, ease of use and less number of control parameters. Like any other evolutionary algorithm, the success of DE is heavily dependent on setting of control parameters. It has three control parameters: (1) the population size N_P (2) the mutation factor f_m, which is a real-valued factor that controls the amplification of differential variation and (3) the crossover factor C_R, which is also a real-valued factor that controls the crossover operation. One of the main problems in evolution strategies of DE is to choose the control parameters such that it exhibits good behavior i.e. it does not prematurely converge to a point that is not globally optimal or stagnate and has an acceptable rate of convergence toward the global optimum. Premature convergence may occur under different situations: the population has converged to local optimum of the objective function, the population has lost its diversity and the search algorithm proceeds slowly or does not proceed at all (Lampinen and Zelinka, 2000). It is seen that DE may sometimes stop proceeding toward global optimum and stagnation occurs. Stagnation may occur under various situations: the population does not converge to a local optimum or any other point, the population is still remaining diverse and occasionally, even if the new individuals may enter into the population, the searching algorithm does progress toward any better solutions (Lampinen and Zelinka, 2000).

The effectiveness, efficiency and robustness of the DE algorithm are sensitive to the setting of control parameters. The best setting for the control parameters depends on the

---

* Corresponding author. Tel.: +91 33 23355813; fax: +91 33 23357254.
E-mail addresses: kkm567@yahoo.co.in (K.K. Mandal), chakraborty_niladri2004@yahoo.com (N. Chakraborty).
[1] Tel.: +91 33 23355813; fax: +91 33 23357254.

doi:10.1016/j.jher.2012.04.001

problem in hand and requirement of computation time and accuracy (Liu and Lampinen, 2002). Although, as reported in the literature, control parameters of DE are not difficult to choose, but rules for choosing control parameters are not general (Storn and Price, 1995). On the other hand, it is also reported that choosing proper control parameters for DE is more difficult than expected (Gamperle et al., 2002). It is important to select optimal parameters for each problem separately and carefully to avoid premature convergence or even stagnation (Lampinen and Zelinka, 2000; Zielinski et al., 2005; Ronkkonen et al., 2005). Brest et al. (2006) assessed the selection of control parameter and reported that efficiency and robustness of DE algorithm are much more sensitive to the setting of mutation factor f_m and crossover ratio C_R than to the setting of the population size N_P. Zaharie (2002) analyzed the relationship between control parameters of DE and the evolution of population variance and reported critical interval for control parameters of DE. Teo (2006) proposed a method of self-adapting population size in addition to self-adapting mutation factor and crossover ratio. Setting of control parameters in evolutionary algorithms like DE can be classified into two categories: Parameter tuning and parameter control. Parameter tuning is the commonly practiced approach that is used in finding proper values for the parameters before the actual run of the algorithm. Then the algorithm is used using these values, which remain fixed during the run.

The optimum scheduling of hydrothermal plants is an important task in interconnected power system operation. The generation scheduling problem of hydrothermal systems has been the subject of intensive research work for several decades. Different methods have been applied successfully over the years to solve this problem. Some of the important methods include dynamic programming (Chang et al., 1990), Lagrangian relaxation technique (Guan and Peter, 1998) etc. In recent times optimal hydrothermal scheduling problems have been solved by different heuristic techniques such as genetic algorithm (Orero and Irving, 1998), simulated annealing technique (Wong and Wong, 1994), evolutionary programming (Yang et al., 1996), particle swarm optimization technique (Mandal et al., 2008; Yu et al., 2007), mixed-integer quadratic programming (Catalao et al., 2010). Recently, Wang et al. applied an efficient and improved technique for optimal operation of hydropower reservoirs and presented encouraging results (Wang and Zhang, 2011; Wang and Liu, 2011).

The generation scheduling problem consists of determining optimum operation strategy for allocation of generations to different units so as to minimize the total operational cost subjected to a variety of constraints. The operational cost of hydroelectric plants is insignificant. Thus, the problem of minimizing the operational cost of a hydrothermal system reduces to minimizing the fuel cost of thermal plants subjected to a variety of constraints of hydraulic and power system network. The main constraints include: the cascaded nature of the hydraulic network, the time coupling effect of the hydro sub-problem, the varying hourly reservoir inflows, the physical limitations on the reservoir storage and turbine flow rate, the varying system load demand and the loading limits of both thermal and hydro plants. The effect of valve point loading of the thermal power plants is also included in the scheduling problem. In this paper, tests for parameter setting are conducted for the short-term economic generation scheduling of hydrothermal systems.

2. Optimal scheduling of hydrothermal systems

Economic generation scheduling of hydrothermal systems involves the optimization of a problem with non-linear objective function subject to a mixture of linear and non-linear constraints. As the fuel cost of hydroelectric plants is insignificant in comparison with that of thermal power plants, the objective is to minimize the fuel cost of thermal power plants, while making use of the availability of hydro-resources as much as possible. For a given hydrothermal system, the problem may be described as optimization (minimization) of total fuel cost as defined by (1) under a set of operating constraints;

Minimize

$$F = \sum_{t=1}^{T} \sum_{i=1}^{N_s} [f_{it}(P_{sit})] \tag{1}$$

where F is the total fuel cost, T is the total number of time interval for the scheduling horizon, N_s is the total number of thermal power generating units, P_{sit} is the power generation of i th thermal power generating unit at time t and f_{it} (P_{sit}) is the fuel cost for P_{sit}.

The fuel cost curve for any thermal power generating unit can be represented by segments of quadratic functions of the active power output of the generator along with a sinusoidal function to take into account the effect of valve point loading (Mandal et al., 2008). Thus f_{it} (P_{sit}) can be defined by (2) as:

$$f_{it}(P_{sit}) = a_{si} + b_{si}P_{sit} + c_{si}P_{sit}^2 + \left| e_{si} \times \sin\left\{ f_{si} \times \left(P_{si}^{\min} - P_{sit} \right) \right\} \right| \tag{2}$$

where a_{si}, b_{si}, c_{si}, e_s and f_{si} are the fuel cost coefficients of the i th thermal generating unit.

The above objective function is to be minimized subject to a variety of constraints as follows:

(i) Active power balance

$$\sum_{i=1}^{N_s} P_{sit} + \sum_{j=1}^{N_h} P_{hjt} - P_{Dt} - P_{Lt} = 0 \tag{3}$$

where P_{hjt} is the power generation of j th hydro plant at time t, P_{Dt} is power demand at time t and P_{Lt} is total transmission loss at the corresponding time. In this work the power loss is not considered for simplicity. However, it may be calculated by using B-loss matrix directly.

The hydropower generation is a function of water discharge rate and reservoir storage volume which can be described by (4) as follow: