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Improved differential evolution for short-term hydrothermal scheduling

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ABSTRACT

This paper presents an improved differential evolution to determine the optimal hourly schedule of power generation in a hydrothermal system. Differential evolution (DE) exploits the differences of randomly sampled pairs of objective vectors for its mutation process. Consequently the variation between vectors will outfit the objective function toward the optimization process and therefore provides efficient global optimization capability. However, although DE is shown to be precise, fast as well as robust, its search efficiency will be impaired during solution process with fast descending diversity of population. This paper proposes Gaussian random variable instead of scaling factor which improves search efficiency. The algorithm is tested on two test problems and three hydrothermal multi-reservoir cascaded hydroelectric test systems having prohibited operating zones and thermal units with valve point loading. The ramp-rate limits of thermal generators are taken into consideration. The transmission losses are also accounted for through the use of loss coefficients. The results of the proposed approach are compared with those obtained by other evolutionary methods. It is found that the improved differential evolution based approach is able to provide better solution.

1. Introduction

Optimum scheduling of generation in a hydrothermal system is of great importance to electric utility systems. With the insignificant marginal cost of hydroelectric operational cost of a hydrothermal system essentially reduces to that of minimizing the fuel cost for thermal plants under the various constraints on the hydraulic, thermal and power system network.

The main constraints include: the time coupling effect of the hydro sub problem, where the water flow in an earlier time interval affects the discharge capability at a later period of time, the cascaded nature of the hydraulic network, the varying hourly reservoir inflows, the physical limitations on the reservoir storage and turbine flow rate, prohibited operating zones of hydroelectric system, ramp-rate limits of thermal generators, the varying system load demand and the loading limits of both thermal and hydro plants.

The hydrothermal scheduling problem has been the subject of investigation for several decades. Most of the methods that have been used to solve the hydrothermal co-ordination problem make a number of simplifying assumptions in order to make the optimization problem more tractable. Some of these solution methods are mathematical decomposition [1], network flow [2], dynamic programming [3], deterministic optimization algorithm [4], Lagrangian relaxation [5], and Benders decomposition [6].

Since the mid 1990s, many techniques originated from Darwin's natural evolution theory have emerged. These techniques are usually termed by “evolutionary computation methods” including evolutionary algorithms (EAs), swarm intelligence and artificial immune system.

With the emergence of evolutionary computation methods, attention has been gradually shifted to application of such technology-based approaches to handle the complexity involved in real world problems. Stochastic search algorithms such as simulated annealing technique [7], evolutionary programming technique [8,11], genetic algorithm [9,10], differential evolution [12–14], and particle swarm optimization [15], clonal selection algorithm [16] and teaching learning based optimization [17] have been applied for optimal hydrothermal scheduling problem and circumvented the above mentioned weakness.

Differential evolution (DE) [18–20], a relatively new member in the family of evolutionary algorithms, first proposed over 1995–1997 by Storn and Price at Berkeley is a novel approach to numerical optimization. It is a population-based stochastic parallel search evolutionary algorithm which is very simple yet powerful. The main advantages of DE are its capability of solving optimization problems which require minimization process with nonlinear, non-differentiable and multi-modal objective functions. The fittest of an offspring competes one-to-one with the corresponding parent, which makes this one different from the other evolutionary algorithms. This competition implies that the parent is replaced by its offspring if the fitness of the offspring is better than that of its parent. On the other hand, the parent is retained in the next

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Nomenclature

a_{si}, b_{si}, c_{si}, d_{si}, e_{si} cost curve coefficients of ith thermal unit
P_{sit} output power of ith thermal unit at time t
$P_{si}^{\min}$, $P_{si}^{\max}$ lower and upper generation limits for ith thermal unit
UR_i, DR_i ramp-up and ramp-down rate limits of the ith thermal unit
P_{Dt} load demand at time t
P_{Lt} transmission loss at time t
P_{hjt} output power of jth hydro unit at time t
C_{1j}, C_{2j}, C_{3j}, C_{4j}, C_{5j}, C_{6j} power generation coefficients of jth hydro unit
Q_{hjt} water discharge rate of jth reservoir at time t
V_{hjt} storage volume of jth reservoir at time t
$P_{hj}^{\min}, P_{hj}^{\max}$ lower and upper generation limits for jth hydro unit
$Q_{hj}^{\min}, Q_{hj}^{\max}$ minimum and maximum water discharge rate of jth reservoir
$Q_{hj,k}^{L}, Q_{hj,k}^{U}$ lower and upper bounds of kth prohibited zones of hydro unit j
$V_{hj}^{\min}, V_{hj}^{\max}$ minimum and maximum storage volume of jth reservoir
I_{hjt} inflow rate of jth reservoir at time t
R_{uj} number of upstream units directly above jth hydro plant
S_{hjt} spillage of jth reservoir at time t
τ_{lj} water transport delay from reservoir l to j
t, T time index and scheduling period
N_s number of thermal generating units
N_h number of hydro generating units
n_j number of prohibited zones for hydro unit j
k index of prohibited zones of a hydro unit

generation if the fitness of the offspring is worse than that of its parent. This one-to-one competition gives rise to a faster convergence rate. However, this faster convergence also leads to a higher probability of obtaining a local optimum because the diversity of the population descends faster during the solution process. To overcome this drawback, this paper proposes improved differential evolution (IDE) which uses Gaussian random variable instead of scaling factor. This maintains the diversity of the population, which guarantees a high probability of obtaining the global optimum.

DE has been used for many power system problems such as economic dispatch [21], power system planning [22], and dynamic economic dispatch [23] apart from hydrothermal scheduling.

This paper proposes improved differential evolution (IDE) for short-term optimal scheduling of generation in a hydrothermal system which involves the allocation of generation among the multi-reservoir cascaded hydro plants having prohibited operating zones and thermal units with valve point loading so as to minimize the fuel cost of thermal plants while satisfying the various constraints on the hydraulic, thermal and power system network including ramp rate limits of thermal generator. To illustrate the convergence property of the proposed IDE method, two test problems and three hydrothermal test systems are used. The test results are compared with those obtained by other population-based evolutionary methods. From numerical results, it is found that the proposed IDE based approach provides better solution.

2. Problem formulation

The hydrothermal scheduling problem is aimed to minimize the fuel cost of thermal plants, while making use of the availability of hydro power as much as possible. The objective function and associated constraints of the hydrothermal scheduling problem are formulated as follows.

2.1. Objective function

$$\text{Minimize } F = \sum_{t=1}^{T}\sum_{i=1}^{N_s}[a_{si} + b_{si}P_{sit} + c_{si}P_{sit}^2 + |d_{si} \times \sin\{e_{si} \times (P_{si}^{\min} - P_{sit})\}|] \quad (1)$$

2.2. Constraints

2.2.1. Power balance constraints

The total active power generation must balance the predicted power demand and transmission loss, at each time interval over the scheduling horizon

$$\sum_{i=1}^{N_s}P_{sit} + \sum_{j=1}^{N_h}P_{hjt} - P_{Dt} - P_{Lt} = 0, \quad t \in T \quad (2)$$

The hydroelectric generation is a function of water discharge rate and reservoir water head, which in turn, is a function of storage.

$$P_{hjt} = C_{1j}V_{hjt}^2 + C_{2j}Q_{hjt}^2 + C_{3j}V_{hjt}Q_{hjt} + C_{4}V_{hjt} + C_{5j}Q_{hjt} + C_{6j}, \quad j \in N_h, \quad t \in T \quad (3)$$

The transmission loss P_{Lt} is given by

$$P_{Lt} = \sum_{i=1}^{N_s+N_h}\sum_{j=1}^{N_s+N_h}P_{it}B_{ij}P_{jt} + \sum_{i=1}^{N_s+N_h}B_{0i}P_{it} + B_{00} \quad (4)$$

2.2.2. Generation limits

$$P_{hj}^{\min} \leqslant P_{hjt} \leqslant P_{hj}^{\max}, \quad j \in N_h, \quad t \in T \quad (5)$$

and

$$P_{si}^{\min} \leqslant P_{sit} \leqslant P_{si}^{\max}, \quad i \in N_s, \quad t \in T \quad (6)$$

2.2.3. Ramp rate limits of thermal generating unit

The power generated, P_i, by the ith thermal unit in certain interval may not exceed that of previous interval by more than a certain amount UR_i, the up-ramp limit and neither may it be less than that of the previous interval by more than some amount DR_i the down-ramp limit of the unit. These give rise to the following constraints.

$$P_{sit} - P_{si(t-1)} \leqslant UR_i, \quad i \in N_s, \quad t \in T \quad (7)$$

$$P_{si(t-1)} - P_{sit} \leqslant DR_i, \quad i \in N_s, \quad t \in T \quad (8)$$

2.2.4. Hydraulic network constraints

The hydraulic operational constraints comprise the water balance equations for each hydro unit as well as the bounds on reservoir storage and release targets. These bounds are determined