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Quadratic approximation based differential evolution with valuable trade off approach for bi-objective short-term hydrothermal scheduling

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ABSTRACT

Short-term combined economic emission hydrothermal scheduling (CEES) is a bi-objective problem: (i) minimizing fuel cost and (ii) minimizing pollutant emission. In this paper, quadratic approximation based differential evolution with valuable trade off approach (QADEVT) has been developed to solve the bi-objective hydrothermal scheduling problem. The practical hydrothermal system possesses various constraints which make the problem of finding global optimum difficult. In this paper, heuristic rules are proposed to handle the water dynamic balance constraints and heuristic strategies based on priority list are employed to handle active power balance constraints. A feasibility-based selection technique is also introduced to satisfy the reservoir storage volumes constraints. To demonstrate the superiority of the proposed approach, simulation results have been compared with those obtained by differential evolution (DE) and particle swarm optimization (PSO) with same heuristic strategies and the earlier reported methods available in literature. The simulation results reveal that the proposed approach is capable of efficiently providing superior solutions.

1. Introduction

The short-term hydrothermal scheduling is one of the most important and challenging optimization problems in the daily operation planning of power systems. The objective of the scheduling is to determine the optimal power output of both hydro and thermal plants in order to meet the required load demand at minimum operating cost while satisfying various constraints. With the insignificant operational cost of hydroelectric plants, the objective of minimizing the operational cost of a hydrothermal system reduces to minimizing the fuel cost of thermal plants. Due to increasing concern over environmental pollution caused by fossil fuel fired thermal power plants, harmful emission produced by the thermal plants must be minimized simultaneously. It is necessary for utilities to take not only the fuel cost but also emission into consideration. Thus, an alternative economic hydrothermal scheduling considering both the fuel cost and emission is required.

Up to now, several techniques have been developed to solve the hydrothermal scheduling problems. Various mathematical programming methods such as programming methodology (Tang & Peter, 1995; Yang & Chen, 1989), lagrangian relaxation (Guan & Peter, 1998), non-linear network flow technique (Brannud, Bubenko, & Sjelvgren, 1986), and decomposition techniques (Pereira & Pinto, 1982) have been applied for solving the hydrothermal scheduling problems. As the hydrothermal scheduling problems are modeled with nonlinear and non-convex curves with prohibited operating regions, the conventional methods are not suitable for dealing with constraints of hydrothermal system. Thus, aside from the above methods, optimal hydrothermal scheduling problems have been solved by stochastic search algorithms like simulated annealing (Wong & Wong, 1994), genetic algorithm (Gil, Bustos, & Rudnick, 2003; Orero & Irving, 1998; Ramirez & Ontae, 2006; Yuan & Yuan, 2002), artificial neural networks (Naresh & Sharma, 1999), evolutionary programming (Sinha, Chakrabarti, & Chattopadhyay, 2003), cultural algorithm (Yuan & Yuan, 2006), tabu search (Bai & Shahidehpour, 1996), differential evolution (Mandal & Chakraborty, 2008) and particle swarm optimization (Yu, Yuan, & Wang, 2007). Various heuristic methods such as heuristic search technique (Dhillon Jarnail, Dhillon, & Kothari, 2007), fuzzy satisfying evolutionary programming procedures (Basu, 2004) and fuzzy decision-making stochastic technique (Dhillon, Parti, & Kothari, 2002) have been applied to solve multi-objective short-term hydrothermal scheduling problems.

In most of these algorithms, penalty functions are used to handle the equality and inequality constraints where infeasible solutions are penalized depending on the amount of constraint violation. Despite the simplicity and ease of implementation of penalty functions, they require tedious process of choosing suitable penalty coefficients. In this work, heuristic rules are proposed to handle the water dynamic balance constraints and heuristic strategies based on priority list are employed to handle active

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power balance constraints. A feasibility-based selection technique is also suggested to handle the reservoir storage volumes constraints. These techniques can also help the evolutionary algorithm avoid premature convergence.

In the present work, a novel interactive bi-objective programming with valuable trade off approach was borrowed from Refs. Kuo (2009a, 2009b) to solve the bi-objective hydrothermal scheduling problem. It can provide a valuable trade off solution for the bi-objective optimization problem. Quadratic approximation based differential evolution (QADE) is proposed to optimize the nonlinear hydrothermal scheduling problem. Differential Evolution (DE) developed by Storn and Price (1997), is one of the most promising evolution algorithms. It has been successfully applied to solve optimization problems particularly involving non-smooth objective functions. The quadratic approximation operator is a nonlinear operator which can accelerate the evolution process by generating a new solution vector lying at the point of minima of the quadratic curve passing through the three selected solution vectors (Deep & Das, 2008). The proposed approach applied for hydrothermal scheduling is evaluated on a sample test system with four cascaded hydro plants and three thermal plants (Basu, 2004). The results obtained with the proposed algorithm were analyzed and compared with the results of differential evolution (Mandal and Chakraborty, 2008) and interactive fuzzy satisfying method based on evolutionary programming (Basu, 2004) reported in the literature. The proposed algorithm is found to be quite encouraging as compared with the earlier reported approaches.

The rest of the paper is organized as follows. In Section 2, the formulation of the hydrothermal scheduling problem is introduced. Section 3 explains the proposed quadratic approximation based differential evolution with valuable trade off approach for hydrothermal scheduling. Section 4 describes heuristic strategies for preserving various constraints. Simulation results and comparison with other approaches are presented in Section 5. Finally in Section 6, the conclusions are derived.

2. Mathematical model of hydrothermal scheduling problem

The short-term combined economic emission hydrothermal scheduling is a bi-objective optimization problem, such that the total fuel cost and emission of thermal plants can both be minimized under various loads and operating constraints within a 24-h period. At the same time, it makes full use of the availability of hydro-resources in order to reduce the production cost of the thermal plants. In the mathematical model, the following objectives and a set of linear, non-linear and dynamic constraints must be taken into account.

2.1. Notations

In order to formulate the hydrothermal scheduling problem mathematically, the following notations are introduced first:

Nomenclature

$f_{it}^{v}(P_{sit})$	fuel cost of thermal plant *i* including valve point loading
$e_{it}^{v}(P_{sit})$	emission of thermal plant *i* including valve point loading
a_{si}, b_{si}, c_{si}, e_{si}, f_{si}	coefficients of thermal generating plant *i*
α_{si}, β_{si}, γ_{si}, η_{si}, δ_{si}	emission coefficients of thermal plant *i*
T	total time intervals over scheduling horizon
N_s, N_h	number of thermal and hydro plants respectively
P_{hjt}	power generation of hydro generating plant *j* at time interval *t*
P_{sit}	power generation of thermal generating unit *i* at time interval *t*
P_{Dt}	power demand at time interval *t*
P_{Lt}	total transmission loss at time interval *t*
C_{1j}, C_{2j}, C_{3j}, C_{4j}, C_{5j}, C_{6j}	power generation coefficients of hydro plant *j*
V_{hjt}	storage volume of reservoir *j* at time interval *t*
Q_{hjt}	water discharge rate of the *j* th reservoir at time interval *t*.
$P_{si}^{\min}$, $P_{si}^{\max}$	minimum and maximum power generation by thermal plant *i*
$P_{hj}^{\min}$, $P_{hj}^{\max}$	minimum and maximum power generation by hydro plant *j*
$V_{hj}^{\min}$, $V_{hj}^{\max}$	minimum and maximum storage volumes of reservoir *j*
I_{hjt}	inflow of hydro reservoir *j* at time interval *t*
S_{hjt}	spillage discharge rate of hydro plant *j* at time interval *t*
τ_{mj}	water transport delay from reservoir *m* to *j*
R_{uj}	number of upstream hydro generating plants directly above reservoir *j*

2.2. Objective functions

(1) Economic scheduling

In reality, one of the major problems in hydrothermal scheduling is to minimize the total fuel cost of the thermal plants. The fuel cost function of a thermal generating plant is described by

$$f_{it}^{v}(P_{sit})a_{si} + b_{si} * P_{sit} + c_{si} * P_{sit}^{2} + |e_{si} * \sin\{f_{si} * (P_{si}^{\min} P_{sit})\}| \tag{1}$$

The total fuel cost associated to the on-line *N* plants for *T* intervals in the given time horizon is defined by Eq. (2) as follows:

$$F = \min \sum_{t1}^{T} \sum_{i1}^{N_s} [f_{it}^{v}(P_{sit})] \tag{2}$$

(2) Emission scheduling

In this study, the amount of emission from each generator can be described as the sum of a quadratic and an exponential function

$$e_{it}^{v}(P_{sit}) = \alpha_{si} + \beta_{si} * +P_{sit} + \gamma_{si} * +P_{sit}^{2} + \eta_{si} * \exp(\delta_{si} * P_{sit}) \tag{3}$$

The economic emission scheduling problem can be expressed as the minimization of total amount of emission release defined by Eq. (4) as

$$E \sum_{t=1}^{T} \sum_{i=1}^{N_s} [e_{it}^{v}(P_{sit})] \tag{4}$$

2.3. Constraints

While minimizing the above objectives, the following constraints must be satisfied simultaneously.

(1) Active power balance constraint

$$\sum_{i1}^{N_s} P_{sit} + \sum_{j1}^{N_h} P_{hjt} - P_{Dt} - P_{Lt} = 0 \tag{5}$$

The hydroelectric generation is a function of water discharge rate and reservoir water head, which can be expressed as follows:

$$\begin{aligned} P_{hji} = {} & C_{1j} * V_{hjt}^{2} + C_{2j} * Q_{hjt}^{2} + C_{3j} * V_{hjt} * Q_{hjt} + C_{4j} * V_{hjt} + C_{5j} \\ & * Q_{hjt} + C_{6j} \end{aligned} \tag{6}$$

(2) Generation limits constraints

$$P_{si}^{\min} \leqslant P_{sjt} \leqslant P_{si}^{\max} \tag{7}$$

$$P_{hj}^{\min} \leqslant P_{hjt} \leqslant P_{hj}^{\max} \tag{8}$$

(3) Reservoir storage volumes constraints

$$V_{hj}^{\min} \leqslant V_{hjt} \leqslant V_{hj}^{\max} \tag{9}$$

(4) Discharge rates limit