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ScienceDirect

Energy Conversion and Management 49 (2008) 751–760

ENERGY CONVERSION & MANAGEMENT

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Short term hydroelectric power system scheduling with wind turbine generators using the multi-pass iteration particle swarm optimization approach

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Received 7 December 2006; accepted 16 July 2007
Available online 29 August 2007

Abstract

This paper uses multi-pass iteration particle swarm optimization (MIPSO) to solve short term hydroelectric generation scheduling of a power system with wind turbine generators. MIPSO is a new algorithm for solving nonlinear optimal scheduling problems. A new index called iteration best (IB) is incorporated into particle swarm optimization (PSO) to improve solution quality. The concept of multi-pass dynamic programming is applied to modify PSO further and improve computation efficiency.

The feasible operational regions of the hydro units and pumped storage plants over the whole scheduling time range must be determined before applying MIPSO to the problem. Wind turbine power generation then shaves the power system load curves. Next, MIPSO calculates hydroelectric generation scheduling. It begins with a coarse time stage and searching space and refines the time interval between two time stages and the search spacing pass by pass (iteration). With the cooperation of agents called particles, the near optimal solution of the scheduling problem can be effectively reached. The effects of wind speed uncertainty were also considered in this paper. The feasibility of the new algorithm is demonstrated by a numerical example, and MIPSO solution quality and computation efficiency are compared to those of other algorithms.

Keywords: Multi-pass iteration particle swarm optimization; Hydroelectric; Wind turbine generators

1. Introduction

Increasing pressure to combat environment damage due to electricity generation has fostered the growth and development of renewable energy generation systems. Wind energy is a promising alternative in power generation because of its tremendous environmental and social benefits. Many expect wind energy to continue increasing due to falling capital costs, market scalability and its low environmental impact. The wind, however, is a diffuse and intermittent energy source. As more wind turbine generators are connected to utility systems, it is becoming more important to study the impact of wind turbine generators on system operations [1].

The objective of hydroelectric generation scheduling is to achieve the optimal hydro plant operation schedule that minimizes total thermal operating cost in a given period of time while preserving system operating constraints [2]. An efficient generation schedule not only reduces operation costs, but also increases system security and maximizes the energy efficiency of the reservoirs [3].

Many studies have discussed the hydroelectric generation scheduling problem. Most of these studies have delivered promising results in terms of reducing operating costs and increasing system security. These approaches include dynamic programming [4], decomposition technique [5], mixed integer programming [6] and Lagrangian relaxation [7] methods. Although these approaches all have different

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doi:10.1016/j.enconman.2007.07.019

features, they have been proposed to reduce computation time or memory requirements.

Stochastic search algorithms, such as the genetic algorithm (GA) [3], evolutionary programming (EP) [2] and simulated annealing (SA) [8], have also been applied to the hydroelectric generation scheduling problem. Although these heuristic approaches do not always guarantee a globally optimal solution, they generally provide a reasonable solution. Genetic algorithms and evolutionary programming were inspired by the principles of natural evolution, but EP differs from GA in two aspects: EP uses real control parameter values, but not coding as in GA. The main procedures of a new generation in EP are mutation and competition, but not reproduction, mutation and crossover as in GA. The disadvantages of EP and GA are the long computing times required to reach a good near optimal solution. Simulated annealing is able to seek the globally optimal solution and obtain quite promising results in terms of operation costs saving. Appropriately setting the SA annealing parameters is a difficult task, however, and computation takes a long time.

Particle swarm optimization (PSO) is a population based optimization approach first proposed by Kennedy and Eberhart [9,10]. It is based on the social behaviors of birds flocking and fish schooling in search of food. PSO is conceptually very simple, efficient in computation and can be implemented in a few coding lines. PSO has been successfully applied to various fields of power system optimization such as hydroelectric system scheduling [11] and economic dispatch [12,13].

This paper proposes an efficient algorithm, modified from PSO [9,10,14] and multi-pass dynamic programming [4], to solve the hydroelectric generation scheduling of a power system with wind turbine generators. This new algorithm is called MIPSO in this paper. Because of its high computation efficiency, MIPSO can evaluate the optimal operating policy of hydroelectric plants in real time applications based on the load conditions of the power system. In off line applications, MIPSO can be used to evaluate the economic benefits of a hydroelectric plant. Test results from MIPSO can further be summarized to develop expert knowledge for real time hydroelectric plant operation.

The results of the proposed method for scheduling a hydroelectric power system with wind turbine generators demonstrate the feasibility and effectiveness of the proposed approach.

2. Problem formulation

This study assumes that the upper reservoirs of pumped storage plants are large enough that storage volume limits will never be violated.

The objective function of short term hydroelectric generation scheduling for a power system with wind turbine generators (WTGs) is to achieve the minimum production cost and to find the generation schedule of conventional hydro units (CHUs), pumped storage plants (PSPs) and thermal units (TUs) while preserving system operating constraints. The objective function is expressed as below:

$$\text{Minimize}\quad \mathrm{TFC} = \sum_{t=1}^{T} \sum_{n\in \mathrm{TUs}} (F_n(P_{n,t}) + \mathrm{SC}_{n,t}) \tag{1}$$

$$\mathrm{SC}_{n,t} = d0\left(1 - \mathrm{e}^{\frac{T^{\mathrm{off}}_{n,t}}{d1}}\right) + d2, \quad t \in T \tag{2}$$

where TFC represents the total fuel cost of the power system, $F_n(P_{n,t})$ denotes the fuel cost of the nth thermal unit, $P_{n,t}$ is the generation of thermal unit n at hour t and T means the number of hours in the scheduling period. Constraints of the objective function are listed as follows:

(A) Power balance equation

$$\mathrm{TG}_t - \mathrm{LD}_t = 0, \quad t \in T \tag{3}$$

where TG_t represents the generation sum of all generators at hour t and LD_t is the system load at hour t.

(B) Available water limits

$$\mathrm{QHb}_h \leqslant \mathrm{QH}_{h,t} \leqslant \mathrm{QHt}_h, \quad h \in \{\mathrm{CHUs}, \mathrm{PSPs}\} \tag{4}$$

where QHb_h means the bottom limit of the reservoir of CHU h or the bottom limit of the lower reservoir of PSP, QHt_h is the top limit of the reservoir of CHU h or the top limit of the lower reservoir of PSP and $\mathrm{QH}_{h,t}$ denotes the water volume of the reservoir of CHU h at hour t or the water volume of the lower reservoir of PSP.

(C) Water discharge limits of hydro units

When generating (for all CHUs and all PSPs),

$$qh\min_h \leqslant qh_{h,t} \leqslant qh\max_h, \quad h \in \{\mathrm{CHUs}, \mathrm{PSPs}\} \tag{5}$$

When pumping,

$$qh_{p,t} \in j_p \times (-qpp_p \times K_p/\mathrm{QU}_{p,t}), \quad 1 \leqslant j_p \leqslant \mathrm{NP}_p, \quad p \in \mathrm{PSPs} \tag{6}$$

$qh_{h,t}$, $qh\ \max_h$ and $qh\ \min_h$ represent the water discharge at hour t, the maximum water discharge and the minimum water discharge of the hth CHU, respectively. j_p means the number of on line pumped storage units of PSP p, qpp_p denotes the amount of water pumped into the upper reservoir by one pumped storage unit when the water volume of the upper reservoir is at its bottom limit, K_p is a constant, NP_p is the number of pumped storage units in PSP p and $\mathrm{QU}_{p,t}$ is the water volume of the upper reservoir of PSP p at hour t.

(D) Unit generation limits.

When generating (for all generation units),

$$P\min_n \leqslant P_{n,t} \leqslant P\max_n, \quad n \in \{\mathrm{CHUs}, \mathrm{PSPs}, \mathrm{WTGs}, \mathrm{TUs}\} \tag{7}$$

When pumping,

$$P_{p,t} \in -j_p \times PPrate_p, \quad 1 \leqslant j_p \leqslant \mathrm{NP}_p, \quad p \in \mathrm{PSPs} \tag{8}$$