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Comparison of particle swarm optimization and dynamic programming for large scale hydro unit load dispatch

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ABSTRACT

Dynamic programming (DP) is one of classic and sophisticated optimization methods that have successfully been applied to solve the problem of hydro unit load dispatch (HULD). However, DP will be faced with the curse of dimensionality with the increase of unit number and installed generating capacity of hydropower station. With the appearance of the huge hydropower station similar to the Three George with 26 generators of 700 MW, it is hard to apply the DP to large scale HULD problem. It is crucial to seek for other optimization techniques in order to improve the operation quality and efficiency. Different with the most of literature about power generation scheduling that focused on the comparisons of novel PSO algorithms with other techniques, the paper will pay emphasis on comparison study of PSO with DP based on a case hydropower station. The objective of study is to seek for an effective and feasible method for the large scale of hydropower station of the current and future in China. This paper first compares the performance of PSO and DP using a sample load curve of the Wujiangdu hydropower plant located in the upper stream of the Yangtze River in China and contained five units with the installed capacity of 1250 MW. Next, the effect of different load interval and unit number on the optimal results and efficiency of two methods has also been implemented. The comparison results show that the PSO is feasible for HULD. Furthermore, we simulated the effect of the magnitude of unit number and load capacity on the optimal results and cost time. The simulation comparisons show that PSO has a great advantage over DP in the efficiency and will be one of effective methods for HULD problem of huge hydropower stations.

1. Introduction

China is endowed with large hydro potential. China's hydroelectric reserves stand at 700 GW, 40% of the country's total conventional sources of energy. It is estimated that the exploitable hydro capacity is 378 GW, ranked first in the world. Since the economic reform in 1980, China has experienced unprecedented economic growth. During past 20 years, China has put priority on hydroelectric projects to meet the rising energy demand of the country's booming economy. As a result, China's gross installed hydropower generating capacity has surged 500% since 1980 and exceeded 100 GW in 2004, making up one quarter of gross installed electric power capacity and providing some 20% of the country's total electric power. Simultaneously, a batch of huge hydro power projects have been developed and developing in the southwest regions in China where 67% of the 378 GW hydro resources are concentrated. The Three Gorges, the largest hydro power plant in the world, lies in the middle stream of the Yangtze River and consists of 26 generators of 700 MW with the total installed capacity of 18.2 GW. The Xiluodu, located in the Jinshajiang River in the upper stream of the Yangtze River, consists of 18 generators of 700 MW with the total installed capacity of 12.6 GW, rank second in the China. There are more than 20 hydro power plants whose total installed capacity are more than 3000 MW, such as the Xiangjiaba (6000 MW), Longtan (4200 MW), et al. With the appearance of the above huge hydro power plants, the challenges to the operation management of these plants are tremendous.

In the determination of optimum operating polices for single hydropower and hydropower system, the hydro unit load dispatch (HULD) problem is one of hydropower scheduling problems. Essentially, the principal objective of HULD is to schedule the turbine-generation units in order to meet the given load demand at the maximum hydropower operating efficiency while satisfying water demands, operational restrictions, reliability constraints, and security requirements. Over many years, plenty of works and researches by means of various mathematical programming and optimization techniques, considering different kinds of constraints or multiple objectives, have been used to solve this problem featuring by non-linear, non-convex, and large-scaled characteristics. The relative methods included branch and bound algorithm [7], mixed integer linear programming (MILP) [22], decomposition

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approach [3], and Lagrangian relaxation [6,11,23]. Especially, as a classic and sophisticated optimization method, dynamic programming (DP) [1,9,14,25,26] has been applied widely and was found to be an effective technique for the hydroelectric generating stations with the small numbers of hydropower units and the low installed capacity. However, these methods based on mathematical computation become helpless and cannot be implemented for scheduling power systems with large numbers of hydropower units and huge installed capacity in real time because of requiring extensive computational resources and much cost time. DP will be faced with the curse of dimensionality for the optimal operation of hydropower units when the scale is huge, such as the number of units is more than 10 or the installed capacity is over 10,000 MW, and this problem has restricted its application to large-scale systems. Therefore, it is crucial to seek for other optimization techniques in order to improve the operation quality and efficiency.

In recent years, particle swarm optimization (PSO) algorithm [15], a population based and self-adaptive search optimization technique, has aroused intense interest due to its flexibility, versatility and robustness in seeking the global optimal solution. It has been increasingly applied to hydropower system such as parameters estimation for hydrological forecasting [5,12], hydrological models [10], water resources management [2], water supply planning [13,24] and multi-reservoir operation [16]. PSO has also been utilized to solve the power generation scheduling problems [4,8,17–21]. However, the reports about the applications of PSO with respect to the HULD problem are relative fewer. In this paper, a practical hydropower unit load dispatch about the Wujiangdu hydropower plant with 1250 MW of installed capacity and five units, is used to compare the performance of optimal operation from calculating time, calculation efficiency and optimization results between PSO and DP. The results show that PSO has a great advantage over DP in the efficiency and will be one of effective methods to solve the problem of optimal operation for the huge hydropower units.

This paper is structured as follows. In Section 2, we present the mathematical formulations for scheduling of hydro units with emission constraints, modeled as a dynamic, mixed-integer nonlinear constrained optimization problem. In Section 3, the flow chart and calculation steps of PSO to solve HULD problem are shown. In Section 4, we present the case study of Wujiangdu hydropower plant and a scheduling time horizon of 96 periods. Then the results from DP and PSO are compared from calculating time, calculation efficiency and optimization results. Finally, Section 5 outlines the main conclusions.

2. Dynamic programming for HULD

2.1. HULD problem formulation

At a hydroelectric generating facility there are normally a number of turbine-generator sets to which the available water can be allocated in order to generate electricity. For different turbine-generator units, their unit capacity, efficiency curve and operating range differ from another. Therefore, it is required to optimize water allocation in order to maximize overall plant efficiency. For the available load curve which is usually allocated by the Electricity Dispatch and Trading Center of the region, one of important tasks for a hydroelectric generating facility is to determine the optimization of units combination in order to cost the economic water. The objective is to minimize the total discharges of turbine-generators for the available load curve, as shown in the following:

$$\min Q(N,h) = \sum_{t=1}^{m} \sum_{i}^{n(t)} Q_{i,t}(N_{i,t}, h_t) \tag{1}$$

where N is the total load for the given load curve; h is the work water head of turbine; $Q(N,h)$ is the minimization of total power generation discharges from all units when the total load N is given out; $N_{i,t}$ is the allocated load and of unit i at the time t; h_t is the work water head at the time t; $Q_{i,t}()$ is the power generation discharge of unit i at time t; $n(t)$ is the number of open turbine at time t; m is the time period for the load curve. Owing to the operational requirements, the minimization of the objective function is subjected to the following constraints:

(1) Load balance constrain.

$$\sum_{i=1}^{n(t)} N_{i,t} = N_t \tag{2}$$

(2) Turbine capacity constrain.

$$N_{i,\min} \leqslant N_{i,t} \leqslant N_{i,\max} \tag{3}$$

(3) Work head constrain of turbine.

$$h_{i,\min} \leqslant h_t \leqslant h_{i,\max} \tag{4}$$

(4) Discharge capacity constrain.

$$Q_{i,\min} \leqslant Q_{i,t} \leqslant Q_{i,\max} \tag{5}$$

(5) Reservoir storage restrictions.

$$V_{\min} \leqslant V_{i,t} \leqslant V_{\max} \tag{6}$$

where the notations used are as follows: N_t is the available load for the hydroelectric generating facility at time t based on the load curve; $N_{i,\min}$ and $N_{i,\max}$ are the allowable turbine capacity of minimization and maximization for unit i; $h_{i,\min}$ and $h_{i,\max}$ are minimum and maximum of water work head for the ith unit; $Q_{i,\min}$ and $Q_{i,\max}$ are minimum and maximum of turbine discharge for the ith unit; $V_{\min}$ and $V_{\max}$ are minimum and maximum of reservoir storage.

2.2. DP for HULD

The resources allocation formulation of DP is particularly well suited to this optimal unit load dispatch problem [1]. Each generating set is designed as a stage in a sequential decision-making process. According to the Eq. (1), suppose that $Q_{i,t}(N_{i,t}, h_i)$ is the minimization of turbine discharge of the ith unit when the allocated load is $N_{i,t}$ and the work water head is h_i. The reserved load $(N_t - N_{i,t})$ should be allocated among units $(n(t) - 1)$. If $Q^*_{i-1,t}(N_t - N_{i,t}, h_{i-1})$ is the optimal policies found at each stage, the DP recursion relation for Eq. (1) is:

$$Q^*_{i,t}(N_{i,t}, h_i) = \min[Q_i(N_{i,t}, h_i) + Q^*_{i-1,t}(N_t - N_i, h_{i-1})] \tag{7}$$

3. PSO for HULD

3.1. Overview of the standard PSO

PSO is a population based optimization tool, by which the system is initialized with a population of random particles and the algorithm searches for optimal results by updating generations. In PSO, each individual searches space by adjusting its flying trajectory towards both its own previous best location and the best location of its neighbor at each time step. Suppose that the search space is n-dimensional, and then the particle i of the swarm can be represented by an n-dimensional vector $X_i = (x_{i1}, x_{i2}, \ldots, x_{in})$. The velocity of this particle can be represented by another n-dimensional vector $V_i = (v_{i1}, v_{i2}, \ldots, v_{in})$. The fitness of each