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Optimization methods applied for solving the short-term hydrothermal coordination problem

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ABSTRACT

Short-term hydrothermal coordination (STHTC) is a very complicated optimization problem. It is a dynamic large-scale non-linear problem and requires solving unit commitment and economic power load dispatch problems. From this perspective, many successful and powerful optimization methods and algorithms have been employed to solve this problem. These optimization methodologies and techniques are widely diverse and have been the subject of ongoing enhancements over the years. This paper presents a survey of literature on the various optimization methods applied to solve the STHTC problem. A review and a methodology-based classification of most of the publications on the topic are presented.

1. Introduction

Short-term hydrothermal coordination consists of determining the optimal usage of available hydro and thermal resources during a scheduling period of time (1 day–1 week) [1,2]. This is to determine, optimally, which of the thermal generating units should run as well as the power generated by the hydro and thermal plants so that the total cost is minimized. Minimizing the total cost in this optimization problem is subject to many control and operational constraints. In addition to reliability and security requirements, hydraulic and thermal constraints may include load balance, generation limits, water discharge, starting and ending storage volume of water and spillage discharge rate. Further, in order to solve the hydrothermal coordination problem, thermal unit commitment and economic load dispatch problems should be solved all together with the hydro schedules. Therefore, the STHTC is a large-scale non-linear and complicated constrained power system optimization problem. Mathematically, the STHTC optimization problem can be formulated, in general, as follows [1]:

$$\min \quad F_T = \sum_{t=1}^{T}\sum_{j=1}^{N} F_j(P_S(j,t))$$

where F_T is the total production cost function; $P_S(j,t)$ the power generation of thermal unit j at time interval t; $F_j(P_S(j,t))$ the production cost for $P_S(j,t)$; N the number of thermal units; T the number of time intervals.

The cost function of the thermal power production is expressed as follows:

$$F_j(P_S(j,t)) = a_j + b_j P_S(j,t) + c_j P_S^2(j,t)$$

The objective function is subject to many constraints including the following:

- Load balance:

$$\sum_{i=1}^{M} P_H(i,t) + \sum_{j=1}^{N} P_S(j,t) = P_D(t) - P_L(t) = 0$$

  where M is the number of hydro units; $P_H(i,t)$ the power generation of hydro unit i at time interval t; $P_D(t)$ the system load demand at time interval t; $P_L(t)$ the system total losses at time interval t.
- Thermal and hydro generation capacity:

$$P_S(j)^{\min} \le P_S(j,t) \le P_S(j)^{\max}$$

$$P_H(i)^{\min} \le P_H(i,t) \le P_H(i)^{\max}$$

  where $P_S(j)^{\min}$ is the minimum power generation for thermal unit j; $P_S(j)^{\max}$ the maximum power generation for thermal unit j; $P_H(i)^{\min}$ the minimum power generation for hydro unit i; $P_H(i)^{\max}$

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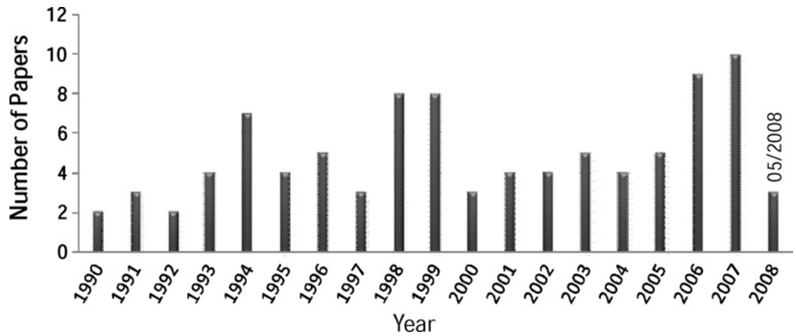

Fig. 1. Number of papers published in each year on the subject of STHTC problem.

the maximum power generation for hydro unit i.

- Total water discharge:

$$Q_{\text{tot}}(i) = \sum_{t=1}^{T} q(i, t)$$

where $q(i, t)$ is the water discharge rate for the hydro unit i at time interval t.

- Hydraulic continuity equation:

$$V(i, t) = V(i, t-1) + [r(i, t) - q(i, t) - s(i, t)]n_t$$

where $V(i, t)$ is the storage volume of the reservoir i at the end of time interval t; $q(i, t)$ the water discharge rate for the hydro unit i during time interval t; $r(i, t)$ the inflow rate into reservoir i during time interval t; $s(i, t)$ the spillage discharge rate of the reservoir i during time interval t; n_t the length of time interval t.

- Water storage limits:
  - Volume limits $V^{\min} \le V(i, t) \le V^{\max}$
  - Starting volume $V(i, t)|_{t=0} = V_s$
  - Ending volume $V(i, t)|_{t=T} = V_E$
- Water discharge rate:
  - Flow limits $q^{\min} \le q(i, t) \le q^{\max}$
  - Fixed discharge $q(i, t) = Q(i, t)$

A variety of optimization methods and techniques have been proposed to solve the problems of power systems optimal operations and planning since the beginning of the last century [2]. Among the earliest optimization techniques applied to the problem were the so-called the base load procedure, the best point loading and the incremental method. A historical survey, which highlights the earliest works in the field, is offered in [2]. At present, several methods and algorithms have been in use to solve power system optimization problems [3,4]. These include mathematical methods, iterative approaches, artificial intelligence tools, and hybrid techniques. Over the years, different methodologies have been applied. With the development of the mathematical and computational techniques, additional details of the problem have been addressed. In the beginning, only the thermal plants were considered and before long, the hydraulic operational and topological constraints were tackled. Fig. 1 statistically illustrates the number of the published research papers on the subject of the STHTC problem during the last 15–20 years (based on IEEE/IET/Elsevier databases).

2. Optimization methods for short-term hydrothermal coordination problem

A wide range of optimization techniques has been applied to solve the STHTC problem. These techniques are principally based on the criterion of local search through the feasible region of solution [3]. Applied optimization methods can be mathematical programming algorithms such as linear and non-linear programming, dynamic programming and interior-point methods [5,6]. Among the other methods are the artificial intelligence techniques including neural networks, fuzzy systems and the evolutionary methods such as genetic algorithms and the simulated annealing. The methods considered in this survey can be classified as follows:

- Lagrangian relaxation and Benders decomposition-based methods
- Mixed-integer programming
- Dynamic programming
- Evolutionary computing methods
- Artificial intelligence methods
- Interior-point methods

These optimization methods can be generally classified into two main groups: deterministic methods and heuristic methods. Deterministic methods include Lagrangian relaxation and Benders decomposition methods, mixed-integer programming, dynamic programming and interior-point methods. Genetic algorithms, particle swarm optimization and other evolutionary methods are heuristic. Most of the methods that have been used to solve the STHTC problem are deterministic in nature. However, modern heuristic methods are getting more attention in solving large-scale optimization problems. To search for the optimal solution, classical deterministic methods, also known as derivative-based optimization methods, apply techniques such as the gradient and Hessian operators. They use single path search methods while heuristic methods use population-based search techniques to search the solution hyperspace. This difference, in fact, is an advantage for the heuristic methods as it helps searching in spaces with non-smooth characteristics. It also improves the convergence for heuristic methods and makes it less dependent on the initial solution points. Being derivative-free, modern methods are applicable to any optimization problem regardless of the linearity or non-linearity of its objective function and constraints. In contrast, different deterministic methods are required for different optimization problems. Another main difference between the two classes is that heuristic methods use stochastic techniques and include randomness in moving from one solution to the next while determinist methods follow deterministic transition rules. This, of course, gives an advantage to heuristic methods in avoiding local minima. In spite of the advantages of the heuristic techniques, classical methods have been used by the majority of research papers covered in this review. The reason is their efficiency in solving optimization problems, the solid mathematical foundation and the availability of software tools [7].

Fig. 2 shows the number of publications and the method applied to solve the STHTC problem in the specified period. In this survey we included, to the best of our knowledge (based on IEEE/IET/Elsevier