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Short-term scheduling of hydro-based power plants considering application of heuristic algorithms: A comprehensive review

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ABSTRACT

Optimal generation scheduling of hydro-based power units has a significant place in electric power systems, which considerably has been dealt with as a subject of investigations for several years. Hydrothermal system is introduced as an important hydro-based power generation system. The objective of short-term hydrothermal scheduling (STHS) problem is obtaining the power generation schedule of the available hydro and thermal power units, which aims to minimize total fuel cost of thermal plants during a determined time period. Many conventional optimization procedures are first introduced for solving STHS problem. Recently, heuristic and meta-heuristic optimization methods, which are defined as an experience-based procedure, are implemented for obtaining optimal solution of generation planning of hydrothermal systems. This paper provides a comprehensive review on the application of heuristic methods to obtain optimal generation scheduling of hydrothermal systems, which compares the implemented procedures from different points of view. Optimal solutions obtained by employment of multiple heuristic and meta-heuristic optimization methods for different test instances are demonstrated and the introduced methods are compared in terms of convergence speed, attained optimal solutions, and constraints. Future research trends are discussed, which can be introduced as the subject of studies in the area of STHS problem.

1. Introduction

Lots of power generation units are built in previous years due to an increment of power demand. The optimal generation scheduling of available generation units is considered as an important issue in power systems, which is handled by researchers in this area. Short-term hydrothermal scheduling (STHS) optimization problem includes optimal generation scheduling of hydro and thermal units to meet load demand in such a way that the total operational cost is minimized considering a variety of constraints. Considering a negligible operational cost for hydroelectric generation units, the objective of STHS is minimization of the fuel cost of thermal units. The STHS problem should be optimized subjected to a variety of constraints of hydro and thermal units including power balance, water balance, limitations of water discharge, water storage limits, and limitations of power generation. Moreover, valve-point loading effects of thermal generation plants, power transmission losses of generation units, complex hydraulic coupling makes the STHS optimization problem a non-convex and a non-linear problem [1–3].

The generation scheduling of hydrothermal units is attracted researchers attention as an attractive research work for many years. Several optimization methods are proposed for handling this difficult problem. Firstly classical mathematical optimization procedures such as linear programming [4,5], non-linear programming [6,7], decom-

Abbreviations: P_{it}^{s}, Power generation of thermal unit i at time t.; F_{it}, Power generation cost of ith thermal unit at time t.; a_i, b_i and c_i, Fuel cost coefficients of unit i.; e_i and f_i, Coefficients of the valve-point impact for thermal unit i.; $P_{i,\min}^{s}$, Minimum capacity limit of ith thermal unit.; N_s, Number of thermal power generation units.; $P_{Load}\,t$, Total load demand of the system at time t.; P_{jt}^{h}, Generation of hydro unit j at time t; $P_{Loss}\,t$, Total transmission losses of the system.; c_{1j}, c_{2j}, c_{3j}, c_{4j}, c_{5j}, and c_{6j}, Coefficients of hydro unit j.; V_{jt}^{h}, Volume of hydro plant j at time t.; Q_{jt}^{h}, Discharge of hydro plant j at time t.; $P_{i,\max}^{s}$, Maximum capacity limit of ith thermal unit.; $P_{j,\min}^{h}$, Minimum power generation of hydro unit j.; $P_{j,\max}^{h}$, Maximum power generation of hydro unit j.; $V_{i,\min}^{h}$, Minimum reservoir storage volumes of hydro unit i.; $V_{i,\max}^{h}$, Maximum reservoir storage volumes of hydro unit i.; $Q_{i,\min}^{h}$, Minimum amounts of hydro plant i discharge.; $Q_{i,\max}^{h}$, Maximum amounts of hydro plant i discharge.; I_{it}^{h}, Inflow rate for hydro unit i at time t.; S_{it}^{h}, Spillage of hydro plant i at time t.; V_{i0}^{h}, Reservoir storage of hydro plant i at time 0.; V_{i24}^{h}, Reservoir storage of hydro plant i at time 24.; $V_{i,init}^{h}$, Initial reservoir storage of ith hydro unit.; $V_{i,end}^{h}$, Final reservoir storage of ith hydro unit.; V_i, Per unit magnitude of voltage at bus i.; $V_i^{\min}$, Per unit amount of minimum limitations of ith bus voltage.; $V_i^{\max}$, Per unit amount of maximum limitations of ith bus voltage.; $BF_i^{\min}$, Minimum limits of power flow through branch i.; $BF_i^{\max}$, Maximum limits of power flow through branch i.; N_{B-1}, Number of buses except slack bus.; N_b, Number of branches in the system.; P_{Gi}, Power generation at bus i.; P_{Di}, Power demand at bus i.; θ_{ij}, Difference of voltage angle of bus i and bus j

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position techniques [8,9], dynamic programing (DP) [10,11], and Lagrange multiplier [12,13] are implemented for obtaining the optimal solution of hydrothermal scheduling problem. In addition to the introduced mathematical methods for providing optimal solution of STHS problem, several heuristic and meta-heuristic optimization procedures are proposed in recent years for solving multi-objective STHS. Heuristic and meta-heuristic methods, which are identified as experience-based methods, are considered as flexible, versatile, and successful in fining the solution of difficult non-linear and non-convex problems.

A review on power production planning methods in regulated and deregulated power markets is prepared in [14], which studied deterministic, heuristic, and hybrid optimization methods. In [15], the authors analyzed the optimal management and operation of reservoir systems, in which high-dimensional, dynamic, nonlinear, and stochastic characteristics of such systems are studied. In this reference, implementation of heuristic optimization methods, neural networks, and fuzzy systems on operation planning of reservoir systems are discussed. A review on research and developments in the field of unit commitment is performed in [16], which studied different optimization procedures for obtaining the optimal solution of unit commitment problem in electrical power networks. The application of particle swarm optimization (PSO) method to the economic dispatch (ED) problem is reviewed in [17], and the contributions of published studies in the area of ED, which employed PSO method, are summarized in this reference. A similar study is published by studying various optimization techniques in [18], which reported a summary of classical and heuristic methods applied to solve STHS problem. The uncertainty of water inflows in generation planning of individual hydro units, and uncertain inflows of energy in STHS scheduling using energy-based aggregate reservoir representation (ARR) are studied in [19]. Such issues are challenged by application of different solution methods, which are reviewed in this reference.

Heuristic optimization producers are experience-based techniques defined as a quick method for obtaining solutions for optimization problems, in which optimal solutions are not achievable using mathematical methods in finite time. The STHS problem has nonlinear, non-convex type objective function with intense equality and inequality constraints. The conventional optimization techniques are not capable to solve such problems as taking into account local optimum solution convergence. Accordingly, different heuristic optimization methods are reviewed in this research study for obtaining optimal solution of STHS problem. Most of the recent research studies are implemented heuristic optimization methods to obtain optimal generation scheduling of hydrothermal system. This paper aims to provide a comprehensive review on implementation of heuristic and meta-heuristic optimization methods for solving power generation scheduling problem of hydrothermal units. Brief definitions of most popular heuristic and meta-heuristic procedures are provided, and employment of the optimization methods for the solution of STHS problem considering the objective functions and different constraints are analyzed. Optimal solutions provided by application of different heuristic and meta-heuristic techniques for various test systems are reported. In addition, the reviewed optimization procedures are compared in terms of convergence speed, attained optimal solutions, and constraints. Short-term hydrothermal scheduling problem is solved by application of different techniques, which include mathematical programming procedures and heuristic methods.

The remainder of the paper is organized as follows: Section 2 represents the formulation of hydrothermal scheduling problem. Section 3 provides a comprehensive review on implementation of popular heuristic and meta-heuristic optimization methods for generation scheduling of hydrothermal units. A comprehensive comparison of introduced optimization procedures is provided with different point of views in Section 4, and the paper is concluded in Section 5.

2. Formulation of hydrothermal scheduling problem

The objective function of the STHS optimization problem is minimization of total operation cost of multiple hydro and thermal plants. The scheduling of power generation of hydro and thermal units is provided during STHS process for a determined time horizon for meeting the load demand.

2.1. Objective function

The main objective of the STHS problem is obtaining optimal water releases of hydro reservoirs and attaining power generation of thermal plants. Hydro generation units needs an operations and maintenance cost [20]; however the power generation cost of such plants can be neglected [21]. The operating costs include production costs and start-up costs. The production costs of hydro generation units are ignorable [22]. The start-up costs have real effect on the short-term planning of hydro plants, which is based on the type of hydro unit [23,24]. Since production cost of hydro units can be ignored, the optimization problem should minimize total generation cost of thermal units. The objective function of total production cost of thermal plants, which is modeled as quadratic function [25], can be stated as follows:

$$F_{it}(P_{it}^s) = a_i(P_{it}^s)^2 + b_i P_{it}^s + c_i \tag{1}$$

where, F_{it} is the power generation cost of ith thermal unit at time t, P_{it}^s is the power generation of thermal unit i at time t. a_i, b_i, and c_i are utilized for demonstrating the fuel cost coefficients of unit i.

The effect of valve-point of the conventional thermal units is required to be modeled in the objective function of the problem considering several steam admitting valves in thermal units. The total production cost of power generation units considering a sinusoidal function for valve-point effect is as follows [26]:

$$F_{it}(P_{it}^s) = a_i(P_{it}^s)^2 + b_i P_{it}^s + c_i + |e_i \sin(f_i(P_{i,\min}^s - P_{it}^s))| \tag{2}$$

where, e_i and f_i are the coefficients of the valve-point impact for thermal unit i and $P_{i,\min}^s$ is the minimum capacity limit of ith thermal unit.

The objective function of STHS optimization problem is minimization of the total fuel cost of thermal plants during a time horizon, which can be expressed as follows:

$$F_{it}(P_{it}^s) = \sum_{t=1}^{24}\sum_{i=1}^{N_s}\{a_i(P_{it}^s)^2 + b_i P_{it}^s + c_i + |e_i \sin(f_i(P_{i,\min}^s - P_{it}^s))|\} \tag{3}$$

In this formulation the number of thermal power generation units is shown by N_s.

2.2. Constraints

The objective function of STHS optimization problem should be solved considering the following constraints:

2.2.1. System power balance

Total power generation of hydro and thermal units should meet total load demand of the power system and total transmission losses, which can be stated as follows:

$$P_{Load}(t) = \sum_{i=1}^{N_S} P_{it}^s + \sum_{j=1}^{N_h} P_{jt}^h - P_{Loss}(t) \tag{4}$$

where, $P_{Load}(t)$ is the total load demand of the system at time t, P_{it}^s and P_{jt}^h are the respective components of generation of thermal and hydro units at time t. Total transmission losses of the system at time t is shown by $P_{Loss}(t)$, which can be stated as [27]:

$$P_{Loss}(t) = \sum_{m=1}^{N_S+N_h}\sum_{n=1}^{N_S+N_h} P_{mt}B_{mn}P_{nt} + \sum_{m=1}^{N_S+N_h} B_{0m}P_{mt}^h - B_{00} \tag{5}$$