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Stochastic hydro-thermal scheduling optimization: An overview

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A B S T R A C T

This paper presents an overview about the hydro-thermal scheduling problem. In an electrical power system power generators have to be scheduled over a time horizon in order to supply system demand. The scheduling problem consists in dispatching the available generators to meet the system electric load while minimizing the operational costs related to fuel and possible load curtailments. In a system with a large share of hydro generation, different from a thermal dominant power system, the uncertainty of water inflows play an important role in the decision-making process. In this setting the scheduling of generators has to be determined considering different future possibilities for water availability. Also, in the existence of a cascade system, the availability of water to produce electricity in hydro plants is influenced by decisions taken in upstream reservoirs. These issues complicate the hydro-thermal scheduling problem that often in the literature is modeled as a multi-stage stochastic program. In this paper we aim to give an overview about the main ideas behind this problem. We present model formulations, a solution technique, and point out to new developments related to this research.

Contents

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1. Introduction

Renewable energy is a key piece in the supply side of power systems as sustainable development becomes a goal of our societies. New investments in renewables are necessary in order to satisfy future energy production requirements. Moreover, the worldwide renewable generation expansion is crucial in helping to mitigate changes in climate due to global warming, while not depriving humans of access to goods and services to which they have become accustomed. In [1] the authors examine the threshold effect of the proportion of renewable energy supply for CO_2 emissions reduction, one of the main causes of global warming, for some countries. The fossil age of the last century contributes to our current way of living but we are facing the cost of that kind of energy. Therefore, the access to clean energy is part of many energy programs in European countries and others [2,3], which are engaged in making a better world to live.

Renewable resources should be part of the solution to fulfill the energy demands of seven billion people. There are many types of green energy like wind, solar, geothermal, biomass and tidal generation, which can be combined to compose a sustainable portfolio of electricity providers. The main drawbacks with these energy sources are their seasonality and storage limitations. Renewable electricity production depends on the natural resources that usually do not match the demand at the time and locations that are necessary. The present storage technologies available for renewables include hydro reservoirs, compressed air energy storage (CAES) [4], and batteries (used to store electricity). In [5], batteries with fuel cells are explored to mitigate intermittency of renewables in power systems. In many countries such storage technologies are limited because of a dependence on natural formations and/or investment attractiveness to be constructed.

There are some exceptions in terms of renewable energy controllability limitations and one example is hydro-energy resources, which reservoir storage can be constructed and used to control the timing of electricity generation. In many countries such as Canada and Norway, most of the hydroelectric generation comes from run-of-river power plants, which depend basically on the ice cycles. In the province of British Columbia, Canada, the clean energy act established that at least 93% of electricity generation has to come from renewable resources [6] and the preferable technology is run-of-river hydro plants [7]. However, in other countries like Brazil and Colombia, a relevant portion of existing hydro plants have large reservoirs, which can be used for optimizing water use. In the Brazilian power system for example, where hydroelectricity approximately corresponds to 80% of the total electricity production, hydro reservoirs have the capacity of providing energy supply for several months ahead even in periods of heavy droughts.

Given a hydro-dominant system with the possibility to optimize the water use and mix the electricity production with thermal plants, the hydro-thermal scheduling problem (HTSP) becomes extremely relevant. In such context the HTSP is one of the most important problems in power systems [8]. In the HTSP one is interested in minimizing the total operational costs related to electricity production demanded by the system during a specific time horizon. These operational costs are derived from the fuel costs that feed thermal plants and the costs of possible demand curtailments. This problem is complicated by the fact that we do not have perfect forecasts for future water inflows into system reservoirs.

Generally, the HTSP is modeled as an optimization program and solved by special-purpose algorithms. In [9] authors discuss the importance of optimization modeling and algorithms in the planning of renewable integration in power systems. A review of the role of optimization techniques in power generation and supply can be found in [10]. The work of [11] presents a review on risk-constrained hydropower scheduling in deregulated power systems from a perspective of profit maximization for generation companies. In [12] a survey on stochastic unit commitment problems for day-ahead market clearing is presented. In other perspective, we focus in a centralized dispatch scheme where the objective is aimed to minimize operational costs over a planning horizon, ranging from months to years ahead, in a system composed by hydro and thermal plants. This paper provides improvements in the knowledge basis by presenting a detailed overview about the HTSP stochastic version, by formulating precise mathematical models and by pointing out and discussing new research developments related to such challenging field.

Section II presents the basic concepts related to the HTSP. Section III gives a general description of the HTSP characteristics and mathematical model formulations to represent such problem in the context of individual hydro plants and aggregated reservoirs. Section IV presents decision-making methodologies that have been used to deal with several mathematical HTSP models and new developments related to this research area. Section V concludes this paper.

2. Basic concepts in hydro-thermal scheduling

In electric power systems where hydro and thermal power generation scheduling decisions are performed in a centralized manner, the independent system operator (ISO) may decide to use the water available at hydro plant reservoirs to produce electricity at any time. Doing so avoids economic expenses required to dispatch thermal power plants, but can risk hydro availability in future time periods. In the HTSP one is interested in minimizing electricity production costs to supply the system demand considering the operation of hydro and thermal power plants.

The water available to produce electricity at each hydro plant is bounded by the reservoir storage capacities and the future water inflows at the river basins where these reservoirs are located. Depending on the share of renewable resources and other system conditions, most of the time thermal generation must be used to complement the electricity supply in order to meet system demand. However, wise use of hydro and thermal system resources by the decision maker can reduce costs over time. The decision process faced by the ISO when operating a hydro-thermal system is presented in Fig. 1.

Hydroelectricity is inexpensive to produce, with virtually no associated costs for water usage once hydro turbines are installed.