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A multiple criteria utility-based approach for unit commitment with wind power and pumped storage hydro

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ABSTRACT

The integration of wind power in electricity generation brings new challenges to the unit commitment problem, as a result of the random nature of the wind speed. The scheduling of thermal generation units at the day-ahead stage is usually based on wind power forecasts. Due to technical limitations of thermal units, deviations from those forecasts during intra-day operations may lead to unwanted consequences, such as load shedding and increased operating costs. Wind power forecasting uncertainty has been handled in practice by means of conservative stochastic scenario-based optimization models, or through additional operating reserve settings. However, generation companies may have different attitudes towards the risks associated to wind power variability. In this paper, operating costs and load shedding are modeled by non-linear utility functions aggregated into a single additive utility function of a multi-objective model. Computational experiments have been done to validate the approach: firstly we test our model for the wind–thermal unit commitment problem and, in a second stage, pumped storage hydro units are added, leading to a model with wind–hydro-thermal coordination. Results have shown that the proposed methodology is able to correctly reflect different risk profiles of decision makers for both models.

1. Introduction

Unit commitment in power generation planning is the problem of determining a schedule for a set of power generating units over a given planning horizon at minimum cost. To evaluate the scheduling decisions it is necessary to solve a sub-problem of the unit commitment problem (UCP): the pre-dispatch problem. This determines the economical production levels at which the committed units must operate to meet the forecasted energy demand and reserve requirements. In its standard format, the UCP handles only thermal power generators. However, a joint coordination with other sources of energy is possible, with hydrothermal scheduling being the most studied problem [1,2]. More recently, not only due to the continuous increase of fuel costs but also for environmental reasons, other renewable energies have been considered: they are generally cheaper and cause a lower environmental impact.

Among renewable energies, wind energy is one of the fastest growing. From the end of 2007 until 2012, annual growth rates of cumulative wind power capacity averaged 25% [3]. Nevertheless, the level of wind power production of a wind turbine depends on the wind speed, which in turn depends on some complex factors such as weather conditions or the pressure gradient. Thus, it is very hard to accurately predict the wind speed and obtain high-quality wind power forecasts (WPF), necessary to calculate the wind power available at each period of a future planning horizon. The wind is characterized by rapid and unpredictable changes in speed over short periods of time, thereby implying risks to the decisions being made in the context of the UCP. An unexpected decrease in wind power production may provoke load shedding (i.e. energy not served), due to technical restrictions of thermal units that may not be able to backup the deviation. On the other hand, a big upward deviation in wind power generation may lead to an unwanted waste of renewable and 'clean' energy when the committed thermal units are operating at their minimum production levels. As the best tools available for wind power forecasting are unable to avoid the uncertainty associated with wind speed [4], the integration of wind power in electricity generation represents an additional challenge that deserves particular attention.

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Notation

Constants

T	length of the planning horizon
$\mathcal{T} = \{1, \ldots, T\}$	set of planning periods
$\mathcal{U}$	set of thermal units
$\mathcal{W}$	set of wind units
$\mathcal{H}$	set of hydro units
D_t	system load requirements in period t
R_t	spinning reserve requirements, in percentage of load, in period t
a_u, b_u, c_u	fuel cost parameters for unit u
W_{wts}	wind power generation of wind unit w, in period t, for scenario s
η_h^{p}	efficiency (%) of the pumping cycle of hydro unit h
η_h^{g}	efficiency (%) of the generating cycle of hydro unit h
$d_h^{\mathrm{l}}, d_h^{\mathrm{u}}$	lower and upper pumping power limits of hydro unit h [MW]
$g_h^{\mathrm{l}}, g_h^{\mathrm{u}}$	lower and upper generation limits of hydro unit h [MW]
$\mathrm{cap}_h^{\mathrm{l}}, \mathrm{cap}_h^{\mathrm{u}}$	lower and upper capacity limits of the reservoir of hydro unit h [MWh]
$\mathrm{vol}_h^{\mathrm{i}}, \mathrm{vol}_h^{\mathrm{f}}$	initial and final levels of the reservoir of hydro unit h [MWh]

Variables – Decision variables:

y_{ut}	1 if thermal unit u is ON in period t, 0 otherwise
p_{uts}	production level of thermal unit u, in period t, for scenario s
w_{wts}	wind power generation, to serve the load demand, of wind unit w, in period t, for scenario s
f_{wts}	wind power generation, to pump water, of wind unit w, in period t, for scenario s
c_{wts}	curtailed wind power generation of wind unit w, in period t, for scenario s
ens_{ts}	energy not served, in period t, for scenario s
v_{hts}	storage volume of water in the reservoir of hydro unit h, in period t, for scenario s [MWh]
q_{hts}	volume of water used for generation by hydro unit h, in period t, for scenario s [MWh]
r_{hts}	pumping input power of hydro unit h, in period t, for scenario s [MW]

Auxiliary variables:

$p_{uts}^{\max}$	maximum feasible production levels for unit u, in period t, for scenario s
z_{hts}^{p}	1 if hydro unit h is in pumping mode, in period t, for scenario s, 0 otherwise
z_{hts}^{g}	1 if hydro unit h is in generating mode, in period t, for scenario s, 0 otherwise

Production costs:

$F(p_{uts})$	fuel cost for unit u, in period t, for scenario s
$S(x_{ut}^{\mathrm{off}}, y_{ut})$	start-up cost of unit u in period t

In relation to the UCP, the uncertainty associated with wind power generation has been tackled by means of providing additional reserve requirements [5], which should be able to cover unexpected downward deviations, or by considering stochastic policies in which the operating reserve is committed implicitly [6]. Most of these approaches reflect conservative attitudes of decision makers (DMs) towards risk, as they try to sidestep load or reserve curtailments by constraining the optimization problem in such a way that the final schedule is able to cover the possible deviations derived from WPF over a set of pre-generated scenarios [7]. Alternatively, some approaches consider a fixed cost per unit of reserve and/or load not served in the objective function [8].

However, none of these approaches fully address the volatile behavior of DMs towards risk. In fact, the risk profile of a generation company (GENCO) varies over time due to the different circumstances that surround different power systems. Therefore, risk management tools should be developed to help them make appropriate decisions based on tradeoffs between production costs and risks caused by wind power generation.

Utility theory has been used to model risk preferences in power systems. In [9], multi-attribute utility theory (MAUT) is used for the purpose of choosing the best among several alternatives previously generated by a linear programming model. In this work, the model is able to incorporate the preferences of a DM for the problem of selecting among investment alternatives for the expansion of local energy distribution systems. Similarly, Loeken et al. [10] demonstrate how MAUT can be used to assist in decision making under uncertainty in a local energy planning problem, comparing it with the analytical hierarchy process method (AHP). In this work, the authors use utility theory exclusively as a method of selecting among a finite and previously known set of alternatives. They concluded that MAUT is more suited for handling uncertainties than AHP. Zelei et al. [11] propose a novel probability distribution for repair times that allows to support risk assessment in power systems operations. They make use of a utility function to measure the dissatisfaction level caused by failures and use utility theory to build risk indices to test their approach. As for wind power generation, Botterud et al. [12] apply a non-linear utility function and conditional value at risk to represent risk preferences of wind power producers with defining their locational marginal prices under uncertainty in wind power and prices. Street et al. [13] study the definition of bidding strategies by GENCOs in long-term contract auctions to maximize their operation net revenue under uncertainty. An exponential utility function is used to represent the GENCOs' risk profiles. However, a limitation of the model is the assumption that all GENCOs are risk-averse. In relation to power generation planning, Xiong et al. [14] propose a solution methodology based on genetic algorithms to solve the UCP with stochastic load demand represented in the form of scenarios. In this paper, the authors model tradeoffs between expected costs and variance as a non-negative risk tolerance parameter added to the objective function, which is to be minimized. But it is known that load demand usually verifies small deviations from the forecasts, so the model lacks practical relevance. Shrestha et al. [15] represent GENCOs' behavior in the form of exponential utility functions to manage price uncertainties in short-term generation planning in competitive power markets. Their price-based unit commitment aims to maximize profit according to GENCOs' risk profiles and do not include renewable and variable sources of energy production and corresponding risks when defining a certain schedule.

Although there are a few studies in the literature using utility theory concepts to model preference structures in power systems, they are mainly used as a means to select or sort previously known alternatives or do not include uncertainties introduced by unpredictable sources of energy production such as wind power. Moreover, most existing studies ignore subjective factors that differentiate the impacts of risk and do not take into account the particular behavior of DMs [16]. Within this context, the need for multi-criteria approaches with the flexibility of modeling attitudes of DMs towards risk arises [17].

In this paper we develop a multi-objective combinatorial optimization model for the UCP with wind power. Utility theory is used for modeling GENCOs' risk profiles a priori, and operating costs and energy not served (ENS) are assumed to be objectives to minimize. Each of these objectives is represented by an individual