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Short-term electricity planning with increase wind capacity

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ABSTRACT

The variable electricity output of the RES (renewable energy sources) power plants, such as wind and hydropower, is an important challenge for the electricity system managers. This paper addresses the problem of an electricity system supported mainly on hydro, thermal, and wind power plants. A binary mixed integer non-linear optimization model with hourly time step is described. The model is applied to a system close to the Portuguese electricity case assuming demand forecasts for the year 2020. The main objective of this paper was to analyze the impact that different levels of installed wind power can have in the operation of this electricity system, taking into account the hourly and intra-annual variation of the renewable resources, the demand projections and also the technical restriction of thermal power plants. The results confirmed wind power as strategic technology to reduce both the marginal cost and CO_2 emissions. According to the simulations run, wind power will not replace hydropower but a decrease of thermal power production is foreseen as more wind power is added to the system. Large wind power scenarios will particularly affect gas power plants performance, reducing both the load level and the number of operating hours.

1. Introduction

Over the passed decades, electricity system generation has gone over a set of different changes. Different technologies start to arise and the importance of RES (Renewable Energy Sources) for electricity generation is now remarkable. RES technologies are usually characterized by zero CO_2 gas emissions, lower operation and maintenance costs but higher investment costs.

The promotion and use of RES for electricity generation is one of the most important greenhouse gas mitigation measures [1]. However, the increasing use of these technologies creates new challenges to the electricity power management. They are frequently characterized by production of variable output, not subject to dispatch, and can benefit from feed-in-tariffs. Nevertheless, in most electricity systems, large thermal and hydropower plants compete in the market for dispatch.

The intra-annual seasonality and the variability of wind power output can be particularly challenging, significantly impacting the performance of thermal power plants operating in the same electricity system. According to Ref. [2]; large-scale wind power development affects short term operation of the electricity system, as well as the optimal generation technology mix since wind increase significantly the variability of energy generation. The variability of wind power into the grid will enforce thermal generators ramping to compensate supplying disruptions or to operate at low load conditions. According to Ref. [3]; increasing variability and unpredictability in the power system, due to wind curve characteristics, will frequently originate the increasing number of start-ups, ramping, and periods of operation at low load levels. In line with this, [4] supports that, with the increase of wind power generation all over the world, the integration of wind power generation in electricity power systems needs to be carefully performed and requires new concepts in operation, control, and management. In their study, a joint operation between a wind farm and a hydro-pump plant is addressed having into account the uncertainty of the wind power forecast.

Other concern that is usually related to RES technologies such as wind and hydro is the difficulty on forecasting their availability. Different studies have focused on this thematic. Ref. [5] studies the impact of wind power forecasting on the unit commitment problem and economical dispatch. A set of different scenarios to deal with wind uncertainty were considered, transforming the problem into a stochastic one. Despite the complexity usually associated to the stochastic problems that usually leads to better results, the authors concluded that a deterministic method combined with an increased reserve requirement can produce results that are

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comparable to the stochastic case. In Ref. [6] a survey of short term hydropower planning with a large amount of wind power in the system is presented. In their study some conclusions were underlying. They have concluded that research when uncertainty is considered is not fully explored and when considered can significantly increase problem size, which may require more advanced solution algorithms and techniques to bring problem size down and make it solvable.

This work aims to contribute to the analysis of the impact of wind power in the operating performance of an electricity system combining thermal, hydro, and wind power plants. For that, an optimization model for short term electricity planning will be presented and used to test different levels of installed wind power, evaluating the effect on cost and CO_2 emissions. The proposed model considers hourly time steps, allowing to capture the hourly variation of the renewable resources and also to take into account the technical restrictions of the thermal power plants.

This paper is organized as follows. Section 2 will present an overview of the unit commitment problem definition. A set of literature examples will be described for a better understanding. In Section 3 the proposed model formulation will be described. In Section 4 a realistic case study of an electricity system with thermal, hydro and wind power plants system is addressed, and the results of the model implementation are analyzed. Finally, conclusions are stated in Section 5.

2. Short-term planning: the unit commitment problem

It is well addressed in the literature that the principal aim of power planning, whether it is applied to long term or to short term planning horizons, is to minimize the operation cost of the system allowing to fulfill a forecasted demand. Optimization models for short-term electricity power generation scheduling are therefore seen as useful and powerful tools to decision makers.

Short-term electricity power generation scheduling also known as UC (unit commitment) problem is essential for the planning and operation of power systems. The basic goal of the UC problem is to properly schedule the *on*/*off* states of all the units in the system. Further on, the optimal UC should meet the predicted load demand, plus the spinning reserve requirement at every time interval minimizing the total cost of production [7]. Ref. [8] describes the short-term electrical power generation scheduling as an optimization problem, in which optimal startup and shutdown schedules need to be determined over a given time horizon for a group of power generators under operational constraints. The objective remains the minimization of the power generation costs meeting the hourly forecasted power demands. Following this idea, Ref. [9] focused on the variations in operating costs caused by integration of an increasing amount of wind power in thermal generation systems. According to the simulation results the authors concluded that wind power brings considerable cost increase on thermal generation. Furthermore, when wind power is integrated in the grid, more flexible generation with higher cost are dispatched in peak load regulation, units start and stop more often and more money is spent on ramping costs, increasing the average cost of the system.

Ref. [10] presented on their work a typical UC problem. A new formulation based on benders decomposition was proposed and the performance evaluated under three case studies for a typical system with 100 units, with each case study assuming different technical constraints for thermal power plants. Ref. [11] addressed on their work the problem of the self-scheduling of a thermal electricity producer in day-ahead energy and reserves markets. Three different startup types are modeled, each one with different start-up costs, synchronization time, soak time, and predefined startup power output trajectories, all dependent on the unit's characteristics. The model was tested for a daily vs weekly scheduling of a fictional producer with five units using a typical load demand curve of the Greek Power System.

Despite the economic interest of these problems the environmental concern is also becoming increasingly relevant. Ref. [12] study focuses on a multi-objective problem formulation with two objective functions, total fuel cost and total emissions. Also Ref. [13] presents a multi-objective problem for the economic emission dispatch of a hydrothermal power systems. On his work two objective functions were presented, one for the total cost and the other for the total emissions allowance. The results show the best cost, the best emission and the best compromise solutions. The pareto-optimal set was also presented, representing the trade-off between the cost and environmental objectives. Ref. [1] presented, in a case study for Belgium, a simulation tool that properly models wind power and its unpredictability, allowing to determine the effects that wind power has on the cost of electricity generation and on CO_2 emissions.

Many other studies addressing the short-term electrical power generation scheduling are well documented in literature with emphasis on the changes that occur in the operation of the thermal units due to increase of wind penetration on system and on the market prices (see for example Refs. [3,14]). In the next section, the proposed model formulation is described, considering all technical constraints of thermal power units such as ramps, minimum up-time and downtime, and startup and shutdown cost.

3. Model formulation

The formulation followed in this work for the unit commitment problem, in a system with high penetration of wind and hydropower, is described in detail in this section. The model assumes a set of different fossil fuel units mostly comprised of coal and gas. In what concern to hydropower units, the model assumes two different types such as: the large hydropower units with reservoir and the run-of-river units. Pumping units were also included in the model. Due to the increase complexity of the model no individual set for wind and hydropower units was considered. Instead, the model assumes all the individual wind power units as one, and the same will occur with hydropower technologies. By assuming wind and hydropower as aggregated units the variability of the output of each independent unit is overlooked. This strategy allows to reduce the complexity of the model and is expected not to severely compromise the results, as no grid bottlenecks in the system are considered in the model.

3.1. Objective function

The proposed model formulation takes into account the economic cost, originating one objective functions to be considered. This objective function is set up by the sum of the variable costs of the electricity system. The variable costs, encompass the variable O&M (Operation and Management) costs, fuel and pumping cost, CO_2 emission allowance costs and shutdown and startup costs for each group. The objective function is measured in € and is defined by:

$$\sum_{t\in T}\sum_{j\in J}\left[C_{t,j}+\mathrm{Su}_{t,j}+\mathrm{Sd}_{t,j}\right]+\sum_{t\in T}\left[\mathrm{CVOM}_{\mathrm{h_d}}\times \mathrm{phd}_t\right] + \sum_{t\in T}\left[\mathrm{CVOM}_{\mathrm{h_r}}\times \mathrm{phr}_t\right]+\sum_{t\in T}\left[\left(\mathrm{Cp_p}\times \mathrm{ppump}_t\right) + \left(\mathrm{CVOM_p}\times \mathrm{ppump}_t\right)\right]+\sum_{t\in T}\left[\mathrm{pwind}_t\times \mathrm{CVOM_e}\right] \quad (1)$$

where T is the set of the time period (in h) considered in the model, J is the set of all groups of thermal power plants included in the

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