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Contribution of a pumped-storage hydropower plant to reduce the scheduling costs of an isolated power system with high wind power penetration

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ABSTRACT

The paper aims at demonstrating that the consideration of constant start-up costs and ramps of the thermal generating units for assessing the contribution of pumped-hydro energy storage to reduce the scheduling costs of hydrothermal power systems with high wind penetration, may yield unrealistic results. For this purpose, an isolated power system is used as a case study. The contribution of a pumped-storage hydropower plant to reduce the system scheduling costs is assessed in the paper by using a hydrothermal weekly unit commitment model. The model considers different start-up costs and ramps of the thermal generating units as a function of the start-up type. The effects of including pumped hydro energy storage in the system on the integration of wind energy, and on the start-ups and capacity factors of the thermal generating units are also evaluated. The results of the paper demonstrate that the consideration of constant start-up costs and ramps of the thermal generating units yields unrealistic results, and that the pumped-storage hydropower plant may help reduce the system scheduling costs by 2.5–11% and integrate wind power and may allow dispensing with some inflexible thermal generating units.

1. Introduction

PHES (Pumped-hydro energy storage) is receiving special attention mainly due to the strong deployment of non-dispatchable renewable energies, which is currently taking place in a vast number of countries all over the world [1]. The role of PHES in future power systems has been highlighted in recent international reports [2]. The contribution of PHES in power systems with significant penetration of renewable energies has been evaluated in the technical literature by using different hydrothermal economic dispatch and/or UC (unit commitment) models.

Until recently, the UC problem was usually solved by using dynamic programming [3] or Lagrangian relaxation [4]. However, during last decade, some approaches based on MILP (mixed integer linear programming) have outperformed dynamic programming and Lagrangian relaxation in terms of both modeling accuracy and computational performance [5].

Recent research on the application of MILP to the UC problem is aimed at accurately modeling the start-up costs and ramps (i.e. power trajectories to be followed during the start-up process) of TGUs (thermal generating units), which depend on the time the unit remained offline since the previous shut-down [6]. As a result of this and other researches, nowadays there exist some MILP based UC models where the start-up costs and ramps of TGUs are accurately modeled.

Other optimization techniques have been applied to the UC problem with varying degrees of success. In Ref. [7], a genetic algorithm was used for the first time to solve the UC problem. In that paper, the start-up costs of the TGUs are modeled as a function of the time the unit has remained offline since the previous shut-down. The violation of the TGUs start-up ramps are properly penalized in the objective function. In Ref. [8] a robust optimization approach is used to solve the UC of a hydro-thermal generation system. In Ref. [8], the start-up ramps of the TGUs are assumed constant, and the start-up costs are neglected. In Ref. [9] a quantum inspired evolutionary algorithm, combined with a differential

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evolution algorithm, are applied to the short-term hydrothermal generation scheduling problem, neglecting the start-up costs and ramps of the TGUs. In Ref. [10], a quantum inspired binary gravitational search algorithm is used to solve the UC problem. In that paper, the start-up costs of the TGUs are modeled as a function of the time the unit has remained offline since the previous shut-down, whereas the start-up ramps are neglected. In Ref. [11], a self-learning group search optimizer is proposed to solve the UC problem. As in Ref. [10], the start-up costs of the TGUs are modeled as a function of the time the unit has remained offline since the previous shut-down and the start-up ramps are neglected.

Notwithstanding the foregoing, to the author's knowledge there is no published work where the effects of PHES on power systems with a high share of non-dispatchable renewable energy have been assessed by considering variable start-up costs and ramps of the TGUs.

In Ref. [12], authors study the optimal sizing of a wind-powered PHES system which operates in coordination with a set of TGUs. For this purpose, authors use a simulation model which assumes that the output power of the TGUs can be modified in real time as a function of the actual load demand and wind power. Start-up costs and ramps of the TGUs were not considered in the simulation. In Ref. [13], authors study the optimal sizing of a wind-powered PHES system which operates in coordination with a set of diesel units. For this purpose, authors use a simulation model similar to the one used in Ref. [12]. Ref. [14] is focused on the profitability of a new PSHP (pumped-storage hydropower plant) in the Greek electric power system. The PSHP is assumed to buy the rejected wind energy at half the instant *marginal system price*, and to sell the energy generated by the turbines at the instant marginal system price. In Ref. [15], the profitability and optimum storage capacity of PHES is evaluated in a liberalized market context. The effects of PHES in the power system are not studied in the paper.

In Ref. [16], authors analyze the value of PHES in balancing a power system with high wind power penetration by using an approach based on linear programming and a priority ranking method. In Ref. [17], authors analyze the impact of wind power and PHES in the generation mix and net load profile of the Irish power system, and assess the revenue obtained from the joint operation of wind and PHES as well as the storage capacity which best exploits the coordination between wind and PHES considering three different heuristic operation strategies. The commitment of TGUs was not considered in the paper. In Ref. [18] authors estimate the scheduling cost[1] savings and the decrease in curtailed wind energy caused by energy storage, by using heuristic algorithms and dynamic programming, and considering constant start-up costs and ramps of the TGUs [19]. In Ref. [20] authors asses the contribution of PHES to reduce the scheduling costs, wind curtailments and carbon dioxide emissions from fossil fuel fired power plants in the Irish power system, considering different levels of wind power penetration. For these purposes, authors use a commercial UC algorithm based on stochastic MILP [21], which considers constant start-up costs and ramps of the TGUs. As stated in Ref. [20], the main benefit from storage is the decrease in wind curtailment. The same algorithm is used in Ref. [22] to analyze the impact of wind power penetration on a wide number of parameters of the all-Ireland power system. A single value of installed power in PHES is considered in Ref. [22]. As in Ref. [20], start-up costs and ramps of TGUs are assumed constant. In Ref. [23], authors assess the contribution of PHES to reduce the scheduling costs, carbon dioxide emissions and the excess electricity production in the Dutch power system. For this purpose, authors use a UC model based on the one presented in Ref. [24], which considers that the start-up costs and ramps of the TGUs are constant. The UC model presented in Ref. [24] is used also in Ref. [25] to study the effects on the Dutch power system of introducing a large number of electric vehicles and increasing the wind power penetration, considering again that the start-up costs and ramps of the TGUs are constant. In Ref. [23], authors conclude that energy storage helps reduce significantly the scheduling costs of the system, the greenhouse gases emissions and the amount of curtailed wind power.

In Ref. [26], authors assess the impact of PHES on operation costs (considering the use of committed reserves by means a 5-min time step intrahour dispatch), energy prices, carbon dioxide emissions, wind curtailments and operation of TGUs in three different power systems, considering different levels of installed wind power. As in Ref. [20], authors use a commercial UC model which considers constant start-up costs and ramps of the TGUs [27]. It is worthy to note that according to the results presented in Ref. [26], the use of adjustable-speed pumped-storage units would contribute to decrease wind curtailments to a significantly greater extent than using conventional fixed-speed pumped-storage units. In Ref. [28], the author studies the impact of hydropower on the energy prices, wind curtailments, operation of TGUs and scheduling costs, considering different levels of installed wind power. For these purposes, the author proposes a smart heuristic UC algorithm, which considers different start-up costs (not ramps) of the TGUs as a function of the time passed since the previous shut-down. Even though PHES is not considered in Ref. [28], the methodology used in the thesis could be easily adapted to include PHES in the analysis. In Ref. [29], authors formulate a deterministic MILP-based transmission-constrained day-ahead UC problem, considering the intrahour coordination of PHES and wind power. The problem is solved by means of a Benders decomposition approach. The results of the paper show that the coordination of PHES and wind power may contribute to reduce the load and wind curtailments, the transmission congestion and the operation costs (considering the use of committed reserves by means of a 10-min step intrahour dispatch), as well as to firming up the wind generation dispatch. Interesting conclusions are drawn in that paper, regarding the influence of the location of the PHES units on the magnitude of the above-mentioned positive effects of wind-hydro coordination. Constant start-up costs and ramps of the TGUs are assumed in the paper. A similar model is proposed in Ref. [30], which does not consider the intrahour coordination of PHES and wind power, but considers both wind and load forecast errors and random forced generator and transmission line outages. TGUs start-ups are not considered in that paper.

In Ref. [31], authors analyze the importance of accurately modeling the diverse constraints to which hydropower systems are generally subject for correctly assessing the capacity of a hydrothermal system to integrate variable renewable generation and the system scheduling costs. The results obtained in Ref. [31] show that both wind power curtailments and system scheduling costs can be reduced by accurately modeling the hydro generation assets in the generation scheduling problem. Even though PHES is not considered in Ref. [31], it is mentioned here since it demonstrates the importance of using realistic models of the generation assets for a correct assessment of the system scheduling costs. Constant start-up costs and ramps of the TGUs are considered in Ref. [31]. In Ref. [32], authors propose a heuristic short-term UC model which minimizes the fuel, start-up and emission costs of a thermal system with PHES, and which considers variable start-up costs and constant start-up ramps

[1] It is important to emphasize that in this paper, scheduling costs refer to the costs corresponding to the unit commitment and dispatch of thermal and hydro power units, considering the reserve requirements, but without considering the use in real-time of the committed reserves or other non-committed reserves, whenever necessary.