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Comparison of advanced power system operations models for large-scale renewable integration

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ABSTRACT

Increased renewable energy sources (RES) penetration requires significant changes in the short-term power system operations practice. Both current industry practices and relevant literature investigate models that operate on variable time scales to address RES uncertainty and variability. This paper presents a comparison of three different integrated short-term power system operations models regarding their ability to deal with large amounts of renewable penetration. The first model is a rolling unified unit commitment-economic dispatch (UUCED) model with variable time resolution, recently introduced by the authors. The second scheduling model comprises a rolling intraday unit commitment and a real-time dispatch with look-ahead capability (two-level model). The third model operates the system on a three-level hierarchy: it comprises a 48-h reliability unit commitment (deterministic or stochastic), a rolling intraday unit commitment and a real-time dispatch with look-ahead capability. The comparison is performed on the basis of an annual simulation of the Greek Interconnected Power System using 2013 historic wind power and load data. Simulation results demonstrate that the UUCED model better accommodates the increasing RES production by minimizing the system operating costs without jeopardizing system security.

1. Introduction

Centrally organized wholesale electricity markets, such as the ISO/RTO markets in the United States, perform their short-term operations scheduling based on the two-settlement system [1] comprising a day-ahead forward market (DAM) with hourly resolution and a real-time market (RTM) with 5-min dispatch period, complemented with a forward or intraday reliability unit commitment (RUC) [2,3]. DAM is a UC market model that clears energy and reserve quantities based on supply offers and demand bids with hourly resolution. RUC is also a unit commitment model, which recommits units based on ISO load and wind power forecasts instead of participant orders. In some markets RUC is not allowed to de-commit units but can only commit additional units [2], while in others RUC may also de-commit resources for congestion relief [3]. The RTM is used to dispatch online resources in real-time, usually, every 5 min, in order to meet the continuous load variation.

Current short-term power system scheduling practice assumes deterministic knowledge (perfect forecast) of system conditions for the next day. System conditions typically refer to load demand and component availability. Component unavailability is addressed with N-1 security criteria and scheduling of contingency reserves, while load forecast errors with scheduling of load-following reserves. The adequacy of the two-settlement market model is based on the notion that the net load can be fairly accurately predicted several hours ahead (DAM and RUC), so redispatching online resources in real-time via RTM is sufficient to meet uncertain demand. Forward or intraday RUCs adapt resource commitment to system condition changes.

The large integration of renewable energy sources in the power system, though, has put into question these practices. The uncertain and variable nature of the primary energy sources (e.g. wind speed and solar radiation) renders the respective RES units partially dispatchable and the System Operator (SO) has to confront increased net load unpredictability. In the literature there are several approaches to cope with the increased uncertainty in the short-term operation of the power system, including advanced

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forecasting tools [5], maintaining increased amounts of reserves [6] and use of stochastic [7–11] or robust [12–14] optimization. Although various advanced stochastic and robust optimization models have been proposed in the literature, SOs are still reluctant to use them in operations practice. Apart from the complexity and the high computational requirements of stochastic optimization, the main reason is institutional: scenario generation and weighting may raise market transparency issues.

Therefore, up to now, SOs rely on implementing more accurate deterministic models and facing uncertainty and variability by maintaining increased levels of reserves, by introducing frequently updated forecasts, additional intraday system operations and faster markets. Maintaining high reserve levels can be uneconomical and could also render the scheduling infeasible. In this context, advanced markets in the US have already begun to restructure their short-term operation and market models by adding and modifying operation functions based on frequently updated forecasts. Some of the most advanced techniques to face increased uncertainty include the following:

- Frequently revised RUC, with hourly granularity, to adapt the commitment decisions based on most recent information on changing system conditions [3,4].
- Intraday rolling unit commitment with sub-hourly time resolution and scheduling horizons up to several hours [15] in order to recommit fast-start units.
- Real-time dispatch with 5-min resolution and look-ahead capabilities (e.g. next hour) [16,17] in order to capture the forthcoming wind energy variations. The benefits of this approach have been explored in [18].
- Real-time dispatch and fast-start unit commitment [19].
- Flexible ramp constraints and new ramp products [16].

In the literature, several deterministic models have been presented to cope with increased uncertainty. In [20,21] deterministic unit commitment models are developed and are executed on a rolling basis. In [22] the effect of RES variability and uncertainty is examined in a one-day simulation across all multiple timescales down to AGC. The advantage of these works lies in that they examine the effect of RES generation in multiple time frames of the short-term power system operations simultaneously, while the majority of other works focus on a single timescale (usually day-ahead or real-time). Motivated by these trends and considering both current operations practice and research findings, the authors in [23] have presented a novel deterministic model that unifies the unit commitment and economic dispatch functions (UUCED) in a real-time tool that uses variable time resolution and a scheduling horizon of up to 36 h to better accommodate large amounts of RES generation.

In this paper, three short-term power system operations models are implemented. The first model (a) is a conceptual model named as "UUCED" [23], which is a single-level operations model. The other two models are based on two distinct current US operator practices. The second model (b) is an operations model based on the concept of the current ERCOT practice [3,4,17], which from now on will be called "two-level model" and the third model (c) is an operations model based on the concept of the current CAISO practice [15,24], which from now on will be called "three-level model". Similar two- or three-level operations models have been introduced to several other North American RTO/ISO-type markets, such as MISO [25,26], PJM [19], etc. We have restricted our comparison to ERCOT and CAISO owing to the large wind penetration in the respective states. The contribution of the paper is the comprehensive comparison of these three fully integrated short-term operations models regarding their ability to deal with large amounts of renewable penetration in a real power system using real data.

The comparison is comprehensive in terms of the following:

- The different short-term power system operations models are fully implemented covering all relevant time frames from the day-ahead scheduling to real-time operation. Day-ahead, intraday and real-time operations are simulated using a 15-min time resolution (and not the 5-min time resolution of the ERCOT and CAISO real-time markets) in order to reduce the simulation time. Detailed unit commitment and economic dispatch mathematical models have been used for this purpose, allowing for the realistic modeling of the various unit operating phases (synchronization, soak, dispatchable, and shut-down), the three-way unit start-up (hot, warm, cold) and all generating unit inter-temporal constraints.
- The simulations cover an extended time period. More specifically annual 15-min rolling simulations of the Greek Interconnected Power System for the year 2013 were performed.
- Real power system data, such as real generator data, historic 2013 wind power and load data (with 1-min resolution), actual 2013 imports and exports were acquired, validated and used in the simulations.
- The simulations are performed for two wind power penetration scenarios: the first is the actual 2013 wind power production and the second is an increased wind penetration scenario with the wind power generation doubled. Additional simulations for the first three months of 2013 are performed including network constraints.
- All types of reserves are calculated "from scratch" for all models and wind power scenarios, since the actual reserves of the Greek power system cannot be applied to the models presented due to their different time resolutions and lead times.

To the best of our knowledge, such large-scale comprehensive comparison of different deterministic models with different time resolutions, look-ahead horizons and real-time models regarding their ability to deal with large amounts of renewable penetration has not yet been performed. Therefore, we believe that this work satisfies an emerging power system need. Simulation results investigate the operational efficiency and the physical meaning of the three distinct approaches in high wind penetration environments and provide useful insights on the requirements of the future short-term operation of power systems. The proposed UUCED model is also compared to a stochastic three-level model in order to explore the effectiveness of using frequently revised unit commitment against stochastic unit commitment models that anticipatively fix the commitment decisions. It is clarified that models (b) and (c) are gross simplifications of the ERCOT and CAISO operating practices for the purpose of our simulations, keeping, however, the basic concept and structure of the respective designs.

2. Models description

The following simplifying assumptions have been used in our modeling:

- A 15-min real-time dispatch period is considered, in contrast to the 5-min period adopted in most wholesale electricity markets, in order to reduce the execution time of the annual simulation.
- DAM closure is considered to be at 11:30, so generator offers are considered to be available at that time point.
- For simulations purposes, all models use generator offers as well as SO wind and load forecasts, while no demand bids are considered.