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# A rolling-horizon unit commitment framework with flexible periodicity

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ABSTRACT

In this work, we develop a mathematical model and framework to represent rolling-horizon unit commitment (UC) processes with multiple periodicities. In control center operations, UC is solved repeatedly to adjust device commands based on new information about load, generation availability, renewable energy production, and other aspects of system state as uncertain conditions are realized. We develop a three-level model including 24-h UC, rolling-horizon UC (RHUC), and economic dispatch (ED) and give formulations for the three problems including interdependencies. This framework allows for evaluation of, among other things, different periodicities of the rolling horizon problem and the benefits of more accurate forecasting information. Experimental results are shown for a 6-bus system and a 3012-bus system with wind generation in two wind scenarios. Although the generation costs are very similar, the deviation between RHUC schedules and actual deployment is noted to be superior for a 20-min periodicity compared to a 30-min periodicity. Additionally, less reserve is deployed in the 20-min RHUC case.



## 1. Introduction

Transmission systems always include a 24-h unit commitment (UC) as part of their operational profile to clear the day-ahead electricity market or, for vertically integrated markets, to synchronize transactions in the day-ahead markets with neighboring systems. However, a 24-h commitment schedule determined several hours in advance of the operating day is not adequate to operate a system reliably and securely. Imperfect forecasting of load and often intermittent, renewable generation as well as unplanned outages of equipment require that changes to the UC schedule be made on a consistent basis. If these changes are made with an entirely ad-hoc approach, it is possible to lead the system into insecure states without adequate generation reserves or headroom. At the very least, there is no way to know whether the system is being operated at minimum cost or how close to the minimum cost the system is.

For these reasons, system operators use a so-called "receding" or "rolling" horizon approach to operations scheduling where successive problems are solved repeatedly as time advances with a constantly progressing look-ahead horizon. Typically, only a subset of the decisions made in each scheduling problem are taken to be fixed, while the others act as "suggestions" for the future. Having a future horizon included in the problem even without any binding decisions in that time frame helps keep the system cost lower over the entire time series of operation and lessens the likelihood of bringing the system to an insecure state. Several of the Independent System Operators (ISOs) have implemented this rolling-horizon look-ahead strategy in their operations. For example, the Midcontinent Independent System Operator (MISO) uses a day-ahead forward reliability assessment commitment (FRAC) and a look-ahead commitment (LAC) before conducting security-constrained economic dispatch (ED) [1]. The FRAC is conducted from the current time to the end of the operating day while the LAC runs every 15 min with a continually receding 3-h horizon. It is estimated that the implementation of the LAC tool has saved approximately $1–3 million each year from the avoidance of about one commitment every 3 days [2]. California ISO runs a short-term UC (STUC) each hour and a real-time UC (RTUC) every 15 min along with a 5-min economic dispatch [3]. PJM uses so-called "incremental" commitment and decommitment alongside its 5-min, time-coupled security-constrained ED [4]. These short-term UC problems must be solved much more quickly than the day-ahead UC problems, which may take over an hour to solve. However, because many generators are already committed in the day-ahead UC, shorter-term UC engines can focus primarily on fast-start resources and reserve or ancillary product dispatch. Solution times of several minutes for real-world cases can be achieved for these short-term UC problems [1].

The rolling-horizon approach allows system operators to make use of data that is revealed as time progresses. Traditionally, the main source of uncertainty in power system operations has been

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in forecasting the load. In deregulated systems, the ISO procures resources to satisfy the expected demand for the next day through the day-ahead market. They may then procure additional resources based on reliability assessments ahead of time. However, real-time operations often require adjustments to dispatch, deployment of reserve products, and unit commitments or decommitments close to the time of operation. As such, short-term and real-time load forecasting tools have been developed to provide updated load forecasts at the sub-hour level, even down to 10 min and below [5,6].

Especially important for modern transmission grid operations are forecasts for wind generation, which are known to be much more accurate an hour or less ahead of time than a day ahead [7,8]. The Electric Reliability Council of Texas (ERCOT), which in 2014 had a total 18 GW of wind capacity planned, implemented a "Large Ramp Alert System" to address the issue of quickly changing wind resources. The system provides operators with updates to wind forecasts every 15 min and uses a look-ahead horizon of 6 h [9]. Increasing penetration of distribution-connected photovoltaic generation may also impact net aggregated demand at the transmission level in the near future.

If UC could be solved instantly and generators could receive and respond to actions without delay, the best strategy for system operators would be to wait until just before commitment decisions are needed and decide using the most reliable information. Of course, they are constrained by the computation time of the problem and by the need to notify generator crews in advance of the schedule. Therefore, as renewables continue to grow in generation share, the rolling-horizon UC (RHUC) problem becomes more critical.

Tuohy [10] discussed the benefits of the rolling-horizon approach and provided a comparison of the rolling-horizon approach to the static approach both when forecasting was perfect and when it was imperfect. However, the RHUC in this case was conducted only with hourly granularity, and no explicit formulations are given. Similarly, Constantinescu [11] conducted hourly RHUC, although the time frame was a shrinking interval between the current time and the end of the current operating day instead of a constant 6 h ahead of the current time. Feinberg [12] provided some formulations for the RHUC, but only for reserve. Further, RHUC is still only conducted on an hourly basis. Guigues and Sagastizábal [13] evaluated the value of rolling-horizon policies for risk-averse hydro-thermal planning. Long-term UC with time horizons of several years and time steps of weeks or months are considered. Qiu et al. [14] studied the combined effects of storage and RHUC look-ahead horizon on generator welfare and total surplus for market design. It is concluded that the look-ahead horizon can have a significant impact on the profitability of storage devices. The RHUC in [14] is conducted on an hourly basis. Xie and Ilić [15,16] also studied rolling-horizon energy scheduling problems including intermittent resources, applying model-predictive control to solve repeated problems. However, this work only considered ED problems instead of UC. In this paper, we focus on day-ahead UC with RHUC being conducted down to a sub-hourly basis.

A rolling-horizon energy management system (EMS) for a renewable-based microgrid was proposed by Palma et al. in [17]. Similar to the framework in this paper, a RHUC problem is formulated to provide regular updates to the energy schedule while an ED problem is solved at a faster rate to provide more accurate power flows at dispatch time. However, the formulations in [17] and the other renewable-based microgrid EMS research such as [18–20] are focused on smaller-scale systems and are not applicable to large-scale power systems with a large portion of conventional generation. By contrast, the formulations provided for RHUC and ED here are intended for and compatible with the traditional large-scale power system UC formulations.

The primary contribution of this paper is much more flexible formulations of RHUC and ED that allow RHUC to be conducted with varying sub-hour granularity. This allows not only comparison between periodicity differences of, in the cases investigated here, 10 min, but also the modeling of the aforementioned multi-level frameworks used in practice, each of which has its own timeline for operations. A further contribution is the modeling of transitional periods of generator startups and shutdowns in both the RHUC and ED. The framework presented here is therefore capable of a wider range of simulations than those existing and conform more closely to the models of RHUC used in industry. Finally, we contribute a framework for adjusting commitment and dispatch in RHUC from the day-ahead UC as well as adjustments to the RHUC generation dispatch in the subsequent ED.

The remainder of the paper proceeds as follows. Section 2 describes in greater detail the structure of the simulations and the inputs and outputs of each module. Sections 3 and 4 describe the formulations of the RHUC and ED problems, respectively. Section 5 describes the 6-bus and 3012-bus test cases and sources of input data and presents the results of experiments. Finally, Section 6 concludes the paper. A baseline mixed-integer programming (MIP) formulation for day-ahead UC is given in Appendix A, and tables of notation are presented in Appendix B.

## 2. Simulation structure

Fig. 1 shows the structure of the rolling horizon simulation with 30-min RHUC. RHUC may be done on arbitrary time scales but is generally conducted on a period of less than an hour to take advantage of the sub-hour startup times of natural gas generators. The blocks labeled "UC" and "ED" represent calculations of the 24-h UC problem and the ED problems, respectively. The solid arrows indicate fixed decisions determined by the UC or ED algorithm at the arrow's source to be applied at the sink. For example, the ED calculated between 0 and 10 min creates the fixed power output decisions at $t = 10$ min. The block labeled "UC-30" represents the RHUC problem that is implemented at $t = 30$ min. Note that to implement a solution at 30 min, the problem should begin computing at 0 min (following the implementation of the previous RHUC), meaning that only the information and forecasts available up to $t = 0$ min may be used to calculate the UC-30 solution. Outputs of UC and ED algorithms may also provide a non-binding suggestion for a good schedule of operations at some future time step. The suggested good schedule may be modified by subsequent UC or ED algorithms upon the acquisition of new information, such as an updated load or wind generation forecast.

Regardless of the period of the RHUC and ED, a classical 24-h UC always precedes the operating day. The 24-h UC will determine the initial operating point for the operating day as well as the first hour, giving the first RHUC problems start and end points to initialize their set points. Now consider the case in Fig. 1. Once the operating day begins, RHUC with a 6-h horizon begins executing at 0 min to finish and apply output control actions at 30 min. Once those control actions are applied, another RHUC begins calculation at 30 min using the updated load and intermittent generation forecasts available at $t = 30$ min for the new RHUC horizon (30 min to 6.5 h). In between the RHUC calculations, successive ED problems adjust the power outputs of committed generators, the deployment of reserve scheduled by UC, and curtailable loads to react to even newer information and make adjustments necessary to account for generators in their startup or shutdown phases.

In many actual power system operations, the operational framework shown in Fig. 1 is implemented more like what is shown in Fig. 2. In this example, the ED update frequency remains 10 min, but ED problems that begin calculating at $t$ minutes have