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On critical timescale of real-time power balancing in power systems with intermittent power sources

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ABSTRACT

From the perspective of power balancing, we consider in this paper the timescale of real-time dispatch in power systems with high penetration of intermittent power sources. Due to the integration of intermittent power sources, real-time dispatch must be employed in the process of power balancing. The hierarchy of power system operation is typically comprised of the short-term scheduling, the real-time dispatch, and the automatic generation control (AGC). Therein, the AGC is the last-level defense of the systemwide power balancing, which has limited power adjustment capability. Consequently, the real-time dispatch must eliminate as much power imbalance as possible, and its capability of doing so depends on its timescale. Based on the statistical forecast uncertainty functions, a quantified relation between the uncertainty level of the power system and the critical timescale for real-time dispatch is established in this paper. Simulations demonstrate the effectiveness of the proposed formula.

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1. Introduction

Intermittent power sources (IPS), including wind farms and solar sites, have been rapidly integrated into power systems due to economic and environmental reasons. As a result, power systems with high penetration of intermittent power sources have already surfaced [1–3]. Unfortunately, IPS suffers from its uncertainty and unpredictability, which may jeopardize the real-time power balancing as well as the security and stability of the power system. It is therefore necessary to develop an effective solution to overcome the issue. Otherwise, extensive wind or solar spillage may occur, and the development of IPS may be stuck at an awkward quandary of “high capacity but low generation”.

In particular, how to get rid of the negative impact of IPS on power balancing has been entitled to a top-level priority of research in recent years. In general, relevant works include threefold: First is “forecasting”, which dedicates to improve the accuracy of the day-ahead forecast of IPS output power to reduce its uncertainty [4–7]; second is “accommodation”, which utilizes conventional power sources, energy storage facilities, active loads, and other controllable resources to offset the power uncertainty of IPS [8–11]; third is “adjustment”, which focuses on the reform of the current design of the dispatch control system to ensure the power balancing of power systems [12–16].

Essentially, involving the weather forecast problem, the forecast of power generation from IPS may encounter bottlenecks in its accuracy. Therefore, the uncertainty of IPS power can be considered as inherent, with intermittence and randomness as its basic characteristics. To solve the problem of power balancing in power systems with high penetration of intermittent power sources, a reasonable blueprint is to acknowledge and accept the nature of unpredictability of IPS and concentrate on the accommodation and adjustment parts, namely, to organically combine the utilization of controllable power sources with the adjustment of dispatch control systems.

From the perspective of a dispatch control system, the power system with IPS is the one in which real-time dispatch must be employed in the process of power balancing. The hierarchy of the current dispatch control system includes three different levels that are coherently connected with each other: Short-term scheduling, real-time dispatch, and Automatic Generation Control (AGC). Thereby, the power balancing, where the power generation from IPS may be an important component, is gradually achieved.

The literature has acknowledged the importance of the design of timescales in the power balancing architecture, offering suggestions on possible timescales such as 4 h, 1 h, and 15 min [17–21]. Nevertheless, neither analytical formulas nor theoretical or systematic studies have been proposed on the timescale of real-time dispatch so far. This could cause two consequences. First, setting the

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timescale of real-time dispatch too long might make AGC difficult to balance the rest of power imbalance from real-time dispatch. Second, setting the real-time dispatch timescale too short might exacerbate the computation burden.

Adequate power sources to accommodate the uncertainty level of IPS and proper design of timescales are the fundamental insurances for the real-time dispatch to achieve the best possible function of power balancing. Therefore, it is highly desirable to design a proper timescale, which essentially represents the tradeoff between the forecast accuracy and the computation efficiency.

From the perspective of power balancing, this paper describes the architecture, functions, and the hierarchical design of the dispatch control of power systems with IPS. We also clarify the relation between the power balancing function of real-time dispatch and accommodation reserve capacities of short-term scheduling, along with the relation between the real-time power forecast accuracy and the power adjustment capability of AGC. Furthermore, based on the statistical function of forecast error that characterizes the statistical forecast uncertainty of a single IPS, this paper presents an analytical formula of a critical real-time dispatch timescale, which represents a desirable timescale from the perspective of power balancing and provides a technical reference for the final quantitative selection of the real-time dispatch timescale.

Note that, the final selection of the real-time dispatch timescale must consider many other aspects besides the power balancing, including the market design, the computation burden, and the security issues [22–24]. Currently, the hierarchical design of the dispatch control system may be of three-level or of four-level. The former includes day-ahead scheduling, real-time dispatch, and AGC, while the later adds an extra level of intra-day dispatch between the day-ahead and real-time levels. Without loss of generality, since the power balancing problem is being discussed, we start with the three-level in this paper.

The remainder of this paper is organized as follows. Regarding power balancing, we first propose a coherent dispatch control system in Section 2. The analytical formula that represents the critical timescale of the real-time dispatch is presented in Section 3. Subsequently, the relations between the real-time dispatch timescale and IPS scale is further discussed in Section 4. The simulation results to demonstrate the above relations are shown in Section 5. Conclusions are finally drawn in Section 6.

2. Coherent dispatch control system regarding power balancing

The error in day-ahead power forecast of IPS is typically substantial, which may exceed the power balancing capability of AGC. Due to the impact of power generation uncertainty of IPS, the real-time dispatch must be employed in the power balancing process. Thereby, a dispatch control system of the power system with IPS that employs the power balancing process can be achieved via the coherent coordination among the three levels of dispatch system that consist of the short-term scheduling, real-time dispatch, and AGC, respectively. Herein, the "forecast" and "correction" define the two pivot components in such a dispatch system.

In this paper, to simplify the expression, we summarize the total power injections from all controllable assets as P_c,[1] including those from traditional generators and controllable storage devices and loads, and summarize the wind power P_w and solar power P_s as the IPS power generation P_{ips}, which can be also regarded as "negative load". We also summarize the IPS power generation P_{ips} and load power P_l as the uncontrollable "equivalent load" P_e, that is

$$P_e(t) = P_l(t) - P_{ips}(t). \tag{1}$$

2.1. Short-term scheduling

The day-ahead forecast is to observe the equivalent load, and the short-term (day-ahead) scheduling is to balance it. The forecast error may be large, implying a vague observation. On one hand, the short-term scheduling utilizes the total controllable power P_c^s to balance the short-term forecast of the total uncertain equivalent load P_e^s and the anticipated power loss P_L^s, that is

$$P_c^s(t) - P_e^s(t) - P_L^s(t) = 0, \tag{2}$$

where the superscript s denotes variables in the short-term scheduling.

On the other hand, the short-term scheduling arranges reserve in controllable power sources to accommodate the latent uncertainty in the real-time dispatch; it also arranges the frequency modulation reserve so that the posterior real-time dispatch and AGC would have enough capability to achieve the power balancing.

2.2. Real-time dispatch

Similarly, the real-time forecast is to observe the equivalent load, and the real-time dispatch is to balance it. Since the time advance of the real-time forecast is much shorter than that of the day-ahead forecast, its forecast accuracy is expected to be significantly improved. Real-time dispatch uses a "clear" real-time power forecast to update the "vague" short-term power forecast. It utilizes the power generation resources from accommodation reserve left in the short-time scheduling P_c^r to balance the real-time power imbalance ΔP_e^r. Specifically, the difference between the real-time forecast value of equivalent load P_e^r and short-term forecast value P_e^s is

$$\Delta P_e^r(t) = P_e^r(t) - P_e^s(t), \tag{3}$$

where the superscript r denotes variables in the real-time dispatch.

The power balancing equation in the real-time dispatch is

$$P_c^r(t) - \Delta P_e^r(t) - P_L^r(t) = 0, \tag{4}$$

where P_L^r is the anticipated power loss in the real-time dispatch.

2.3. AGC

AGC is based on the local observation of frequency. Equivalently, it faces towards actual situations with an accurate observation of equivalent load. AGC takes "actual" observation to fix a "clear" real-time power forecast. It utilizes the power generation resources from frequency modulation reserve P_c^a to balance the actual power imbalance ΔP_e^a. Specifically, the difference between the actual value of the equivalent load P_e and the real-time forecast value P_e^r is

$$\Delta P_e^a(t) = P_e(t) - P_e^r(t), \tag{5}$$

where the superscript a denotes AGC.

The power balancing equation in AGC is

$$P_c^a(t) - \Delta P_e^a(t) - P_L^a(t) = 0, \tag{6}$$

where P_L^a is the actual power loss.

Based on frequency measurement, AGC is employed to observe the equivalent load. It adjusts the power generation autonomously based on frequency deviation and achieves power balancing with zero frequency deviation.

[1] Without special description, all power defined in this paper are scalers which represent the total amount in the power system.

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