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Balancing power and variable renewables: Three links ☆

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ABSTRACT

Balancing power is used to quickly restore the supply-demand balance in power systems. The need for this tends to be increased by the use of variable renewable energy sources (VRE) such as wind and solar power. This paper reviews three channels through which VRE and balancing systems interact: the impact of VRE forecast errors on balancing reserve requirements; the supply of balancing services by VRE generators; and the incentives to improve forecasting provided by imbalance charges. The paper reviews the literature, provides stylized facts from German market data, and suggests policy options. Surprisingly, while German wind and solar capacity has tripled since 2008, balancing reserves have been reduced by 15%, and costs by 50%.

Contents

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1. Introduction

Electricity generation from variable renewable electricity sources (VRE), such as wind and solar power, has grown rapidly during recent years and is expected to continue to grow. The fact that these generators are distributed, non-synchronous, and weather-dependent causes specific challenges when integrating them into power systems [54,68,71]. With increasing amounts of VRE in many countries, system integration has become a major public policy debate with a particular emphasis on the stress that forecast errors put on balancing systems.

Balancing power is used to stabilize the active power balance of integrated power systems on short time scales from seconds to hours. In AC power systems, the demand–supply balance has to hold at every instant of time to ensure frequency stability at, usually, 50 Hz or 60 Hz. Frequency deviations have a number of problematic consequences, one being that they can mechanically destroy rotating machines such as generators. Technical procedures and economic institutions have evolved to prevent frequency instability, and the most important of these is "balancing power"[1].

Electricity generation from VRE has been growing rapidly in many countries, driven by technological progress, economies of scale, and deployment subsidies. Global solar PV capacity has reached 140 GW, a fourteen-fold increase since 2007, and there has been a four-fold increase in wind power to 320 GW [100]. Several power systems now accommodate VRE shares of 15% to 40%, including Eastern Inner Mongolia, Denmark, Spain, Portugal, Ireland, Lithuania, and Germany. The IEA [72] projects that medium-term growth will continue and long-term models forecast that VRE shares by 2050 will need to be several times higher than today [47,84,81]. Hence, system integration will remain challenging.

This review paper explores the interaction of wind and solar with balancing power. We identify and discuss three major links between VRE and balancing systems (Fig. 1). Each link has been previously discussed in the literature, but to the best of our knowledge this is the first attempt to comprehensively account for the interactions between VRE and balancing power.

First, and most obviously, VRE generators, being weather-dependent and hence inherently stochastic, are subject to forecast errors which increase the need for holding and deploying balancing reserves. Second, however, VRE generators can also supply balancing services, although this requires policies and markets to be appropriately designed; balancing services supplied by VRE generators obviously reduce the pressure on the balancing system. Finally, the imbalance price which is the financial penalty for forecast errors, determines the size of forecast errors given its influence on the behavior of VRE generators. If set correctly, the imbalance price can stimulate more accurate forecasting and incentivize VRE generators to improve system stability. The three links are not independent, and policy that is only targeted at one of the channels is likely to be suboptimal. We hope our holistic view generates a more comprehensive understanding of the balancing challenge and explores the entire solution space for policy makers, market participants, and system operators.

The aim of this paper is to stimulate and structure the discussion on the interaction between VRE and balancing power. It particularly targets practitioners such as policy makers, regulators, system operators, market participants, and VRE investors. It aims to provide an overview of topics, a guide through the literature, and a summary of policy proposals. We complement the literature review with model results and empirical data where appropriate. We study German markets and policies in detail, but most observations and recommendations also apply to other European markets, and, albeit to a lesser degree, to U.S. power systems. Germany is an interesting case not only because of the extent and rapid growth of VRE penetration, but also because of data availability, cooperation between system operators, and market design reforms.

We believe that three broad conclusions can be drawn from this review. First, we find the impact of VRE on the balancing system to be less dramatic than sometimes believed. VRE growth has had moderate impact on volumes and costs of balancing power at best; in many circumstances other factors had a larger impact. Second, the design of balancing power markets constitutes an unnecessary entry barrier to this market, and prices in balancing and imbalance markets do not regularly reflect marginal costs. With appropriate market design, VRE wind and solar not only consume but can also provide balancing services. Finally, VRE and balancing systems interact via various channels. Policies interact with each other and should be considered in context. Usually, multiple policies exist to achieve the same objective, a fact that might ease implementation challenges.

The paper is organized as follows. Section 2 gives an overview of balancing systems. Sections 3–5 review the three links: reserve requirements, balancing power markets, and imbalance settlement. Section 6 concludes.

2. Fundamentals of balancing systems

We define the balancing system (or "balancing regime") as the set of technical and economic institutions that are used to maintain

[1] There are a multitude of names for "balancing power". Inconsistent and diverging nomenclature is a major problem in this field. Here we use the most internationally common generic term "balancing power". European transmission system operators have used the term "control power" [115], but are replacing it by "operational reserves" [37]. In Germany and Nordic countries, "regulating power" is more commonly used. Other names are "balancing reserve", "frequency control", and "reserve power". Certain types of balancing power are sometimes used broadly, such as "regulation", "load following", "contingency reserves", "frequency containment reserve", "frequency restoration reserve", or "replacement reserve". Inertia, or "inertial response", which is an active power response similar to balancing power, driven by the electromechanical properties of synchronous machines, takes place at even shorter time scales and is not discussed in this paper (see [33]).