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A review on the recent history of wind power ramp forecasting

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ABSTRACT

Forecasting large and fast variations of wind power (the so-called ramps) helps achieve the integration of large amounts of wind energy. This paper presents a survey on wind power ramp forecasting, reflecting the increasing interest on this topic observed since 2007. Three main aspects were identified from the literature: wind power ramp definition, ramp underlying meteorological causes and experiences in predicting ramps. In this framework, we additionally outline a number of recommendations and potential lines of research.

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1. Introduction

Wind energy shows clear advantages as compared with traditional energy sources. However, one of the main drawbacks of wind energy is that it exhibits intermittent generation greatly depending on environmental conditions. Intermittency adds complexity to the management of power systems because supply and demand must be balanced almost instantaneously. Potential solutions are demand response techniques (such as plug-in vehicles) and large scale storage (such as supercapacitors and hydrogen storage) [1], though these might be available only in the middle/long-term. Instead, wind power intermittency can be partly mitigated through forecasting techniques, which aim at reducing the uncertainty of future wind generation of a wind farm or portfolio. In a few decades, approaches to wind power forecasting have evolved rapidly, with special emphasis in the short-term (prediction horizons up to one day). For a detailed review on the topic, readers are referred to Costa et al. [2], Giebel [3], and Jung and Broadwater [4].

In the last few years, the so-called *ramp events* have attracted growing interest in the wind power forecasting community. The idea behind the notion of a ramp is that a local event (in the form of a large and fast power variation in a wind farm or portfolio) is critical enough to deserve special attention. By critical we mean that the potential damage or cost associated to a bad management of the event is considered too high or, at least, qualitatively higher than that associated to non-ramp situations. An example would be a scenario of load curtailments due to a severe drop of wind power generation. Real experiences of critical events from the grid operator standpoint have been documented by Ela and Kirby [5] and Wan [6]. Energy traders operating in electricity markets might also be affected by ramps, as inaccurate bids during these events may derive in expensive penalties [7]. Despite these situations, according to Potter et al. [8], the impact of ramp events may be occasionally undervalued by forecasters because wind power forecasting traditionally focuses on minimising

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the overall error committed in long time periods (i.e. months, years). This would justify *ramp forecasting* as a particular case of wind power forecasting specifically oriented to improve the forecast of such events.

The booming importance of wind power ramp forecasting is observed in the increasing number of studies and projects on this topic, as illustrated in Fig. 1. This figure shows the number of wind power ramp-related works on a yearly basis since 2007 (for a detailed list of references, see Table 1). Data for each year are broken down according to type of work (technical report, conference paper, doctoral thesis, non-JCR paper and JCR paper). It is noted that records concerning 2014 are computed only up to August, meaning that the final number of works published in this year is likely to fit with the general positive trend observed in the picture. Another interesting remark is that publications in the form of technical reports predominate in a first stage (2007–2008), while conference papers become more frequent since 2010, followed by a noticeable increase of JCR articles experienced in recent years.

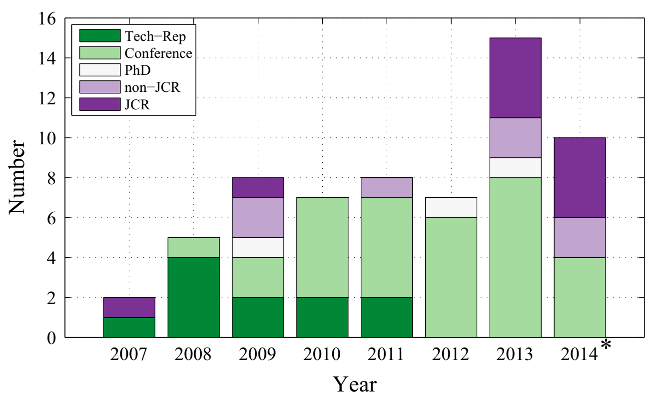

Fig. 1. Number of wind power ramp-related works depicted on a yearly basis and broken down according to type of work. * denotes data up to August 2014.

Table 1
References of the works considered in Fig. 1.

Year	Technical report	Conference	Ph.D.	non-JCR	JCR
2007	[9]	–	–	–	[10]
2008	[5,11–13]	[14]	–	–	–
2009	[15,16]	[8,17]	[18]	[7,19]	[20]
2010	[21,22]	[23–27]	–	–	–
2011	[6,28]	[29–33]	–	[34]	–
2012	–	[35–40]	[41]	–	–
2013		[42–49]	[50]	[51,52]	[53–56]
2014*	–	[57–60]	–	[61,62]	[63–66]

*Denotes data up to August 2014.

The geographical distribution of the case studies considered in wind power ramp-related works is shown in Fig. 2. As expected, ramp events have become a concern in regions with significant levels of wind power penetration. In particular, North America accumulates most of the case studies addressed in the reviewed works: 13 case studies in the Electric Reliability Council of Texas (ERCOT), 9 in the area managed by the Bonneville Power Administration (BPA) and 6 in the Alberta region. Other regions with prominent research activity on wind power ramps are Europe (16 case studies, half of them located in the Iberian peninsula) and Australia (in particular, South Australia and Tasmania). More recently, a few publications considered case studies in growing economies (China and India), where wind power is being developed rapidly.

This paper is devoted to provide an overview on wind power ramp forecasting, along with a brief summary of current open questions and future lines of research. It is noted that a review on this topic was already published in 2010 [22]. Nevertheless, research on ramp events has experienced a noticeable increase since then, as shown in the figures above. For this reason, this paper also aims to update the aforementioned work.

The paper is organised as follows. The following three sections deal with the main aspects on wind power ramps identified from the literature: Section 2 addresses the notion of ramp event; in Section 3 relevant findings on ramp underlying meteorological causes are reviewed; Section 4 gathers approaches and experiences oriented to wind power ramp forecasting. The paper ends with Section 5 highlighting some of the weak points identified from the literature, and suggesting potential lines of research on the topic.

2. Ramp definition

Generally speaking, a ramp event represents a large and fast variation in power in a wind farm or portfolio. According to the literature ([22] and references therein), a ramp can be characterised by the following parameters:

- Magnitude (ΔP_r): the variation in power observed during the event.
- Duration (Δt_r): the time period in which a large variation takes place.
- Ramp rate, which is derived from the previous variables ($\Delta P_r/\Delta t_r$) and provides an idea of the ramp intensity.
- Timing (t_0): a time instant related to the ramp occurrence. This parameter can be defined either as the starting time or the central time of the event.

Fig. 2. Regional distribution of the case studies considered in wind power ramp-related works (see text for details).