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Identifying and characterising large ramps in power output of offshore wind farms

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ABSTRACT

Recently there has been a significant change in the distribution of wind farms in Great Britain with the construction of clusters of large offshore wind farms. These clusters can produce large ramping events (i.e. changes in power output) on temporal scales which are critical for managing the power system (30 min, 60 min and 4 h). This study analyses generation data from the Thames Estuary cluster in conjunction with meteorological observations to determine the magnitude and frequency of ramping events and the meteorological mechanism.

Over a 4 h time window, the extreme ramping events of the Thames Estuary cluster were caused by the passage of a cyclone and associated weather fronts. On shorter time scales, the largest ramping events over 30 min and 60 min time windows are not associated with the passage of fronts. They are caused by three main meteorological mechanisms; (1) very high wind speeds associated with a cyclone causing turbine cut-out (2) gusts associated with thunderstorms and (3) organised band of convection following a front. Despite clustering offshore capacity, the addition of offshore wind farms has increased the mean separation between capacity and therefore reduced the variability in nationally aggregated generation on high frequency time scales.

1. Introduction

To meet ambitious carbon reduction targets, global renewable energy deployment has expanded dramatically. In the UK, the capacity of wind power has grown steadily from 2.9 GW in 2008 to 17.9 GW by June 2017 [1]. Due to the increasing penetration of wind power, extreme wind power generation events are of growing concern. In particular, ramps in generation provide challenges for the transmission system operator who schedule reserve holding in advance and require long term strategies for system balancing [2]. Consequently, a number of studies have focused on understanding and improving the predictability of wind power ramping events [3–6].

For the UK, Cannon et al. [7] used wind speed data derived from the MERRA reanalysis dataset to quantify the magnitude and frequency of nationally-aggregated wind generation ramping on time scales of 6 h and greater based on the 2012 wind farm distribution. However, in recent years there has been a significant change in the distribution of wind farms in the Great Britain [8]. Since 2012, the capacity of offshore wind farms has increased from 2.4 GW to 5.0 GW with much of this capacity spread over a small number of very large wind farms located in clusters. For example, in the Thames Estuary alone there is approximately 1.7 GW of capacity. Drew et al. [3] showed this has led to large regional ramps in generation on time scales of minutes to hours as local meteorological phenomena simultaneously impacts production in several large farms. Given the large capacity of the farms, these ramps can present a challenge in maintaining the balance between supply and demand on a national scale, particularly if they are not accurately forecasted.

The problem posed by local ramping events is expected to be exacerbated in the coming years, given the trend for clustering capacity in large offshore wind farms looks set to continue. The latest phase of offshore wind development in the UK, launched in 2009, identified 9 zones within which a number of individual wind farms could be located with a total capacity of over 30 GW [9,10]. Consequently, following the construction of the round 3 wind farms the majority of GB wind capacity would be located offshore in clusters of very large wind farms [11,12].

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To improve the performance of operational wind power forecasts there is an increasing need for a clear understanding of the meteorological features responsible for the extreme local ramping events [13]. For example, Trombe et al. [14] showed that high frequency ramping of large Danish offshore wind farms can be associated with heavy rainfall and therefore considered the scope for using data from the rainfall radar to adjust the forecast in real-time if necessary. This study investigates whether such an approach could be applied to ramping events in the Thames Estuary wind farms.

In addition to the problems posed by local ramping events, there are concerns that clustering capacity could lead to an increase in the variability of the nationally aggregated wind generation (i.e. a reversal of some of the smoothing benefits gained by the spatial dispersion of turbines). A number of studies have investigated the reduction in wind power variability due to geographical dispersion of turbines for single European countries. For example, Kubik et al. for Northern Ireland [15], Hurley and Watson for Ireland [16], Hasche for Germany and Ireland [17] and Giebel [18], Landberg [19], Buttler [20] and Huber et al. [21] considered the whole of Europe.

For the UK, Sinden [22] and Earl et al. [23] used wind speed data measured at Met Office surface stations to quantify the inter-annual, seasonal and diurnal variability of UK aggregated wind generation. However, these studies did not consider offshore sites and assumed the distribution of wind capacity matched the distribution of weather stations which can lead to large errors [24]. To address this problem, Cannon et al. [7] used wind speed data derived from the MERRA reanalysis dataset to determine the characteristics of wind power in Great Britain over a 33 year period. The study provides a detailed climatology of ramping on time scales of 6 h and greater.

Using the approach outlined in Cannon et al. [7], Drew et al. [12] showed that the increased penetration of offshore wind farms has little impact on the ramping of GB-aggregated wind generation on time scales of greater than 6 h. However, due to the resolution of the model, MERRA reanalysis data cannot be used to determine the high frequency GB-aggregated power swings (minutes to hours) or quantify the magnitude of wind power ramps at high spatial resolutions (below 300 km), both of which are important considerations for managing the power system.

In the UK, the electricity market is managed in 30 min windows, known as settlement periods. For each period, suppliers and generators contract electricity up to 1 h prior to the delivery time, a cut-off time known as “gate closure”. It is then the responsibility of the system operator (National Grid) to take any necessary actions in order to balance the grid within each settlement period. The electricity network in the UK is largely isolated with relatively few interconnectors to neighbouring countries and therefore there is a reliance on large conventional power plants to manage the system. However, these plants generally require a period of notice prior to generation to ramp up, generally assumed to be at least 4 h. To manage the power system, it is therefore important to understand the possible ramps in power that could occur on time scales shorter than the ramp up time of a conventional power plant (4 h), between gate closure and settlement period (1 h) and from one settlement period to the next (30 min).

The aim of this study is to use a 30-min averaged time series of wind power generation from a number of regions across Great Britain (GB) in 2014 to investigate how the increased penetration of clustered offshore wind capacity has affected the characteristics of generation at high spatial and temporal resolutions. The first section considers the impact on high frequency variability of wind generation on both a national and regional scale, particularly the magnitude of ramping in generation on time scales of less than 4 h. The second section determines the meteorological causes of extreme regional ramping events using the Thames Estuary as a case study.

2. Datasets and analysis methods

One of the main challenges when investigating the variability of wind generation in the UK at high spatiotemporal resolutions is the limited availability of suitable data. Actual metered data from the individual wind farms is protected by commercial interests; therefore there is a reliance on nationally aggregated data. However, analysis using this data is unable to quantify the regional power swings or indicate how the variability has been affected by the change in wind farm distribution. Cradden et al. [24] used an hourly 11 year hindcast derived using the Weather Research and Forecasting model (WRF) at 3 km resolution to assess the variability of generation from 13 different regions in the UK.

This study introduces a new dataset which details the aggregated power output from four offshore clusters (Anglia, Cumbria, N.Wales and Thames) and five onshore regions; Argyll, Ayrshire, Central, Lothian and SSENW (see Fig. 1) at 30 min resolution from 1st January 2014 to 31st December 2014 (see Table 1 and Fig. 1). The total capacity across the 9 regions is 6.5 GW, which is approximately 70% of the total installed wind capacity of Great Britain.

A number of wind farms have been excluded from the analysis for two reasons (1) they the sole wind farm in a region therefore it was not possible to produce anonymous, aggregated generation data or (2) the data was not of sufficient quality. Despite the reduced number of wind farms, the dataset provides a good representation of the wind resource. For example, the GB-aggregated capacity factor for 2014 was calculated to be 31%, which compares well to the figure of 30.2% for the full wind farm distribution [25].

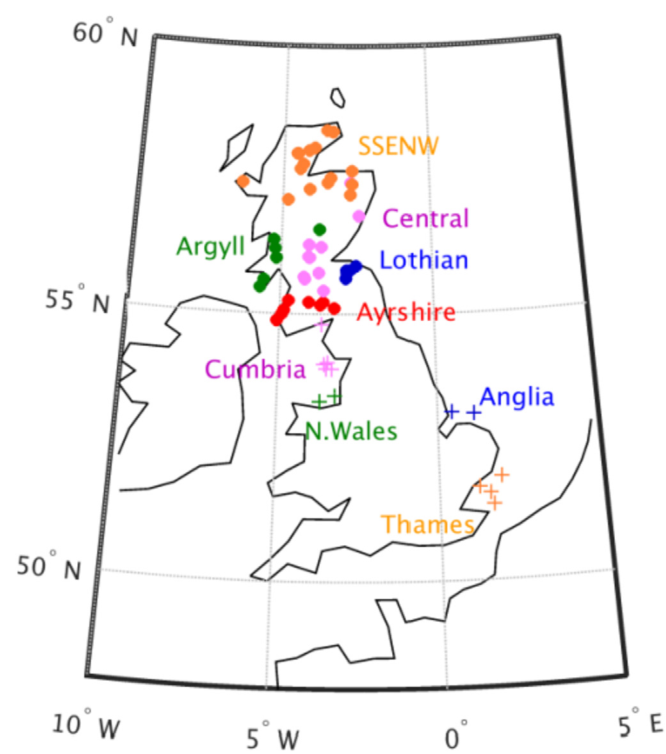

Fig. 1. Map of the wind farm distribution used in this study. The onshore and offshore farms are represented by the circles and crosses respectively.