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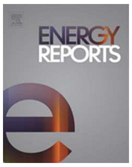

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An analysis of frequency events in Great Britain

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Abstract

With increasing penetration of wind and solar generation on electricity grids around the world, concerns are being raised about the effect this has on system stability. One measure of system stability is the volatility of the grid frequency. In this paper, an analysis is performed using one second resolution frequency data from Great Britain. We demonstrate that the number of frequency events has increased dramatically in the last couple of years, which coincides with the rapid increase in renewable penetration (wind and solar). We further demonstrate that the number of times the frequency is too high, corresponding to periods of more generation than demand, occurs roughly twice as often as when the frequency is too low. The different types of events (high and low) occur, on average, at different times in the day. The change in event severity and correlation between rate of change of frequency and settlement period boundaries is also presented. This study provides a useful insight into the state of stability of the electricity grid in Great Britain and when the system is at its most vulnerable.

Peer-review under responsibility of the scientific committee of the 4th Annual CDT Conference in Energy Storage and Its Applications, Professor Andrew Cruden, 2019.

Keywords: Grid stability; Frequency events; Frequency response; Renewable penetration

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1. Introduction

To help countries meet climate change targets [1,2], electricity grids around the world are decarbonising. In Great Britain (GB), a lot of progress has been made in this regard. There has been a transition away from large fossil-fuel thermal plant to renewable and decentralised generation. Currently, just short of a third of electricity generated in GB is now renewable, which is mostly due to increases in wind and solar generation over the last few years [3]. It is predicted that 25% of generation will be decentralised by 2022 and renewable generation output will hit 60% by 2025 [4].

The evolution of the grid is raising concerns about its stability. One measure of grid stability is the volatility of the AC frequency of the grid. If the grid frequency deviates too far from the nominal value, generators can trip offline to avoid damage (possibly exacerbating the situation), and demand can be disconnected. The disconnection of demand results in blackouts, which are costly and dangerous. The system operator ensures that the frequency

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stays near the nominal value through various measures, but the rise of wind and solar generation is making this job harder. Wind and solar hinder the balancing of generation and demand for three reasons: their inherent intermittency and unpredictability, their lack of inertia (inertia is a property of grids that dampens large frequency deviations), and their lack of frequency response capability. Decentralisation is also adding to this stability problem because embedded generation is largely invisible to the system operator, so generation forecasts are harder.

To provide a better understanding of the state of GB grid stability, an analysis of 5 years' worth (2014–2018) of one second resolution GB grid frequency data is performed in this paper. The data is available via the National Grid ESO (the system operator in GB) website [5]. The analysis focuses on frequency events, which are times when the frequency has deviated beyond acceptable limits.

This work builds on the analysis performed in [6] by including more recent time periods and considering the changes in frequency event severity. Historic frequency data was also used in [7–9] to investigate the efficacy of energy storage for frequency response delivery. As hinted to above, renewables reduce the level of inertia in power systems, and the impact of this has previously been studied in [10].

The remainder of the paper is structured as follows: Section 2 provides a background and some useful definitions that are used throughout the remainder of the paper, Section 3 shows the number of frequency events that have occurred in the 5 year period and when they have occurred, Section 4 analyses the change in severity of these events, Section 5 presents a link between frequency and settlement periods, and Section 6 concludes.

2. Background

The frequency of the electricity grid indicates the balance between generation and demand. If generation is greater than demand, the frequency of the grid rises and vice versa. The system operator of the grid has a responsibility to keep the frequency very near the nominal frequency, which is 50 Hz in Great Britain. The Grid Code [11] sets out two types of limits on the frequency. The operational limits are ±0.2 Hz: during normal grid operation, the system operator should aim to keep the frequency within these limits. The statutory limits are ±0.5 Hz: any frequency excursion outside these limits is deemed unacceptable and should be extremely infrequent and caused by unprecedented incidents.

Within this paper, a frequency event is defined as below:

- *High frequency event*: when the frequency goes above 50.2 Hz (upper operational limit) for any length of time.
- *Low frequency event*: when the frequency goes below 49.8 Hz (lower operational limit) for any length of time.

Fig. 1 shows an example of a low frequency event and the definitions of event start, event end, event duration, and event magnitude. The event duration is the time difference between the event start (when the frequency moves outside the ±0.2 Hz boundary) and the event end (when the frequency moves back within the ±0.2 Hz boundary). The event magnitude is the maximum absolute difference between 50 Hz and the frequency during an event. These definitions are used throughout this paper.

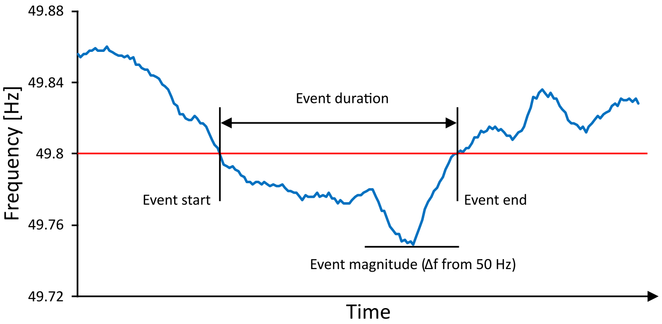

Fig. 1. Frequency event definitions (using the example of a low frequency event).

Frequency events are most often caused by unexpected changes in demand or generation. To mitigate against this, the system operator procures frequency response: generation or demand that can quickly alter their power output/demand to correct imbalances in the system. There are currently three main types of frequency response in Great Britain: primary, secondary, and high. Primary and secondary response are used when the frequency falls below 50 Hz, and high response is used when the frequency rises above 50 Hz. Primary and high response are provided within 10 s and last for 30 s. Secondary response is provided within 30 s and lasts for 30 min. The holding volumes for the three types of frequency response are roughly equal [12].

3. Number of frequency events

3.1. Each year

Fig. 2 shows the number of frequency events (total, high, and low) that occurred during each year from 2014 to 2018. The total number of frequency events for 2014, 2015, and 2016 are fairly similar: 708, 454, and 529 respectively. However, in 2017, this increases to 1268, and then in 2018 it increases again to 1990. This rough doubling of total number of frequency events from 2017 onwards is due to an increase in both high and low events. A likely reason for the rapid increase in frequency events since 2017 is the rise in renewable penetration on the GB grid (in the same timeframe) because this has been facilitated by a rise in wind and solar, which are intermittent and offer no inertia. Overall, there were 4949 frequency events in the 5 year period, but there was never a time between 2014 and 2018 when the frequency deviated past the statutory limits (±0.5 Hz).

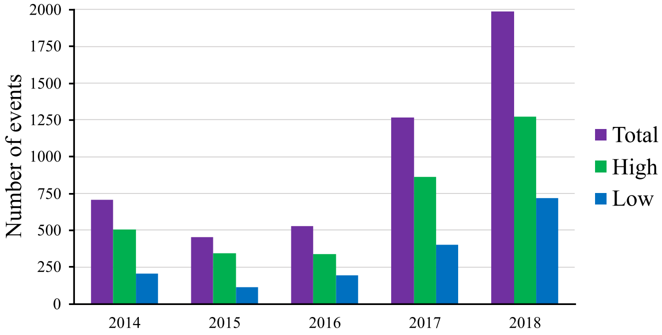

Fig. 2. Number of frequency events each year.

Notably, as can be seen in Fig. 2, in every year there are more high events than low events. The number of high events is between 63% and 76% of the total number of events for each year. In other words, the number of high events is consistently about double the number of low events. This suggests that it is more common to have periods when generation has unexpectedly risen higher than demand than the other way around. There are more individual demand units than generating units on the grid at any one time. Obviously for overall power balance, the average demand unit demands fewer MWs than an average generation unit supplies. If we assume that there is an equal probability of an individual unit, demand or generation, tripping/failing then it follows that there will be more demand unit trips/failures throughout the year. This may go some way to explaining the greater occurrence of high events. There may also be more frequency response available when the frequency falls compared to when it rises because primary, secondary, and high are held in equal volumes, and two of them act for falling frequency.

3.2. Hourly and monthly occurrences of frequency events

Fig. 3 shows the average number of high and low frequency events each month and hour over the 5 year period. The total number of high events over the 5 year period is almost exactly double the total number of low events, which is why the scales on the two heatmaps differ. The following can be observed:

- more events are seen in the late autumn, winter, and early spring (excluding December) with fewer events in the summer;
- high events occur most often in the evenings all year round;
- low events occur most often in the mornings (all year round) and the autumn/winter evenings;

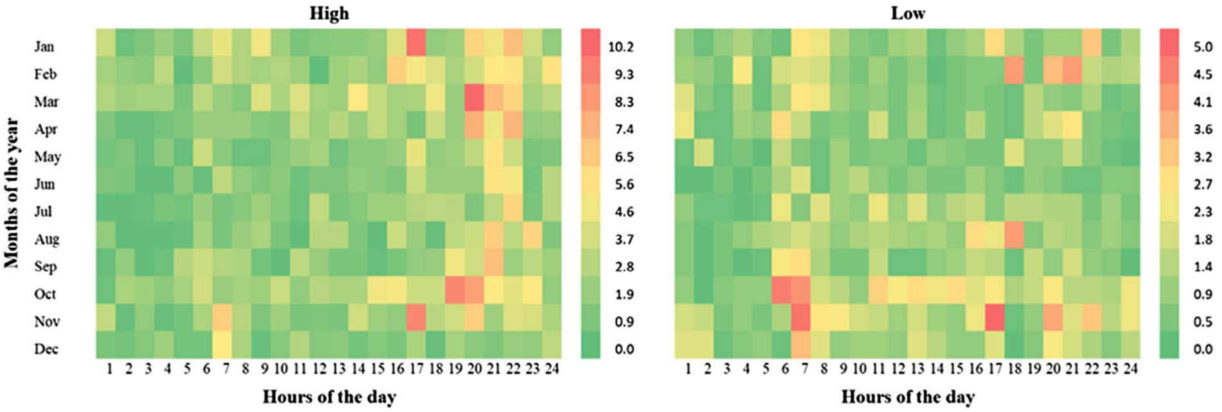

Fig. 3. Average number of frequency events each month and hour over the 5 year period.

- in October and November, low events occur throughout the day.

The rate of change of demand peaks in the mornings and evenings, so the temporal nature of the frequency events suggests a possible correlation between the number of events and the rate of change of demand. A grid with a fast changing demand is harder to balance than one where demand is constant.

4. Severity of frequency events

Two measures of the severity of a frequency event are the duration and magnitude of the event, defined earlier in Section 2. Here, the difference in severity between high and low events and change in severity over the 5 years is analysed. Table 1 provides a summary, and the following can be observed:

- high events generally have a longer duration than low events;
- the duration of high and low events does not significantly change from 2014 to 2018;
- high and low events have a similar magnitude;
- the magnitude of high and low events does not significantly change from 2014 to 2018.

Table 1. The median values of frequency event duration and magnitude for high and low events for each year and all years.

	2014	2015	2016	2017	2018	All
Duration						
High	8	8	10	10	9.5	9
Low	7	5	6	5	5	5
Magnitude						
High	0.206	0.206	0.208	0.207	0.208	0.208
Low	0.212	0.209	0.209	0.208	0.207	0.208

4.1. Duration of events

Fig. 4 shows the distribution of the duration of high and low events over the 5 year period, up to an event duration of 30 s (1 s resolution). The number of high events at each event duration decreases as event duration increases. High events with a 1 s duration form the highest proportion of high events (14%), after which the proportions rapidly decrease. Beyond an event duration of 10 s, the low event duration distribution is similar to the high event one, with there being fewer and fewer events at longer durations. However, the low event duration distribution has a peak at 4 s (15%), not 1 s.

Fig. 5 shows the proportion of events at different duration ranges over the 5 year period. The proportion of low events with a duration ≤10 s is 74%, and for high events it is 55%. Also, 10% of low events last longer than 30 s

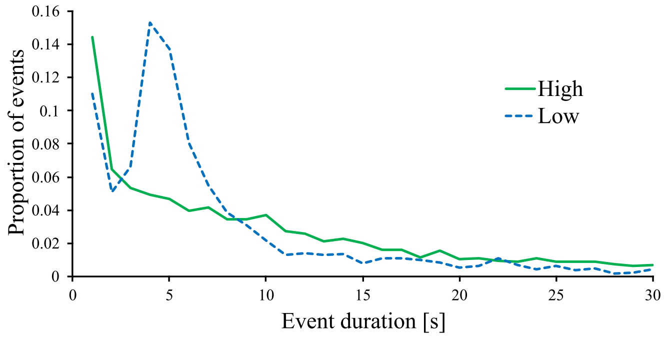

Fig. 4. Distribution of the duration of events (1 s resolution) over the 5 year period.

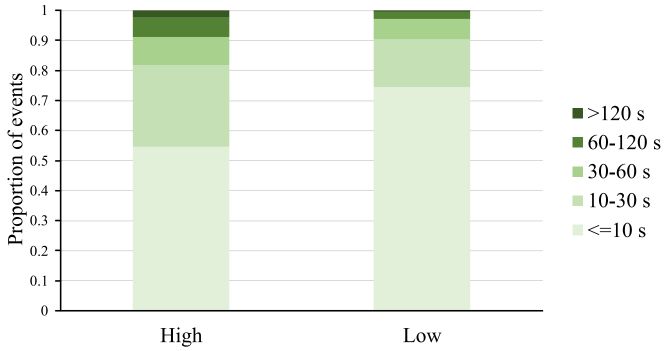

Fig. 5. Proportion of events at different event duration ranges over the 5 year period.

compared to 18% for high events. This explains why the median event duration is longer for high events than low events.

As already mentioned, the median duration of high and low events does not significantly change from 2014 to 2018, and the event duration distributions are similar for each year. The most notably change is that the proportion of low events with a duration ≤10 s increased from 65% in 2014 to 77% in 2018. This accounts for the very slight drop in the median duration for low events seen in Table 1.

4.2. Magnitude of events

Fig. 6 shows the proportion of high and low events at different magnitude ranges over the 5 year period. The proportions are quite similar for the two types of events: 61% of high and low events have a magnitude ≤0.21 Hz and 18% of high events and 19% of low events have a magnitude between 0.21 and 0.22 Hz. Only 8% of low events and 4% of high events have a magnitude >0.25 Hz. The greatest deviations from 50 Hz during the 5 year period are −0.444 Hz and +0.410 Hz.

As already mentioned, the median magnitude of high and low events does not significantly change from 2014 to 2018. The most notably change is that the proportion of low events with a magnitude ≤0.21 Hz increased from 46% in 2014 to 66% in 2018. This explains the very slight drop in the median magnitude for low events seen in Table 1.

5. Frequency and settlement periods

The Balancing Mechanism is a tool that the system operator uses to balance electricity supply and demand close to real time. Each day is split into 48 half-hour settlement periods. The system operator forecasts demand in each of these settlement periods a long way in advance and the aim is for generation to match this through planning and trading via the electricity wholesale market. Gate closure occurs one hour before the settlement period starts,

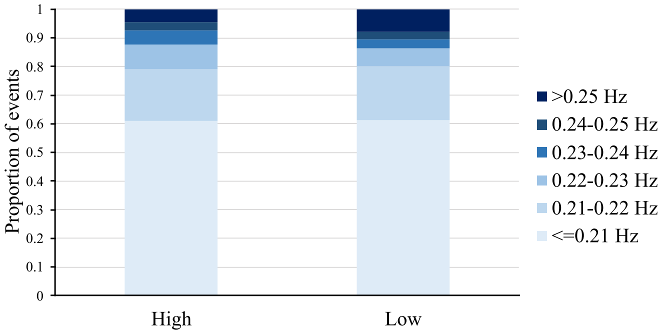

Fig. 6. Proportion of events at different event magnitude ranges over the 5 year period.

and at this point trading stops and generators and suppliers must submit information about their positions (power output, ramp rates, etc.) for the settlement period in question. In the hour before the settlement period starts and during the settlement period, the system operator sends instructions to Balancing Mechanism participants to either increase or decrease generation or demand to keep the system balanced in real time.

Fig. 7 shows the rate of change of frequency (RoCoF) of the average minute-by-minute frequency profile in 2018. Between the hours of 00:00 and 07:00, there are large negative spikes in the RoCoF on the half-hour marks, with the largest spike being at 00:30, reaching −0.07 Hz/min. At 07:00, the largest positive spike in RoCoF of the day occurs and reaches 0.02 Hz/min. Between 07:00 and 18:30, there are positive and negative spikes but mostly of a reduced magnitude. The spikes in this period generally lie on or near the half-hour marks. From 18:30 to 00:00, the large negative spikes occurring exactly at the half-hour marks return. Fig. 7 tells us that there are imbalances in generation and demand at the start of a lot of settlement periods. The negative RoCoF spikes indicate that demand is greater than generation and the reverse is true for the positive spikes. The time periods with the largest negative spikes do not correspond with time periods when low frequency events most often occur. This suggests that the settlement period boundaries might not actually be causing frequency events. The Balancing Mechanism is successfully keeping the system balanced during each settlement period because the RoCoF quickly returns to near 0 Hz/min after spiking.

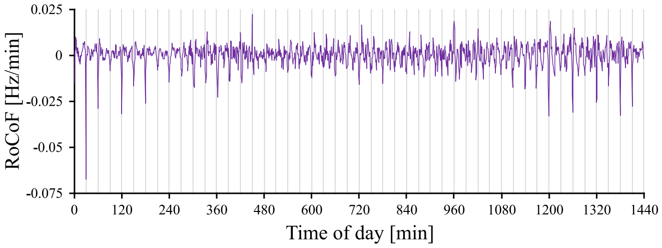

Fig. 7. RoCoF of the average frequency profile in 2018.

6. Conclusions and future work

An analysis was performed on 5 years' worth (2014–2018) of one second resolution GB grid frequency data to investigate the state of grid stability in Great Britain. This study reveals that GB frequency volatility is increasing and illustrates the temporal nature of the volatility. The following is a brief summary of the main, take-away, findings of this analysis:

- the number of high and low frequency events roughly doubled in 2017 and again in 2018;
- the number of high events is consistently about twice the number of low events;

- more events are seen in the late autumn, winter, and early spring (excluding December) with fewer events in the summer;
- high events occur most often in the evenings whereas low events occur most often in the mornings (although this is not true all year round);
- the severity of the frequency events has not significantly changed in the last 5 years;
- RoCoF spikes coincide with settlement period boundaries.

Within this paper, reasons have been suggested for why high events occur more often than low events, for the temporal nature of the events, and for why the number of events has increased in the last two years. Further investigation is required to fully understand the correlation between frequency events and other grid factors: rate of change of demand, frequency response, and penetration of wind and solar. This would provide useful insight into the primary causes of grid instability and highlight the difficulties in the ambition to further increase wind and solar penetration in Great Britain.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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