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THE PROBABILITY OF LONG PHASES OF VERY HIGH AND LOW WIND POWER FEED-IN AND RESIDUAL LOAD

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Overview

Long phases of very low or high wind power are a potential thread to future energy systems with a high share of renewable energies. A frequent occurrence of these and similar situations would imply an increased need for energy storage or controllable power capacities in order to cover energy demand at any time in future energy systems or – in the case of very high feed-in – a very high grid load. Furthermore, current energy system research analyses the future effect of high renewable feed-in using historical weather or renewable energy feed-in time series data (Jónsson et al. 2010, Benitez et al. 2008, DeCarolis and Keith 2006). However, an understanding of the representativeness of these time series with respect to long phases of low or high wind speeds is still limited apart from average wind speeds and associated power feed-in. In particular the frequency and duration of extreme events such as very long periods of low or high wind speeds and low renewable feed-in have not been analysed in detail yet. But the latter are important to understand and evaluate the outcomes of complex energy system models. At present, complex energy system models optimise whole energy systems but the details of how to arrive from a particular weather time series at a full energy system is involved and almost impossible to trace. Wind speeds and extreme weather events have been studied by statistical methods including extreme value theory (Cook 1982, Palutikof et al. 1999, Simiu and Heckert 1996). It has been argued that climate change alters future wind speeds and patterns but current research on this topic is not conclusive yet (Nolan et al. 2012). However, the focus of these studies is either on the statistical distribution of wind speeds (Conradson et al. 1984) or the probability of very high wind speed peaks. The occurrence and duration of phases of low wind and their consequences for energy system models has – to our knowledge – not been analysed yet.

Methods

We use wind power feed-in data for seven years from Germany from 2006–2012 as time series with an hourly resolution. Residual load time series data have been obtained by combining the wind power feed-in data with solar power and load data. We understand residual load as the net power consumption minus the onshore wind and photovoltaics (PV) power feed-in. Load data for Germany is available from Entso-E for the whole period of 2006–2012.

Extreme value theory provides statistical tools to quantify the behaviour of a process at extremely large values (Coles 2001). Two methods are used in extreme value analysis to estimate the asymptotic distribution of an extreme for a given problem: the block maxima method and peak-over-threshold method. Since we are interested in long periods of little wind power feed-in or residual load which can extend over one week or longer, the peak-over-threshold is more suitable. In the application, a threshold u dividing extreme and normal values has to be defined. We use the 80% quantile that is the largest 20% of the data are treated as extreme. We checked the robustness of our results against the choice of threshold. The parameters of the asymptotic distribution function, the generalised Pareto distribution, have been found by maximum likelihood estimates (Coles 2001). Plots of the probability of extreme events are difficult to read since the events of interest have extremely low probability. We thus display the magnitude of the extreme event as a function of (the logarithm of) the return period. Such a return level plot is easy to read and the predicted magnitude of extreme events is easily integrated.

Results

We obtain the return level plots for long phases of low (see Figure 1) and high wind power feed-in. The longest observed calm period in the data was seven days long and has a return period of seven years. Furthermore, longer calms of wind power feed-in of more than one week duration occur quite frequently and periods of more than ten days every 25 years are consistent with the data (i.e. within the 95% confidence band). Additionally, a one-hundred-year calm in wind power feed-in could last for almost two weeks.

We find the average duration of low wind power feed-in phase to grow linearly with the threshold: Phases with a wind power feed-in of less than two percent of installed power are typically four hours long and phases with less than five percent feed-in are on average seven hours long. However, a period of wind power feed-in below eight percent of installed power that lasts one week occurs every two years and a period of more than ten days occurs every ten years.

We now turn to long phases of low residual power. During the observation period the PV and wind power capacity increased and the individual years are not directly comparable with the respect to the residual load. Yet in a future energy system residual load will spread even more and it is interesting to understand the present day situation before analysing a potential future energy system. The seven years of residual load data 2006–2012 in Germany have been searched numerically for phases with residual load below 35, 40, 49, and 60 GW as threshold values roughly correspond to the 3, 8, 32, and 64%-quantiles of observed residual load.

The return level plot demonstrates that during the seven years of observation the longest phase with residual load smaller than 35 GW was about a whole day long and that up to three days are consistent with the data. For a threshold of 49 GW, several days with residual load below that threshold have been observed.

Using the base scenario of the German federal government for 2030 and 2050, we analysed potential future time series of residual load. As expected, we find phases of negative load not only to occur more frequently in the future, but also with noteworthy long durations.

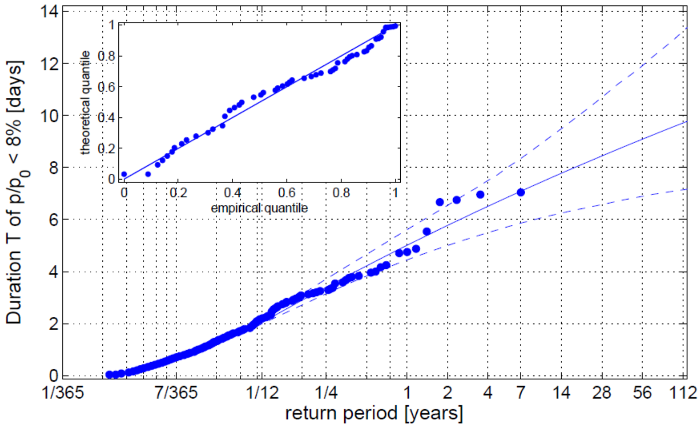

Figure 1: Return period plot for long periods of below 8% wind power feed-in (circles) and regression of extreme values (solid blue line) and 95% confidence band (dashed lines).

We analysed the seven years of observation individually for phases of low wind power feed-in and compared them to the seven-year average. We measure the similarity of an individual year to the complete data set 2006–2012 by a chi2-measure and compare the mean duration of phases with wind power feed-in below a bound to the long time average of that duration. We find that the years 2007 and 2012 show the highest similarity to the long year behaviour for the duration of phases with low wind power feed-in. The years 2008 and 2011 show the lowest similarity to the long-term average.

Conclusions

We analysed phases of low wind power feed-in and low residual load in Germany 2006–2012. Our results show that a period of wind power feed-in below eight percent of installed power that lasts one week occurs every two years and a period of more than ten days occurs every ten years. Furthermore, we find the average duration of low wind power feed-in phase to grow linearly with the threshold. In a future energy system, periods of negative residual load and a growing spread between minimal and maximal residual load can be expected. Today's energy system models optimise the whole system (under given constraints) without detailed analysis of intermediate steps. For future energy systems, the duration and frequency of phases with low or high wind power feed-in and resulting extreme residual load are a major factor determining the economics of energy storages (Benitez 2008, DeCarolis and Keith 2006). In this context, our results show that long phases of low wind power occur more frequently than commonly expected and that individual years differ in the duration of wind power feed-in phases.

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