Variability of residual load time series and its implications for energy storage demand in Germany

Abstract

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Energy storage is expected to play an important role in balancing fluctuations of renewable electricity generation in the future. The identification of storage demand is the focus of various models developed to support power system planning. However, model results are highly dependent on the time series that are used to characterise generation and demand and often cannot be explained by merely consulting mean value or standard deviation of the respective time series. Apparently, the distribution of residual demand and surplus energy over time also has a significant impact on storage demand. To enable a more detailed characterisation of residual load time series, we present a method to measure short-, mid- and long-term variability.

The annual time series of residual load is decomposed into its high-, mid- and low-frequency components. By integrating each signal the theoretical storage capacities required to balance all fluctuations of the residual load are determined. As these capacities are dependent both on the amount of energy and its temporal distribution, they are scaled to the corresponding maximum storage capacities that would be necessary, if both residual demand and surplus energy occurred over a contiguous period of time. Thus, normalised variability indices are obtained that exclusively characterise the distribution of energy over time within the three frequency ranges.

The introduction of variability indices allows for a more detailed analysis of the drivers of energy storage demand. Based on weather data for the period 2000-2012 residual load time series are synthesised for a high renewable penetration scenario in Germany. Storage capacities are determined both theoretically for each frequency range and by using a cost minimisation model of the German power system. Results show that for time series with similar amounts of residual demand and surplus energy the long-term variability index is a strong indicator for long-duration storage demand.

Variability of Residual Load Time Series and its Implications for Energy Storage Demand in Germany

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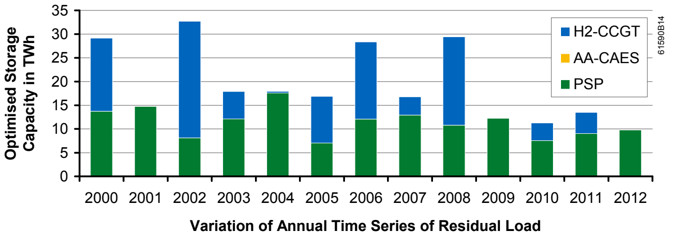
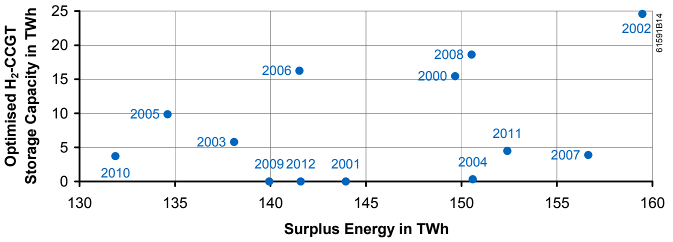
Motivation

- storage demand is determined with a cost-minimisation model of the German power system (Kuhn 2012)
- 100 % RES scenario, assuming economic integration of RES and gas-fired backup capacity
- time series (temp., wind, solar) are taken from Janker (2014)
- load is modeled based on temp. time series (Heilek 2006)

➔ especially H_2-CCGT capacity is highly dependent on time series



➔ varying results for long-duration storage demand are not sufficiently explained by annual surplus energy

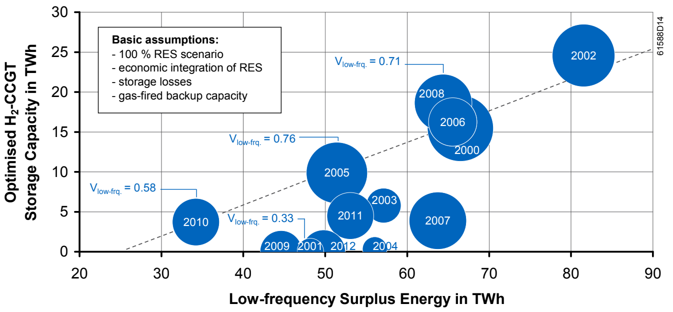


Thesis: the temporal distribution of residual demand and surplus energy has a significant impact on storage demand

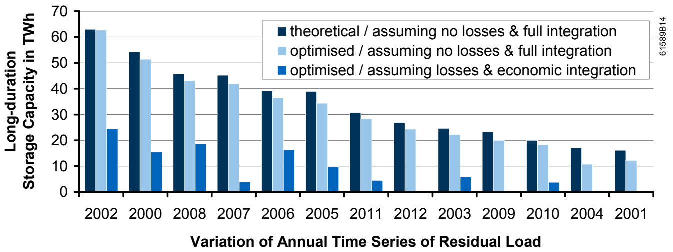
Aim: developing a **method to measure variability *** of residual load time series

Results

➔ analysis of long-duration variability improves the understanding of the impact of residual load time series on storage demand

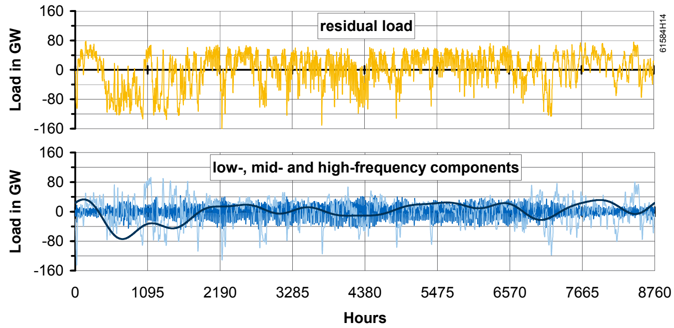


➔ theoretical long-duration storage capacity is an even better indicator under scenarios with full integration of RES



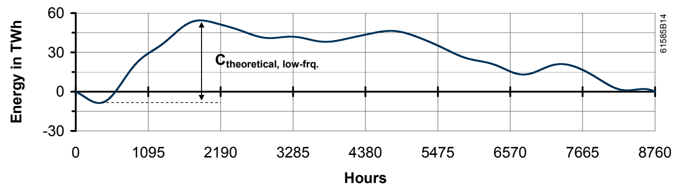
* Methodology

- the residual load time series is decomposed into its high-, mid- and low-frequency components (and its constant component)
- high-frequency range: 0 h < T ≤ 24 h
  mid-frequency range: 24 h < T ≤ 30 d
  low-frequency range: 30 d < T ≤ 365 d

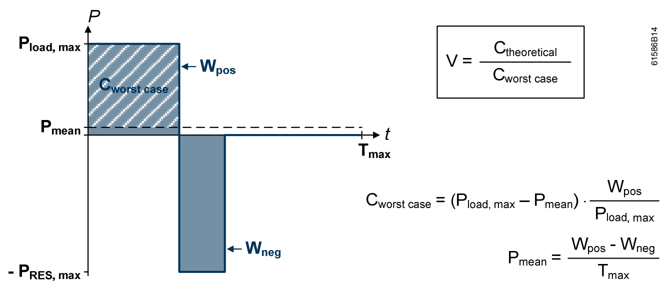


- by integrating each load component, the theoretical storage capacities required to balance all fluctuations are determined (assuming no storage losses)

➔ theoretical storage capacities are dependent both on the amount of energy and its temporal distribution



- by scaling the theoretical storage capacity to the corresponding worst case storage capacity, the **variability index V** is obtained
- the worst case capacity is the highest capacity detected in an interval of length T_{max}, assuming that both residual demand and surplus energy occur over a contiguous period of time

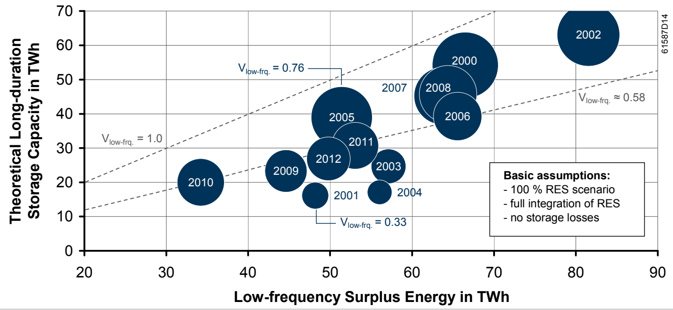


$$V = \frac{C_{theoretical}}{C_{worst\ case}}$$

$$C_{worst\ case} = (P_{load,\ max} - P_{mean}) \cdot \frac{W_{pos}}{P_{load,\ max}}$$

$$P_{mean} = \frac{W_{pos} - W_{neg}}{T_{max}}$$

➔ the normalised variability indices characterise the distribution of energy over time within each frequency range



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