Geophysical Research Abstracts
Vol. 20, EGU2018-16883, 2018
EGU General Assembly 2018

Extreme net load events in fully renewable power systems: A 30 year case study for Sweden

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Long term time series of variable renewable energy (VRE) generation and electricity demand (load) provide valuable insights on the feasibility of fully renewable power systems. However, the coverage of electricity statistics is usually too short or temporal resolution too low to study interannual correlations of VRE generation and load or the impact of meteorological extreme events. We assess the frequency, duration, and magnitude of extreme net load events in two scenarios with a share of VRE generation of about 50%. One scenario with wind power only and a second with both wind and PV generation. Therefore, we use a statistical model that uses MERRA reanalysis temperature data to derive long term time series of hourly load. The temperature dependent load is then coupled with simulated time series of VRE generation in an optimization model to account for the flexibility of hydro power to balance fluctuating VRE generation. The model minimizes the total net load by adjusting hydro power generation taking into account the simulated runoff of Swedish rivers as well as installed hydro power generation capacities, ramping capabilities and hydro reservoir capacities. The resulting hourly time series of net load (= load – VRE - hydro) is used to quantify the occurrence of extreme net load events. The analysis of seasonal correlations confirms that wind power and load are positively correlated, while solar power and load are highly negatively correlated with solar generation peaks during summer when load is lowest and vice versa. The comparison of interannual fluctuations reveals a negative correlation between the annual wind generation and electricity demand, which further increases the pressure on the balancing capabilities of hydro power. The analysis of extreme net load events shows a significant increase of net load events in both scenarios. The majority of events lasts shorter than one day and could be theoretically compensated by current thermal backup capacities or power imports. However, on average every fourth year occurs an event that lasts longer than a week with a power deficit of more than 50% of peak demand. Increasing the share of solar power results in even more extreme net load events as most events occur during the winter month when solar generation is close to zero and thus not able to counterbalance low wind events.