Layout of island power supply based on multi-decadal meteorological sets – reliability discussed in view of inter-annual variability using the case of the Faroe Islands power system

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Abstract

The layout of renewable power supply systems – the sizing of its generation capacity (here: wind and solar) and its storage capacity - are complicated by the interannual variability of the meteorological conditions. To deal with this problem the use of multiannual sets is mandatory. Here both the sensitivity of the layout parameters on the length of the datasets negotiated, and the reliability of the sizing based on set sections compared to the sizing by a complete set. For this purpose, a 56-year set of daily data of wind speed and solar radiation for the location of the Faroe Islands (North Atlantic) is applied to study the sensitivity of the storage sizing to variations of the number of years considered.

Keywords: island systems, sizing, meteorological data

1 Introduction

To reach the aim of a secure, non-fossil coverage of the load in island grids leads – due to the volatility the wind and solar resource on all temporal scales – to the need for the inclusion of storage capacity and/or a remarkable oversizing of the renewable generation park. The identification of reasonable combinations of storage capacity and oversizing is usually done by use of time step simulations based on at minimum annual data sets of the meteorological conditions. The selection of the these sets – especially their length has been recognized as a critical issue (see e.g. Heide et al 2010, Bryce et. 2018, Pfenninger and Staffell 2016). Here, this issue will be discussed with focus on the sensitivity of the layout identified to the length of subsets selected from a set covering 56 years of wind and solar data. The example will be performed using a simple model that neglects any storage losses and assumes perfect availability of the generation for a full renewable power supply for the Faroe Islands (a group of small Islands in the Northern Atlantic at ~62°N, ~7.5°W). Results are intended to cast a light on the requirements on the quality of predictions of future meteorological conditions to reflect details of the statistics of the data sets.

2 A case study: analysing fully renewable electricity supply for the Faroe Islands using a 56-year data set

A fully renewable power supply for the Faroe Islands is due to its exceptional wind conditions (> 3000 full load hours for wind turbines) expected to by mainly based on wind farms. Starting from this, scenarios (Anonymous 2017, Trondheim et al. 2018, Beyer and Custodio 2018, Katsaprakakis 2019) had been analysed to identify the best mix for a wind/hydro/solar generation mix in combination with a pumped hydro storage scheme with a capacity of about week of average load. All these schemes had been based single year data sets. To widen the perspective and test the reliability of system sizing based on short temporal bases, following Pfenninger and Staffell 2016, Bryce et al. 2018, data sets covering decades are called into service here.

A respective analysis and is tried for a period covering 56 years. For this period system performance is simulated with a daily resolution. The example used concerns the identification of combinations of generation mixes and storage sizes for a fully renewable electricity supply. The results refer to “frozen-in” data of the actual load and hydro-generation of 2017, and wind and solar generation data simulated according to the variability of the meteorological data. The storage is modelled as an ideal one without losses.

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2.1 Data Base on wind and solar generation

The data base used here applies windspeed data for the years 1958-2013, taken from a hindcast set as described by Reistad et. al. 2011. From this data, given for the synoptic hours, Windfarm power output is simulated using a model derived in Trondheim 2020 form data of a windfarm on the Faroe Islands. Data are aggregated to model daily generation as function of daily mean wind speed.

Long term time of daily irradiance sums for that period are deduced from 1958-1013 station cloud cover data used as proxy. Time parallel satellite derived irradiance data for the years 2005-2013 from the JRC/SARAH data base (Müller et al. 2015) are used to correlate the daily mean cloud cover to the daily irradiance sum for the synoptic hours to set up a respective model. Fig. 5 shows as example 4 years of satellite derived and cloud cover based modelled daily irradiance sums to give an impression of the cloud-cover-based set.

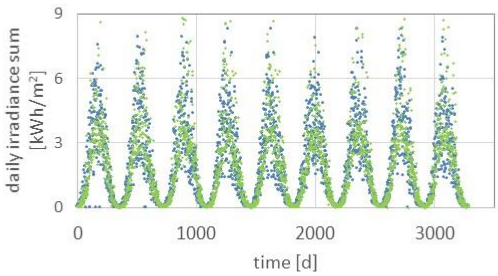

Fig. 1: Series of hourly radiation sums as given by satellite data (blue) and by model based on cloud cover data tuned to the satellite derived data.

For modelling daily PV-generation from daily irradiance sums a correlation scheme derived from the analysis of daily sums stemming from the hourly simulations of the power output of inclined PV modules (see Beyer and Custodia 2018) is used. A first application of the respective scheme was done in Beyer 2019.

2.2 Method for the identification of suitable combinations of generation and storage

The scheme starts with a setting of the generation capacities (minimal sizing of the generation capacity equal the long-term load). For the determination of the storage size required for complete load coverage given a certain generation capacity a method derived from a scheme given by [Haas 94] is used. The storage size required for save supply is estimated by analysing the series of the accumulated balance of generation and load over the (multi) annual period inspected. The storage requirements can be assessed by the analysis of the relative maxima and minima of the balance series.

3 Examples for system sizing

As start a system with wind capacity sized to be capable to equal the long-term average of the remaining load (load – hydro generation) is analysed. This results in a storage capacity equal to about 220 days of load. Double the wind capacity results in a system with required storage size reduced to about 13 days.

Figure 1 gives the 56-years sequence of the storage content for this case. It is remarkable, that the storage is challenged by singular “events”. As shown by Beyer and Custodio 2018, for the conditions at the Faroe Islands a further reduction of the required storage capacity is more easily achieved by adding generation by photovoltaics then by a further increase of the wind capacity. For the current case, an example shows that addition of PV generator giving a long-term generation of 17% of the long-term consumption brings the required storage size down to about 5 days (fig. 2). A remarkable change of the location of the challenging situations is visible

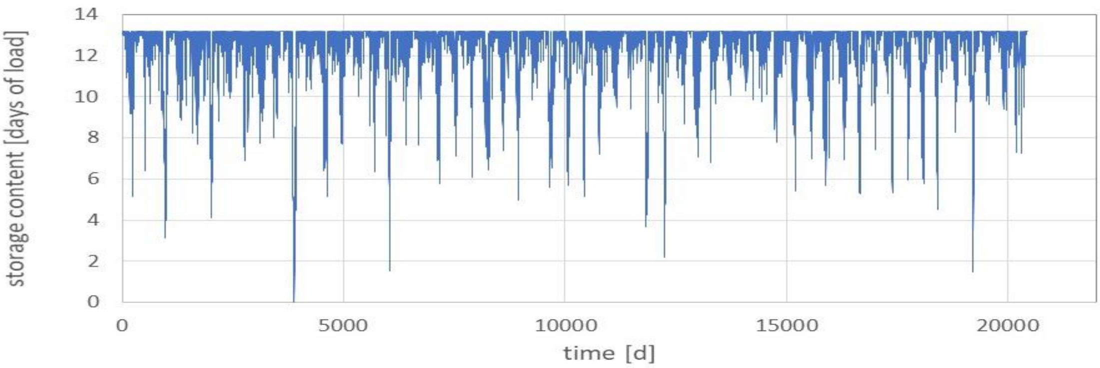

Fig. 2: 56-year time series of the storage content for a system with a wind capacity to equal the annual remaining load (load – hydro generation). Storage capacity set to assure save supply.

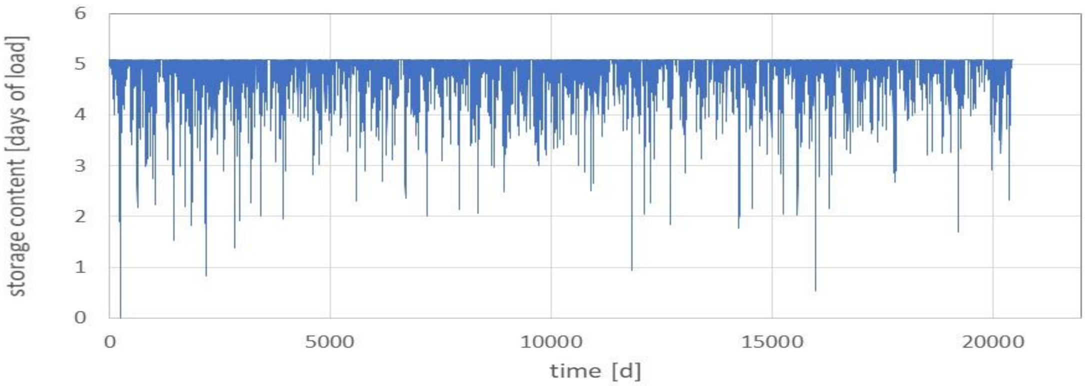

Fig. 3: Same presentation as fig. 3, but for a system with added PV capacity able for a generation of 17% of load consumption.

4 System sizing and time pattern of generation and load

These patterns shown in fig. 2 and fig. 3 give rise to the question whether the storage defining situations can be linked to properties of the balance series to allow for a more direct identification of critical years or time sections.

For this, the long-term evolution of the balance of wind power to remaining load (load - hydro generation) may be presented by its multiply days sliding average for better marking conditions challenging the storage. Fig. 3 and fig. 4 show this for the 365 days average of the balance for the two configurations inspected.

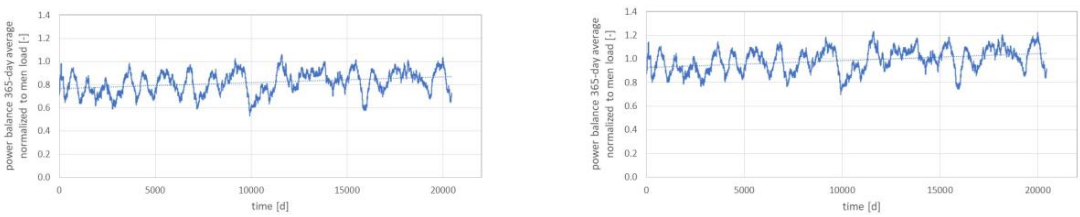

Fig. 4: 55 years time series of the balance (generation -load) presented as sliding 365 days averages. Series refer to the sytems presented in Fig. 2 (left) and 3 (right).

It has to be stated, that there is no obvious link of these average balance series with the storage evolution. This indicates that annually averaged balances do not contain the information needed to analyse a system with the sizing under inspection (oversized generation, storage of about weeks of load).

Thus, averaging over shorter periods (month, weeks) is tested. Results are given in figs, 5 a-c and 6 a-c using the scatter plot of the daily storage content versus the sliding average representing the period before that date.

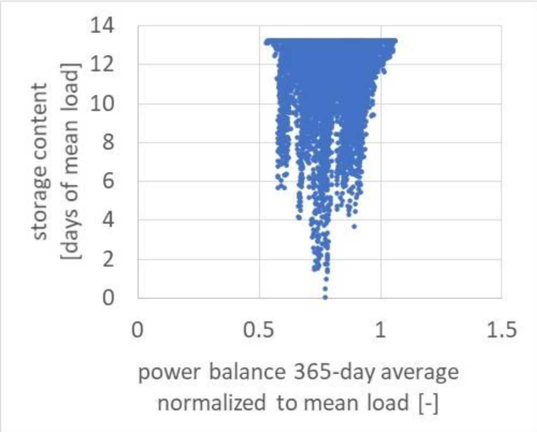

Fig. 5a: Scatter plot of storage content versus 365-day average of the normalized power balance for system presented in Fig, 1.

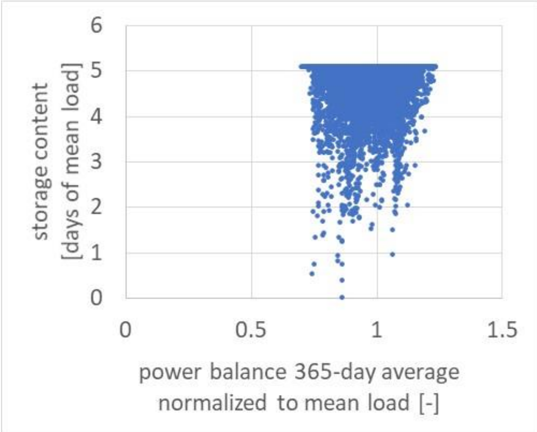

Fig. 6a: Same as 5a, but for system presented in Fig, 2.

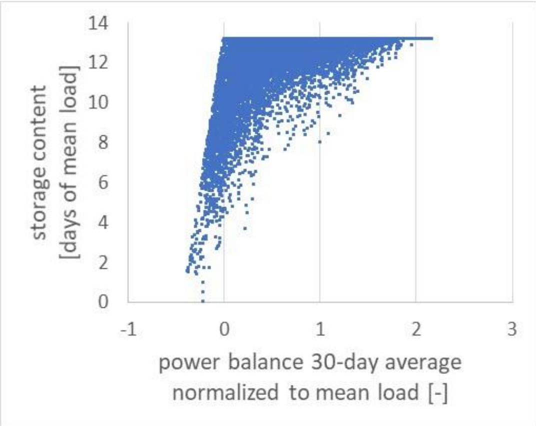

Fig. 5b: Same as 5a but for the 30-day average of the normalized power balance.

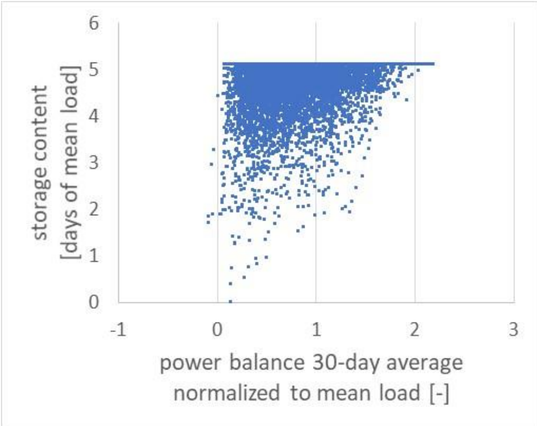

Fig. 6b: Same as 6a, but for the 30-day average of the normalized power balance.

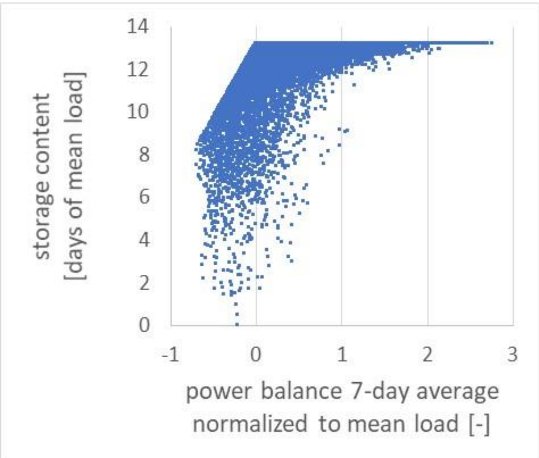

Fig. 5c: Same as 5a but for the 7-day average of the normalized power balance.

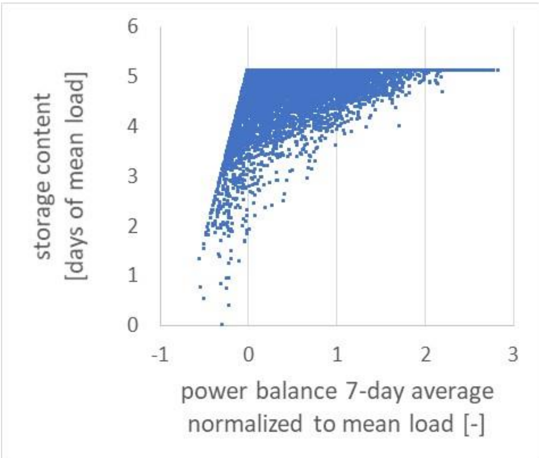

Fig. 6c: Same as 6a, but for the 7-day average of the normalized power balance

It can be remarked that for both configurations inspected, as expected from the time series plots, the lowest (here zero) storage contends appear at unexceptional values of the 365-day averaged balance. For the monthly and weekly balances, the ordinate positions of the points representing depleted storage refer to lower averages of the balance. Thus, averaging the balance over appropriate time sequences can give an indication on when to expect the occurrence of critical storage conditions. For an exact identification of the critical case, a more complex time series analysis or the detailed time series simulation appears unavoidable.

With the system sizing governed by the occurrence of singular event sets the request to data bases used to cover that specific period. Obviously, using but sections will always leave uncertainties of the level of security of supply that can be promised.
As example, the storage histories given in fig. 2 and fig. 3 are used to extract the storage requirement identified when only analysing sections of the set with limited length. Fig. 7 a-c and Fig. 8 a-c 10 show the results when sections of 10-, 5-, and 2-years length are analysed. The values give the storage sizes stemming from the period ending with the ordinate position given.

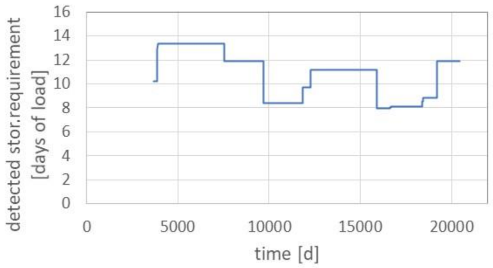

Fig.7a: Storage requirement stemming from the analysis of 10-year sequences of data referring to system shown in Fig.2. The values refer to the period ending with the ordinate position given.

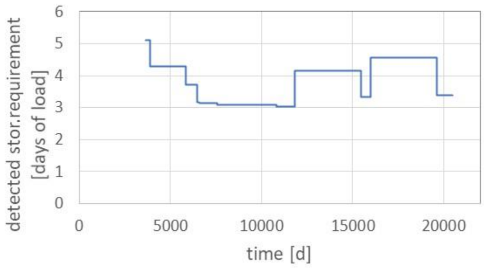

Fig. 8a: Same as Fig. 7a, but data referring to system shown in Fig.3-

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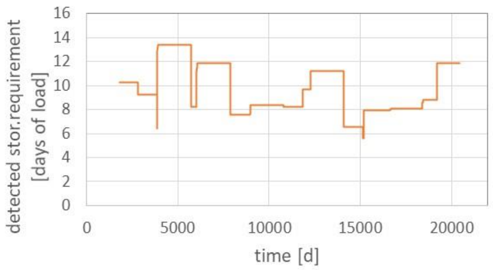

Fig. 7b: Same as Fig. 7a, but for 5-year sequences.

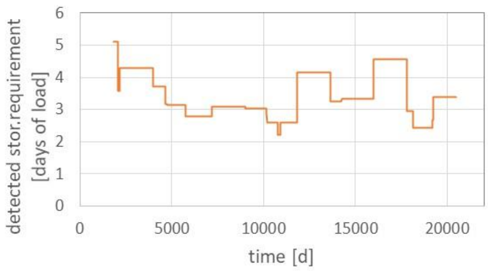

Fig. 8b: Same as Fig. 8a, but for 5-year sequences.

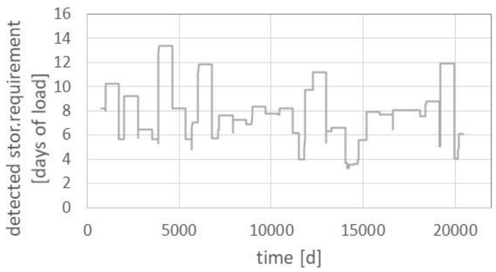

Fig. 7c: Same as Fig. 7a, but for 2-year sequences.

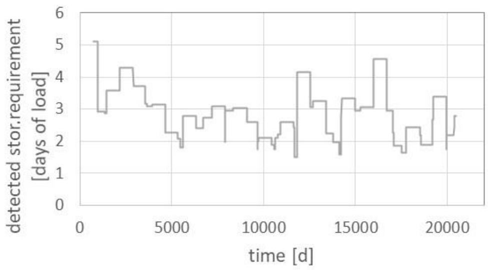

Fig. 8c: Same as Fig. 8a, but for 2-year sequences.

From this information one can derive - in retrospect - e.g. with which probability a randomly selected sequence may return a required storage size which is at minimum 80% of the requirement for the whole period. Table 1 gives respective probabilities for the 2, 5, and 10 years sequences for the two systems analysed.

Table 1: Probability that the use of a randomly selected sequence of 10, 5, and 2 years length would return a required storage size of 80% or more of the requirement stemming from the analysis of the complete set.

Length of sequence/ System	10	5	2
1	0.64	0.36	0.15
2	0.56	0.31	0.12

Thus - given that the variability of the meteorological time series is stable – a layout based on 10-years sequences may lead to remarkably undersized systems when the 100% reliability is the set as goal.

5 Consequences from undersized storage

To analyse the consequences of operating the systems with undersized storage capacity in more details, beyond the fact that there is no full load coverage, the time series of the storage evolution for the systems with the "perfect storage" for 100% coverage shown in figures 2 and 3 can be exploited. Figs. 9 and Fig. 10 give the numbers of days with uncovered load when decreasing the storage size.

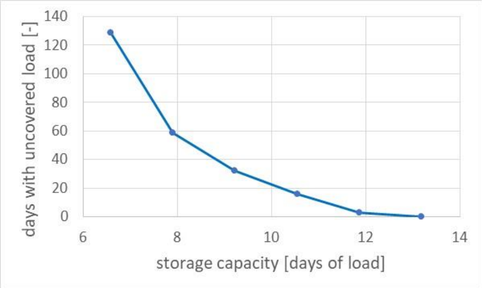

Fig. 9: Number of days with uncovered load in the 56-years sequence for a system as presented in Fig. 2 when reducing the storage size.

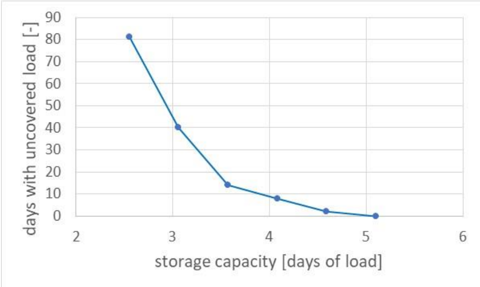

Fig. 10: Same as Fig. 9 but referring to the system presented in Fig. 3.

As indicated by the finding that the storage requirements detected here are determined by singular events, the use of a storage undersized by up to about 20 – 30% of the "complete set"-sizing lead to quite small numbers (with respect to the 56 years base well below 1 day per year)-

Combining this with the information on the probability that the use of short sequences for determining the storage size may result in an under-sizing (see e.g. figs. 7b and 8b) , gives some hope that sequences of about 5 years may be used as manageable basis for the layout. However, measures for handling (rare) events of critical storage states must be prepared.

6 Conclusion

It could be confirmed that the layout of island power supply systems that aim at a secure supply by renewable sources only has to be based on multi-annual data sets. Analysing the application of these sets it gets obvious that the aim of a system design for 100% security of supply or any other exact performance figure seems unreasonable. As this case study is a retrospective study, these results could only be usable for real world application if perfect long-time forecasts would be available. Thus, the uncertainties discussed here will be augmented by the uncertainties of the projections of the future meteorological conditions, Unfortunately the results presented here highlight the fact that the requirements regarding the accuracy of the forecasts go well beyond the correct representation of the long-term average resource.

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