Analysis of the match of heating load and wind turbine production – a case study for the Faroe Islands

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Abstract

In search for options to replace the fossil based heat supply of the housing stock of the Faroe Islands, the application of electrical heating in combination with an increase of wind power penetration in the electricity grid is analyzed. This option is favored by the – as compared to other geographical regions - good seasonal match of the wind generation and the temperature driven heating load at this location. For this case the requirements for oversizing of the wind generation capacity, inclusion of storage and/or use of back-up energy for a save load supply are analyzed.

Keywords: heat supply. wind power, Faroe Islands

1. Introduction

The Faroe Islands - located remotely at 62° North, 7.5° West in the North Atlantic - have a population of ~55 thousand people. Due to the Gulf Stream, the climate is comparatively mild showing an annual mean temperature of about 10°C with only limited deviations in summer and winter. This results in an overall moderate heating load for the housing stock but calls for heating in all month. Currently the heat supply is almost completely based on oil. According to the aim of reducing the dependence on fossil fuels and limiting CO_2 emissions, replacements are needed here. With the - due to the high latitude - limited solar resources in winter but an elevated wind power potential, the use of electrical heat (with the option of using heat pumps) powered by a grid with a high wind power penetration can be considered as option for an alternative heat supply. Additional benefits of linking wind power to heat supply systems are discussed e.g. by Østergaard 2013, Xydis 2015 and Zhang et al. 2015. This paper will give a more detailed assessment of this option by inspecting first the seasonal match of monthly heat demand and monthly energy gain of wind turbines. For the Faroe Islands – showing a favorable seasonal match – details on system performance are analyzed by simulations based on on-site wind and temperature data with 10min time resolution.

As bases for these studies the next section will show a simple approach for modelling the heat requirements of buildings based on temperature information used here for the assessment of the characteristics of both the monthly and short term energy demand. With a similar simplified approach, the characteristics of the monthly energy gain and short term power output of a wind turbine installation are assessed. Heat demand and wind generation are set in relation by scaling the heat demand according to turbine generation, i.e. a selection of an appropriate number of houses to be heated (or heated space area) by a wind installation.

2. Characteristics of the heat demand

For the assessment of the characteristics of the heating load, a simple linear dependence of required heating power to ambient temperature is assumed. Heating is assumed to be necessary when ambient temperature is lower than 18°C, the required power rises linear with the with temperature difference to 18°C. Rated heating power is set to refer to an ambient temperature of -18°C (see. eqn.1). The required monthly or annual energy can be evaluated based on time series information on the ambient temperature and the rated heating power as given by eq. 1. The temperature information can be compressed into the parameter heating degree days (HDD) – basically the (monthly or annual) time integral of the difference of 18°C and the ambient temperature taken for situations with ambient temperatures < 18°C.

doi:10.18086/swc.2017.37.02 Available at http://proceedings.ises.org

$$E = \sum_i \delta * (\ (18°C - T_a(t)) * \frac{1}{36°} P_{(-18C)}$$

$$\delta = \begin{cases} 0\ if\ T_a \geq\ \ 18°C_{\circ\circ} \\ 1\ if\ T_a <\ \ 18°C \end{cases} \qquad \text{(eq. 1)}$$

$$E = HDD * \frac{1}{36°} * P_{(-18C)}\ ,$$

HDD: heating degree days [°C days]

A first impression of the temperature conditions can be gained from the monthly mean temperatures. Fig.1 gives these numbers for the site Tórshavn, Faroe Islands. Monthly mean temperatures vary but in the rage of 6-12℃. These data are all taken from the RETScreen data base (Anonymous, 2014).

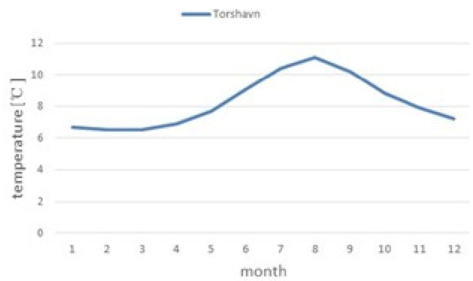

Fig. 1: Mean monthly temperatures for the Town of Tórshavn, Faroe Islands. Data taken from the RETScreen data base].

The respective values of the HDD - as indicator for the heating load as sketched above – for Tórshavn are shown in Fig.2, They are also supplied by the RETscreen data base. For comparison, data for a site in Norway (Ålesund) are given. As compared to Torshavn, that site shows an overall higher heating demand with a well pronounced reduction of needs in summer. For Torshavn there is less variability in the monthly heating requirements. The heating load in summer remains at about half of the heating load in winter.

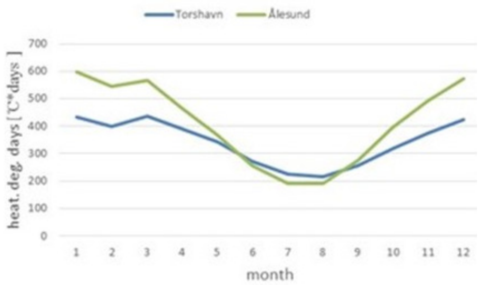

Fig. 2: Monthly heating degree days (HDD for Tórshavn and Ålesund (Norway). Overall, there is less need for heating in Torshavn, but a remaining requirement in summer.

3. Characteristics of wind turbine generation

For the calculation of the monthly turbine generation, based on information of monthly average wind speeds at 10m above ground level (information offered by the RETScreen data base) speeds are scaled up to 50m agl. (a conservative assumption for larger wind turbines) assuming a logarithmic profile for a roughness length of 0.15m. A monthly energy gain is calculated with the assumption of Rayleigh distributed wind speeds, using a power curve for a typical $1MW_{rated}$ turbine.

A first view on the wind resource on the Faroe Islands is given by Fig.3. Shown are the monthly mean wind speeds at 10m agl. as supplied by RETScreen. This indicates good wind conditions with an annual mean wind speed of ~6.5m/s at 10m above ground level in an industrial/harbor environment. The good wind conditions on the Faroe Islands are confirmed by data on the annual performance of a commercial wind farm close to Torshavn (Annonymous 2017).

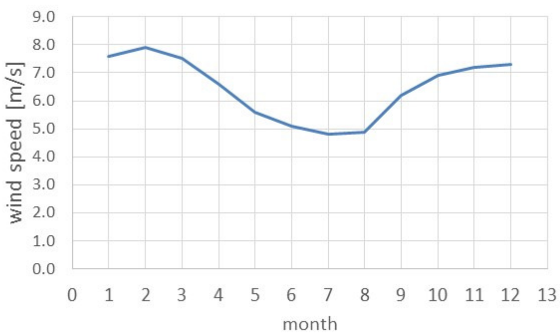

Fig. 3: Monthly means of the wind speed in Tórshavn at 10m above ground level. Data are taken from the RETSrceen data base.

Based on the monthly mean wind speeds scaled up to a hub height of 50m as described above, and assuming a Rayleigh distribution of the of wind speed, the monthly mean power output of a typical 1MW turbine is estimated (see Fig. 4). With the assumption of 0.15m roughness length used for this site, the results are conservative estimates of the energy gain.

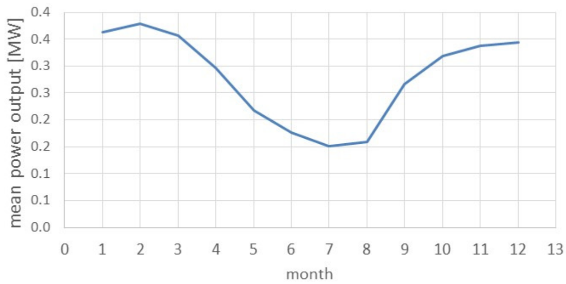

Fig. 4: Estimated monthly mean power output of a 1MWrated turbine at Tórshavn.

4. Linking wind resource and heating load

Comparing the pattern of the monthly heating load as determined the pattern of HDD values and the monthly power generation for Tórshavn, the good match of these sets is obvious (see Fig.5, correlation coefficient of the two sets is 0.87). However, not for all month a wind turbine sized to cover the annual demand would be able to cover each monthly load).

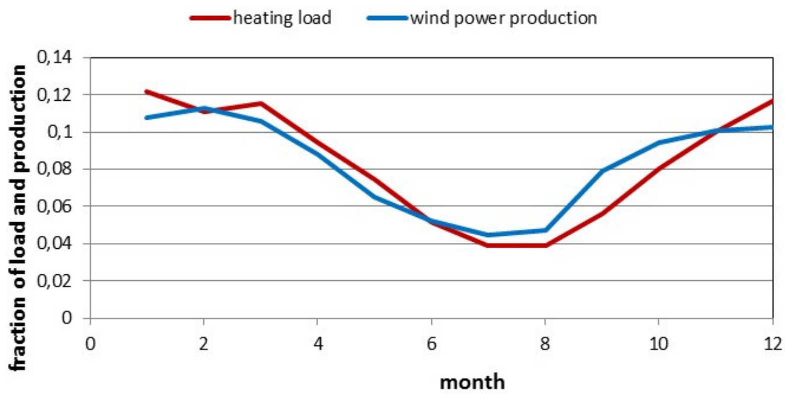

Fig. 5: Estimated normalized monthly energy gain from a wind turbine together with the normalized monthly heating load calculated on basis of the heating degree days (site: Tórshavn). Both production and demand are given as monthly fraction of the annual sum.

This pattern can now be compared to that of other locations. With the scaling of the heating load applied, it should be remarked that the results for each location refer to different relations of heated space to turbine size (the $1MW_{rated}$ system used as standard here), resulting from the specific wind and temperature (HDD) conditions.

The sites scanned here comprise of different locations in Northern and North-Western Europe including the Atlantic isles. Fig 6 gives with the comparison of the load and generation patterns for two locations on the Faroe

Islands, besides Torshavn the site of Akraberg on the southernmost of the Islands. Fig.7 gives the data for the sites Lerwick, Shetlands and Ålesund, Western Norway, Fig 8 for Bremen, Germany and Cardiff, Wales.

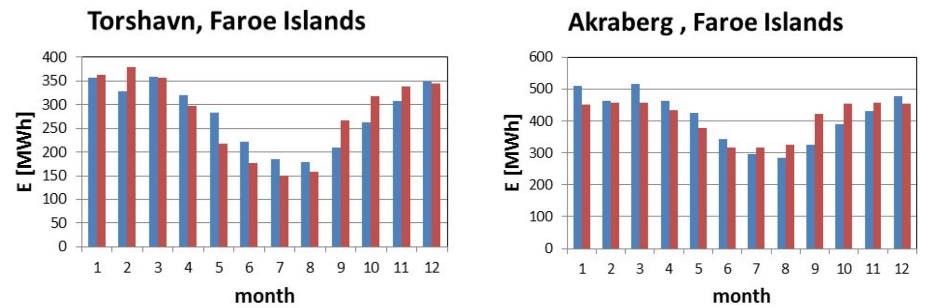

Fig. 6: Estimated normalized monthly energy gain from a wind turbine together with the normalized monthly heating load calculated on basis of the heating degree days. Both production and demand are given as monthly fraction of the annual sum.

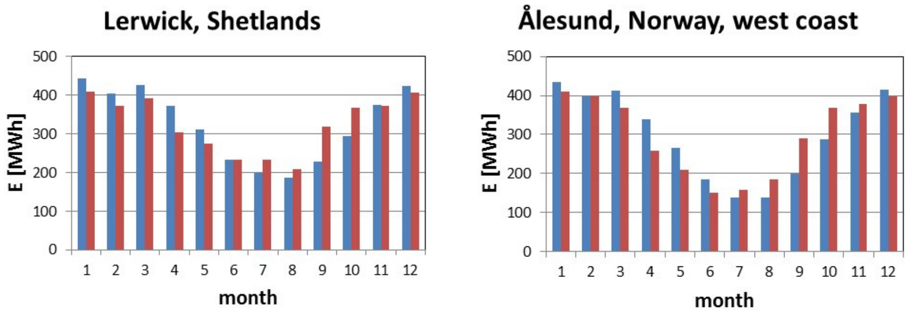

Fig. 7: Same as Fig.5, but for the Sites Lerwick and Ålesund, showing similar pattern as the Faroe Islands sites

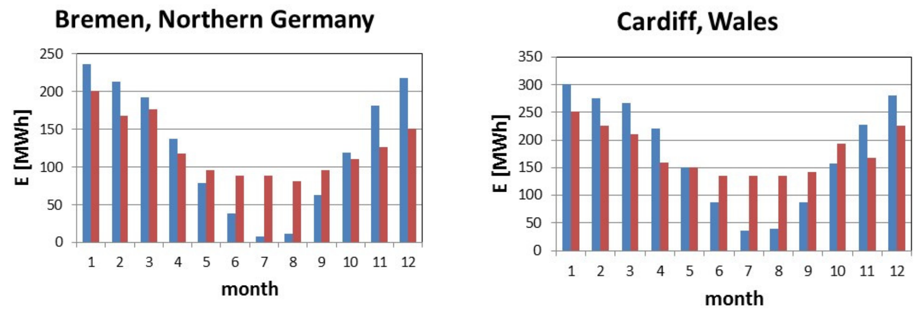

Fig. 8: Same as Fig.5, but for the sites Bremen and Cardiff. For these sites, except for magnitude, the pattern remains similar to those of the more northerly sites. Difference is in the heating load (blue) in summer being reduced to almost zero, causing a larger spread of the pattern of the monthly heating loads.

For Akraberg – with wind speeds superior to those at Torshavn, the monthly pattern in wind generation is even less pronounced than for Torshavn. For both sites monthly wind generation and load are closely correlated with a similar spread. This pattern is repeated for Lerwick and Ålesund, with Ålesund showing a higher parallel sprread in both monthly load and generation. For Bremen and Cardiff, with less favorable wind conditions and thus lower wind generation. With the load scaling according to annual production a remarkable surplus in generation occurs in the summer month. This is due to the heating load approaching zero in summer. In contrast production deficits occur in winter. With still a good correlation of production and load, the mismatch is a consequence of the different spreads of the two series – variability of the monthly heating load much bigger than variability of the monthly production.

The quality of the match of these series of monthly energy data can be related to basic characteristics of the meteorological series. To show this kind of dependency, the Root mean square of the differences in monthly generation and load, both normalized by the respective annual sums is extracted for an extended set of stations (all represented in the RETScreen set) in North-Western Europe (see Tab.1).

Tab. 1: Maximum difference of monthly normalized HDD and normalized wind speed and root mean square of the monthly difference of normalized load and production

site	RMS mon. en. miss.	max. mon. met. missmatch
Akraberg, Faroe Islands	0.116	0.209
Torshavn, Faroe Islands	0.139	0.143
Lerwick, Shetlands	0.139	0.206
Aberdeen, Scotland	0.168	0.424
Ålesund, Norway Westcoast	0.170	0.246
Røros, Norway Interior	0.200	0.366
Brest, France, Bretagne	0.217	0.499
Plymouth, England Chanal Coast	0.271	0.456
Cardiff, Wales	0.341	0.524
Bremen, Northern Germany	0.377	0.688
Lille, Northern France	0.380	0.780
Dresden, Eastern Germany	0.435	0.876
Bo ulonge Seine, Northern France	0.466	0.746
Karlsruhe, Suth-Western Gernaby	0.494	0.929

In addition, as a measure for the similarity in the monthly sets of wind speed and ambient temperature is set up. It is given as the maximum difference of the normalized monthly HDD and the normalized monthly wind speed, both normalized by the average of the respective set. The values for the sites selected are also given in table 1. Fig. 9 shows the relation of the energetic mismatch to the meteorological mismatch, presenting a good correlation of the two sets. Thus, the feasibility of wind heating systems at a site can be pre-assessed by inspecting the sets of monthly HDD's and wind speeds.

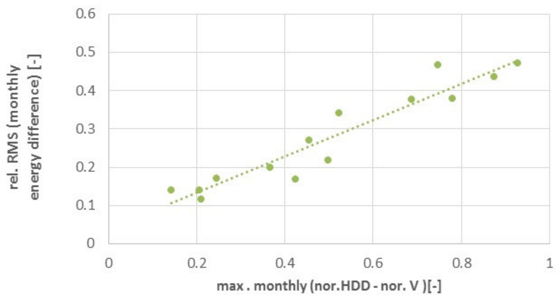

Fig. 9: Relation of the root mean square of the monthly difference of normalized load and production -as measured of the energetic mismatch – to the maximum difference of monthly normalized HDD and normalized wind speed as measure of 'meteorological mismatch' (data see tab.1).

5. Analyses of system performance at a well matched site with higher time resolution

For more insight in expected system performance, a more detailed study is done based on annual 10min time series of wind speed and ambient temperature measured at one of the smaller Faroe Islands, Nólsoy. These sets, showing a time resolution of 10min had been measured by the Danish Meteorological Institute. The annual set for 2008 is used here, showing a mean wind speed of 9.4m/s. These data are used directly as input to calculate the power output series of a 1MW wind turbine. The heating load is calculated according to the linear dependence that forms the basis of eqn.1. Thermal inertia of the building is neglected here, which, for the prevailing wood-based construction type on the Faroe Islands - and as the heating system of the houses contain but the storage capacity of conventional oil-fired systems – should be not too far from reality here.

Fig. 10 gives a first impression of the system performance based on the 10 min. data. Given are the evolution of the accumulated heating load and the accumulated turbine generation over the year. As for the monthly resolved data for Torshavn discussed above, there is a lack in generation in the late spring/early summer months. From an in-depth analysis of the series of the accumulated deficit (see e.g. Haas 1995), a storage dimensioned to host 30 times the average daily load is identified to be necessary for a continuous supply of the load.

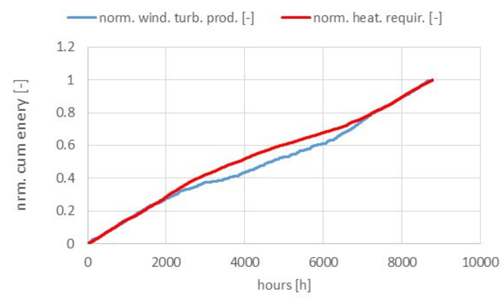

Fig. 10: Annual evolution of normalized cumulated heating load (red) and normalized cumulated wind turbine production for temperature and wind conditions at the site Nólsoy and matched annual load and production.

This requirement for storage could be reduced by an oversizing of the wind turbine. Combinations of oversizing of the wind generation and required storage size resulting from this type of calculation are given in Fig. 11. It has to be remarked that these calculations to not take into account storage losses that would provoke an increase in turbine size.

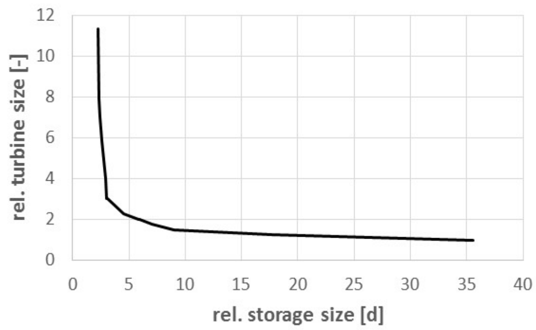

Fig. 11: Combinations of relative turbine and storage size for systems assuring the continuous supply of the load based on the data set for the site Nólsoy, Faroe Islands. Turbine size is normalized by the size of the turbine assuring the annual match of production and load, the storage size is normalized to the average annual load.

For a storage with the indicated almost monthly capacity pumped hydro may be considered as the only practical option – a solution currently discussed for the Faroe Islands to stabilize the isolated grid on the isle of Suðuroy (see Ludescher-Huber, 2017). On a smaller scale, thermal storage, buffering the heat on a daily scale may be applied, as demonstrated be a dedicated wind/heating micro grid in operation for some year on Nolsøy (Thomsen et al, 2015).

The requirement for storage may be reduced by an oversizing of the wind generation. Fig. 12 gives the combinations of storage size and turbine size representing the limit sizes for autonomous systems, i.e. systems not allowing for a loss of load.

As example a wind generation doubled as compared to the matching size would reduce the required storage size to about 5 days – a magnitude not totally out of reach for battery based electricity storage or thermal storage, depending on the absolute system size.

Another option for avoiding the need for large storage sizes is to either allow for a loss of load or the use of backup energy, i.e. the use of a backup power source. Fig. 9 gives the fraction of unserved power for systems with various turbine sizes and a 1-day storage. For a system with the turbine sized to match the annual load the annual unserved load – or need for backup energy - amounts to ~60 days of consumption.

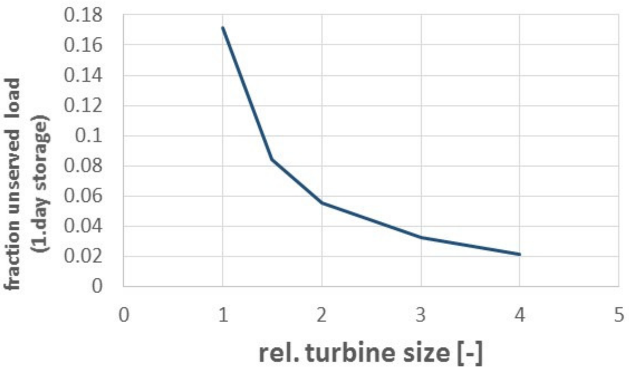

Fig. 12: Fraction of unserved power (normalized by the annual load) in systems using a storage to cover one day of load and various turbine sizes (data base and normalization as for fig. 11).

Thus, even in a region with a favorable seasonal match of heating load and wind turbine generation the effort for a complete coverage of the load by wind generation remains substantial and asks for dedicated studies on optimal system design,

6. Conclusion and outlook

As given here, the monthly pattern of power generation of wind turbines matches quite well to the heating load of houses for the inspected Atlantic and North-Sea climates. For the case of turbines scaled to match the annual load, however, some deficit will occur in the April to June period. As counter measures, either an over dimensioning of the wind capacity and/or the inclusion of storage or the limited use of backup energy has to be considered.

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