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MODELLING AND COMPARING THE SEASONAL AND DIURNAL COMPONENTS OF ELECTRICITY DEMAND, WIND SPEED, WAVE HEIGHT AND WAVE PERIOD; FOR THE ISLES OF LEWIS AND HARRIS

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ABSTRACT

The location of the Isles of Lewis and Harris, off the west coast of mainland Scotland (Figure 1), is favourable for the generation of renewable electricity from both the wind and ocean waves. However the islands' position on the UK electrical grid's periphery, with restricted local network capacity and only a limited connection to the mainland, makes it more challenging to capitalise on this advantage. This study sought to explore the relationship between the local wind and wave resources and consider how they track the islands' indigenous demand for electricity.

This was accomplished by using a mixture of Fourier analysis and auto-regressive techniques to model and de-trend local electricity demand data gathered over a 365 day period; and similarly process the wave and wind parameters associated with renewable generation, obtained from Hebridean metrological measurements recorded over the same interval.

Results confirm that due to the partially complimentary relationship between wind and wave power, balancing generation across these sources is more likely to be efficient at matching customer demand, rather than a reliance on electricity from wind power alone. This would seem particularly significant for relatively isolated networks with only limited local network capacity and modest quantities of conventional generation available to balance any fluctuations in renewable supply.

In conclusion, for the Isles of Lewis and Harris over the 365 day period studied, where grid capacity is restricted and such resources are available, it appears advantageous in terms of network efficiency to combine generation from wind and wave sources.

INTRODUCTION

As part of its efforts to encourage developments in the resource rich areas around Scotland, the Scottish Government has sought to incentivise the marine energy sector. This strategy has included funding the Saltire Prize, a £10m award to be presented to the first developer able to generate 100GWh of electricity from wave or tidal sources, over a two year interval [1].

In addition, agencies of the Scottish Government have initiated Hebridean Marine Energy Futures (HMEF), a programme that brings together commercial organisations from across the marine energy sector with academic institutions, in order to promote the skill and knowledge growth required to progress the Scottish marine energy sector towards full-scale industrialisation and future market expansion. Work on HMEF project has included site surveys and resource assessments; investigation of grid connection issues; planning consent strategies; and the development of a business case for encouraging future investments.

This study was completed as part of HMEF Work Package 3, which sought to consider the effects of marine energy on power system operation; specifically endeavouring overall to quantify the amount of spare capacity on the Lewis/Harris grid that may be available to accommodate marine energy developments, both as it is currently configured and subsequent to a new HVDC interconnector that has been proposed for reinforcing the connection between the Isles of Lewis/Harris and the Scottish mainland [2].

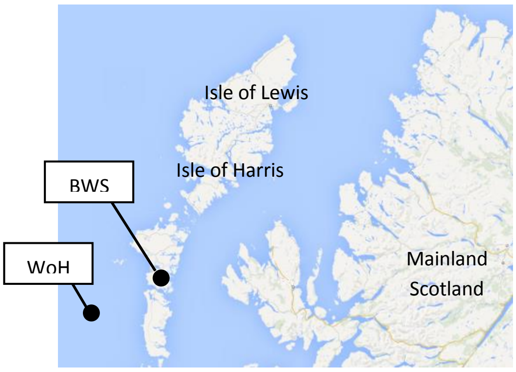

Figure 1 : The Isles of Lewis and Harris

A. Aim

The objective of this exercise was to study the underlying trends than combine to make-up the overall pattern of consumer demand for electricity on the Isles of Lewis and Harris; and to similarly deconstruct the meteorological parameters relevant to local wind and wave generation, over the same period (1st of April 2011 to 30th of March 2012); so that these trends may be contrasted and compared in order to understand how demand, wave and wind generation tend to vary relative to each other and thus how they may influence the spare generation capacity of the Lewis/Harris grid.

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B. Data Sources

Data representing the spot demand for electricity on the Lewis/Harris grid, recorded at 30 minute intervals over a 365 day period, was supplied by SSE, the local electricity network operator.

Wave data recorded at the West of Hebrides (WoH) site, part of the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) WaveNet buoy network, was retrieved from their website [3], again representing observations taken at 30 minute intervals over the same 365 day period.

Wind measurements logged at the Benbecula Weather station (BWS) were downloaded from The British Atmospheric Data Centre (BADC) website [4]; in this case the observations were recorded at hourly intervals, over the 365 day period of interest.

C. Data Quality Issues

The demand data was supplied by SSE as a complete time series with a recorded observation for every half-hour point over the 365 day period. However in the case of the wind and wave time-series, 3.0% and 5.2% of the respective observations were blank. To compensate for these omissions, consecutive blanks were replaced by assuming persistence from the last known measurement; and single gaps were filled by averaging the known previous and subsequent values.

D. Previous Work

The work of [5], [6] and [7] were the main inspirations for the methodology adopted here, referenced broadly in order of their level of influence. In [5] the long-term wind resource of locations are characterised and modelled for wind energy forecasting using a de-trending process to extract the individual components of their overall distribution, firstly by using Fourier Analysis to define and extract the underlying annual trend and then using a similar approach to define and extract the diurnal or daily trend, split by season; leaving a near stationary probability distribution that can be represented by an auto-regressive moving average model.

In practice during this study, it was found that when modelling the wave parameters in particular, a four model seasonal approach was insufficient for capturing the daily variation. Therefore the method adopted by [7], to group the diurnal trends by month, rather than by season, was used. As a consequence, twelve monthly diurnal models were extracted for all of the parameters of interest, providing an opportunity for like for like comparisons.

The wind turbine power curve and wave energy conversion matrix and the methodology adopted in [6] were used to transform the wind and wave attributes into electrical outputs that would theoretically have been generated in those conditions using a notional 3MW wind turbine and a hypothetical 3MW wave energy convertor (WEC).

METHODOLOGY

A time plot of the raw half-hourly demand data is illustrated in Figure 2:

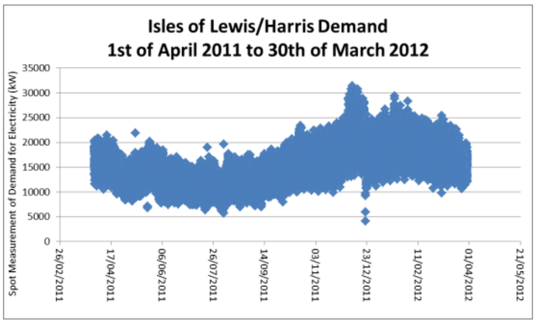

Figure 2: Scatterplot of raw demand data

The average monthly demand was determined (Figure 3) and was filtered from the raw data:

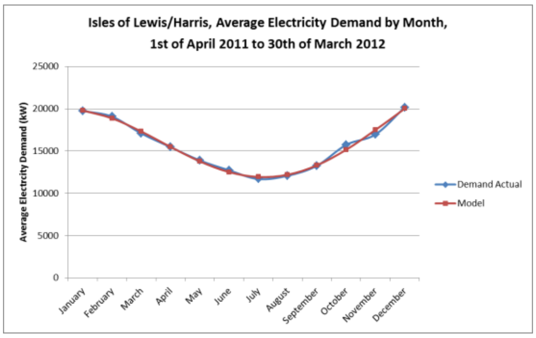

Figure 3: The annual demand trend

The diurnal trends for each month were plotted (Figure 4) and modelled, the trends were filtered from the annually de-trended data:

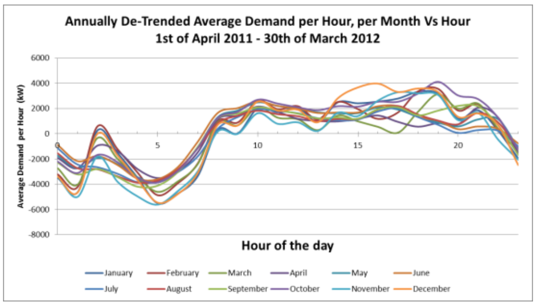

Figure 4: The monthly diurnal trends

Figure 5 shows how the demand data is transformed during the de-trending process, by consecutively extracting the annual and then monthly patterns:

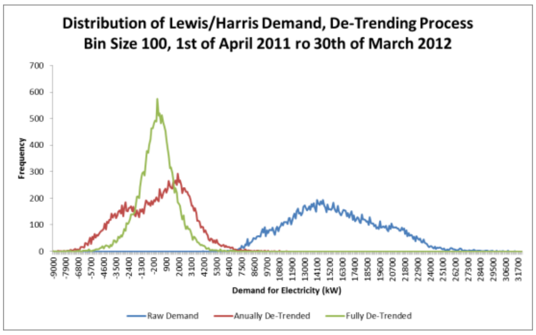

Figure 5: Illustration of de-trending process

OBSERVATIONS

The normalised annual trends of demand and the wind/wave parameters are plotted in figure 6:

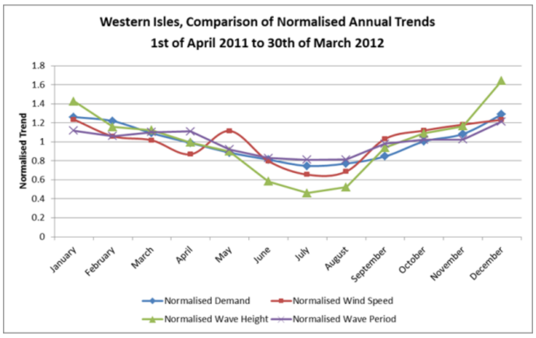

Figure 6: Comparison of annual trends

The trends have been normalised, by dividing each value by the average of the overall trend, to simplify cross parameter comparisons. The wind speed, wave height and period have correlation factors of 0.80, 0.94 & 0.90 respectively, versus demand.

Figure 7 illustrates how when combined, the monthly diurnal models of the annually de-trended wave and wind parameters vary relative to the monthly diurnal models of annually de-trended demand; with correlation factors of 0.49, 0.08 and -0.03 for wind speed, wave height and period respectively, relative to demand.

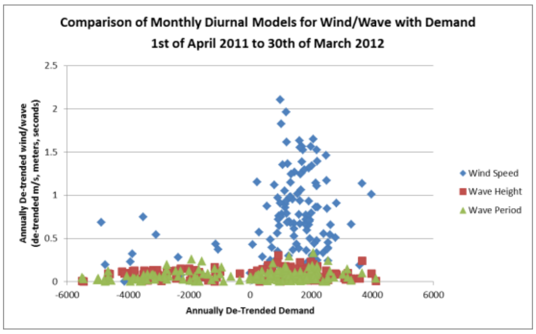

Figure 7: Diurnal models - Wave/Wind Vs Demand

When the underlying wind and wave time-series are used in conjunction with the power curve of a 3MW wind turbine and the power matrix of a 3MW wave energy convertor, specified in [6]; the electricity that could have been generated by these devices, under these conditions, can be estimated. Results reveal that the total electricity generated over the course of each day using the wind turbine has a correlation factor of 0.36, when compared to the total daily demand for electricity. This correlation factor increases to 0.43 when the total daily electricity theoretically generated by the wind turbine is combined with the WEC's notional output.

ANALYSIS

The results illustrated in Figure 6 demonstrate a strong correlation between the normalised annual trends, which conveniently suggests that the magnitude of the wind and wave resources track seasonal demand for electricity closely.

For the diurnal monthly models illustrated in Figure 7, the wind speed has moderate correlation [8] to demand; while the wave parameters do not correlate with demand. The increased correlation between notional generation and demand that results from combining wind and wave generation does seem to demonstrate that demand can be matched more closely by diversifying sources, compared with reliance on wind alone. This benefit is consistent with the findings of [6] and [9].

Some caution is advisable before seeking to draw broad conclusions from data limited to a 365 day period; since based on this evidence, it is not possible to confirm whether these relationships are valid outside this period or location. Data over a longer period across locations would be required for more conclusive results. However for the purposes of this study the data has been assumed to be representative & consistent at least for Lewis/Harris. This assumption seems reasonable for demand, since SSE growth predictions are limited to 1.1% per year between 2012/13 and 2017/18 [10]; it is however more difficult to be confident of the consistency of future meteorological patterns.

CONCLUSIONS

The seasonal variation of both the wind and waves appear to track well with changes in demand for electricity on the Isles of Lewis and Harris. For the daily changes in demand, wind and wave it is more challenging to define a relationship, although there does appear to moderate correlation [8] between wind-speed and demand. However co-generating electricity from both sources seems to track demand more closely than relying on the wind alone. Therefore in conclusion, for the Isles of Lewis and Harris, over the period studied it appears advantageous in terms of network efficiency to combine generation from wind and wave sources.

ACKNOWLEDGEMENTS

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