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# Developing Methodologies for Quantifying the Impact of Tidal Current Energy Variability

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## Abstract

**This paper presents research being undertaken as part of the EPSRC Supergen FlexNet consortium to analyse the spatial and temporal behaviour of tidal current resources. The study explores the availability of tidal current energy at a particular location and examines its timing with respect to electricity demand. Actual performance data from a tidal device is not available; therefore a representative hypothetical device is used to simulate electrical generation output from the available tidal resource. The variability of the power generated is compared with realistic demand data and the level of perturbation is calculated. As the study only considers generation output at one location, the importance of aggregation is highlighted. Two scenarios are presented; 10% and 20% penetration of tidal current energy generation in a small network with variability characteristics similar to the UK system demand. Increasing penetration leads to larger power excursions in the system due to the addition of variable generation.**

**Keywords:** Demand and supply fluctuations, Electricity network integration, Resource assessment, Tidal analysis.

## 1. Introduction

The United Kingdom has an excellent tidal current energy resource potential, and the development of this resource could make a meaningful contribute to meeting out future energy requirements. With a range of tidal current devices being developed and prototype full scale devices being tested, deployment will be enhanced by reliable evidence about the resource, its characteristics, potential environmental impacts and economic cost.

It is important to assess the generation potential at each location where tidal current energy resources are to be deployed, and understand what might be the consequence of absorbing the energy generated into the existing network system. No electricity system can be 100% reliable, since even with conventional generation there is a small chance of major power failure. Addition of variable generation will introduce additional uncertainty, which needs to be quantified.

Each tidal site has very specific characteristics so no two sites are exactly the same, but it is possible to compare some of the generic responses of energetic tidal current sites and assess how much these locations can contribute to the future energy mix if appropriately developed. The aim of this paper is to explore issues associated with the operation of the electricity network with the addition of tidal current energy.

This paper looks at the output from one particular location and assesses its potential impact on the network with the future intention of expanding this analysis to all the key tidal current locations in the UK. The aggregate effect of wind is studied in a similar manner in [1]. [1] draws upon actual wind data from the western Denmark electricity system to illustrate the variability of wind and makes comparisons with demand fluctuations. The outcome from [1] highlights that the system is inherently capable of coping with intermittency and shows that there already exists room for perturbations. Importantly, there are large power excursions that need to be managed by the system when significant amount of wind generation is included, but the number of extreme excursions and their occurrences are manageable.

Current work would involve using a similar methodology to evaluate the impact of tidal current energy from a specific site in the network with the aim of developing a number of test sites to assess the aggregate impact on the network. The analysis presented here is the first step in this process, developing the methodological approach and demonstrating application through a case study scenario.

Conventional generation can lose output as a result of mechanical or electrical faults and the entire plant can shut down. For a farm of (tidal) devices, it is much more likely that one or two devices will shut down due to failure but the shutdown of the entire farm is unlikely. Renewable resources are often termed 'intermittent'. For example wind and wave can stop generation instantaneously at the point of cut-out in extreme conditions for example. For tidal generation 'variable' is a much better description. It has periods of no generation but there will be a constant transition from rated to no generation over a period of time. This makes the output variable, but instantaneous shutdowns are unlikely.

## 2. Tidal Resource

As the rise and fall of the tide depends upon the rotation of the Earth-Moon-Sun system, tidal variability is highly predictable, with small additional variations due to other factors such as local meteorological conditions. The predictability of tidal energy is a major advantage over other intermittent renewable energy resources for integration into the network. Even with numerical weather prediction models wind and wave predictions are not nearly as accurate or precise as tidal analyses based upon appropriate data sources and application of harmonic analysis. The accuracy of numerical weather predictions diminish over time, whereas tidal perditions can be conducted accurately for many years.

However, a challenge with tidal energy is that the peak power that can be extracted occurs 50 minutes later each day as it is governed by the Moon's orbital period of 24 hours and 50 minutes. This may or may not coincide with the peak demand potentially causing complications. None the less, the predictability of tides should help with the planning of day to day network integration of electricity generated from this resource.

### 2.1 Case Study

Only about 0.15% (1269 km$^2$) of the UK continental shelf has a peak flow of 3 m/s or greater [2]. This represents the main region of interest in terms of economic energy extraction due to the characteristics of the technologies proposed for harnessing the available energy. Therefore obtaining data across all of UK continental shelf area is not necessary. Instead what would be most beneficial would be a detailed survey of sites that have high peak flow velocities. This would capture all the information needed to carry out the analysis and assess the sites feasibility, but high quality tidal data tends not to exist for the areas of interest. Prior to the rise of interest in tidal current energy, these regions were not previously deemed of much interest, and therefore not much data exists A methodology to combine publically available datasets to produce an improved resource assessment methodology is discussed in [3].

The sources of data being considered here as in [3] are:

1. British Oceanographic Data Centre (BODC) UK Moored Current Meter Data, [4];
2. DTI Atlas of UK Marine Renewable Energy [5-6].

Figure 1 shows an extract from the DTI Atlas indicating the case study region in the Irish Sea near the Island of Anglesey off the north Wales coast. The potential suitability of this location for tidal energy development as identified by a leading early stage tidal current energy technology developer [7] is one reason for selecting this site for analysis. The other key driver to select this region is the existence of three historic BODC buoy records available in this region. Two of the records are located on the same mooring, one located at 3 metres depth (near surface) and the other one located at 30 metres depth (near bed), in a total water depth of approximately 40 metres. The third buoy is located 1.07 km away at 3 metres depth also in approximately 40 metres of water depth.

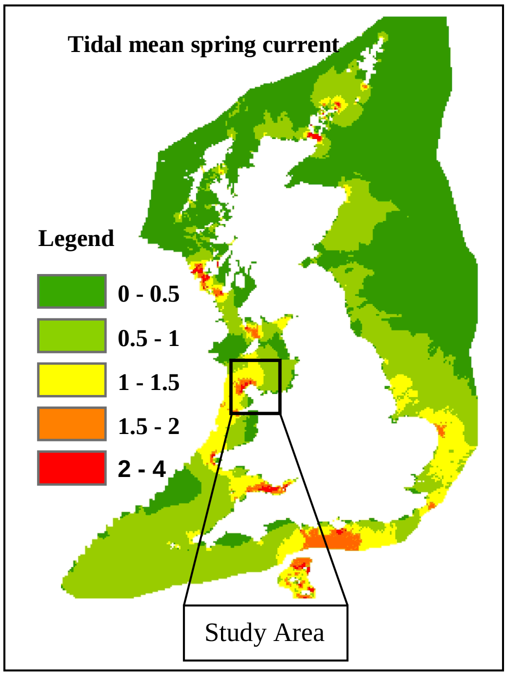



**Figure 1:** Mean spring peak current. © Crown Copyright. All rights reserved 2008.

The buoy records do not coincide in time, so direct comparison between the data is not possible. Therefore, harmonic decomposition and analysis of the original buoy data is used to construct datasets that are coincident in time. This was achieved through least square analysis using National Oceanic and Atmospheric Administration (NOAA) Centre for Operational Oceanographic Products and Services (CO-OPS) Tidal Current Analysis Procedures and Associated Computer Programs [8].

The data is reconstructed from the derived harmonic constituents to generate a time series for the complete year of 2009. The choice of the year is such that it has a nodal factor as close to unity as possible for the nodal cycle (18.6 years). For the present period this happens to be in the year 2011, but demand data is only available from April 2001 to April 2010 [10].

The buoy data is a true in-situ record of sufficient length to allow confidence in its fidelity, therefore for this analysis it is reasonable to treat reconstructed moored buoy data as the 'gold standard'. The only concern is that this data is not for the exact location of interest, the original buoy data was recorded about 7.5 km from the area of interest. The average peak values identified in [5-6] are used to scale up the resource. Using this approach helps retain the correct phase of the tidal signal as well as provide the most accurate tidal current velocity for the location. Although tides are spatially very varied, this is the best way to combine the data sets without carrying out a full scale site assessment which would require extensive and expensive in-situ survey and numerical modelling activity.

## 3. Demand

Half hourly demand data is published online and available from National Grid, the Transmission System Operator in Great Britain. The IO14_DEM values are used; this is the sum of all the generation. It takes into account station load but not pump storage pumping [10].

Figure 2 shows the mean daily profile demand for the year 2009. Also illustrated are the days when peak and lowest demand occurred in 2009. This graph shows the extent of diurnal variation in electricity demand and how they vary reflects seasonal effects. It is worth noting that the mean day has very distinct characteristics. There is an increase in the profile between the hours of 1600 and 1800. This two hour slot is usually when demand reaches its peak over the winter period, used by National Grid to determine the charge it levies on the electricity supplier know as Triad demand.

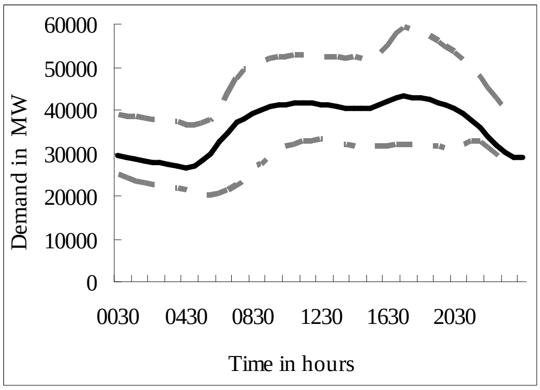
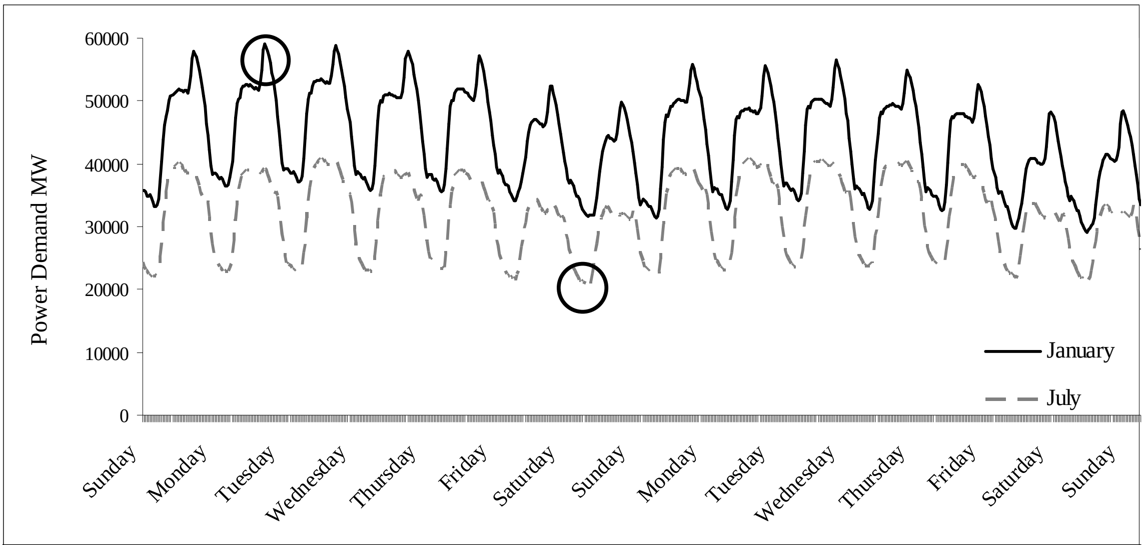



**Figure 2:** Mean demand daily profile for the year 2009.

### 3.1 Fluctuation in Demand

The UK electricity system has an average demand of 36449 MW, with a Standard Deviation of 7774 MW. Demand for electricity peaked at 59140 MW in 2009. The lowest demand is 34% of this peak value and the average demand is about 62% of this peak. This peak is estimated to be around 62.8 GW by 2016/17, assuming a growth rate of 1.2% per year [11]. Figure 3 shows the load profile covering two 14 day periods in January (winter) and July (summer). The January period includes the occurrence of peak demand, on the 6th of January between the hours of 1700 and 1730. The July trend shows where demand is at its lowest on the 2nd of August at 0600.

Load patterns are very distinct in this graph, for example demand for working days (Monday –Friday) can easily be distinguished from non-working days (Saturday and Sunday). The seasonal variation can also be identified here. On average about 7GW are consumed more during the winter period than during the summer period. This demand pattern is distinct to the UK and most northern European countries where the winter season is dominated by short daylight time and the need for heating along with the normal working




Demand in UK over a 14 day period in 2009. Data for the month of January from 5th to 18th and for 27th July to 9th of August. The graphs caputre periods of peak demand (6th January, 1730) as well as periods when the demand is at its lowest (2nd August, 0600).

**Figure 3:** Demand in UK over a 14 day period in 2009

load gives it its 'peaky-ness'. The daily and seasonal demand pattern can significantly vary in countries that experience different weather conditions or work practices.

Generators require periodic maintenance and occasionally there will be unplanned outages. Therefore power systems are designed to deal with demand fluctuations and periods when several power stations are unavailable due to planned shutdown or unexpected failure. A range of plants are used to meet the daily demand, from some that mainly provide a base load output and can be slow in reaction to change in demand to flexible plant that meet rapid swings in demand [12].

Understanding demand trends will help forecast future demand patterns. This can in turn be used to 'match' with variable resources. Timing is a very crucial and a key factor as demand for electricity is high at very specific times of the day and supply response needs to be instantaneous for the system to be stable. Figure 4 shows inter half-hourly analysis of demand fluctuation in 2009, obtained by measuring the difference in demand between each half hour period.

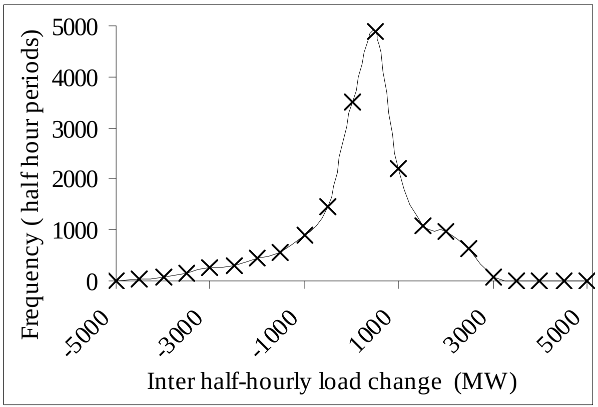



**Figure 4:** Inter half-hourly demand change in UK during 2009.

### 3.2 Scaled Demand

As this paper is only investigating the impact of one generation facility on the network, it is necessary to scale the demand down to simulate the response of a regional distribution network. It is assumed that the scaled demand will have similar demand timing characteristics to a local distribution network which would likely be the connection point of a small array of first generation tidal turbine devices.

Demand for electricity has been scaled down from 59.1 GW peak demand to 200 MW, so that demand and supply for tidal generation are comparable to each other while maintaining likely demand variability patterns.

## 4. Supply

The supply considered here is the output obtained for the chosen site with two hypothetical farms. The first scenario consists of 40 devices that have a rated power of 0.5 MW, making rated power generation 20MW. The second scenario consists of 80 devices with a total generation potential of 40 MW.

For both scenarios, it has been assumed that the tidal current energy resource is not impacted by the operation of extraction devices. As the scale of energy extraction increases, the energy available in the system for extraction will be reduced to some extent [13]. For a larger development project, it will become more important to take appropriate considerations of the potential reduction of resource available for harvesting.

Figure 5 shows the power curve of the hypothetical generic device appropriate for this site. The diameter is assumed to be 16 meters, cut in velocity of 0.7 m/s and the rated velocity of the device is 2.25 m/s. This velocity was obtained by considering the 3rd quartile of the highest velocity recorded in the time series [14].

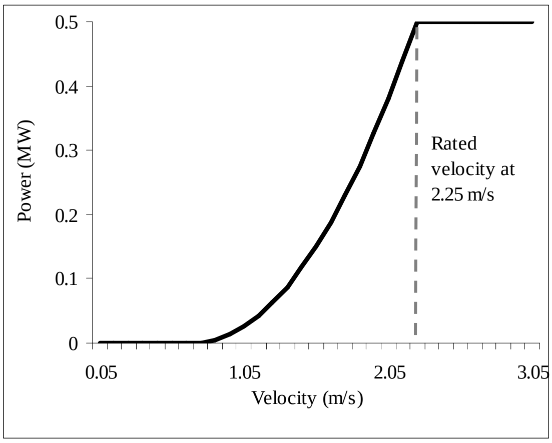



**Figure 5:** Power curve of a typical tidal device. Power rated at 0.5 MW

For this device the efficiency has been assumed to be about 42% on the basis of [15].The annual energy production for each device at this site is the sum of all the energy produced within the operational range of the turbine. In this case, the actual production is 1327.3 MWh which represents a capacity factor of 30.3%. This is substantially lower than what conventional power plants achieve but comparable with other variable renewable technology approaches such as wind.

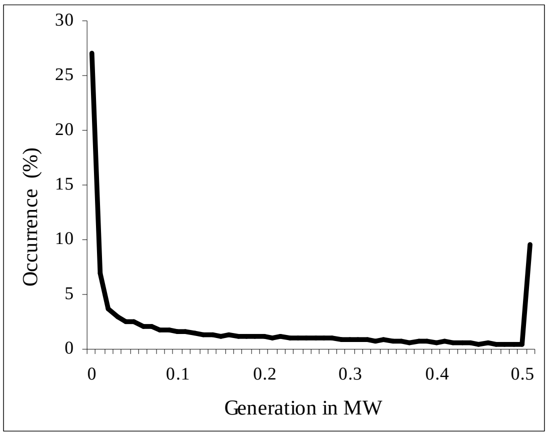



**Figure 6:** Tidal power generation and its occurrence by the postulated hypothetical generic tidal device.

Figure 6 illustrates the percentage of time the device generates a specific amount of power. Device characteristics are such that, it operates at rated power for 9% of the time and is idle for 27% of the time.

### 4.1 Supply variation

Intermittency is part of the electricity system; it needs to cope with plant shutdown and variability in demand as it follows different daily and seasonal trends (as already discussed). How much difficulty will the addition of variable generation from tidal energy harvesting pose the network operator with increasing levels of penetration?

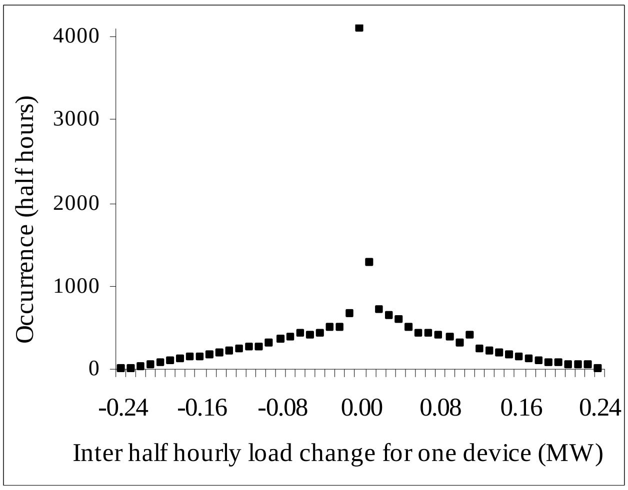



**Figure 7:** Tidal power fluctuation for one device.

Figure 7 illustrates the fluctuations generated by one 0.5 MW tidal power device. The frequency of occurrence (change over a half-hour period) is very high at 0 MW as there are periods of no generation during slack and neap cycles when the velocity is too low for generation. When the device is operating at rated power, the change observed is also zero hence adding to the accumulative 0 MW change. Outputs from figure 7 are different to the wind generation pattern shown in [1] as the nature of the resource is different and importantly [1] looks at the aggregated output from a number of sites. The asymmetry of the graph is an indication of site specific resource characteristics.

## 5. Demand and Supply fluctuations

Figure 8 shows demand fluctuations on the day of peak and lowest demand. Also plotted on the same graph are the simulated 20MW and 40MW generation scenarios. At the exact moment of peak demand, the tidal resource is generating no power. The tides are in their neap cycle, so generation potential is low even if the demand and supply peak were coincident. The generation at 1500 hours does not help service peak demand. As demand is increasing, tidal generation is reducing – therefore it is an even bigger swing for the network to cope with in this case. This may potentially imply that this site has a low capacity credit, depending upon the variation of the tidal cycle and how it progresses with respect to demand. This would require further analysis that is currently under development.

On the other hand, looking at the day when demand is lowest – generation from tidal production can meet more than 50% of the demand. This could be cause for concern as combined with base load generation supply may exceed demand. If this is the case, the system operator may choose to export excess power or curtail the output of the tidal power plant depending upon the network capacity. This will in turn affect the operational cost as the site may be underutilised.

The penetration level at which supply exceeds demand is not a limit for the resource. After this initial level of generation the market value and cost of generation will change to accommodate the need for curtailments or exporting energy elsewhere [1].

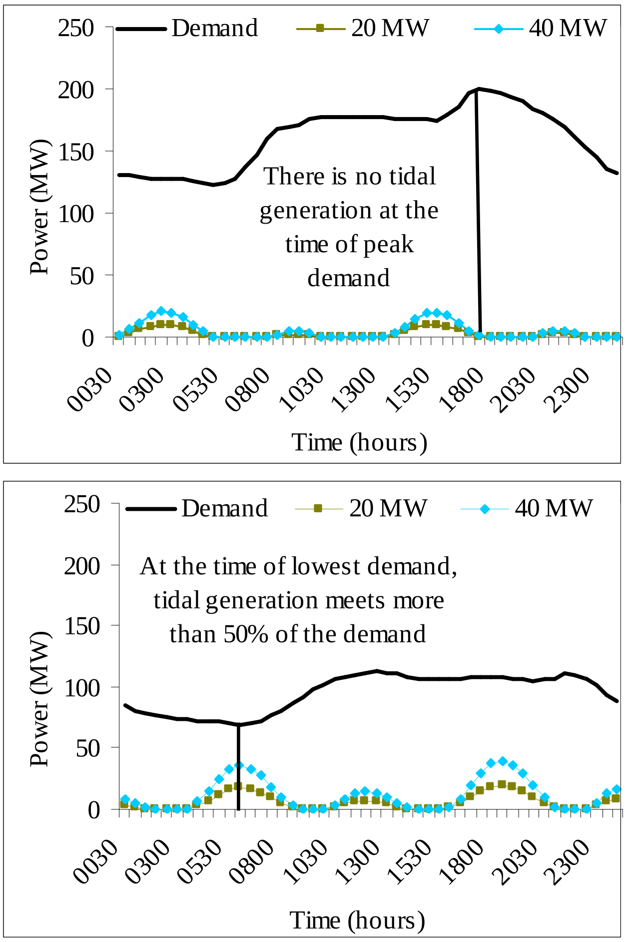



**Figure 8:** Demand and tidal production in the two scenarios.

### 5.1 Perturbation at 10% and 20%

Figure 9 shows a more systematic way of investigating the extent to which the introduction of tidal energy affects the perturbation observed by the system operator. Comparing this to the work done in [1] shows that there is more excursion at both the tails of the distribution curve. This is mainly because only the output from one generation location is being considered here and does not benefit from aggregation of locations to dampen the 'peaky' operational characteristics of tidal current energy generation. The aggregate effects of a number of tidal current energy locations would be expected to produce an excursion characteristic more in line with those produced for wind. Additional sites will be geographically diverse and bring individual site characteristics to the equation along with phasing aspects associated with tidal energy.

The extreme case for negative changes above 17MW and below 9MW are summarised in table 1.

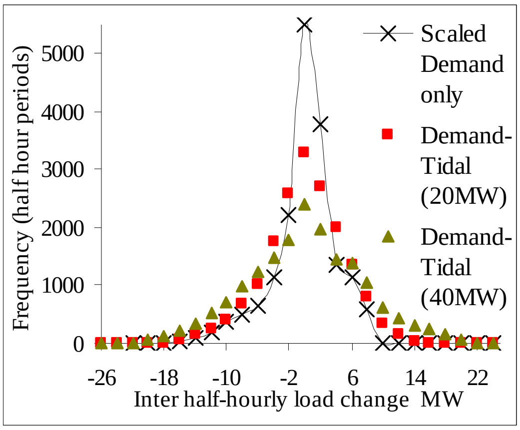



**Figure 9:** Inter half-hourly demand changes in UK for 2009 along with what the system operator would see if there was 20 MW and 40MW (Demand –Tidal) tidal generation.

| Tidal Penentration % | | | |
|---|---|---|---|
| | None | 10% | 20% |
| Maximum decrease: MW | 18.51 | 20.83 | 26.03 |
| Number of decreases of 17 MW and above | 1 | 17 | 211 |
| Maximum increase: MW | 9.38 | 15.82 | 23.91 |
| Number of increases of 9 MW and above | 12 | 538 | 1811 |

**Table 1:** Key data for half hour power excursion in scaled demand.

## 6. Conclusions

This work presents outcomes from examining one generation facility. This analysis shows that more and larger power excursions are created that need to be handled by the system operator. Another aspect to consider is the aggregate impact of a number of sites on the network. Further work will look UK wide and assess the potential cumulative impact on the network.

The electricity network will potentially require extra reserves to deal with higher power excursions. These extra reserves add to the cost of increasing variable generation on the network. The idea is not very different from adding conventional generation, except in this case the plant may have a low capacity credit. At higher levels of penetration this situation may change.

The consensus presented for wind demonstrates that there are no barriers to the implementation of wind in the network and the cost associated with the uncertainty can be as little as £2/MWh with 10% penetration [1]. Further work needs to be done in the tidal current energy case before a similar conclusion can be reached. The work presented is being further expanded to work towards this final goal.

## Acknowledgements

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