DEMAND FOR WIND, MAXIMISING THE VALUE OF WIND POWER THROUGH DEMAND SIDE MANAGEMENT

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ABSTRACT

'Demand for Wind' is a research and development project which seeks to investigate the ability of demand side management to address the variability in large scale and small scale wind power generation. This paper describes the innovative work carried out by the following project partners: Econnect Ventures, specialists in the development of grid integration technologies for renewable energy; Good Energy, the 100% renewable energy supplier; University of Durham, the Energy Research Group in the School of Engineering. This paper presents the Demand for Wind concept and the work carried out to date on the practical system, including results from household trials, the live web technology, and planned further work.

INTRODUCTION

The anticipated proliferation of large and small scale wind power generation has the potential to substantially improve the sustainability of electricity supply internationally. Wind power however is a variable generation source determined by prevailing meteorological conditions. Large scale storage of electrical energy is problematic and expensive, demand side management (DSM) has the potential to address the variability issues associated with wind power generation in a cost effective manner.

Demand side management is not a new concept, it is already used by network operators in a number of situations such as load shedding in emergencies, frequency control in autonomous grids with renewable energy [1] and it has been investigated as a means of providing voltage control in distribution networks with high level of distributed generation [2]. A comprehensive review of demand side management techniques and future opportunities can be found in [3]

The research described in this paper focuses on the use of demand side management techniques to influence consumer demand such that the impacts of the variability of wind power can be mitigated and such that in a future high wind penetration scenario additional demand for wind generated electricity can be created.

The main aims of the Demand for Wind project are:

1) Develop a technology to
    a. perform automatic, semi-automatic and advisory load control in households
    b. monitor household electricity usage
    c. communicate electricity usage data and control signals between households and the Control System via the Internet
    d. communicate electricity usage data and control signals within the household
    e. determine whether the wind generation situation is such that loads should be turned on or not. This should take into account both variations in time and in geographic location
2) Replace the use of fossil fuel in water and space heating with wind generated electricity
3) Minimise electricity export from micro-generation to the grid
4) Develop simulation scenarios to
    a. identify market uptake of the DSM technology developed in this project
    b. identify the future fuel prices required for this system to provide direct cost savings
    c. calculate how much CO_2 would be saved using this system under a range of wind penetration levels
5) Measure the change in consumer energy use patterns in the presence of DSM and a comparison between the impact of direct and indirect DSM measures

Research and development has been carried out to develop a demand side management system where household modems communicate with a control centre using web enabled technology.

Household electricity usage is monitored, and control signals are regularly retrieved, causing automatic switching of loads (e.g. water heating) and an advisory signal to be updated, prompting the household user to manually switch loads on or off (e.g. dishwasher) as they desire.

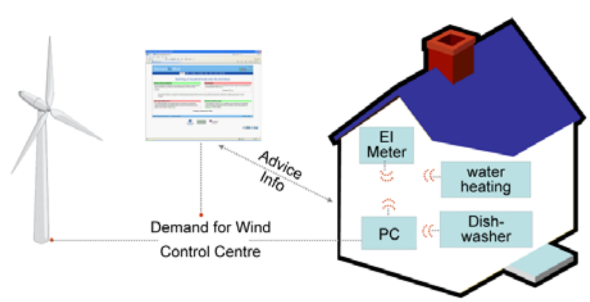

Figure 1: Demand for Wind System

The control centre determines whether there is a surplus of wind power, and regularly updates the control signals for each load being automatically controlled.

User control is maintained through a detailed configuration of how loads are controlled (that can be updated anytime). In case of faults on the Internet connection or in the control centre, the system enters a failsafe mode. The user interface is a dynamic website where each user can view personalised data and graphs displaying near real-time electricity usage. Figure 1 shows an illustration of the Demand for Wind system.

The project involves household trials and will include analysis of system performance and user behaviour.

WEB TECHNOLOGY

The Demand for Wind system is enabled by web technology. Each participant is linked to the demand side management control techniques through a broadband internet connection.

The platform for the Control System is dictated by the hosting technique. The main processing functions run on a Windows based computer in the Econnect offices, while the data store and the main components of the processing software run on a remote Linux server using MySQL and PHP scripts. The website is also hosted on a Linux server (www.demandforwind.co.uk). The high-level software architecture is shown in Figure 2.

The Demand for Wind website hosts a web service which the household system accesses every minute to upload data and download recommended demand side management actions. The web service communicates with the household system using the Web Consortium recommended HTTP/SOAP standard [4].

The website has the following functionality:

- Public access with aggregated demand data.
- Individual participants log in, with access to personal demand data.
- Calculation and display of a demand side management advisory signal.
- A discussion forum for the participants in the demand for wind trials.

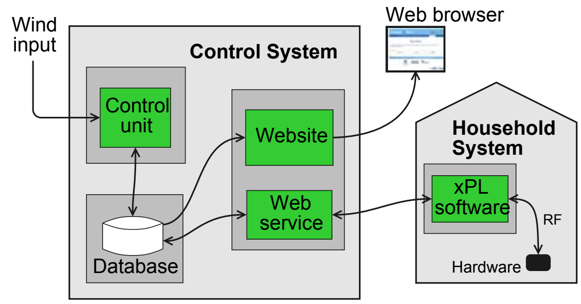

Figure 2: Demand for Wind Web Technology

HOUSEHOLD DSM SYSTEM

The household system consists of two elements, household processing and household communication. The equipment required to be installed in each participant's house varies depending on the type of demand side management methods they wish to adopt. The types of demand side management methods offered are as follows:

- Monitoring
- Advisory
- Semi-automatic
- Automatic

The monitoring level of involvement does not involve any control of the loads. These participants benefit from understanding their domestic load profiles and the research project benefits through the collection and analysis of uncontrolled domestic energy consumption patterns. Table 1 provides a description of the three levels of control that can be adopted by the Demand for Wind participants

Automatic	Controlling loads with no input from user required. For the trials, this will only be done for hot water by controlling an electric immersion heater.
Semi-automatic	Controlling loads with some user input required, e.g. user has to press a button. Typical examples are dishwasher and washing machine.
Advisory	Providing user with a signal enabling him or her to perform manual control of loads. A suitable example is use of a vacuum cleaner.

Table 1: Load control types

The system is designed to create a demand for wind, and it does this by turning loads on when there is a surplus of wind generation. This is principally different from switching loads on and off in response to over- or under-generation (or automatic frequency response). What is meant by enabling and disabling loads is summarised in Table 2.

Enable load	Enables the load to turn on. Whether it actually turns on may depend on additional factors like the thermostat, whether the 'on' button on the dishwasher has been pressed etc.
Disable load	Disabling a load would turn the load off (disabling its power supply). However, the system should not do this unless the user configuration specifies this, or the load has completed a cycle and has already turned itself off.

Table 2: Load enabling and disabling

CONTROL TECHNIQUES

The control techniques used in the demand for wind system can be broken down into two sections, micro-wind mode and large scale wind mode.

Micro-wind mode

- The control software is designed to influence the household load such that it follows the household micro-wind generation output as closely as possible. This means that the power exported from the micro-wind generation is kept to a minimum. This is advantageous for the house owner as the retail cost of electricity is significantly higher than the wholesale price achievable for the micro-wind generated electricity.

Large scale wind mode

- The control software is designed to influence the demand across a large number of households in response to periods of excess of wind energy. The aim, in this future high wind penetration scenario, is to avoid wind energy being curtailed by creating an additional market for this electricity. This demand can be created through conventional demand side management approaches but also by temporarily changing household heating fuels from gas to electricity for heating at times of excess wind power. The excess wind power would be traded at a reduced tariff to incentivise consumers to take part in the demand for wind scheme.

If there is a conflict between large wind surplus and micro-wind surplus, the household micro-wind system takes preference.

A fundamental issue for the Demand for Wind control system is that of how best to determine whether there is a surplus of wind generated electricity that can be exploited by influencing consumer demand. This is problematic, since currently, wind penetration levels in the UK are relatively low and situations of excess wind power are rarely if ever encountered. In the future with higher penetrations of wind generation, this is likely to be different, but the mechanisms that will regulate wind generation are not yet known.

Current approach to determining wind energy surplus

Whether there is a surplus of wind is based on four factors: The current generation, G, from turbines included in the scheme, the generation capacity, C, of the same turbines, the daily demand profile, $p(t)$, for Great Britain, and a given threshold factor f. The demand profile is normalised, i.e. the average value of $p(t)$ is one. These factors are used to compute a real-time Demand for Wind threshold, T, which the wind generation can be compared against. Surplus of wind is defined as any generation above this threshold, $surplus = G - T$.

The threshold is computed at regular intervals, using the latest available information about generator capacity, according to

$$T = f \times p(t) \times C ,$$

where the constant factor f sets the scale for how large the generation/capacity ratio has to be for the generation to exceed the threshold. Assuming a flat profile, $p(t) = 1$, a factor of e.g. $f = 0.7$ would give a threshold equal to 70% of the capacity. The normalised profile in the expression above ensures that the threshold will be lower at times of low demand (early morning) and higher at times with high demand. As an example, assume capacity $C = 100$ MW, generation $G = 60$ MW and $f = 0.7$. At 3am with $p(3\text{am}) = 0.45$, this would give a surplus of 29.6 MW, while at 7pm with $p(7\text{pm}) = 1.73$, it would give no surplus at all ($G < T$).

FIELD TRIALS

Currently the Demand for Wind project has approximately 70 participants. Some of the participants have monitoring equipment installed and a small number have indirect or direct load control capabilities. It is envisaged that the numbers of participants with monitoring and control capabilities will grow over the coming months. The target is for 40 monitoring participants, 20 semi-automatic participants and 5 direct load control participants.

The field trials are seen as an important part of the project as they not only test the web technology and the demand side management technology but they also provide interesting insights into the social aspects of demand side management systems. A constant dialogue will be maintained with the participants to elicit information regarding how involvement in this system may have changed their attitudes and behaviour towards energy.

A key aspect of the project is to monitor and understand in greater detail domestic electricity consumption patterns. Fig

3 shows some of the demand data already collected from a participant of the demand for wind system. This data was gathered using the web service software described previously. The data can be logged with a temporal resolution of up to 30 seconds. The data in figure 3 is taken every minute. From looking at figure 3, it is possible to identify individual consumer loads, which is useful when trying to understanding the degree to which the consumer demand can be influenced. Each participant has a period of time during which their consumption is logged without any load control taking place such that their demand profile can be characterised and such that the new demand profiles produced as a result of the demand for wind system can be compared and benefits or otherwise can be quantified. Figure 3 shows the demand of a particular house from 8pm to midnight. It is possible to see that the kettle was used at approximately 9 pm and that the dishwasher started its cycle at approximately 10:30 pm. The website enables the participants to provide supplementary information regarding their consumption to aid with the identification of power consumption peaks associated with particular load devices.

Clearly the main thrust of this research is to actively influence consumer demand. Figure 4 shows how the semi-automatic element of the demand for wind system has been implemented. Figure 4 shows the demand for a particular house over a 24 hour period. The participant accessed the website in advance of the period shown, and identified their washing machine as a load available for semi-automatic control. They also specified a time by which the washing machine must have started, which in this case was 10 am. The simulation being run caused the software to decide that an excess of wind power had occurred at 3 am. Therefore at this time the Demand for Wind web service instructed the washing machine to begin its cycle (denoted by the dashed line). It can be seen on figure 4 that the washing machine was successfully initiated soon after 3 am.

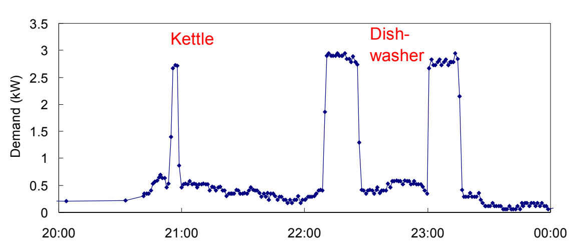

Figure 3: Web accessed consumption data

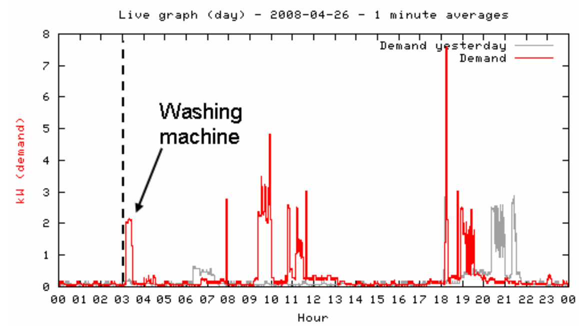

Figure 4: Semi-automatic load control

CONCLUSIONS

This paper has described the Demand for Wind concept and the web enabled system that is being evaluated. 70 participants have registered for the pilot scheme. Monitoring data has been gathered and analysed. The participants are benefiting from greater visibility of their electricity consumption through the web site which in itself changes consumption behaviour. Preliminary demand side management has been successfully carried out through the web site with encouraging results. Further development and testing of the control techniques is required, some of which will be carried out on the micro-generation laboratory at Durham University. Extrapolation of the results for a UK wide adoption of the scheme is required to evaluate the potential benefits of such a scheme, particularly for future high wind penetration scenarios.

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