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Demand side management of a domestic dishwasher: Wind energy gains, financial savings and peak-time load reduction

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HIGHLIGHTS

- ▸ Intermittent energy sources require demand side flexibility to minimise curtailment.
- ▸ Financial savings can be achieved concurrently with increased demand on wind energy.
- ▸ Price optimisation of load provides benefits for consumers and grid operators alike.
- ▸ Dishwashers offer wide time frames within which load can be rescheduled.
- ▸ Price optimisation offers significant peak load reduction capabilities.

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ABSTRACT

Ireland is currently striving to achieve an ambitious target of supplying 40% of electricity demand with renewable energy by 2020. With the vast majority of this being met by wind energy, an intermittent and non-dispatchable energy source, it is inevitable that frequent substantial curtailment will occur during times of excessive generation. This paper investigates the potential for demand side management to limit the requirement for curtailment and further facilitate the integration of renewable energy by shifting the timing of electrical demand in response to various signals including pricing and wind availability. Using a domestic dishwasher as an example, significant increases in the amount of renewable electricity consumed are demonstrated with simultaneous financial savings for the consumer. Furthermore, secondary benefits such as peak-time demand reductions in excess of 60% are observed. The impact of employing demand side management based on imperfect day-ahead market predictions is also analysed and the resulting deficiencies are quantified.

1. Introduction

As with other European Union (EU) members, Ireland's strive towards a higher penetration of renewable energy has been driven by a necessity to achieve overall reductions of greenhouse gas emissions (GHGs) with the promotion of energy from renewable sources. Furthermore, Ireland's resilience against fluctuations in foreign fossil fuel markets has continued to weaken since the mid 1990s, hitting an all-time low in 2007 with imported fuels accounting for 91% of annual consumption [1]. These factors highlight the need for Ireland to exploit the island's vast quantities of indigenous renewable energy from wind, wave, tidal, and biomass sources. As a result, Ireland's electricity generation from renewable sources (RES-E) has increased from 2% in 1995 [2] to approximately 14.4% in 2009 [3] and is set to increase to approximately 40% by 2020 [4]. Wind generated electricity has surpassed hydro power as the dominant contributor to Ireland's RES-E and is planned to contribute up to 72% of the 2020 target [5]. However as wind penetration increases so do the occurrences of excessive generation during which time wind generators must be curtailed [6]. In order to utilise the otherwise wasted energy greater grid flexibility must be achieved. Demand side management (DSM) offers the potential to accomplish the required flexibility by shifting the timing of grid loads in response to various stimuli. Unlike industrial loads that are often application specific, domestic electricity loads largely comprise of a small number of appliances with mass penetration rates. Furthermore domestic electricity consumption accounts for 32% of total final electricity consumption in Ireland [7]. Hence, the development of DSM control for domestic appliances offers a highly replicable model with the potential to achieve widespread deployment.

This paper examines how various electricity market signals can be used to implement demand side management (DSM) in order to time-shift the wash cycles of a domestic dishwasher with an aim to

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maximise the amount of renewable energy consumed while reducing the subsequent cost and demand on thermal generation plant.

2. Penetration rates and energy demand of household appliances

Domestic appliance ownership has increased significantly over the last century generating increased demand for energy. Household's appliance penetration data was sourced from Economic and Social Research Institute (ESRI) of Ireland and the central statistics office (CSO) [8,9]. An index of possessions was accumulated from 1987 up to 2005 which covered nine household appliances: Vacuum Cleaner Clothes Dryer Washing Machine, Dishwasher, Refrigerator with Freezer, Separate Deep Freeze, Microwave Oven, Stereo, Home Computer and two or more TVs. The combined index has increased from 28.9% to 66.3% showing a significant rise in household appliances ownership. This increased penetration has led to an increase in electricity consumption. In Ireland (1990 up to 2006), the ratio of residential electricity demand to population increased by 62% reaching 1909 kWh per person per annum [10]. Mandated efficiency standards for energy-using household appliances have being implemented to tackle the issue and reduce energy consumption of large household appliances [11]. Penetration rates showed an overwhelming increase across the board from 1995 to 2005, with between 70% and 90% of appliances purchased being 'A' labelled [12]. A survey conducted in Ireland of the top 10 white goods retailers, showed that the cheapest washing machines available were all 'A' rated. This is predominately due to energy efficiency policies and improved consumer awareness through energy labelling. Yet as energy efficiency technological advancements approach their limits, further improvement will have minimal effect on the life cycle energy demand of the appliance. However, generation from renewable sources continue to play an increasingly significant role in electricity production. These sustainable resources can offer energy with little environmental impact dramatically changing the outcome of the life cycle energy demand profile of an appliance.

Therefore more emphasis needs to be placed on how the energy is created and how appliances can optimise the use of the energy sources available to it.

3. Curtailment of wind generation

Times of excessive wind generation require the curtailment of wind generators. In order to maintain frequency, transient and voltage stability a certain amount of conventional generation plant is required to remain online at any given time to provide grid stability. Currently this constrains instantaneous excursions of wind generation in excess of 50%. Beyond this point wind generators are instructed to reduce output and the potential generation is wasted. A study commissioned by EirGrid (TSO) and published in June 2010 concluded that this wind penetration threshold could be extended to 60–80% of net load with minimal infrastructural upgrade requirements [6].

For installed wind capacities up to the point at which curtailment is required, the amount of conventional generation that can be displaced is primarily dependent on the capacity factor of wind in the region. For Ireland this is approximately 34% which means that installed wind generation will on average generate at 34% of its maximum export capacity. When the installed capacity of wind generation exceeds the limit of what can be managed without constraint, incremental gains in the amount of net demand that can be supplied by wind requires the addition of substantially increasing amounts of installed capacity. This diminishes the feasibility of incremental displacement of conventional generation plant by wind. This is demonstrated in Fig. 1 which depicts the impractical amounts of additional installed wind capacity required to make marginal gains in useable energy beyond the curtailment threshold.

However, in order to maximise the realisable benefits of the available wind generation it will be necessary to increase the flexibility of load on the electrical grid using techniques such as DSM.

4. Demand side management

Wind generated electricity is inflexible as it cannot be truly dispatched or rescheduled due to the nature of its energy source. In order to increase the amount of conventional generation that can be replaced by wind it is necessary to achieve flexibility elsewhere. This has traditionally been considered the realm of large scale energy storage. In contrast to energy storage which aims to reallocate excessive supply to times of greater demand, demand side management (DSM) aims to reallocate demand to times of increased wind generation. This is achieved through the use of dynamic load shifting. Conventional energy storage suffers from the inefficiencies inherited from the mechanical or chemical properties of the plant being employed. However, DSM has the potential to be 100% efficient as it does not require the conversion of energy to and from an intermediary form; instead it is the timing of the intended task that is displaced [13]. Schroeder [14] suggests that centralised storage is more promising than DSM due to the complexity associated with a utility managing the shedding of distributed loads; however, here we are examining price based DSM in which loads passively react to a pricing signal rather than being actively dispatch by the utility. Although this approach avoids the need for centralised dispatch, it is necessary to ensure that the pricing signal encourages a response that is desirable to the utility. A number of studies have shown that DSM can indeed be used to shift demand to achieve financial savings for the customer [15–17]. The objective of this study is to examine whether such methods cannot only achieve savings for the customer but can simultaneously induce a response that facilitates the increased use of wind generation in the context of Ireland's electricity market.

A number of DSM initiatives are currently implemented by Ireland's TSO such as Short Term Active Response (STAR) [18,19], Powersave [20], Winter Peak Demand Reduction Scheme (WPDRS) [21,22], and Demand Bidding [23,24]. However, these strategies are limited to load shedding whereas in order to use DSM to provide the ancillary services needed to support the facilitation of wind energy, there is greater value in possessing an ability to increase demand as opposed to decrease demand as demonstrated in Paulus and Borggrefe [25] which examined the benefits of DSM

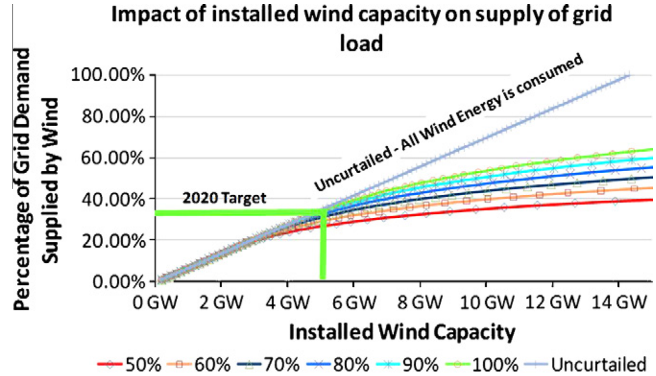

Fig. 1. Effect of various levels of curtailment on the feasibility of increasing wind penetration rates.