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Increased Penetration of Renewable Energy using Demand Side Management: Immersion Heater Analysis

P. Finn[1], C. Fitzpatrick[1] , M. Leahy[2] and L. Relihan[3]

[1] Department of Electrical & Computer Engineering
University of Limerick
Limerick, Ireland
Phone number: +353 85 1499 257, e-mail: paddy.finn@ul.ie, colin.fitzpatrick@ul.ie

[2] Department of Physics
University of Limerick
Limerick, Ireland
Phone number: +353 61 213 056, e-mail: martin.leahy@ul.ie

[3] ResourceKraft Ltd.
EAC Building, Moylish Park
Limerick
Phone number: +353 61 490 144, fax: +353 61 490 153, e-mail: liam.relihan@resourcekraft.com

Abstract. This paper examines the potential for Demand Side Management and Dynamic load shifting to increase the theoretical limit imposed on Wind Energy integration.

This limit is determined by the financial implications of wind energy curtailment. The following analysis uses the heating schedule of a domestic immersion water heater to show that price driven demand flexibility can increase this limit while offering financial benefits to the consumer. Furthermore, the increased use of wind generated electricity and a minimal increase in overall demand results in reduced consumption of conventionally generated electricity.

Key words

Demand Side Management, Real-Time Pricing, Dynamic Load Shifting, Demand Response.

1. Introduction

Since the early 1990's, Wind Generated Electricity has become increasingly dominant in Ireland's electricity generation portfolio. Current 2025 targets aim to reach the economically feasible limit of wind energy penetration as proposed by the All Island Grid Study [1]. It is clear that demand flexibility techniques will have to be employed if these targets and limits are to be exceeded.

Unlike large scale energy storage, Demand Side Management (DSM) offers the potential to increase demand flexibility with an efficiency of, or very close to 100%. By employing dynamic load shifting, DSM achieves this flexibility by strategically rescheduling certain loads to more suitable times. Because the energy is being converted to its final form rather than stored in an intermediary form DSM very high efficiency levels.

To assess the potential of DSM is it first necessary to examine the drivers behind wind energy integration in Ireland and the role it plays in Ireland's electricity market.

2. Ireland's Wind Generation Portfolio

As with other European Union members, Ireland's strive towards a renewable future has been driven by necessity to achieve overall reductions of green house 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 1990's, hitting an all time low in 2007 with imported fuels accounting for 91% of annual consumption [2].

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. In response, Ireland's electricity generation from renewable sources (RES-E) has increased from 2% in 1995 [3] to approximately 12% in August 2009 [4] and is set to increase to upwards of 40% by 2025 [5]. Wind generated electricity has surpassed hydro power as the dominant contributor to Ireland's RES-E and is planned to contribute 86% of the 2025 target.

A. Drivers behind Ireland's current integration of Wind Generated Electricity

In line with the general European Union energy policy, in 1993 the Irish Government established a specific framework for implementing its commitment to renewable and alternative energy sources. Under the framework, the Irish Government imposes on the State owned electricity distribution company, the Electricity Supply Board (ESB) to purchase under long-term 15 years' contracts, the electricity generated by a number of independent green electricity producers, at a guaranteed price. The associated revenue stream was sufficient to allow developers to secure bank debt to finance the capital costs (typical debt is 75% of €1.1 million / MW built). The ESB was compensated for the net additional costs it incurred from a Public Service Obligation (PSO) levy funded by electricity consumers. These tenders are known as "Alternative Energy Requirements" (AER) [6, 7].

In September 2001 the European Parliament and Council of the EU released a directive on the promotion of electricity produced from renewable sources. This mandated targets set by the 1997 white paper, "*Energy for the Future: Renewable Sources of Energy,*" and set individual targets for each of the member states. The targets laid down aim to provide a structure to help member states achieve compliance with the package of measures required by the Kyoto protocol more quickly. An overall EU target proposed the doubling of the share of energy sourced from renewable sources from 6% in 1997 to 12% by 2010 and a total RES-E contribution of 22.1%, with Ireland's directed to aim towards a RES-E target of 13.2% [8].

The AER market support mechanism was succeeded in May 2006 by the Renewable Energy Feed in Tariff (ReFIT) which aimed to provide support of €119m to renewable energy projects over a fifteen year period. The scheme aimed to compensate RES-E developers trading in the newly liberalised electricity market by subsidising prices up to the following price caps [6]:

1) Large wind energy (> 5 MW) 5.7 cent/kWh
2) Small wind energy (< 5 MW) 5.9 cent/kWh
3) Biomass (landfill gas) 7.0 cent/kWh
4) Hydro & other biomass technologies 7.2 cent/kWh

Achieving RES-E penetration of 12% in August 2009, Ireland looks set to reach its 2010 target of 13.2% [4, 8].

B. Ireland's Renewable Future

In January 2007 the EU Commission issued a communication, "Renewable Energy Road Map; Renewable energies in the 21st century: building a more sustainable future", to member states. To continue the accelerated growth of renewable energy sources, the Commission suggested an overall legally binding EU target of 20% of renewable energy sources in gross inland consumption by 2020 as part of its strategic vision for the energy future of Europe. It was recommended that RES-E should account for approximately 34% of overall electricity consumption with wind energy being the predominant contributor [9].

In anticipation of these recommendations becoming law, the Department of Communications, Marine and Natural Resources published a Government White Paper in March of the same year. The white paper, "Delivering a Sustainable Energy Future for Ireland", detailed an energy policy framework to take Ireland through 2007 to 2020 and highlighted a commitment to the shared European goal of a 20% energy reduction by 2020.

"The Government is committed to delivering a significant growth in renewable energy as a contribution to fuel diversity in power generation with a 2020 target of 33% of electricity consumption. Wind energy will provide the pivotal contribution to achieving this target." [10]

In October 2008 it was announced that the domestic RES-E target of 33% was to be increased to 40%. Fig. 1 shows the current and planned installed capacity of wind generation on the Irish electrical grid [11].

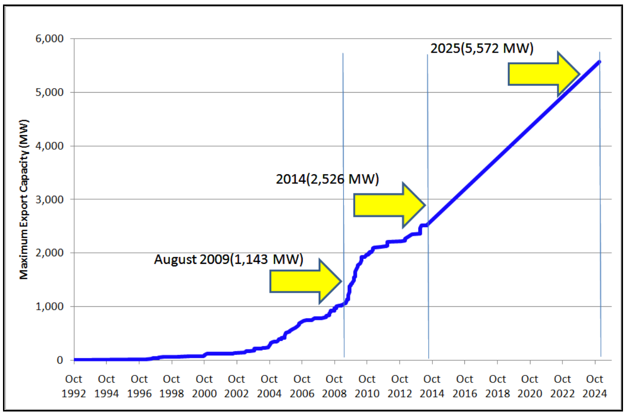

Fig. 1 Current and planned installed capacity of wind generated electricity according to "Criteria for gate 3 renewable generator offers & related matters" CER/08/260

As part of the RES-E increase, sustainable cost effective Demand Side Management programmes will be put in to place to enable ESB Networks and EirGrid to plan better and to manage and modify customer demand. This is being implemented through the national rollout of smart metering to all electricity customers which is currently undergoing behavioural trials [12].

The Council of the European Union issued a press release in April 2009 announcing the adoption of the climate-energy legislative package containing measures to fight climate change and promote renewable energy. This package, known as the "20/20/20 Directive", aims to achieve an overall EU environmental target of a 20 % reduction in greenhouse gases and a 20 % share of renewable energy in the EU's total energy consumption by 2020 [13].

C. *Issues Limiting RES-E Penetration*

In January 2008 the Energy Minister Eamon Ryan and his Northern Ireland counterpart Nigel Dodds, published the All-Island Grid Study[14], the most advanced and comprehensive of its kind in the world. The study examined:

- a range of generation portfolios for Ireland;
- the ability of the power system to handle various amounts of electricity from renewable sources;
- the investment levels required, and
- the positive externalities that would accrue with regard to climate change and security of supply.

This study was the first full assessment of the ability of the power system to facilitate significant penetration of renewable energy onto the system with the primary objective of assessing the technical feasibility and costs and benefits of 6 different renewable penetration scenarios. In all simulated scenarios, wind was the dominant source of RES-E. The constraint payments associated with the curtailment of wind generated electricity impose a limit on the amount of wind penetration that is economically feasible. This defines a goal of maximum wind penetration and minimum curtailment.

The chosen portfolio (portfolio 5) imposes a limit of 42% RES-E, 81% of which would be provided by wind generated electricity. This portfolio would result in 0.02% wind curtailment for reasons other than the provision of spinning reserve. Due to constraint payments made to reimburse generators during times of constrained output, the requirement of wind curtailment has a negative economic impact on the continued grid connection of wind turbines beyond the limit set by the 42% RES-E portfolio. Fig. 2 depicts wind generated electricity as a percentage of total demand. It is based on 6 months actual data that has been scaled to represent the 42% RES-E penetration scenario. Three areas of excess supply are highlighted to show times when curtailment would be required.

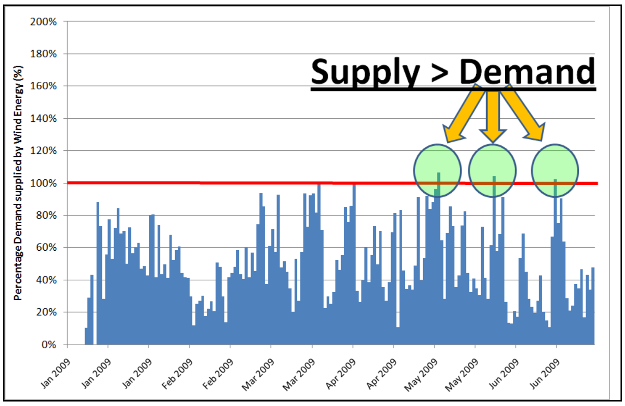

Fig. 2 Wind generated electricity as a percentage of total demand scales to represent 42% RES-E Penetration. Based on data from www.sem-o.ie

Portfolio 5 already exploits the storage capacity offered by Turlough Hill, a 1.59 GWh pumped storage plant, built in the 1970's that operates with an efficiency of 70%. In order to overcome the theoretical limit of wind penetration imposed by the requirement to minimise curtailment, it is necessary to further increase the flexibility of grid demand. As well as considering the flexibility that can be offered by large-scale energy storage plants, it is important to evaluate the increased flexibility that can be offered by employing distributed demand side management and dynamic load shifting.

3. Demand Side Management of RES-E

A. *Benefits of Demand Side Management*

In contrast to energy storage which aims to reallocate supply to times of greater demand, DSM aims to reallocate demand to times of increased RES-E production. 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. Fig. 3 illustrates the implementation of DSM during a time where wind generated electricity exceeds demand. Load is reallocated from a time of high demand to a time of excess generation. This avoids the curtailment of wind power while reduce the amount of conventional generation plant required during the originally designated time.

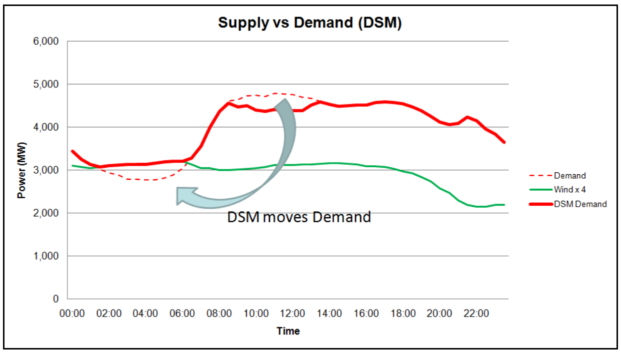

Fig. 3 Demand and Wind generation data from May 7th 2009 scaled to represent 42% RES-E scenario. DSM illustrated where Supply > Demand.

B. *Price as an indicator of real time RES-E penetration*

Ireland's electricity market operates as a gross mandatory pool, called the Single Electricity Market (SEM), into which all electricity generated, or imported into Ireland must be sold and all wholesale electricity for consumption or export must be purchased.

Each trade day comprises 48 half hourly trading periods. Competitive bidding takes place one day ahead of delivery during which all dispatchable generators provide price and quantity information for each trading period. The spot market demand is cleared for each trading period and dispatch schedules are determined. The clearing price is the price per MWh declared by the highest price generator required to meet demand. This determines the system margin price (SMP) which will be awarded to all scheduled generators in a given trading period (Fig. 1). The anticipated prices are then published at 16:00hrs one day ahead of the trade date in question. [15]

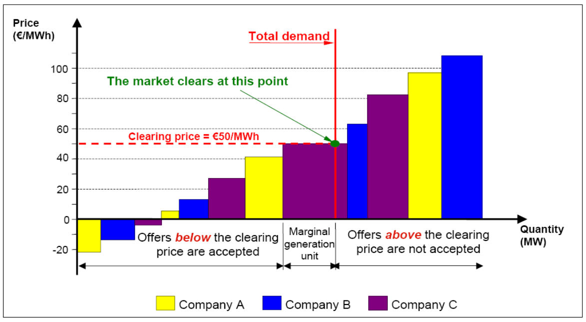

Fig. 4. Competitive bidding process illustrating clearing price and market spot demand.

During dispatch scheduling wind generated electricity is treated as a negative load. This results in all available wind power being accepted onto the grid. Wind generators are treated as price takers rather than price makers. Consequently periods of high wind require the dispatch of fewer price making conventional generation plant resulting in lower prices. Hence half-hourly pricing trends are indicative of RES-E penetration levels and this correlation will become more significant as the amount of wind generation increases. Evidently the current spot-price market structure lends itself to the implementation of DSM by offering financial incentive to reallocate demand while simultaneously promoting the increased use of renewable energy.

Traditionally real-time pricing tariffs that reflect the SMP have only been available to large scale industrial customers due to the requirement of interval metering. Since 2008 a nationwide domestic smart metering programme has been undergoing technical and behavioural trials. Trials are due to conclude in the 2nd quarter of 2011 and will be followed by a nationwide rollout of the selected technology. Recent press releases have indicated that this technology will offer the potential of interval metering to the domestic market, enabling the promotion of DSM of RES-E [12].

C. DSM Heating of a Domestic Hot Water Cylinder

As part of this study a power usage telemetry system was installed in an on-campus student apartment in January 2008. The system, installed by ResourceKraft Ltd., monitors seven electrical circuits, as detailed in table I, which combined account for the total electrical consumption in the apartment. The measured data is transmitted using the GSM network and is made available online within 1 hour of occurrence via the ResourceKraft data interface. The aims of this installation were to gather data for future analysis, highlight areas for potential energy savings, and model how a time based tariff might be automated.

Table I – Monitored Circuits

Lights	Immersion (Water Heating)
Sockets	Space Heating (Storage)
Cooker	Space Heating (Panel Heaters)
Bathroom Heaters	

Each of the circuits were analysed for their DSM suitability. As a result of this analysis the immersion water heater was chosen as the most demand side manageable load. The immersion offers demand side energy storage in the form of hot water. The details of the immersion water heater are as follows:

- The Immersion accounts for 30% of the apartment's total load
- Water is heated using a 3 kW resistive heating element
- Water is stored in a 300 litre factory insulated cylinder
- The cylinder dissipates heat through the insulation at a rate of 150 W
- Daily demand ranges from 0 – 25.38 kWh depending on usage behaviour with an average of 8.38 kWh as shown in Fig. 5.
- Timed operation scheduled from 12am – 8am and 4pm – 8pm daily which is governed by a thermostatically controlled heat limit of 65°C.

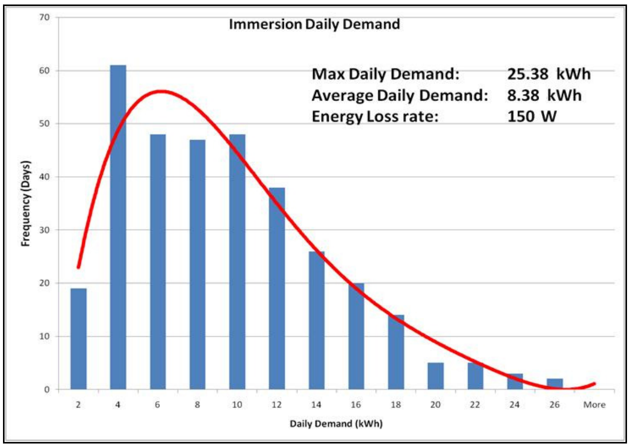

Fig. 5 Analysis of the daily demand of immersion heater over a 1 year period.

A rescheduling algorithm was developed to test the hypothesis that price optimised demand side management of the immersion heater would promote the increased use of wind generated electricity. The algorithm seeks to reallocate heating intervals to alternative times prior to the originally scheduled times in an effort to minimise cost. The algorithm accounts for the energy loss of "x" Wh for every hour that the load is shifted by. This limits the number of time intervals by which any given load can be shifted. The inputs are:

1) *Measured demand profiles (Quarter hourly resolution)*
2) *System marginal price (Quarter hourly resolution)*
3) *Rate of energy loss (Watts)*

The algorithm was run using one year of data gathered throughout 2008 and using the experimentally measured immersion heat loss rate of 150 W. Fig. 6 illustrates rescheduling on a day where average savings were achieved.

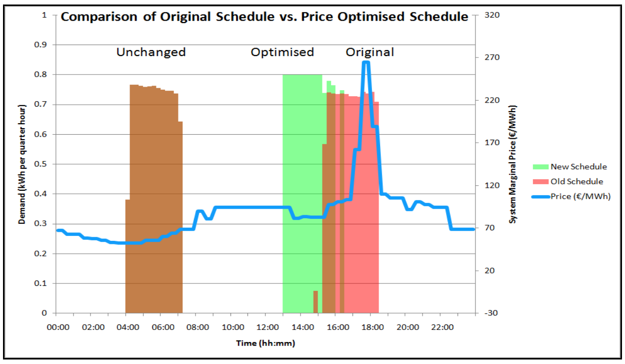

Fig. 6 Example of Original Schedule vs. Price Optimised Schedule. The 5th November is chosen as an example of average financial saving.

The algorithm was also run to consider energy loss rates ranging from 25 W to 300 W in 25 W increments to assess the DSM potential of systems with greater or lesser efficiency. The results from this analysis are detailed in table II.

Table II - Optimisation Results

Energy Loss Rate	Financial Saving	Demand Increase	Wind Energy Increase	Conventional Energy Decrease
25 W	30.06%	2.05%	22.74%	-1.68%
50 W	19.50%	1.73%	11.63%	-0.81%
75 W	15.28%	1.64%	5.51%	-0.32%
100 W	14.23%	1.96%	5.03%	-0.25%
125 W	13.33%	2.12%	4.56%	-0.20%
150 W	11.73%	2.14%	4.22%	-0.17%
175 W	10.45%	2.06%	3.74%	-0.14%
200 W	8.56%	1.91%	3.15%	-0.10%
225 W	6.58%	1.68%	2.33%	-0.05%
250 W	4.23%	1.17%	1.65%	-0.04%
275 W	3.62%	1.08%	1.51%	-0.04%
300 W	2.53%	0.86%	1.20%	-0.03%

These results show the increased load flexibility that can be achieved by demand side managing a system that offers a lower energy loss rate due to time displacement. A maximum yearly demand increase of 2.14% translates to an efficiency of 97.86%. A strong correlation is observed between financial savings, wind energy demand increase, and reduced conventional energy demand in relation to the various energy loss rates explored despite stable overall demand increase as shown in Fig. 7.

This provides evidence that price optimised demand side management consistently promotes the increased use of wind generated electricity and reduce reliance on conventional power plants.

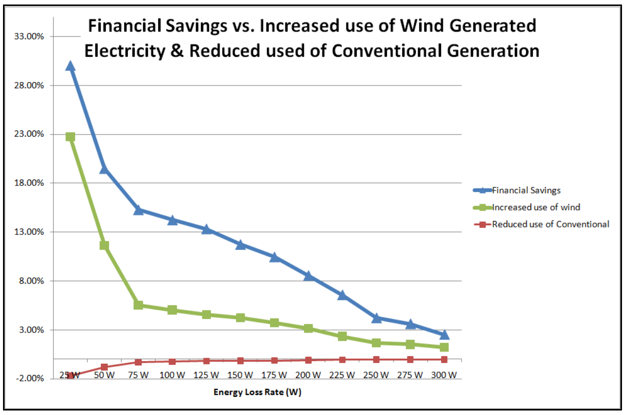

Fig. 7 Financial Savings and Increased use of wind generated electricity based on a range of energy loss rates.

4. Conclusion

As RES-E penetration levels continue to grow in Ireland, it is clear that grid flexibility will be forced to become more dynamic. This is generally considered to be the realm of supply side energy storage systems. Using domestic water heating as an example, it has been shown that aligning task scheduling with spot price electricity market prices also promotes an increase in the demand of RES-E while reducing the demand of conventional generation plant.

Increased efficiency levels and greater cost reductions can be achieved by applying DSM to systems that offer a lower energy loss rate due to time displacement. Furthermore as the role of wind energy becomes increasingly dominant on Ireland's electricity grid, the inherent price instability would be expected to amplify the results obtained during this experiment. This project will continue to develop on this concept for the scenario of Ireland's electrical grid by translating the discussed algorithm to optimise the charging of an Electric car and the heating of a house using a geothermal heat pump and under floor heating.

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