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Large Scale Hydrogen Fuel Cells – A Facilitating Solution for Renewable Energy

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Abstract – The generation of electricity by renewable energy sources such as wind, wave, tidal and ocean current generation technologies has made the operation of electricity systems more difficult. These difficulties arise due to the problems associated with the predictability, variability, and controllability of these energy sources. This paper proposes a solution to this problem using energy storage for generation in an electrolysis manufactured fuel - hydrogen - from reversible fuel cell technology used for electrolysis and power generation.

Index Terms – Electrochemical processes, Energy storage, Fuel cells, Hydrogen, Power system security, Tidal energy, Wind energy

I. INTRODUCTION

The electricity system on the island of Ireland is itself practically an isolated island system (there is a small 400MW interconnector between Northern Ireland and Scotland). The all-time peak system demand in the Republic of Ireland (ROI) was 4903MW (January 2008), whereas the Summer Night Valley falls to 1750MW. Before the year 2000 there was practically no wind generation in ROI, but there is now over 800MW of wind connected to the system. This obviously leads to huge variability in wind generation, varying between practically zero to over 700MW. This variability is graphically shown on Fig 1. The electricity grid on the island comprises the interconnected ROI and Northern Ireland (NI) systems. The combined peak demand of both systems is approximately 6500MW. Since November 2007 a single electricity market has operated on the island. The ROI demand characteristics shown in Fig 1 are similar in ROI and NI.

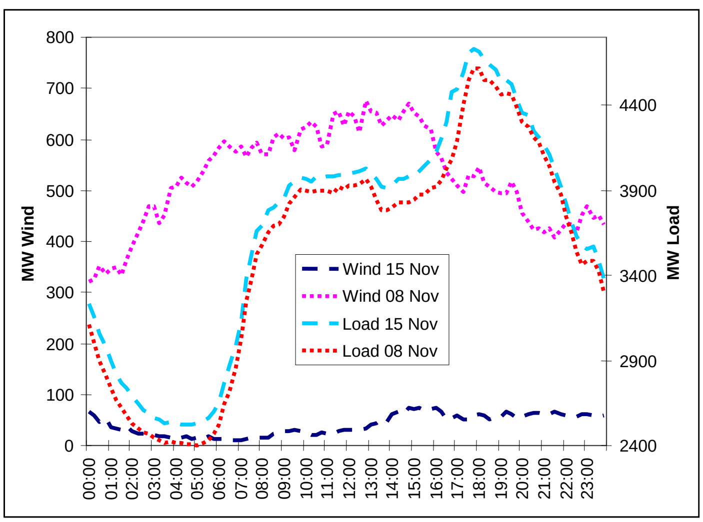

Fig. 1: System Load vs. Wind Output
Nov. 8th and 15th 2007

Clearly demonstrated in Fig. 1 is the extremely steep ramp rate in electricity demand in ROI in the mornings between 06:00 – 09:00. This necessitates starting up and/or ramping up large thermal plants in the mornings and ramping and/or shutting them down in the evenings. This requirement added to the variability and non-dispatchable nature of wind generators leads to the system frequency regularly moving between 49.85Hz and 50.15Hz, as shown on Figs 2 & 3.

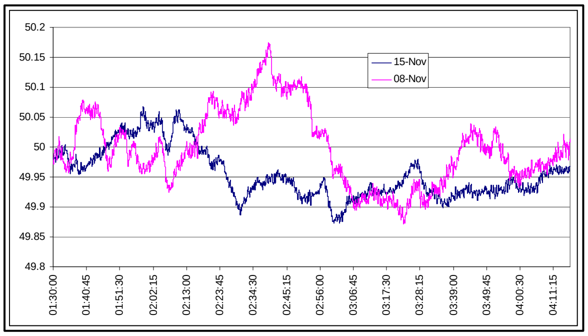

Fig. 2: System Frequency
Nov. 8th and 15th 2007, 01:30 – 04:00

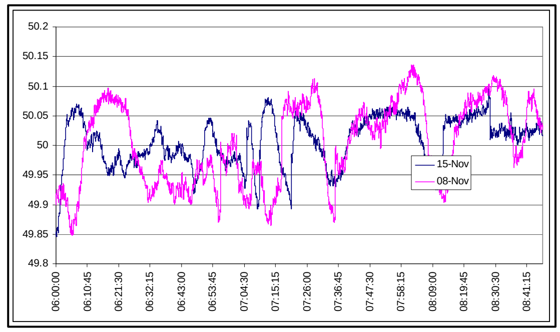

Fig 3: System Frequency
Nov. 8th and 15th 2007, 06:00 – 09:00

Government targets in ROI are for 3000MW of wind generation and 500MW of ocean energy generation by 2020. It is patently obvious that for a grid as small as that in the ROI and NI a number of major problems need to be overcome. The variability of wind and wave power will inevitably mean that negligible electricity generation will be available on many occasions when a high pressure atmospheric system exists over the country in winter – the time when the demand is highest. On the other hand the available generation from wind and wave will exceed the total system demand during windy nights in the middle of summer (it should be noted that similar problems will exist in the UK – which has set a target of 25,000MW of offshore wind by 2020). To allow for the development of large scale renewable energy generation, while ensuring acceptable system operations capability, one or more of the following measures need to be implemented:

1. Development of large scale energy storage facilities
2. Building large numbers of peaking plants
3. Building large scale interconnection facilities between ROI, NI, the UK, and possibly France
4. Ensuring greatly improved dispatchability of all types of renewable energy generating plant

This paper proposes a solution for option 1 above using large scale energy storage for generation, in a manufactured fuel – hydrogen – which is produced from a reversible fuel cell that facilitates electrolysis to make hydrogen and power generation from hydrogen [1] [2].

II. History

The power industry on the island of Ireland began with small independent power providers, these power stations sprung up across the country in the late 19th and early 20th centuries. In 1927 the Electricity Supply Board the (ESB) came into existence as a result of the Electricity (Supply) Act. Initially the ESB was formed as many of the existing power plants were having problems with customer supply and reliability of supply. Many of these plants were integrated into the ESB and the initial Republic of Ireland power grid was formed. ESB power plants were built and the fleet included hydro, petroleum and other fuels. ESB power lines were installed across the island and a stable power grid was established. In the 1950s Ireland began to produce power from peat, an indigenous energy source within the island. After the 1973 "Oil Crisis" more power plants were built using peat as a fuel to give Ireland an independent supply. In the 1980s a 915MWe coal fired power plant was added to the mix and gas fired boilers were built. In the 1990s and early 2000s several 400MWe to 800MWe Gas Turbine stations (GTs) and Combined Cycle Gas Turbines (CCGTs) were installed. Since 2000 many new wind-farms were added to the grid.

III. Impact of the Growing Irish Grid

For more than a decade ROI's economy and population has grown dramatically. Grosse Domestic Productivity (GDP) grew on average by over 6% p.a. from 1994 to 2007. The phenomenal growth was dubbed the "Celtic tiger" by the media [3]. The growth was stimulated by the introduction and expansion within the ROI of industries such as microchip, pharmaceutical, software and data storage [4]. As a result of this economic and population growth the demand for electricity grew by an average of 5% p.a. during the same period.

As the demand for electricity grew, producing and delivering stable power became a major challenge for the ESB and EirGrid, the ROI grid operator. Additionally the European Union introduced requirements for clean power generation technology which increased the workload for the ESB with major retrofits being installed to comply with EU pollution control directives [5].

The ROI and NI combined Irish grid is an isolated grid with a peak demand of approximately 6,500MW. As stated, the Irish grid has only one inter-connector with other grids – the 400MW DC link to Scotland. As such, a stable and free flowing connection to the vast grid that exists for power companies located upon continental land masses does not exist on the island of Ireland.

After the introduction and rapid growth of wind farms and wind power in Ireland, problems associated with variability, controllability and the necessity for backup thermal plant became evident. These problems were exacerbated by the size and isolation of the Irish grid.

The Irish grid, due to its size in this case, foreshadows events that can and eventually will be a problem for larger grids. These events are due to a rapid increase in renewable power generation and to the types of generation now being used worldwide, which are not steady state and can fluctuate on and off the grid almost instantly. In Ireland when the wind stops blowing in one part of the island it will generally stop everywhere on the island. The wind availability, of wind generators in Ireland is typically around 30%, whereas traditional thermal plant has generation availability of about 85%. We are proposing that a solution to the intermittent nature of a lot of renewable energy technologies is to use excess electricity at times of high generation to make hydrogen in a reversible fuel cell, and to use the hydrogen to generate electricity at times of low generation.

IV. Energy Storage

If energy storage is a viable solution to facilitate the growth of electricity generation by renewable sources, then it stands to reason that a simple solution would be advantageous both economically and technically. Hydrogen is a simple to produce chemical energy storage medium. When compressed or liquefied it has an attractive energy storage density by mass and volume [6].

A simple solution which this paper proposes is the use of hydrogen as an energy storage tool. Chemically hydrogen's energy storage capacity is approximately 3.3MJ thermal, per liter at 350bar [7]. Using this chemical property, stored hydrogen in a spherical vessel with a 10 metre diameter at 350 bars would hold 524m^3. Therefore hydrogen stored in this vessel would be able to supply, approximately 20MW thermal, for 24hrs.

V. Reversible Fuel Cells and Their Efficiencies

Currently organizations such as the University of California Irvine are researching Integrated Reversible Fuel Cell Systems for use in residential fuel cell applications [8].

The efficiency of reversible fuel cell technology is related to the efficiency of the fuel cell as an electrolysis device multiplied by the efficiency of the fuel cell as an energy supply device. The efficiency of the average fuel cell used as an electrolysis device is approximately 75% [2] (this depends upon the manufacturer, make and model of each device). The efficiency of a commercially available fuel cell used as an energy supply device is approximately 50% with an extra 15% recoverable power due to the addition of a turbine used as an energy scavenger through expansion of the fuel cell exhaust [1]. These combined devices have a theoretical total efficiency of 65%. Thus the efficiency of the total process - converting electrical energy to hydrogen and back again - would be 65% x 75% or approximately 49%. This number should improve as the technology improves.

Some energy will be lost due to the parasitic affect of hydrogen compression, at 350bar approximately 10% of the power stored would be required for compression and some of that compression power could be recovered due to expansion. This energy could come from either the renewable power source or from the manufactured hydrogen, see Fig 4.

At 49% process efficiency half of the energy produced during times of excess resources (e.g. wind) can be stored and delivered to the grid through a period of time which may be hours or days to allow the grid to bring traditional thermal power plants on load and to allow these plants to reach their operating conditions in a stable manner.

VI. THE CONCEPT

Under the all island market of NI and ROI, if a generator is greater than 10MW by law, it must sell to the market. The generator is licensed to construct and then licensed to generate. The license has a capacity number assigned to the generator.

Any generator is entitled to sell to the market and to receive the market clearing price plus a capacity payment. As the Irish grid becomes saturated with these renewable resources the price paid will decrease. Thus, due to supply and demand and system control requirements, there will be a limit to the amount of renewable power resources which the Irish grid can sustain. Therefore if renewables wish to make more money, they will have to store their power, or to market their power in places other than the grid.

The concept of storing power in the form of hydrogen created by excess power from renewable resources is a simple concept and with the current advances in fuel cell technology the authors of this paper believe it to be a viable concept.

The components necessary to produce hydrogen and then reuse it as electrical power are as follows, see Fig 4:

- A reversible fuel cell
- A source of demineralized water
- A hydrogen gas compressor
- A pressurized hydrogen gas storage container

The Irish island grid operator must dispatch in accordance with the daily predicted market schedule. Renewable power sources such as wind are dispatched first. When there are operational constraints the grid operator can modify the market dispatch schedule and if the renewable power becomes an operational constraint the operator could be forced to reduce the generation incentives (i.e. money) to alleviate the problems. A proposed mitigation method to this grid incentive reduction which would end up constraining renewable power generation is as follows; if the grid can control renewable power's ability to dump power to the grid, then the grid can shunt power off the system and into the storage scheme. Thus when power is not being paid for by customers (i.e. there is more supply than demand) a portion of that power can be stored. When power has been reduced by the nature of the renewable resource (i.e. there is no wind or waves) that stored portion of the power resource is discharged to the grid.

Using a reversible fuel cell can make the system as simple as flipping a switch and since the response time of the fuel cell is quicker than a power plant the grid will experience fewer disturbances without the time lag for startup required by conventional thermal generation plant.

Fig 4 the schematic of the system design concept, shows a renewable resource connected to the grid via pulse width modulation PWM rectifier/inverter contained within the Fuel Cell box which matches grid frequency as the Fuel Cell produces power as DC [9] [10]. The renewable power source is connected to a switch which can route power to a fuel cell or to the grid. This fuel cell in turn would be connected to a demineralized water reservoir which in turn would be electrolyzed by the fuel cell and converted into hydrogen and oxygen. Hydrogen would then be compressed and stored in the hydrogen storage tank.

When the grid needs more power the hydrogen will be combined with oxygen in air in the fuel cell, thus power is delivered to the grid. This process could increase grid reliability for hours or even days, depending upon the storage capacity of the tanks. The chemical combination of oxygen and hydrogen produces demineralized water as a result of the combination of the oxygen and hydrogen chemistry. Thus the water can be stored and the electrolyzation process can take place again and again with minimal demineralized water consumption and cost.

Additionally this fuel cell could produce pure oxygen from demineralized water when electrolyzed by the fuel cell. Hydrogen and oxygen would then be compressed and stored in the storage tanks as separate individual chemicals. This would require the addition of the following:

- An oxygen gas compressor
- A pressurized oxygen gas storage container

As oxygen is produced naturally from the electrolysis process it can be captured. Thus the use of oxygen in the fuel cell as a recombination chemical might be advantageous, but it is likely that recombining with air is a more economical source of oxygen for the fuel cell's recombination process.

Energy is invested in the splitting of oxygen and hydrogen in the electrolysis process, but as a byproduct, that pure oxygen is not required to recombine with the hydrogen. Thus this O_2 is a commodity that can be exploited and sold on the open market.

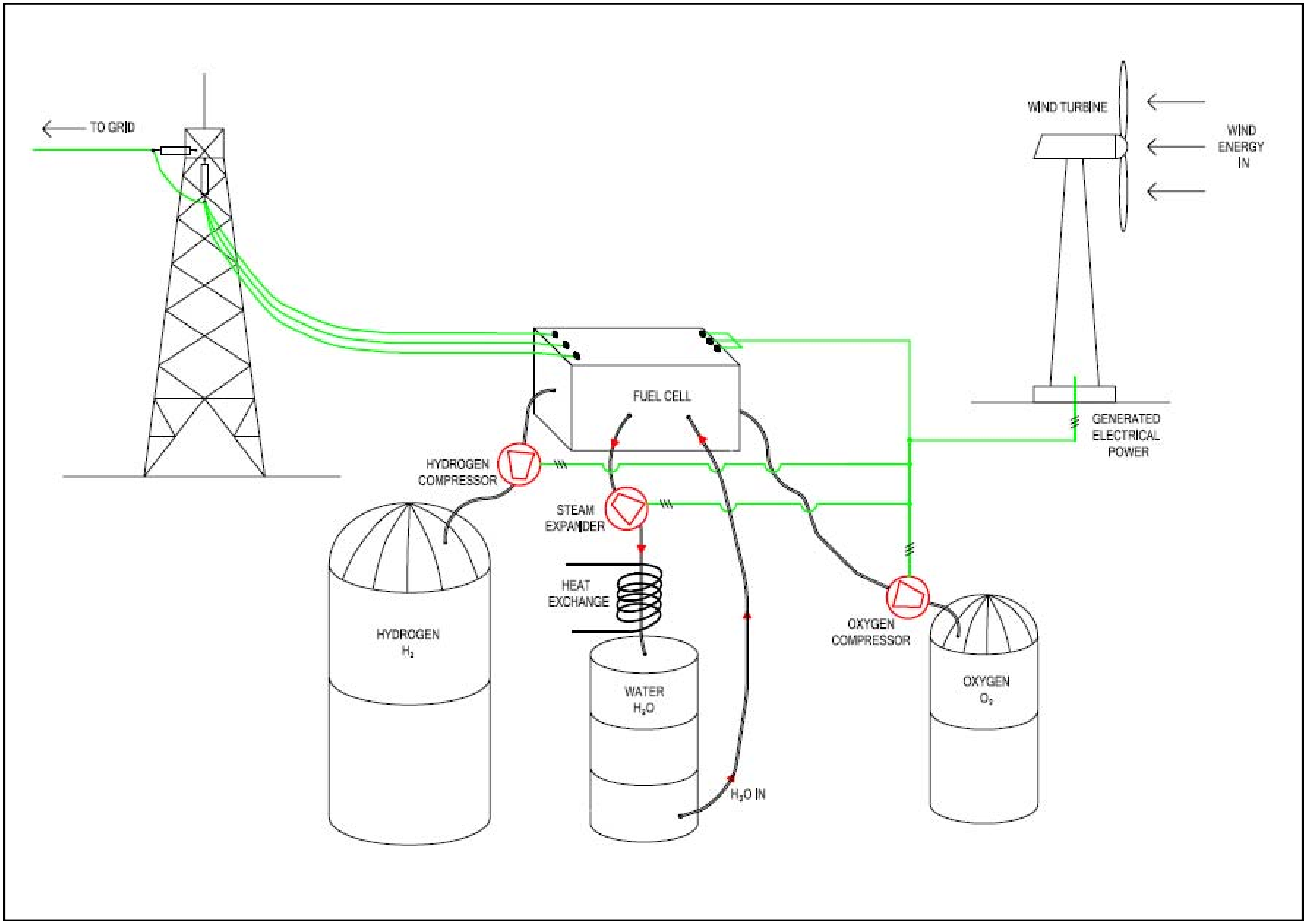

Fig 4: Schematic for High Density Energy Storage for Renewables

VII. CONCLUSION

The Irish grid is small and as such it is a good model for grid behavior throughout the world. As renewable generation issues are emerging on the Irish grid so too will they emerge on larger grids. Increasing power consumption in Ireland will require the grid to supply even more power.

The growth of renewable energy technologies must be facilitated if the world is to tackle climate change issues. The maximum quantities of energy should be harnessed when available, and therefore large scale energy storage is essential for times when renewable generation exceeds that which can feasibly be fed into the grid. High efficiency reversible storage also eliminates the need for some expensive back-up thermal plant.

The authors of this paper propose that using energy storage for generation - with hydrogen as a high density energy fuel - with reversible fuel cell electrolysis and generation technology could greatly facilitate the maximum possible use of renewable energy sources and greatly contribute to tackling the global climate change imperative.

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