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Most promising flexible generators for the wind dominated market

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HIGHLIGHTS

- Future efficiency and stability of the wind dominated require flexible generators.
- Energy storage systems are the most technically advantageous flexible generators.
- The advanced flexible CCGT is the most efficient solution from an economic point of view.
- Traditional peaking plants (OCGT) is the least advantageous flexible generator.
- The governments will play a key role in integration of the flexible technologies.

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ABSTRACT

The intermittent nature of wind power and other forms of variable renewable energy requires complementary dispatchable flexible generators in order to guarantee the efficient, reliable and secure operation of electricity systems. The most popular solution to date has been peaking plant, usually in the form of open-cycle-gas- turbines (OCGT). Energy storage technologies have so far been considered too expensive, however technology development, as well as challenging renewable targets could potentially make storage economically viable. Although new advanced flexible combined-cycle gas turbines (CCGT) have been developed by some manufacturers, they have not yet been investigated in electricity market models. This paper describes a techno-economic assessment of the most suitable flexible technologies for the wind-dominated all Ireland electricity market (the Single Electricity Market (SEM)). The analysis is conducted by considering the impact of a series of policy scenarios which are compared in an electricity market model. The comparison is quantified using three primary metrics: technical benefits to the system, economic advantages to the consumer and investment viability. Modelling results suggest that advanced CCGT and energy storage solutions are the most advantageous, however they need strong governmental support to attract potential investors and guarantee deployment in the market.

1. Introduction

In order to diversify energy supply, reduce greenhouse gas (GHG) emissions and to promote a low-carbon economy, many countries have implemented challenging targets for integrating variable renewable energy (VRE) technologies such as wind and solar power into national systems. For example, the European Union, along with the governments of the United Kingdom, Northern Ireland and the Republic of Ireland have set ambitious targets both for the reduction of GHG emissions and the proportion of energy demand to be served by renewable sources. Because it is mature and economically competitive, and because of the exceptional resources available, onshore wind power is the foremost VRE technology proposed to meet these targets. The governments of the Republic of Ireland and Northern Ireland (hereafter Ireland) have committed to serve 40% of demand with renewable energy in the all-island Single Electricity Market (SEM) and aim to facilitate the instantaneous penetration of up to 75% of load by non-synchronous power (NSP) by 2020 (DCNER, 2009), (DETINI, 2010). Given the near absence of hydro and the relative isolation of the Irish power system, these high targets make it perfect case study for the investigation of potential for flexible technologies in accommodating high levels of wind energy.

Integrating such high levels of VRE into a system built predominantly around large baseload generators has already resulted in significant levels of off-design operation for thermal plant and curtailment of VRE generation (Market Monitoring Unit, 2010), (Keatley et al., 2013), (Troy, 2010). The most common solution to the variability management problem to date has been the use of

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peaking generators like OCGTs. These have been favoured by investors due to their relatively low capital cost, flexibility and well-understood construction and operating processes. OCGTs are the only flexible generation technology which is expected to join the market by 2023, according to the latest Generation Capacity Statement report (Eirgrid and SONI, 2014). However, the high operating costs, low efficiency and consequently high GHG emissions of OCGTs have prompted the consideration of alternative, more efficient and less polluting forms of variability management for the future.

Recently, leading producers of thermal plant have announced the development of new advanced CCGTs, which are expected to be fast, flexible and highly efficient in cyclic operation. These units, designed to meet the need for flexible dispatchable generation in high VRE-penetration scenarios, will be available for the commercial deployment from 2015 (Probert, 2011). However, no installations of such generators have as yet been proposed or investigated for the SEM.

Grid-scale energy storage has also been proposed as a means to manage the increased variability of net load when high levels of non-dispatchable VRE are integrated into power systems (Edmunds et al., 2014), (Heide et al., 2011). Until now the main barriers to more widespread deployment of energy storage systems have been their high capital costs and, in the case of grid-scale systems such as pumped hydro and compressed-air energy storage, specific geographical requirements.

Previous studies on the deployment of centralised energy storage systems in the SEM concluded that there were potentially significant benefits in terms of reduced wind curtailments (Mullane, 2009), carbon emissions and spot prices, and increased security of supply. Connolly (Connolly et al., 2010) indicated highly favourable geographical sites for the building of pumped hydro systems, whilst the Triassic bedded salt formations in the north east of Ireland are promising for construction of compressed air energy storage (CAES) (Evans et al., 2006). Nyamdash et al. concluded that energy storage systems become viable options only with a great uncertainty in the system, e.g. wind power penetration of 50% and higher (Nyamdash et al., 2010). High capital costs are expressed as the major barrier for energy storage technologies installations in a number of studies (Connolly et al., 2012), (Foley, Díaz Loberaa, 2013), (O'Donnell, 2009), (Foley et al., 2015), (Tuohy, 2011).

Demand side response is another option to manage wind variability, which includes a wide range of possible solutions, owned and managed by final consumers. Demand side electric or thermal energy storage, smart metres and electric vehicles are among the most popular solutions being discussed in the scientific literature today. Implementation of demand response is not considered in this paper as it is a discrete area of research, which requires separate analysis, including the impact of human behaviour on the use and operation of demand-side technologies. This paper considers the requirement for optimal flexibility from the market point of view, although the potential contribution of demand side response replicates that oflarge scale energy storage as they have the same aim; to shift energy demand from periods of low electricity prices or high wind availability to periods of high prices and low wind availability.

It is evident that selecting the optimal solution to the variability management problem is not a straightforward process. Different studies give different answers to the question of the most technically and economically efficient options. The primary goal of this paper therefore is to make a comparative analysis of the most appropriate technologies to be deployed in the SEM, in terms of technical advantages for the system, financial viability for the investor and economic benefits for the consumer.

The research for this paper arose from the SPIRE (Storage Platform for Integration of Renewable Energy) project, which aims to quantify the potential for energy storage in the SEM. Analysis of historical electricity market operation shows that regulatory framework, market factors and operating characteristics have a significant impact on the profitability and overall viability of any generating unit. Analysis is therefore based on a model of the SEM developed with Plexos electricity market simulation software, which evaluates which flexible units (OCGT, CCGT or storage) are most likely to be scheduled to maintain system security and complement VRE, and to assess their potential profitability and consequent investment viability.

The modelling is focused on two time horizons: 2020 (with a renewable energy target of 40% (DCNER, 2009), (DETINI, 2010)) and 2030. As government targets for VRE generation have not yet been established for post-2020, 2030 is used as an indicative timeframe with two scenarios for renewable energy penetration, reflecting high and low levels of progress with respectively 45% and 52% of electrical energy demand served by VRE as assumed by the SEM committee in its studies (SEM Committee, 2014a, 2014b, 2014c).

Future market scenarios are developed from an extensive review of policy literature regarding SEM development, and possible alternative scenarios are suggested by the authors.

2. Modelling methodology

2.1. Market model

In order to analyse and compare the technical and economic characteristics of different flexible generators it is necessary to create a market model which is able to replicate SEM trading arrangements and is flexible enough to simulate a range of scenarios and market strategies. Plexos software was chosen for the design and simulation of the SEM model. This is one of the leading simulation tools for modelling aspects of electricity markets including investment planning, risk assessment, energy storage optimisation, electricity price forecasting and others (Energy Exemplar, 2010), (Bianco et al., 2015). The regulatory authorities of the SEM utilise Plexos for the market performance simulation and assessment, and investigation of market operation strategies (CER, NIAUR, 2012).

A schematic representation of the SEM model in Plexos is presented in Fig. 1. The SEM is a mandatory gross pool market with two interconnection links to the Great Britain market with a total capacity of 1 GW. The Plexos model of the SEM therefore consists of the two regions: the SEM and GB markets, connected by two links representing the Moyle and East-West interconnectors. The SEM region is simulated with a detailed representation of all available generation units in the market in order to replicate spot price settlement, while the GB region has a simplified structure in order to reflect only import to and export from the SEM. Under current SEM market rules, all generators submit complex bids into the market which reflect short-run marginal costs (fuel and carbon costs, variable operational and maintenance costs) and exclude any fixed costs or profit components (CER, NIAUR, 2011). Spot price is based on an unconstrained market and is defined by the costs of the marginal unit that meets system demand for every half hour period. Spot price and unit commitment is defined by chronological market optimisation using a mixed integer algorithm based on the economic and technical characteristics of individual power plants. The objective function is total system costs minimisation.

The GB region is represented by a generation stack model, where all power generators are grouped by fuel type and efficiency characteristics. The GB market price is optimised separately