Energy xxx (2014) 1–11

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Impact of offshore wind power forecast error in a carbon constraint electricity market

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ARTICLE INFO

Article history:
Received 11 November 2013
Received in revised form
6 June 2014
Accepted 9 June 2014
Available online xxx

Keywords:
Offshore wind
Electricity markets
Forecast error
Scheduling
Dispatch

ABSTRACT

This paper investigates the impacts of offshore wind power forecast error on the operation and management of a pool-based electricity market in 2050. The impact from offshore wind power forecast errors of up to 2000 MW on system generation costs, emission costs, dispatch-down of wind, number of start-ups and system marginal price are analysed. The main findings of this research are an increase in system marginal prices of approximately 1% for every percentage point rise in the offshore wind power forecast error regardless of the average forecast error sign. If offshore wind power generates less than forecasted (−13%) generation costs and system marginal prices increases by 10%. However, if offshore wind power generates more than forecasted (4%) the generation costs decrease yet the system marginal prices increase by 3%. The dispatch down of large quantities of wind power highlights the need for flexible interconnector capacity. From a system operator's perspective it is more beneficial when scheduling wind ahead of the trading period to forecast less wind than will be generated.

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1. Introduction

The European Union (EU) has developed a long-term framework for reducing greenhouse gas emissions by 80%–95% by 2050 compared to 1990 levels [1]. This framework aims to help the EU become a competitive low carbon economy by 2050 by setting policy plans in areas such as transport, energy and climate change. The power sector is the most significant for achieving the 2050 targets as the EU roadmap specifies that carbon dioxide (CO2) emissions from the power sector are to be almost completely eliminated by 2050. The Republic of Ireland and Northern Ireland have developed national roadmaps for achieving the EU 2050 targets [2,3]. They estimate renewable resources could provide 74% and 60% of the electricity generated in the Republic of Ireland and Northern Ireland respectively. In both countries the renewable electricity comes mostly from onshore and offshore wind power. The total installed wind power in the Republic of Ireland will be 12,000 MW consisting of 6000 MW offshore and 6000 MW onshore. In Northern Ireland the total installed wind power by 2050 will be 2800 MW with 1200 MW offshore and 1600 MW onshore [2,3]. The all-island generating capacity for 2050 will be 24,942 MW with the offshore wind in the Republic of Ireland and Northern Ireland making up 24% and 5% of the generating capacity respectively.

The disadvantage of wind power is that it is variable and stochastic by nature which makes the role of the system operator (SO) even more challenging. Studies have shown that the inclusion of significant levels of wind generation into an electricity system can have major impacts on the system security, scheduling and dispatching of units [4,5]. Connolly et al. [6] concluded the ramping capabilities of the generating units are crucial to the deployed of high wind generation. The operating reserve and flexibility of the power system were found to be crucial to the development of wind energy in electricity markets [7,8]. Hong et al. [9] concluded that to accommodate the increasing amount of wind energy onto the Jiangsu's power system more flexible gas generating units are required rather than coal and nuclear power plants. Inflexible power systems with large penetrations of wind energy have been shown to have major problems with wind curtailment [10]. The variability of the wind power and responses of conventional generation at short notice is crucial to system balancing and understanding of high levels of renewable generation that a grid in the future can incorporate [11]. The SOs of the Single Electricity Market (SEM) in the Republic of Ireland and Northern Ireland released statistics on the wind forecast accuracy for the month of December 2012 [12]. The report highlighted a maximum and minimum

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http://dx.doi.org/10.1016/j.energy.2014.06.037
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Please cite this article in press as: Higgins P, et al., Impact of offshore wind power forecast error in a carbon constraint electricity market, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.06.037

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forecast error of +798 MW and −634 MW for a total installed wind capacity of 2088 MW. A maximum normalised mean absolute error of 48.8% and average 12.2% were experienced. The large planned wind capacity for 2050 will consequently mean wind power forecasting will become a critical power system planning tool. Onshore wind power forecasting techniques have improved dramatically and continue to advance but Offshore Wind Power (OWP) forecasting is more difficult due to limited datasets and knowledge [13]. As offshore wind generation increases the variability will become more pronounced and better planning techniques and forecasting will be required [14].

The accuracy of wind forecast has been shown to be considerably lower over an entire transmission zone rather than over a single zone and that averaging over wider areas increases forecast accuracy [15,16]. The wider spatial spread of wind farms and increased offshore wind generation has been found to be the main factors in the reduction of wind curtailment [17]. In Ref. [18] the impact of Ireland's 2020 wind energy targets with varying limits for wind curtailment was examined and it was shown that approximately 7%–14% of wind production was not dispatched. It was also shown that increases in wind forecast accuracy also resulted in reductions in wind curtailment but provided no improvement in emissions production [19]. A study of the SEM with 6000 MW of installed wind capacity stated ‘improving wind forecasting will lead to relatively small savings in system costs on a percentage basis but may account for millions of euros’ [20]. For a system like the SEM in 2050 with over 14 GW of wind power, wind forecasting could have a substantial impact on the operation of the system.

Studies have highlighted the interconnector capacity between Great Britain and Ireland as critical during moments of high wind and low load [17,21,22]. Tuohy et al. [23] included Monte Carlo simulations for wind and load uncertainties and found that the mid-merit, peaking units and the interconnections were the most affected components of the electricity system. The method implemented in Ref. [23] involved analysing the difference between a perfect foresighted model and a stochastic optimisation model. Other studies with similar techniques have determined that a stochastic optimisation for an electricity system produces an increase in production costs in comparison to a model with perfect foresight [24,25]. The difference with this research is the impact of the magnitude of the OWP forecast error is being analysed not the optimising technique.

The OWP forecast error not only affects the operation and management of the electricity system but also the financial aspect. In Ref. [26] wind power predictability as an investment factor for selecting onshore wind farm sites was investigated and it was found that predictability can play an important role in the operation and maintenance of offshore wind farms due to improved availability from reduced downtime periods. In Ref. [27] the financial profits of individual generating units are also affected by increased wind generation. An increase of wind energy on the system pushes more thermal/conventional generation off the system. This reduces the System Marginal Price (SMP) and therefore the potential profits for conventional plants. This new wind generation also requires the existing plants to operate more flexible which can increase running costs and downtime for maintenance as well as shortening the plant life. The increased pressure from conventional generators running with variability and the impact offshore wind forecast error has on the SMP and merit order means some conventional generators could find it difficult to survive on unpredictable future SMPs.

This research shows that a considerable amount of work has been performed on the impacts of increasing wind generation on electricity systems, however, only a small amount has analysed the impact of OWP forecast error. The novelty of this work is the analysis of the impact of offshore wind forecast error on an electricity system with over 60% of generating capacity originating from renewable energy resources. This paper is structured in five sections. Section 1 is the introduction. Section 2 presents the test system and describes the methodology used to investigate the impact of OWP forecast error in the SEM in 2050. Section 3 presents the results of the analysis. Section 4 discusses the impacts of OWP forecast error in the SEM in 2050 and conclusions.

2. Test system and methodology

2.1. Single electricity market (SEM)

The SEM is a mandatory all-island wholesale pool market through which generators and suppliers trade electricity. The market operates over three trading periods: before, intra-day and after. The before trading period consists of each generating unit bidding their commercial offer data and technical offer data for each half hour interval in the intra-day. The commercial offer data and technical offer data contain price/quantity bids and no load costs. The SOs produce the reserve constrained unit commitment (RCUC) schedule based on forecasted wind generation, price/quantity pairs from all generating units and the SEM system stability requirements. The difference between an unconstrained unit commitment and RCUC is the inclusion of transmission constraints. From the RCUC schedule the SOs inform each generating unit of their required generation and operating hours before the start of intra-day trading. The intra-day period involves the real time application of the generation schedule. Both SOs implement the schedule and are responsible for delivering an efficient operation of the wholesale power market. The SO's continuously analyse the wind forecast, generating capacity and system demand requirements prior to the trading period based on updates to maintain system stability. The four days after the intra-day the Single Energy Market Operator (SEMO) calculates the SMP for each trading period during the intra-day. These four days are known as the after period. This SMP is the price applicable to both generators and suppliers receiving/making payments for electricity generated/used [28].

2.2. PLEXOS model

The majority of research for modelling unit commitment and dispatch scheduling of electricity systems have used either deterministic or stochastic optimisation techniques [18–20,23,25,29]. The main difference between both techniques is that deterministic modelling with perfect foresight ‘may provide lowest cost solutions for system dispatch but also may provide unrealistic results’ [30], whereas stochastic optimisations mimic real power systems dispatches. For this research a mixed integer, stochastic optimisation will be applied using Energy Exemplar's PLEXOS for Power Systems version 6.208R03 with the Xpress optimiser [31]. Xpress was set with mixed integer programming at a relative gap of 0.05%. Xpress aims to minimise the objective function, shown in Equation (1) which is conditional of a number of constraints:

$$\min \sum_{t \in T} (c_{jt}.U_{jt} + n_{jt}.V_{jt} + m_{jt}.P_{jt} + \mathrm{vl.use}_t + \mathrm{vl.usr}_t) \quad (1)$$

where t indexes time periods in chronological order $t = 1, \ldots, T$, c_{jt} is the start cost of unit j in period t, U_{jt} is a binary quantity representing if unit j has started the period before t, n_{jt} is the no load cost of unit j, V_{jt} is a binary quantity representing the generating status of unit j, m_{jt} is the production cost of unit j, P_{jt} is the power output of

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