The Impact of Short Term Storage on Power System Operation

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***Abstract*— Increasing installed capacities of wind power in an effort to achieve sustainable power systems for future generations pose problems for system operators. Volatility in generation volumes due to the adoption of stochastic wind power is increasing. Storage has been shown to act as a buffer for these stochastic energy sources, facilitating the integration of renewable energy into a historically inflexible power system. This paper examines peak and off peak benefits realised by installing a short term discharge storage unit in a system with a high penetration of wind power in 2020. A fully representative unit commitment and economic dispatch model is used to analyse two scenarios, one 'with storage' and one 'without storage'. Key findings of this preliminary study show that wind curtailment can be reduced in the storage scenario, with a larger reduction in peak time ramping of gas generators realised.**

***Index Terms*—Generation Dispatch, Power Generation, Power System Simulation, Wind Energy Integration.**

I. INTRODUCTION

The traditionally fossil fuel dominated power system is in a state of flux. The rise of renewable energy, driven by legislation, is ensuring that sustainability is at the cornerstone of the future power system. In the single electricity market of Northern Ireland and the Republic of Ireland (SEM), the installation of wind power has been the favoured means of integrating sustainability into the power system. By 2020, it is envisaged that wind power will account for 31% of installed capacity [1] contributing to the 40% electricity production from renewables target [2]. Thus Ireland is an interesting case study for other power systems developing large wind penetrations. Such a high penetration of wind power results in significant problems for the system operator. The main concern relates to the stochastic nature of the resource, given that it is not fully dispatchable by the system operator [3]. In addition, wind forecast error during day ahead dispatch of thermal generation can negatively influence the unit commitment and economic dispatch problem, placing increased operational stress on typically inflexible thermal plant to fulfil the residual demand [4].

Energy storage provides a method by which the variability of wind power can be compensated for, reducing the need for thermal generation to fulfil the residual demand [5] and increasing the level of system flexibility [6]. Storage units are also a key component in the establishment of smart grids and can provide system services as well as contributing to peak load shaving [7], by discharging energy stored from the grid at off peak times. This strategy is not only beneficial to system operators, but also provides an opportunity for plant owners to take advantage of arbitrage between the peak and off peak electricity prices [8]. Despite clear benefits of storage, the business case is difficult to justify or develop in current liberalised electricity market regimes [9] [10]. Currently, the only method of storage in the SEM is provided by pumped hydroelectric storage (PHES) at the Turlough Hill plant. This plant utilizes four turbines and provides 292 MW to the system. Two other projects are planned, a 268 MW compressed air energy storage (CAES) plant in Larne [11] and a 100 MW battery plant at the Kilroot power station [12]. Both of these projects are situated in Northern Ireland, with the Turlough Hill unit in the Republic of Ireland. Both PHES and CAES are site specific, requiring very precise geography and geology [13]. Battery storage is a field experiencing a large amount of research activity regarding optimal sizing [14] and control [15] in power systems with high wind power penetrations.

The majority of work concerning the SEM and energy storage has considered high capacity PHES and CAES plants in 2020. The influence of 270MW of CAES in the 2020 SEM was considered in [16]. It was found that CAES reduces the volume of electricity generated by gas and coal fired generating units, whilst a significant increase in system marginal price was observed, negatively impacting the retail market. In [17], a 500MW PHES plant with 10 hours of storage substituted 500MW of conventional plant in the SEM. This work focused on analysing the ability of storage plant to replace existing capacity, and did not fully consider the use of storage purely for short term operation. The 10 hour storage capacity was shown not to be an attractive investment, unless the wind penetration on the system reached over 50%. Wind

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curtailment was shown to decrease with storage at high wind penetration levels.

In [18], the attractiveness of PHES storage is analysed based on improvements in SEM operational costs and unit size. It was found that PHES has the ability to reduce operational costs, but costs would increase if 100% wind integration was to be achieved. It was also shown that turbine capacity does not show the same increases as pumping capacity in the presence of increasing wind penetration. However, the use of domestic heat pumps were also shown to be as economical and less sensitive to oil prices, highlighting the need to consider all a range of opportunities for renewable integration.

This work differs from those referenced by looking at storage operation over much smaller time frames. The system wide effects of such small storage are envisaged to cumulate as storage economics becomes more attractive. The work presented in this paper is preliminary, and focuses on small improvements in curtailment levels in order to reduce the operational stresses placed on thermal generation at peak time. This is achieved by analysing the state of the system at key time periods over the year considering operational metrics instead of economic considerations. This paper contains five sections. Section 1 provides an introduction and brief literature review. Section 2 outlines the simulation methodology and describes key assumptions and data inputs. Section 3 documents the analysis, considering storage profiles, wind curtailment, effects on unit commitment, peak time generation capacity utilisation and ramping for the with and without storage scenarios. Section 4 discusses the results relating to peak and off peak operation of the storage unit from the point of view of the system operator. Section 5 concludes and outlines future work direction.

II. METHODOLOGY

A. Test System

The SEM was chosen as the test system for this analysis due to the level of wind capacity planned for 2020. Due to the size of the system, installed wind capacity is forecasted to make up 31% of total installed capacity [1]. This provides a very interesting set of challenges for the transmission system operators (TSO i.e. EirGrid and SONI respectively). In an effort to mitigate the risk associated with high penetrations of stochastic wind energy, the system operator imposed a limit on the quantity of non-synchronous generation on the system at any time. This is referred to as the system non synchronous penetration (SNSP) limit and can be seen in (1). Currently, the limit is set at 50%, with step increases to 75% by 2020 [19]. The 75% limit is used in the simulation discussed below.

$$\frac{Wind\ Generation - |Imports|}{Demand - |Exports|} < 75\% \qquad (1)$$

The SEM is a mandatory pool market. All generators eligible to dispatch must generate into the pool, and all buyers much purchase their electricity from the pool at the System Marginal Price (SMP). Units are dispatched according to the price quantity pair bids they submit to the market. These bids are based on each unit's technical specifications such as ramp rates, start up and no load costs [20]. Generators available to be dispatched are sorted with respect to their short run marginal cost (SRMC), with the cheapest units used to satisfy system demand. The SMP is then set by the summation of shadow price and uplift payments. Shadow price accounts for the SRMC of in merit generation units, whereas uplift seeks to reimburse the cost associated with start-up and no load costs not recovered by the infra-marginal rent earned in that period [21].

B. Model

The generation and demand profiles used in the simulation are based on those outlined in [1]. Total installed wind capacity on the system was 4700 MW, with 3500 MW installed in the Republic of Ireland and the remaining 1200 MW installed in Northern Ireland. The wind generation profile in 2020 was assumed to be similar to that of 2011, scaled by the appropriate factor to match the increased installed capacity. Fuel prices for thermal generators were derived from the price predictions published in [22] via the fuel price calculator used in [23]. A carbon tax of €30/t was assumed in accordance with [24].

This analysis is only concerned with the system operator's perspective, and the model construction reflects this. During each run of the simulation, two models (RCUC/SCUC and Dispatch Quantity) are executing in interleaved mode, passing information between them and re-optimising for each time step. The first part of the simulation is concerned with reserve constrained unit commitment and security constrained unit commitment (RCUC/SCUC). This model has a wind forecast standard deviation error of 13% to reflect the time between the day ahead scheduling and the real time dispatch. The second model in the simulation utilises the price quantity pairs from the RCUC/SCUC model run, re-optimises for the assumed no wind forecast error and passes the new generation schedule to the RCUC/SCUC model to progress to the next time step. The outputs of the Dispatch Quantity model are analysed in the remainder of this paper.

C. Scenarios

The aim of the work conducted is to analyse the effects a storage unit can have at both off peak times via charging, and at peak times via discharging onto the grid. Therefore, two scenarios, 'with storage' and 'without storage' were used. The inclusion of storage is the only change made between both models in order to gain meaningful comparison and to ensure the only deviations are due to the presence of storage.

D. Storage Unit

It is thought that the parameters of the storage unit could be interpreted as any form of storage (e.g. a battery bank) ensuring that this analysis remains technology neutral. Maximum power of the unit was 100 MW, split over two constituent units (i.e. 50MW each) with a total of 100MWh of energy storage capability. Selection of theses parameters was influenced by power of the planed battery storage plant at Kilroot [12] and relative storage capacity of battery units described in [25]. A round trip efficiency of 80% was assumed as a conservative estimate based on [26].

III. RESULTS AND ANALYSIS

A. *Storage Scheduling*

Storage charge and discharge times are treated differently in the test system. Charge times were identified by determining the periods where the highest wind curtailment occurs, in order to maximise the positive impacts of storage by adding load with a view to absorbing extra wind generation. The test system with no added storage showed that the hours between 1am and 4am showed the highest levels of curtailment during 2020 and can be seen in Fig. 1. This would be expected considering low demand and the requirement to maintain system balance and minimum thermal generation. The storage unit was constrained to charge during these periods at a rate of 25MW per hour.

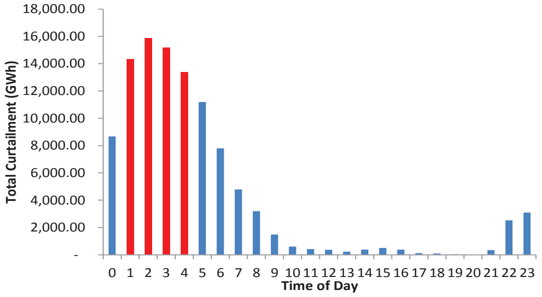

Figure 1. Total Curtailment by Hour in 2020

Storage discharge was not placed under any constraints in the system. The solver was free to optimise discharge considering the storage device's variable operation and maintenance charge (VO&M) of 150 €/MWh, which directly impact the unit's SRMC. This figure was set slightly below the average peak time SMP of the 'without storage' scenario in order to prevent undue distortion of the merit order, whilst still ensuring frequent unit commitment. This resulted in a SRMC indicative of peaking plants in the test system and ensured discharge occurred at times of interest to this study. It should be noted that the test system is a system operator model and not a market operator model, thus the prices used are not fully indicative of the real system and are for reference purposes between generation units only. The discharge profile, shown in Figure 2, follows the system demand well, with the majority of discharge occurring at peak times, with a modest increase during the mid-morning peak.

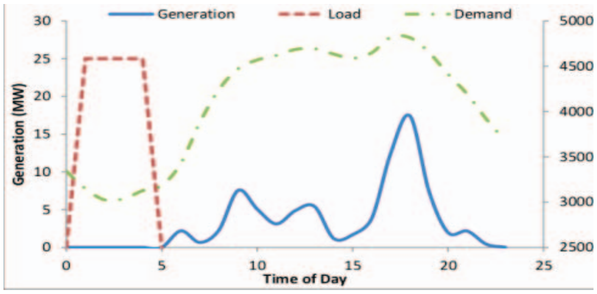

Figure 2. Storage Operational Profile

B. *Wind Curtailment*

Due to the high 75% SNSP limit, curtailment in the no storage scenario is forecasted to be 224 GWh during 2020. This corresponds to 1.8% of total available capacity based on 4700MW of wind on the system. By scheduling the storage unit to add load to the system during peak curtailment times, a reduction in wind curtailment of 6 GWh to 1.7% of total available capacity was achieved. As shown in Figure 3, time averaged curtailment showed the largest decrease during storage charging periods. Further investigation of the occurrences of wind curtailment during storage charging hours showed that despite the storage unit being connected to the system, it was wind that directly charged the unit 72% of the time. In these instances, the difference between both scenarios was exactly 25 MW (the hourly charging capacity of the storage unit) and suggests that storage enables execution of a load for curtailment swap in the system.

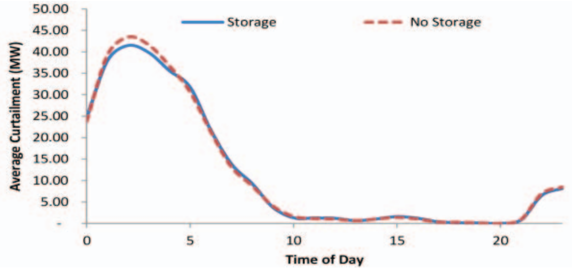

Figure 3. Time Averaged Curtailment

C. *Unit Commitment*

The ability of storage assets to cause alterations in unit commitment for both charging and discharging timeframes was well illustrated. During the periods 00:00 to 05:00 on 17th February 2020, large uncharacteristic differences in levels of wind curtailment occurred between both scenarios and are shown in Table I.

TABLE I. LARGE DIFFERENCE IN WIND CURTAILMENT

		Total Thermal Generation (MW)	
Time	Change in Wind Curtailment (MW)	Storage	No Storage
00:00	0	1543	1543
01:00	25	1507	1507
02:00	234	1298	1507
03:00	222	1310	1507
04:00	37	1507	1519
05:00	-209	1519	1310

At 00:00, there is no difference in curtailment since the storage unit is inactive. Normal operation occurs at 01:00, with a wind curtailment reduction of 25 MW in the storage scenario. Total thermal generation was the same in all four cases. The large decreases in curtailment experienced at 02:00 and 03:00 are due to the shutdown of the Poolbeg gas generator unit in the storage scenario, enabling a large

amount of wind to come onto the system for both periods. Characteristic amounts of curtailment occur again at 04:00 due to Poolbeg coming back online. The opposite occurs at 05:00, where the 'without storage' scenario unit commitment results in the shutdown of Poolbeg, enabling more wind to be accommodated for that period.

The difference in utilisation of online capacity can be determined by analysing undispatched capacity (capacity that is online but not utilised). Using data for 17 February 2020, it is shown that the storage scenario uses much more online capacity than the no storage scenario. Figure 4 shows this undispatched capacity, where large fluctuations indicate changing unit commitment. When Poolbeg is shutdown, a large drop in undispatched capacity occurs signifying the loss of capacity above the previous generation level.

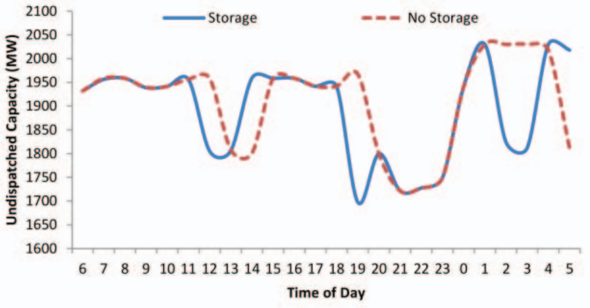

Figure 4. Undispatched Capacity

D. *Peak Time Generation*

Due to the operational constraints of thermal plant, ramping, the rate at which a unit can alter its output to meet demand, is a key concern for maintaining security of supply at peak times, as well as facilitating the high variability of wind generation. Due to its dual operation, storage has the ability to both increase wind generation on the system during charging, but also reduce the necessity of thermal plant to ramp during discharge. Total ramping up, .i.e. the upwards change in generation from period t to t+1 over 2020, is shown in Figure 5. The ramp up conducted in the system decreased by 3% in the storage scenario. All providers of this flexibility saw decreases in their provision.

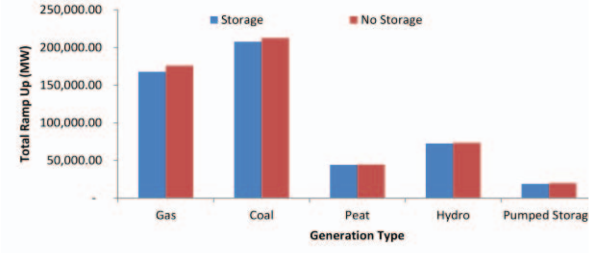

Figure 5. Total Ramp Up

The largest decrease in ramp up provision was by gas generation, providing 5% less ramp up in the storage scenario. The time averaged provision for gas plant during peak time is shown in Figure 6. It is clear that storage has had the largest impact on the ramping conducted in the time before peak demand, as expected due to the physical constraints on the plant. Ramping at peak time was reduced by approximately 9% as a result of storage.

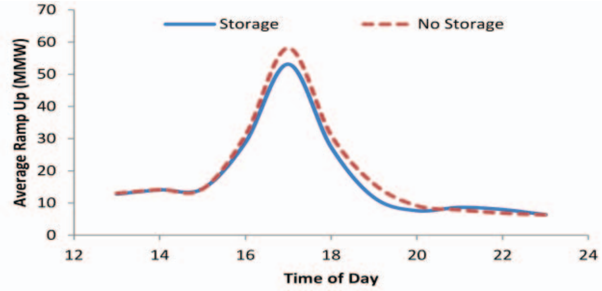

Figure 6. Average Gas Unit Ramp Up

E. *Total Generation Cost*

Despite increasing the level of wind generation on the system, and a frequent reduction in the number of units committed, the addition of storage to the system increased total generation costs by €7.4 million. The main contributor to this increase in cost was the storage unit itself, due to costs for charging and discharging. Total thermal generation output decreased from 18,319 GWh to 18,298 GWh in the storage scenario. Gas fired generation, due to its dominance in the fuel mix, showed the largest decrease in generation volume of 36 GWh. Due to the decrease in curtailment, wind generation increased by 6 GWh.

IV. DISCUSSION

Ultimately, the inclusion of a relatively small amount of storage on the system has wide ranging implications for thermal and renewable generation alike. In charging mode, storage has shown its ability to absorb wind that would otherwise not have been put on the system. The quantity of wind curtailment reduced is directly proportional to the size of the storage unit, and in this study the overall reduction is quite small given the size of the unit. Studies investigating other methods of storage in the SEM have documented larger increases in wind generation, whilst analysing larger storage units and increased wind generation [16], [17]. This analysis proves that small storage devices can have a measurable impact on the integration of renewables. In addition, it has been shown that the storage unit in some instances can cause dramatic shifts in the unit commitment of thermal generation. The knock on effects of such changes in the optimisation strategy have yielded fewer committed units in the periods presented. Therefore, the potential to utilise small storage units as part of a generation portfolio could potentially benefit generating asset owners in portfolio optimisation, as well as providing fast ramping supply for the TSO. The unique characteristics of storage can reduce the residual impact wind has on thermal generation operational profiles, enabling better operation of generating assets.

The main finding of this work relates to the peak time operation of the storage unit. By design, the storage unit has a large impact at peak times since the four hour off peak charge has the ability to be released in one hour. A marked decrease of 5% in the ramping up conducted in the system was achieved by including storage. By reducing ramping at this time, stress placed on thermal generation is decreased. Ramping is becoming an increasingly sought after commodity in power systems with high penetrations of wind power, since it is ramping that counters the inherent stochastic nature of wind. The SEM TSO EirGrid is planning to reward this flexibility by creating three new system services for ramp up provision [27]. Reduction in the necessity of short term ramping up provision is the key benefit of introducing storage capability.

Despite lower levels of unit commitment in some instances, total generation costs for the storage scenario increased by 0.5%. This is mainly due to the fact that the storage unit was scheduled to run every day at peaking plant costs. However, excluding storage operating costs, the cost of thermal generation decreased by 0.2%. The presence of storage prompts changes in the merit order, enabling more economic dispatch of thermal units during peak and off peak periods. However, overall costs increase and the ability of storage to generate economic value is beyond the scope of this preliminary study.

V. CONCLUSION

This paper analysed the impact of both charging and discharging a grid scale storage unit in the SEM during 2020, and compared this to a scenario with no storage available. The test system was modelled using a least cost optimisation strategy in order to achieve sufficient unit commitment and economic dispatch. The main findings of this preliminary study relate to wind curtailment and ramp up provision. In the 'storage scenario' wind curtailment was reduced, enabling more wind to be dispatched on the system during periods of significant curtailment in the 'without storage scenario'. The quantity of ramping up conducted by thermal generation in the periods before peak demand showed a significant decrease in the 'storage scenario'. This shows that relatively small storage units designed for short term generation can reduce the stress placed on traditional generating units at critical times. Finally, in the next part of this research, more detailed analysis will investigate the optimal pricing strategy of the storage device in order to contribute system services, but also to achieve effective energy arbitration in the SEM. The relationship between storage and thermal generation will also be further developed, with a virtual reduction in generator minimum stable levels during charging hours.

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