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System Operational Costs Reduction with Non-Conventional Reactive Power Sources.

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Abstract. Wind energy installations are increasing in power systems worldwide and wind generation capacity tends to be located some distance from load centers. A conflict may arise at times of high wind generation when it becomes necessary to curtail wind energy in order to maintain conventional generators on-line for the provision of voltage control support at load centers. Using the island of Ireland as a case study and presenting commercially available reactive power support devices as possible solutions to the voltage control problems in urban areas, this paper explores the reduction in total generation costs resulting from the relaxation of the operational constraints requiring conventional generators to be kept on-line near load centers for reactive power support. The paper shows that by 2020 there will be possible savings of 87€m per annum and a reduction in wind curtailment of more than a percentage point if measures are taken to relax these constraints.

Keywords: Wind energy, wind curtailment, voltage control, reactive power, system operational constraints, Ireland

1. Introduction

The European Union (EU) is currently pursuing a policy of encouraging the increased use of renewable energy technologies for electricity generation [1]. This is part of a wider group of polices to reduce the overall carbon intensity of energy consumption in the EU. These policies are primarily due to increasing concerns over climate change [2] and EU member states' dependence on imported fossil fuels. As part of the renewable electricity generation policy, the Republic of Ireland (ROI) and Northern Ireland (NI) have agreed to generate 40% of their electricity demand from renewable sources (RES-E) by 2020 [3] [4]. As a result wind energy will generate in the region of 30-37% of the all-island of Ireland[1] (AI) electricity in 2020.

The voltage control on an electricity system is important as it affects the efficiency of the transportation of the electricity as well as the stability of the system itself. Voltage stability is maintained by the balancing of the quantity of reactive power on all nodes of the system with conventional generation sources [5]. In the event of a fault, an increase in load or an increase in non-synchronous generation, voltage stability can be affected negatively if the system is not capable of providing sufficient reactive power to meet the reactive power demand of the node where the event took place [6].

Another issue for grid stability is frequency response which requires sufficient amounts of inertia to be maintained on a power system in order for the frequency to remain within specified limits. This is achieved in AI by the use of a system non-synchronous penetration (SNSP) limit. The SNSP is the instantaneous portion of generation that comes from non-synchronous sources such as wind energy or high voltage direct current imports on interconnectors [6].

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Unlike frequency, which is constant across the system, voltage levels are required to be managed locally as the transmission system varies based on location, and reactive power consumption alters from node to node. This results from the inability to transport reactive power over long distances. This issue requires injections of reactive power at nodes where voltages begin to drop [6]. The reactive power capabilities of generators are important for maintaining voltage stability on the system. It is has been traditional practise to assume that each transmission node would be able to provide a sufficient amount of reactive power to maintain the local voltage levels.

Conventional generators have historically been located locally within urban areas of high demand in order to provide active as well as reactive power. If local generation in high-demand urban areas has to be reduced in favour of power inflows from an outside area, there is a corresponding decrease in local reactive power support that must be compensated for locally. With the large increase in wind energy planned for AI, there will be times where the total system demand of the island will be comparable to total wind energy output. The majority of wind energy in Ireland is located in rural areas in the west and located hundreds kilometers from the main urban areas. This issue of voltage stability in urban areas [7] leads directly to the need for specific System Operational Constraints (SOCs) to maintain a minimum numbers of conventional generators on-line in certain areas such as [8] Dublin and the North West of Northern Ireland, as shown in Table 1. The locations of these areas are illustrated in Figure 1. Dublin also has issues related to cabling of the transmission system producing reactive power [7]

Therefore there is a clear incentive in the future not to have conventional generators operating at their minimum stable levels in order to maintain voltage stability if wind energy is simultaneously being curtailed.

Table. 1: System operational constraints (SOCs), for local urban voltage control [8].

System Operational Constraint	SOC code	minimum no. of generators on-line
Dublin Generation	Dub(2/3)	2/3 (day/night)
NI-NW Generation	CPS(1)	0/1 (if load>1.0GW)

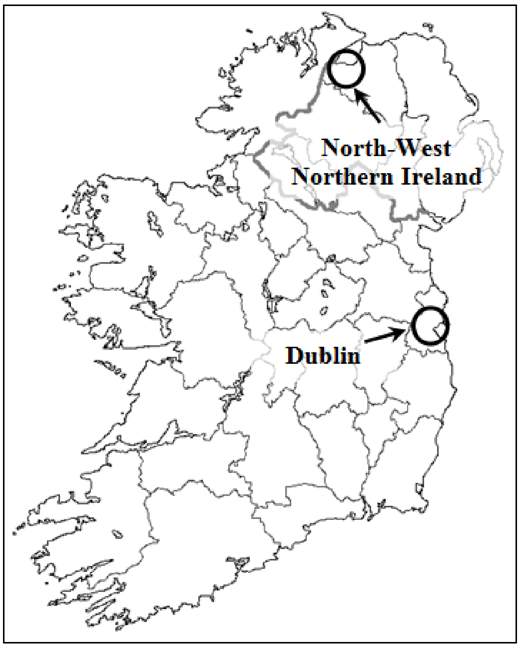

Fig. 1: A map of the island of Ireland indicating the Dublin and North-West of Northern Ireland areas.

However, reactive power can be provided separately to active power. There is a range of dynamic reactive power supporting devices, with the most suitable as follows:

- Static synchronous compensators (STATCOMs)
- Synchronous condensers

STATCOMs are capable of providing fast acting reactive power support as well as supplying variable amounts of reactive power depending on local network demand. Synchronous condensers mimic a flywheel synchronised to the electricity system and are capable of consuming and generating reactive power [9]. Use of the synchronous condensers has already been looked at a preliminary stage in [6]. Estimates of the installation costs of these reactive power support devices are shown in Table. 2. Changes to how reactive power is provided to the AI system is seen as an important part of allowing AI meet its RES-E targets [9].

Table. 2: Cost estimates of installation of reactive power support devices [9].

Device	**Unit size** (VARs)	**Total cost** (€m)
STATCOM	50	5.43
Synchronous Condenser	75	4.73

The objective of this work is to illustrate the overall potential benefits to the island of Irelands electricity system of allowing the relaxation of the voltage control system operational constraints through the installation of dedicated reactive power support.

2. The Model

The model simulates the 2020 Single Electricity Market (SEM) of the island of Ireland’s electricity system and was developed from Single Electricity Market Operator (SEMO) forecast model of 2011-2012 [10]. The mixed integer unit commitment/economic dispatch modelling tool PLEXOS® for Power Systems (Energy Exemplar Pty., Adelaide, Australia) was used to build and simulate the models in this study. Version 6.208 (R08) of PLEXOS® was used on a Dell OptiPlex 380 Desktop with an Intel® CoreTH2 Duo Processor. The XpressMP solver was used at a relative gap of 0.05 for the DA model and the RT model with the average model run taking 4 hours.

The predicted generation portfolio for the AI electricity system in 2020 is taken from All-Island Generation Capacity Statement 2013-2022. The model simulated the day-ahead unit commitment schedule of large generators by utilising a interleaved technique incorporating a day-ahead and real time model, described in detail in [11]. A day-ahead wind forecast of at 6% mean absolute error (MAE) was assumed, details of which are given in [11].

2.1. System Operational Constraints (SOC) Relaxation Scenarios

To illustrate the effects of the relaxation of local urban voltage control SOCs it was decided to examine five scenarios. The reader is referred to [8] for a detailed description of the SOCs used on the AI system.

The first is a “Base” scenario which was developed from [8]. This Base scenario has a number of changes from the current SOCs used on the AI system and were changed to better reflect the likely 2020 AI electricity system. These changes are as follows: a system non-synchronous penetration (SNSP) limit of 70% is assumed; “Inter-Area flow” is assumed to be at 2000MW both ways due to the proposed North-South interconnector; “Ballylumford Generation” and “Moyle Interconnector” constraints are ignored due to assumptions that transmission grid restrictions will no longer have effect; “Replacement Reserve” in ROI is increased to allow a maximum open cycle gas turbine (OCGT) generation of 1034MW, which still keeps 300MW in reserve due to capacity to be added by 2020.

From the Base scenario the second scenario “Dub(1/2)” is the relation of the “Dub(2/3)” SOC shown in Table 1 from a minimum of 2 or 3 generators maintained on-line dependent on day or night time respectively down to 1 or 2 generators on-line. From the Base scenario the third scenario “CPS(0)” is the removal of the “CPS(1)” SOC shown in Table 1 which consists of the Coolkeeragh CCGT generator (SEM unit ID: CPS) which currently must be on-line if NI demand exceeds 1000MW. From the Base scenario the fourth scenario “Dub&CPS” is the relaxation of the both “Dub(2/3)” and “CPS(1)” SOCs together, a combination of second and third scenario. To illustrate the large effect of the “Dub(1/2)” and “CPS(0)” a fifth scenario allowing the SNSP limit increase to 75% is shown.

3. Results

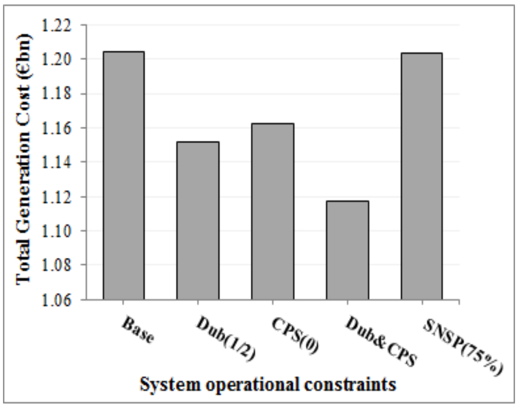

Fig. 2: The total generation cost, in Euro, for the island of Ireland under five different SOC scenarios.

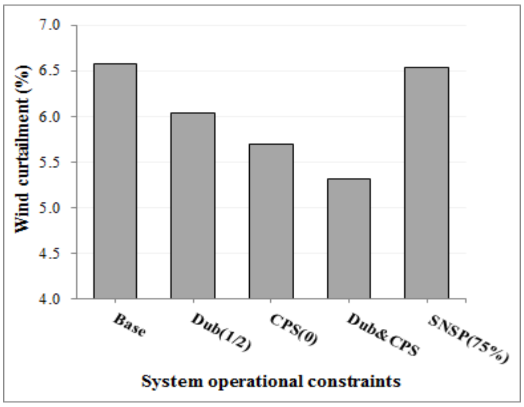

Fig. 3: The percentage of wind curtailment occurring for the island of Ireland under five different SOC scenarios.

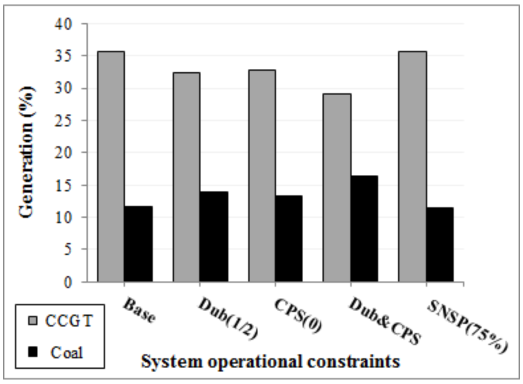

Fig. 4: The percentage of generation from CCGT and Coal Steam turbine technology for the island of Ireland under five different SOC scenarios.

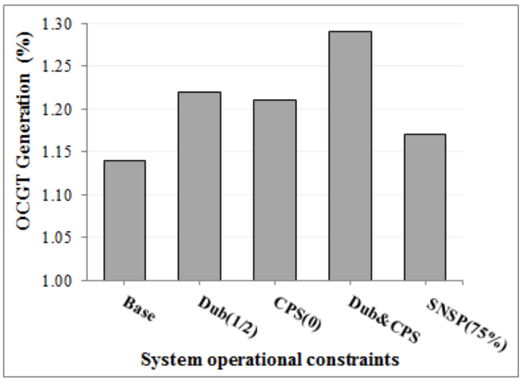

Fig. 5: The percentage of generation from OCGT technology for the island of Ireland under five different SOC scenarios.

4. Discussion and Conclusion

From the results it is clear in Figure 2 that there is the potential for large savings, of the order of €87 million Euro annually, to be made in the total generation cost for the AI system with the relaxation of voltage control SOCs. Even with the individual relaxation of SOCs to Dub(1/2) and CPS(0) there is savings respectively of €52 and €41 million in total generation costs annually. Comparison of these generation savings to the cost figures presented in Table 2 for installation of voltage control support devices strongly supports further investigation of reactive power support devices as even the installation of ten of these devices will still result in pay back in approximately one year if the Dublin voltage control SOCs can be relaxed. There is also a clear benefit, shown in Figure 3, in the reduction of wind curtailment with removal of the voltage control SOCs. Wind curtailment is reduced from the Base case figure of 6.5% down to a possible 5.3% of total wind generation. This would help ROI and NI to meet their 2020 RES-E targets as well as creating a more efficient generation system. This reduction in wind curtailment is achieved by allowing the CCGTs in the urban areas with high minimum stable level of generation, that are current constrained to be on-line, to be replaced with cheaper coal plant that have lower minimum stable levels. It is interesting however to note that while it is more cost effective to relax Dub(2/3) it is more beneficial in terms of wind curtailment to relax CPS(1).

Figures 4 and 5 help to explain the total generation cost reductions achieved in Figure 1. There is a clear trend of replacement of CCGT for Coal steam turbine generation and added to this there are trends of increasing Coal generation and OCGT usage as more SOCs are relaxed. This indicates that it is a cheaper solution to maintain coal plant on-line with low minimum stable generation levels and supplement generation with fast acting OCGT usage in times of large decreases in wind generation.

Finally it is shown here through the scenario of a 75% SNSP limit that allowing a system-wide SOC associated with frequency stability has almost negligible effects on all the results of Figures 2-5 relating to local voltage control. This illustrates the importance of dealing with the voltage control SOCs on the system as a priority.

5. Acknowledgements

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