AN ASSESSMENT OF PRINCIPLES OF ACCESS FOR WIND GENERATION CURTAILMENT IN ACTIVE NETWORK MANAGEMENT SCHEMES

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ABSTRACT

The growth of wind generation embedded in distribution networks is leading to the development and implementation of Active Network Management (ANM) strategies. These aim to increase the capacity of Distributed Generation (DG) that can connect to a network. One such ANM strategy is generation curtailment where DG is given a non-firm connection under which the network can instruct a generator to reduce its output under specified conditions. Currently in the UK the Orkney distribution network operates a curtailment scheme for wind and other renewable generation [1]and a similar scheme is being developed for the Shetland Islands [2].

The main objective of this paper is to explore the options for Principles of Access (PoA) for curtailment of wind generation on distribution networks which employ ANM. The PoA define the commercial rules by which a DG unit obtains access to the distribution network and under an ANM curtailment scheme the PoA defines the curtailment instructions that would be sent to different DG units when network constraints occur. The scenarios studied in this paper are based on the Orkney distribution network.

INTRODUCTION

In order to increase the volume of renewable generation connected at distribution level, alternative methods of granting connection agreements and improved management of the system is required. One method of doing so is to grant ‘non-firm’ connections under an ANM scheme to generators wishing to connect to the system when there is no available network capacity to facilitate the connection. Under a ‘non-firm’ connection, generators may be asked to curtail generation during periods of constraint on the network. The rules which dictate the order and frequency of these curtailments are known as ‘Principles of Access’ (PoA). The current PoA used in the Orkney ANM scheme is ‘Last In First Out’ (LIFO) which sees the last generator connected to the network as the first generator to be curtailed regardless of technical specification. While this method is straightforward to implement, it is not necessarily the most electrically or economically efficient way of managing the network.

A number of PoA are considered in this paper, including LIFO, Technical Best, Pro-Rata and a Market scenario. MatPower [3] is used to run power flow analysis of different PoA methods for a number of generation levels at selected sites. The results of each power flow analysis are collated and the capacity factor (CF) of each wind farm compared to assess the performance of each of the PoA options.

This paper reviews current research and examples of different PoA. It then looks at the Orkney distribution network, explaining the creation of the simulation model and the results of various PoA scenarios. The paper concludes with possible solutions to the problem of constraint management and suggests further research.

PRINCIPLES OF ACCESS CONCEPTS

There are only a small number of ANM schemes which demonstrate a method of constraint management including the Orkney and Shetland ANM schemes, however we can learn from examples in transmission systems [4]. A paper by Currie et al [5] has highlighted a number of contractual arrangements which could be applied to ANM curtailment schemes. Prior work provided an initial assessment of the PoA options against set criteria which considered the technical, commercial and regulatory strengths of each approach [6]. LIFO and Market Based approaches are noted as the most feasible solutions to curtailment by the authors. LIFO is simple to administer but it does not provide the optimal use of resources and in some cases can lead to generation being unnecessarily curtailed under specific network conditions. A Market approach would see the creation of a market mechanism which allows generators to submit bid/offers for curtailment. This method would not impact on existing generation connections. There is also potential to extend the market to incumbent generators. Significant effort and cost may be required to develop a new market for this approach.

A further option is the Shared Percentage method which shares the required curtailment volume between all generators contributing to the constraint on a pro-rata basis. No regulatory change is required; however there is a difficulty in assessing the long term impact of this method as an increase in the number of generators connected to the network would reduce the percentage share of generation of those connected previously.

In addition to the aforementioned PoA, a combination of arrangements could be adopted. This might include the creation of a Rota arrangement to determine the order of curtailment. Generators could bid for positions on the rota, which would then take the form of LIFO for a pre-agreed period.

ANALYSIS OF POA FOR CURTAILMENT ANM

The Orkney distribution network is one of three Registered Power Zones (RPZs) [7] in the UK where incentives were provided to implement innovative solutions for generation connection. By normalising wind data from a representative Scottish island wind farm, it is applied to the wind generation sites on Orkney. The demand points on the network were allocated a percentage load share based on measured substation maximum demand data. Both wind power and demand data are at half-hourly intervals for the full study year of 2009.

In order to determine the optimal method of curtailment, a 'base case' network model was created using PSS/E. This model was then imported into MatPower where the curtailment analysis was carried out. Figure 1 shows the network as created in PSS/E. The model consists of 67 buses, 71 branches, 22 transformers, 15 generators and 10 load points. The Newton–Raphson iterative method for the power flow analysis was used to identify congestion on the network.

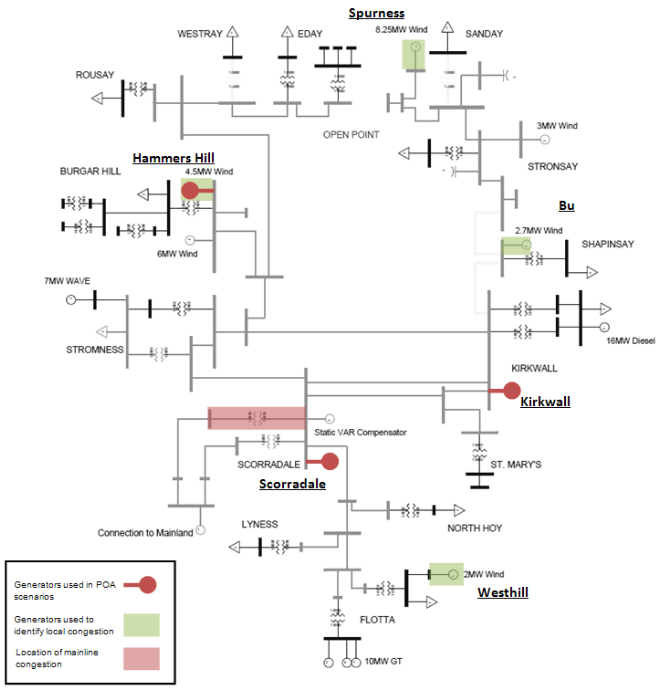

Figure 1 Orkney Distribution Network Model

Congestion was created on the network on the mainline i.e. the line between the connection to mainland GB grid and the node at the first major substation on the islands at Scorradale.

The base model for PoA simulations has 8MW at the Hammers Hill site, 10MW at Scorradale and 10MW at Kirkwall (it should be noted that these names refer to the network locations and not specific generating units connected at these sites now or in the future). The connected capacity of generation at Scorradale and Kirkwall is increased by 1MW each round of simulations.

When congestion is identified, the generation output of the selected wind farm (as determined by the PoA) is decreased by 0.1MW increments in each power flow solution until constraints on the network have been resolved.

Four PoA have been selected for comparison. These are 'Technical Best', LIFO, 'Shared Percentage' and 'Market Based'.

The 'Technical Best' method determines which wind farm should be curtailed to mitigate network congestion based on power flow analysis of the network. The wind farm which can minimise the network losses by being curtailed will be selected.

The 'Shared Percentage' PoA curtails each wind farm by a proportion of the curtailment level required based on the maximum capacity of the wind farm. All wind farms are curtailed simultaneously.

In the LIFO scenario, the last wind farm to connect will be curtailed first. Any further curtailment to relieve the circuit congestion will be provided by the second last to connect, and then subsequently connected generating units. For the purpose of comparison, the LIFO scenario is run three times, with the priority order of Hammers Hill, Kirkwall and Scorradale changing each time.

Two 'Market Based' scenarios have been established for comparative purposes. Bid scenarios are created based on initial investment cost, Operation & Maintenance costs and eligibility for Renewable Obligation Certificates (ROCs) and Feed-in Tariffs (FITs) [8-10]. Generators offer a bid price to the DNO in order to remain connected during periods of congestion. The DNO will compare bids, and curtail the wind farm which offers the lowest bid price for each 0.1MW of required curtailment. The price which the remaining wind farms pay to remain connected is determined by the cost at which congestion on the network is solved, i.e. the 'curtailment market clearing price'. The possible profits per MWh at each wind farm are listed in Table 1 below.

Table 1 Possible profit per MWh

	Scenario I	Scenario II
Hammers Hill	£46.43	£40.31
Kirkwall	£40.31	£39.11
Scorradale	£39.41	£40.31

In Scenario I, Hammers Hill consists of one co-operatively owned 1MW turbine which is eligible for FITs, and the remaining 7MW are owned by a commercial generator, and are eligible for ROCs. Kirkwall consists of ten 1MW turbines, owned by a commercial generator who receives ROCs. At Scorradale, there are two 1.5MW non-commercial turbines which receive FITS, and a further 7MW of turbines owned by the commercial generator that receive ROCs. In Scenario II, Hammers Hill has a capacity of 8MW, and Scorradale a capacity of 10MW. All turbines on these sites are owned by commercial generators and receive ROCs. At Kirkwall, two 2MW machines are privately owned and eligible for FITs, and a further 6MW are eligible for ROCs.

POA ASSESSMENT RESULTS

The annual CFs for Hammers Hill, Kirkwall and Scorradale are shown in

Table 2 for each of the scenarios. The current LIFO POA for curtailment provides a comparator for the other POA options. To appreciate the full impact of LIFO, each of the wind farms had their priority rotated. In all instances, the wind farm at the top of the priority list i.e. last to curtail, experienced no curtailment. The depth of curtailment in the LIFO generating units depends on the level of curtailment required and the size of other wind farms available for curtailment.

The 'Technical Best' PoA scenario demonstrates the importance of the location of congestion in relation to generation. Regardless of increased generation at Kirkwall and Scorradale, Hammers Hill is always the wind farm location which ensures the lowest losses on the network when curtailed.

The Hammers Hill wind farm location is the furthest generator from the congestion and therefore when looking at overall network losses, will always produce the largest reduction in losses when curtailed. By way of comparison, if the generator nearest the congestion i.e. Scorradale, is curtailed this will result in the minimum value of curtailment experienced at the three sites.

The maximum feasible combination of generation is 8MW at the Hammers Hill location and 13MW at both Scorradale and Kirkwall locations. This combination sees the CF at the Hammers Hill location fall to a value of 0.3683, from a maximum value of 0.5128. Connecting any more generation at Hammers Hill, Kirkwall or Scorradale would results in a CF of lower than 0.35 and this is considered to be the lower limit at which generators would consider applying for connection in Orkney.

The 'Shared Percentage' PoA ensures all three wind farm sites are treated equally and achieve the same CF. It does not favour or discriminate wind farms based on location or size (or even connection date). However, as the level of generation increases, the CF of all wind farms reduces. This has the potential to discourage the connection of new generation due to uncertainty in long term CFs from potential generation connections.

The Market scenario outcomes depend on the bid price of the wind farms.

In scenario I, Kirkwall offers the lowest bid price and is therefore the first to be curtailed followed by Scorradale. The 'Curtailment Market Clearing Price' is determined at each congested period and is £39/MW on average for each half hour period. This is significantly lower than the bid prices offered by Hammers Hill meaning that both generator and network operator make a profit. In order to prevent curtailment, Kirkwall will have to increase its bid price to be competitive with the other wind farms.

Table 2Annual CFs for Orkney Generators – Hammers Hill, Kirkwall and Scorradale.

		Technical Best	Shared	Market I	Market II	LIFO		
						1st - Hammers Hill 2nd - Kirkwall 3rd - Scorradale	1st - Kirkwall 2nd - Scorradale 3rd - Hammers Hill	1st - Scorradale 2nd - Hammers Hill 3rd - Kirkwall
Round 1								
Hammers Hill	8MW	0.4784	0.5039	0.5128	0.5128	0.4784	0.5128	0.5127
Kirkwall	10MW	0.4884	0.5039	0.4886	0.5099	0.5125	0.4885	0.5128
Scorradale	10 MW	0.4899	0.5039	0.5125	0.4923	0.5128	0.5127	0.4899
Round 2								
Hammers Hill	8 MW	0.4487	0.4969	0.5128	0.5128	0.4487	0.5128	0.5127
Kirkwall	11 MW	0.4702	0.4969	0.4717	0.5043	0.5112	0.4702	0.5127
Scorradale	11 MW	0.4728	0.4969	0.5112	0.4802	0.5128	0.5127	0.4728
Round 3								
Hammers Hill	8 MW	0.4110	0.4880	0.5128	0.5128	0.4110	0.5128	0.5127
Kirkwall	12 MW	0.4476	0.4880	0.4528	0.4938	0.5075	0.4476	0.5127
Scorradale	12 MW	0.4516	0.4880	0.5075	0.4685	0.5128	0.5127	0.4516
Round 4								
Hammers Hill	8 MW	0.3683	0.4772	0.5128	0.5128	0.3683	0.5128	0.5126

Kirkwall	13 MW	0.4210	0.4772	0.4340	0.4787	0.4996	0.4210	0.5127
Scorradale	13 MW	0.4265	0.4772	0.4997	0.4573	0.5128	0.5125	0.4265

In scenario II, Scorradale offers the lowest bid price, followed by Kirkwall and Hammers Hill. In this scenario, the market price clears on average, at £40/MW. This will result in lower profits for Hammers Hill and Kirkwall when compared with Scenario I.

The Market Based PoA allows wind farms to have more control over their network access and more efficient generation will have more scope to pay for network access thus making them more competitive. This is advantageous when compared with the network determining allowable generation on their behalf in the other PoA. However further analysis is required to fully understand the impact of a Market Based PoA on both the wind farms and the network as different market designs (e.g. 'Market I' and 'Market II') produce quite different results in terms of overall costs and curtailment and also the allocation of both costs and curtailment.

CONCLUSIONS

Using the case study of the Orkney distribution network, it is possible to highlight the advantages and disadvantages of a number of PoA for wind farm operation in congested distribution networks.

The 'LIFO' PoA is simple to implement and the rules of curtailment are clear for all generation developers wishing to connect to the network. However, adopting this PoA could discourage the increase of DG in certain networks as newer generation receives a less favourable level of network access. Changing the PoA would be beneficial to both the network operator and new wind farm developers.

The 'Shared Percentage' PoA allows a fair share of available access to all new generators connecting to the network, however as more generators connect this share will decrease but some economically feasible floor should be reached. The difficulty in assuring long term CFs may discourage developers unless the DNO can provide a maximum limit for connected generators *a priori*, or else clear routes through to network capacity expansion are provided.

The 'Technical Best' PoA is highly dependent on location of congestion. If there are problem areas on the network which experience congestion frequently (as simulated in the case study scenarios and as experienced in real networks) then it is likely that the same wind farm(s) will experience curtailment on a regular basis. This has the advantage of sending a message to developers about the best location in which to connect a new wind farm.

The 'Market Based' PoA is suggested as the most promising PoA in terms of appeal to both generators and the DNO. By implementing a market with a bidding system, it allows generators to offer a price to access the network and generate during congested time periods. This gives control to the generators in terms of CF. Bids could be tailored to suit peak periods of demand on the network or available wind (or even other generation side requirements).

FUTURE WORK

Further work is currently being undertaken into developing principles of access for wind generators, in particular the aspects surrounding market based arrangements and how such a system might work at distribution level.

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REFERENCES

[1] Scottish and Southern Energy Power Distribution. (2012, 12th November). *Orkney Smart Grid*. Available: http://www.ssepd.co.uk/OrkneySmartGrid/ProjectInformation/

[2] Scottish and Southern Energy Power Distribution. (2012, 13th November). *Northern Isles New Energy Solutions (NINES)*. Available: http://www.ssepd.co.uk/News/NINES/

[3] R. D. Zimmerman., C. E. Murillo-Sanchez., and D. Gan. (2011, 9th Feb). *MATPOWER: A MATLAB Power System Simulation Package*. Available: http://www.pserc.cornell.edu/matpower/

[4] J. Rogers, S. Fink, and K. Porter, "Examples of Wind Energy Curtailment Practices," NRELJULY 2010 2010.

[5] R. A. F. Currie, O'Neill, B., Foote, C., Gooding, A., Ferris,R., Douglas, J. , "Commercial Arrangements to facilitate active network management," in *CIRED 21st International Conference on Electricity Distribution*, Frankfurt, 2011.

[6] ESB National Grid, "Options for Operational Rules to Curtail Wind Generation," CER/04/247, 2004.

[7] Ofgem. (2012, 7th September). *Innovation*. Available: http://www.ofgem.gov.uk/Networks/Techn/NetwrkSupp/Innovat/Pages/Innvtion.aspx

[8] DECC. (2012, 6th July). *Renewables Obligation*. Available: https://restats.decc.gov.uk/cms/renewables-obligations/

[9] Ofgem. (2012, 11th July). *Feed-in Tariff Scheme Tariff Tables*. Available: http://www.ofgem.gov.uk/Sustainability/Environment/fits/tariff-tables/Pages/index.aspx

[10] European Wind Energy Association, *Wind Energy*

- *The Facts: "A Guide to the Technology, Economics and Future of Wind Power"*: Taylor & Francis, 2012.