Analysis of Market and Non-Market Principles of Access for Wind Generation connection to Active Network Management Schemes

Laura KANE
University of Strathclyde – UK
laura.kane@strath.ac.uk

Graham AULT
Smarter Grid Solutions Ltd – UK
gault@smartergridsolutions.com

Laura HANNANT
UK Power Networks - UK
laura.hannant@ukpowernetworks.co.uk

Sotiris GEORGIOPOULOS
UK Power Networks – UK
sotiris.georgiopoulos@ukpowernetworks.com

ABSTRACT

The growth of renewable generation (and wind generation in particular) in distribution networks has led to the development of Active Network Management (ANM) systems which aim to increase the capacity of renewable and distributed generation (DG) that can connect to distribution networks. One such strategy is generation curtailment where DG is given a non-firm connection under which the network operator instructs the DG unit to reduce its power output under specified conditions and this is practically achieved through the implementation of automatic control in the ANM scheme. The rules which define the order of curtailment are often referred to as Principles of Access (PoA).

This paper presents a number of PoA, and using an Optimal Power Flow (OPF) method of analysis, the impact of different PoA and the capacity factors of wind generators are compared.
When looking at non-market arrangements; compared with Last In First Off (LIFO), Pro Rata and Rota offer an improved capacity factor for the majority of DG connected in lower priority positions. Market arrangements, conversely, lead to the DG having increased control over whether to participate in curtailment markets and the opportunity to increase revenue. However these arrangements would require a significant change in the way in which distribution networks operate.

INTRODUCTION

In the UK there are several Active ANM schemes which are currently operating, or plan to operate a curtailment scheme for wind powered and other renewable generators [1]–[4]. The rules which define the method of curtailment are often referred to as Principles of Access (PoA).

PoA for ANM enabled generators has been identified as an area of serious concern for generators, distribution network operators (DNOs) and other stakeholders. Questions exist in the underlying philosophies for PoA, the design of PoA mechanisms and the implications of alternative PoA for DG, network operators and consumers.

There are a number of alternative PoA which have yet to be explored or trialed. The authors have selected five PoA for assessment, and a qualitative and quantitative analysis is provided. An Optimal Power Flow (OPF) method is used to assess the impact of different curtailment strategies on wind generation connected to an ANM scheme and the capacity factor (CF) of each generator is compared against a base case.

OVERVIEW OF PRINCIPLES OF ACCESS

There have been a number of initial discussion papers surrounding PoA [5]–[7]. In this paper, PoA are grouped into Non-Market and Market Arrangements to highlight the level of control which the System Operator and curtailable generation i.e. non-firm generators (NFG) have over curtailment levels.

Non-market Arrangements

Non-market arrangements use predetermined rules to curtail NFG. These rules are decided by the DNO and NFG must adhere to these rules in order to connect to the network. Non-market arrangements are simpler when compared with market arrangements for the DNO to implement as no changes to current rules and regulations are required.

Last In First Out (LIFO)

Under this method, the first NFG to be curtailed under a constraint event is the chronologically last NFG to request a connection to the network or added to an active network management (ANM) scheme. Adding a new NFG connection to the LIFO priority list (in the position of least priority) does not alter the priority position of existing NFG. This approach is consistent, transparent and easy to implement within the current UK regulations. However, this method would not necessarily be the best way of fully utilising the available network capacity or the available renewable generation. For example, the lowest priority generator may be located furthest from the constraint which would result in a higher volume of curtailment required when compared with a generator located closer to the point of congestion. As the number of NFG increases, the CF for those at the bottom of the priority list may begin to approach unacceptable levels, and discourage any new NFG connections.

Pro Rata
The Pro Rata method divides the required curtailment equally between all NFG contributing to a network constraint. The total amount of curtailment would be shared by each of the NFG based on the ratio of rated or actual NFG output to total required curtailment. Implementing this method would grant equitable access for multiple NFG. However, it is difficult for the DNO to calculate the long term volumes of curtailment of this method since, as more NFG is connected, the level of curtailment of each NFG, including those already connected with NFG contracts, will increase. To some extent, this can be solved by setting a cap on the level of generation which can be connected to a particular network location without the network being reinforced. This then gives a minimum CF which allows generators to calculate return on investment.

Rota
This method curtails NFG based on the order specified in a predetermined rota. This rota could be changed on a daily, weekly or monthly basis using the network operator's discretion. As the number of generators connected under a Rota arrangement increases, the level of curtailment may increase however the length of time spent at the bottom of the priority stack would decrease. This uncertainty could be eased if the DNO were to set a cap on the amount of generation that can connect to the network, thus calculating a minimum CF that each NFG might experience however uncertainty regarding the organisation of the rota could still impact on generation investment decisions.

Market Arrangements

Under a market arrangement generators may submit bids to indicate their willingness to be curtailed, and the system operator would curtail the generators who bid in at the lowest cost to the network.
These arrangements would not impact on existing connections (assuming they have a firm connection and their rights are 'grandfathered') and, in principle, would be sustainable for future network developments. In addition, there is potential to extend the market to existing firm connected generators should they choose to participate.
These approaches will require the largest change from existing practice in distribution networks, and require the development of market rules and structure under which the generators could operate. This will require a large input from all bodies involved – generators, SO's, regulators etc. and a potentially complex set of market procedures.

Pay-As-Bid (PAB)
In a pay-as-bid market, generators are paid the price they have bid for curtailment of energy. This gives control of curtailment to the generator and allows them to indicate their willingness to curtail through the bid price. It also ensures that generators are certain the price in which they will be paid, should curtailment be requested of them. This leaves little control in hands of the market operator to influence curtailment prices, and bids may not necessarily reflect the true cost of lost energy to wind generators.
Curtailment Market Clearing Price (CMCP)
In this arrangement, compensation for curtailment is based on the system price. Generators submit individual bids, and the market operator would determine the price generators are paid for curtailment depending on the price at which the curtailment was cleared. This is the system adopted by National Grid as GB System Operator for determining the System Buy/Sell Price. It ensures efficient market operation and encourages generators to enter bids which reflect true profit loss.

MODELLING METHOD

In order to analyze the impact of different PoA on wind capacity factors, this paper will use an OPF method to curtail non-firm wind generation, using generator cost functions and solve the network according to other network constraints such as voltage and thermal limits. This method has been used previously by Dolan et al [8]. Details of the modelling method are explained in the following section.

OPF Problem Formulation

The OPF method works by using generator costs to control the order in which they are curtailed. By using this method the OPF ensures network operation within limits at all times. The costs of the NFG are set at a level which informs the OPF algorithm the order in which to curtail them and so different PoA can be implemented within the OPF. Depending on the location of the constraint, the OPF will determine which generators are contributing to the constraint and curtail in the appropriate order.

OPF Formulation
The OPF formulation is as follows

$$\min_x \sum_{i=1}^{n_g} f_P^i(p_g^i) + f_Q^i(q_g^i) \qquad (1)$$

Subject to

$$l < A[x] < u \qquad (2)$$

Where

$$x = \begin{bmatrix} \Theta \\ V_m \\ P_g \\ Q_g \end{bmatrix} \qquad (3)$$

Polynominal cost functions were used to apply curtailment to NFG. The function takes the form:

$$f(p) = c_n p^n + \cdots + c_1 p + c_0 \quad (4)$$

Where n=3 was chosen for all generators.

Additional constraints are added to the OPF formulation for the Pro Rata arrangement to ensure that the NFG output is related to other generators behind the same constraint.

Market Bid Logic

For market arrangements, the bids or costs associated with each generator will change every 24hrs. In order to inform this change, simple logic controls are used to inform the generator whether to increase, decrease or hold the same bid based on actions in the previous time step. The bids are based on the profit which generators would expect to make without any curtailment i.e. £/MWh received from the sale of electricity and the allocation of ROCs/FITs

The basic principles of calculating the curtailment clearing price are shown in Figure 1 below.

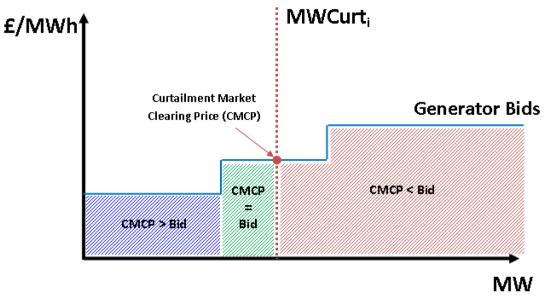

Figure 1 Diagram of System Price market

RESULTS

The POA were modelled on the Orkney distribution network and results shown are based on one year of demand and generation data. The following results demonstrate the impact of different POA on the CF of NFG. All generators are located behind a single constraint.

The results in Figure 2 demonstrate the change in capacity factor of non-market arrangements when moving away from LIFO. Generators A and B receive no curtailment under LIFO, and therefore experience the largest negative change in capacity factor when moving to any of the other non-market arrangements. Similarly, generators F-K experience the largest positive changes in capacity factor as they experience the majority of curtailment under LIFO.

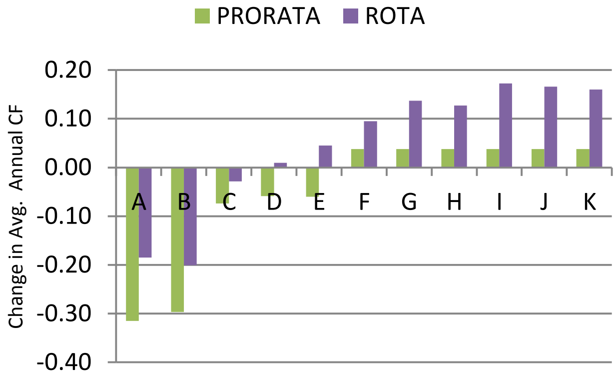

Figure 2 Change in average annual capacity factor for non-market arrangements compared against LIFO base case.

In Figure 3 the CF of all non-market arrangements are shown. The Rota arrangement provides a relatively even distribution of curtailment across all NFG when compared with other non-market arrangements. The Rota arrangement results in an increase of average CF to 0.29 compared with 0.25 under LIFO, and 0.22 under Pro Rata.

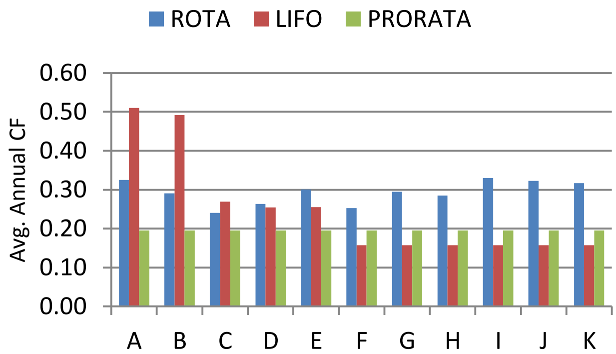

Figure 3 Generator average annual capacity factors under non-market arrangements

In Figure 4, the average annual CF of the market arrangements is compared to the LIFO base case. The results are for one run of bid simulations. The results of the market could change should generators decide on different bid strategies. Generators with high pre-curtailment profits, B, C, D and H have higher capacity factors due to higher bid levels. All generators in this simulation are wind and therefore there is a small variability in costs between turbines. In a more varied market the results could vary significantly as competition increases.

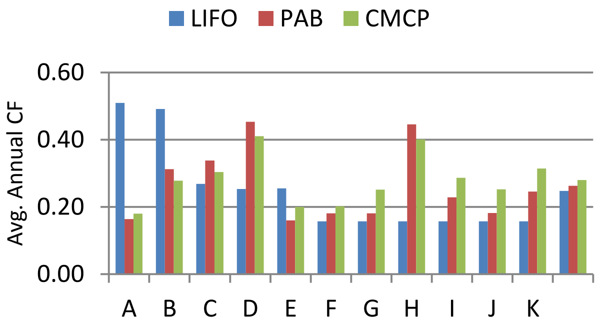

Figure 4 Generator average annual capacity factors under Market arrangements compared to LIFO

EXPERIENCE OF NETWORK OPERATORS

Currently in the UK, non-market arrangements are the PoA of choice. They do not require any changes to regulatory framework and experience has shown that generators are prepared to accept an ongoing cost of curtailment (based on a suitable minimal CF) in exchange for a lower upfront capital cost of connection. While simple in concept, non-market arrangements can be complex to implement e.g. rota arrangement would require the creation of a rotating curtailment order in the ANM logic controllers.
Market arrangements represent a significant leap in terms of network operation for DNOs, and there is currently no trials using market arrangements for energy movements in their networks. However national System Operators uses markets to balance transmission systems and methods could be adopted, and adapted from transmission to apply at distribution level.

The introduction of Demand Side Response and Energy Storage solutions may lead the way to market trading at distribution level. Already on Orkney, a 2MW storage battery operates under a commercial contract to help balance the distribution network and minimise curtailment of renewable sources. [9]

CONCLUSION

This paper has presented a number of PoA which can be applied to non-firm generators connected to ANM schemes.
The results demonstrate that moving away from LIFO PoA can, in the majority of cases, result in a smaller range of capacity factors across the non-firm generators behind a single constraint.
Non-market (administered) arrangements are simple to implement and transparent. Adopting alternatives to LIFO can result in a more balanced CF between non-firm generators (e.g. generators A and B perform well under a LIFO arrangement but suffer under all other arrangements as their network access priority is altered).
Market Arrangements allow control to be handed to the generator and reduces generator loss during constraint periods (assuming there is a counter party in a local curtailment market). However the transfer of risks and the practicalities of implementing market based PoA is a disadvantage in the current regulatory framework and many changes to technical and commercial codes would need to take place.

In the UK, DNOs are moving forwards with non-market arrangements. While LIFO is still the most popular PoA, trials exist of other arrangements such as UKPN FPP network which uses a combination of Pro Rata and LIFO arrangements. The learning and experience gathered from these trials is continuous. DNOs are still a long way from applying market arrangements to their networks however with the development and introduction of demand side response and storage devices the types of PoA used could progress quickly. Significant stakeholder engagement is required to progress towards the next step of commercial arrangements, in addition to new processes and skills for the DNO to become a Distribution System Operator.

Further work by the author on the sensitivity of the results on the market arrangements is proposed in order to further develop market arrangements as a principle of access for ANM schemes through a deeper understanding of the impacts and outcomes for generators.

AKNOWLEDGEMENTS

This work has been funded by the EPSRC, project reference number EP/G037728/1.

REFERENCES

[1] Scottish and Southern Energy Power Distribution, “Orkney Smart Grid,” 2012. [Online]. Available: http://www.ssepd.co.uk/OrkneySmartGrid/ProjectInformation/.

[2] UK Power Networks, “Flexible Plug and Play.” [Online]. Available: http://www.ukpowernetworks.co.uk/internet/en/innovation/fpp/. [Accessed: 03-Apr-2013].

[3] Scottish Power, “ARC: Accelerating Renewable Connections,” 2014. [Online]. Available: http://www.spenergynetworks.co.uk/pages/arc_accelerating_renewable_connections.asp.

[4] Scottish and Southern Energy, "Project Updates - NINES," 2012. [Online]. Available: http://www.ssepd.co.uk/ProjectUpdates/.

[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*, 2011.

[6] S. Jupe and P. Taylor, "Strategies for the control of multiple distributed generation schemes," in *Electricity Distribution - Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition on*, 2009, pp. 1–4.

[7] Baringa Partners and UK Power Networks, "Flexible Plug and Play Principles of Access Report," 2012. [Online]. Available: http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Flexible-Plug-and-Play-(FPP)/Project-Documents/FPP_Principles_of_Access_report_final.pdf.

[8] M. J. Dolan, E. M. Davidson, I. Kockar, G. W. Ault, and S. D. J. McArthur, "Distribution Power Flow Management Utilizing an Online Optimal Power Flow Technique," *Power Syst. IEEE Trans.*, vol. PP, no. 99, p. 1, 2012.

[9] C. Foote, R. Johnston, F. Watson, D. Macleman, and A. Urquhart, "Second Generation Active Network Management On Orkney," in *22nd International Conference on Electricity Distribution, Stockholm*, 2013, no. 0659, pp. 10–13.