TECHNICAL AND COMMERCIAL IMPACTS OF ACTIVE NETWORK MANAGEMENT ON TRANSMISSION SYSTEM OPERATION

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ABSTRACT

Active Network Management (ANM) is an alternative way of facilitating cost effective and timely connection of Distributed Generation (DG) through utilisation of latent distribution network capacity. The principles of ANM are being demonstrated at Grid Supply Points (GSPs) to aggregate multiple and diverse resources in the distribution network to deliver the required changes in real (P) and reactive (Q) power at a GSP, in order to manage transmission network constraints.

ANM deployment at GSPs provides alternative options to the Transmission System Operator (TSO) in managing constraints, through utilisation of distribution connected resources, which results in lower operational cost than using traditional methods of balancing transmission connected generation real and reactive power through a balancing mechanism.

This paper describes the technical and commercial challenges of implementing ANM at the DNO/TNO/TSO interface whilst discussing the complexities arising from the interaction of a number of different stakeholder businesses in a liberalised regulatory environment.

INTRODUCTION

It is over a decade since Active Network Management (ANM) was first proposed as a technically and commercially viable approach of connecting distributed energy resources in the UK [2]. ANM is based on investment in automation and control as an alternative, which may provide a more cost-effective means than traditional network reinforcement, for the connection of generation and demand. Applications of ANM include: power flow management around thermal constraints; voltage management; fault level management; and the use of Dynamic Line Rating (DLR) to maximize grid utilization [1].

Traditionally, a distribution network planning department approves a connection offer based on the ability of the DG unit to run unconstrained during a worst-case scenario, e.g. minimum demand/maximum export for network intact at high Voltage (HV) and N-1 at Extra High Voltage (EHV). Voltage rise tends to be the more common constraint issue in HV network while voltage step change and thermal constraints are often the limiting issue in EHV networks, - each limiting DG connection capacity. ANM has proved to release more capacity to generators through controlling generators and other devices such as AVC, demand or storage [2].

ANM-enabled generation control schemes addressing distribution network constraint issues have already been deployed and tested, in the South East of England (in the UK Power Networks projects ‘Flexible Plug and Play’ and ‘Low Carbon London’) as well as on Orkney, with SSEPD the host DNO where the ‘Registered Power Zone’ ANM scheme has been operating successfully since 2009.

In 2013, Scottish Power Distribution (SPD) commenced the “Accelerating Renewable Connections” (ARC) project, aiming to deliver innovative connection arrangements and technical solutions to achieve a significant change in the process of connecting new generation [4]. In contrast with previous ANM trials, the DG units wishing to connect to the distribution grid in the trial area also impacted by constraints on the transmission network. The ARC project is demonstrating the active management of those generators such that limits at distribution are not breached and generation is managed during contingencies on the transmission grid. ANM-enabling of the Grid Supply Points (GSPs) through installation of the necessary telecommunications, control and automation infrastructure will result in enhanced management of the transmission/distribution interface. In this manner, TNO/TSO could benefit from harnessing resources connected at distribution level. These resources include generation, controllable demand, energy storage and a variety of network devices. Co-ordinated control of these diverse resources can be achieved by extending the proven capabilities of ANM.

The deployment of ANM in previous and current projects has primarily been to help DNOs offer less expensive and faster connections to generators, where the reinforcement costs associated with traditional connections are prohibitive. TNO/TSO can build on existing ANM functionality to provide technical support and constraint management for transmission system operation. ANM schemes deployed on distribution networks could aggregate and control different resources for the purpose of maximising the voltage, thermal and stability capability of the transmission network.

This paper provides a timely overview of the impact of distribution-level ANM on transmission system operation whilst drawing on the authors’ experience in United Kingdom and mainland Europe. Topics covered include reactive power support and voltage control for transmission, congestion management at the DNO/TSO boundary, and how implementation of an ANM scheme impacts on system balancing at local and national levels. The paper also includes discussion of non-technical aspects such as impacts on energy markets and existing contractual arrangements.

TRANSMISSION OPERATION CHALLENGES

The complexity of power system operation at transmission level is continuously increasing and innovative solutions are essential in helping TNO/TSOs manage their system operation challenges. Until now, the use of special protection schemes or generator operational inter-trips has been sufficient to solve the majority of network problems under normal network operating conditions and even under N-2 conditions. This has allowed management of network constraints whilst maintaining safety and reducing the impact of network disturbances.

Increasing penetration of wind power, onshore and offshore, and its natural intermittency, makes the determination of pre- and post-fault control actions more difficult. One reason is because the pre-fault status of the generation can be different from the one expected and configured on a special protection scheme. Therefore the actions pre-loaded in the special protection schemes may not be effective, leaving the network under stress. The ability to know the 'state' of the transmission and distribution networks in real time and actively monitoring the behavior of the system is key to proposing the most effective operational decisions and strategies to optimise the balance between system security, system access and cost. Smart solutions need to assist operators in minimising system balancing costs and meeting license obligations in providing access to the system.

National Grid, in the role of Great Britain System Operator (GBSP), calculates and analyses numerous constraints across the whole system on a day ahead basis (i.e. one day before the plan is handed over to control room for real-time execution). The uncertainty and complexity of the network is increasing rapidly and therefore these constraint values could be subject to error and inaccuracy.

Furthermore, the transformation of the distribution system to an active network with large numbers of small scale renewable generation sites (e.g. Photovoltaic) and increasing volumes of new electrical demands such as electric vehicles (EVs) will significantly change the system characteristics. The development of a smart transmission system becomes important, with the ability to determine which devices and resources can offer the most efficient usage and minimise the disturbance felt on the grid during post fault conditions.

Greater access to dynamic shunt equipment could provide enhanced voltage capability under varying operating conditions, especially overnight where low demand causes high voltages across the network. Utilisation of transmission network assets such as dynamic shunt equipment, Static VAr Compensators (SVCs), voltage control circuits switching, transformer tap changing and Quad Booster (QB), in addition to generator reactive power dispatch, are crucial in managing the power system reactive power balance. It is important to highlight that the utilisation of transmission network assets, with lower operational cost rather than reactive power dispatch of generators, is crucial to minimising the cost of managing system limits and balancing the system.

Energy storage provides greater flexibility to manage real power flow and constraint relief in the transmission network to achieve the operational objectives of quality, security and economic operation and management of the power system.

The increasing penetration of asynchronous generation and the decommissioning of old synchronous power stations contribute to reduction in total system inertia. New tools and methods are needed to manage demand side response and energy storage to enhance frequency control capability through providing rapid frequency response. Delivery of rapid power injection/reduction from the distribution system is one method that could help to reduce the generation and demand imbalance, helping with frequency containment and response.

TNO/TSOs could benefit from harnessing resources connected at distribution level through an ANM scheme. These resources include generation, controllable demand, energy storage and a variety of network devices. Co-ordinated control of these diverse resources can be achieved by extending the proven capabilities of ANM.

This paper highlights a number of challenges and opportunities for ANM. They are described below along with the business case for ANM. However, the two case studies presented in this paper hint at a potential role of ANM in a future distribution system operator (DSO) model, whereby ANM could be a mechanism for a DSO to provide a range of services to the Transmission System Operation (TSO) from an ANM-enabled GSP.

TECHNICAL ASPECTS

This section describes how ANM-enabled generation control schemes on the distribution network can be used to manage constraints in the transmission network in the ARC project. Furthermore, the experience in mainland Europe is discussed, where transmission and distribution operators in Belgium are assessing ANM as an alternative to network reinforcement to increase DG penetration while managing congestion problems.

Accelerating Renewable Connections Project

The location of this project is in South-East Scotland which is replete with sources of renewable energy. Three GSPs were selected for this trial where a number of generators are interested in connecting to the distribution network but also face transmission network constraints, and so face additional costs and time delays that threaten the financial viability of their planned generation developments. The first activity is the pre-selection of suitable ANM zones, in this case GSPs. Once suitable GSPs have been identified, the feasibility assessment determines the spare network capacity available for new connections and then estimates the capacity of generation that might practically connect in the area, given the network's local conditions and assumptions. This assessment can be extended to different network voltage levels, e.g. Primary or even Secondary substation level. The information obtained from this analysis might be integrated into Heat Maps to help developers estimate their connection feasibility in different areas. As illustrated in Figure 1, the ARC project is “ANM-enabling” the GSPs in the trial area by installing the necessary telecommunications, control and automation infrastructure for ANM. The ARC project is demonstrating the active management of generating units such that limits on the distribution network are not breached and generation is also managed during contingencies on the transmission grid. The interaction between distribution and transmission requires close collaboration between multiple stakeholders.

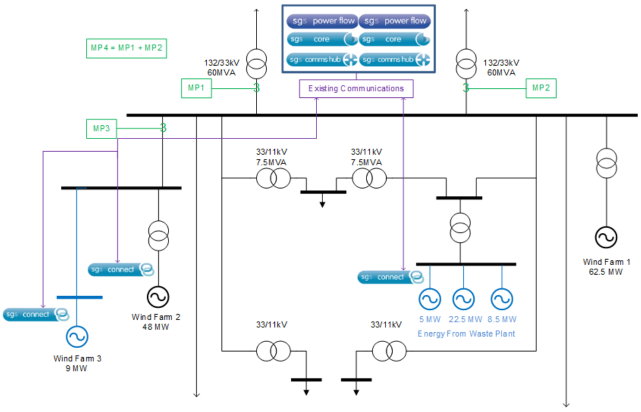

Figure 1: ANM-enabled GSP [2]

The aim is to provide the TSO with visibility of DG operating status and the contribution to energy export from the GSP and also the operation of the ANM system managing generation connected below that GSP. This project demonstrates the ability of ANM to manage power flow constraints beyond the distribution network boundary. The deployment of ANM at GSPs is expected to avoid network reinforced such that contracted and connected generation has an interruptible connection under intact conditions and N-1 contingencies.

At the DG point of connection on the distribution network, a Remote Terminal Unit (RTU) hosts **sgs connect** implementation, which acts as the interface to the generators control system. This local control platform can regulate the DG export, trip the local circuit breaker if required, it can also implement the local control logic to default the generator to a fail-to-safe state should communications be lost with main control system in the GSP. To allow control of power flow at constraint locations, the **sgs power flow** application uses a series of escalating control actions to ensure that network power flows remain within operational limits. These control actions are triggered by the breaching of thresholds at the identified constraint locations, i.e. measurement points MP1 to MP4 as illustrated in Figure 1.

Each measurement point normally has four threshold levels set such that the thermal rating limit of the circuit concerned is not violated even under failure of DG units to respond to control instructions. These ‘standard’ ANM system thresholds will be reviewed in the light of transmission system operation requirements. Further details regarding the description of threshold levels can be found in [2].

The Principles of Access (POA) define the order and volume of curtailment instruction issued to each generator behind a given constraint. In the shown network, SPEN has decided to implement a POA based on Last In First Out (LIFO). This means that the last generator to be connected will be the first one to be curtailed. Only if this generator is required to be fully curtailed, will the next generator in the priority stack be curtailed. The situation presented here is an example of wider system reinforcement being required on the transmission network to accommodate a distribution connection. The works associated with this wider network reinforcement are likely to incur a delay of at least five years before the connection can be made. The indicative cost of the connection for this generator includes the cost to the transmission network owner of £19m for the wider reinforcement works in addition to the connection cost of £5.6m.

The deployment of ANM at the GSP which interfaces with existing and new generation would result in a reduction in network reinforcement cost. The reduced reinforcement scheme would require upgrading of the transmission transformers only and this would cost in the order of £3m. The proposed solution requires the implementation of a communications link to the System Operator to allow visibility of the operation of the generation and ANM scheme. As a result of the implementation of the method, the cost of the connection would continue to be £5.6m for the assets to connect into the GSP, however the wider reinforcement cost would be reduced to £3m and could be completed within the two year period in which the generator wishes to connect. Furthermore, ANM-enabled GSPs will provide visibility, for transmission system operators, of the increasing levels of renewable generation connected to distribution network.

Belgian East Loop Project

This case study illustrates the Belgian East Loop transmission network which is supplying a number of distribution substations in the Liege area of Belgium. The 70 kV transmission circuits are managed by Elia and the distribution networks are managed by Ores [3]. A schematic representation of the East Loop network is shown in Figure 2. The network has several circuits that are subject to potential thermal overload in worst case conditions. A Dynamic Line Rating (DLR) system is currently being employed to resolve an overload that arises in N-1 conditions on one section of the network. With the existing network, loads and generators there are 21 different N-1 conditions that may result in thermal overloads.

It has been estimated that the area served by the East Loop might host up to 500 MW of new wind generation capacity. Elia, the transmission Network Operator, predicts power flows exceeding the thermal limits of the existing circuits but do not expect to have any problems maintaining voltages within limits. The existing network is expected to come under increasing strain and there is a need for an acceptable and cost effective solution to existing and future problems arising from the connection of generators in this area. This project has assessed the feasibility of an ANM scheme to address these problems.

The objective is to design an ANM scheme to manage power flow problems on the East Loop network. The solution will be defined in terms of the locations where limits are threatened and the principles of access to be applied in assessing generator curtailment. The locations where limits are threatened are the "bottlenecks" or "pinch-points" for power flow. These locations represent the boundaries of ANM zones with all generators within the zone contributing to power flow at the boundary. A simplified topology of this network is shown on Figure 2.

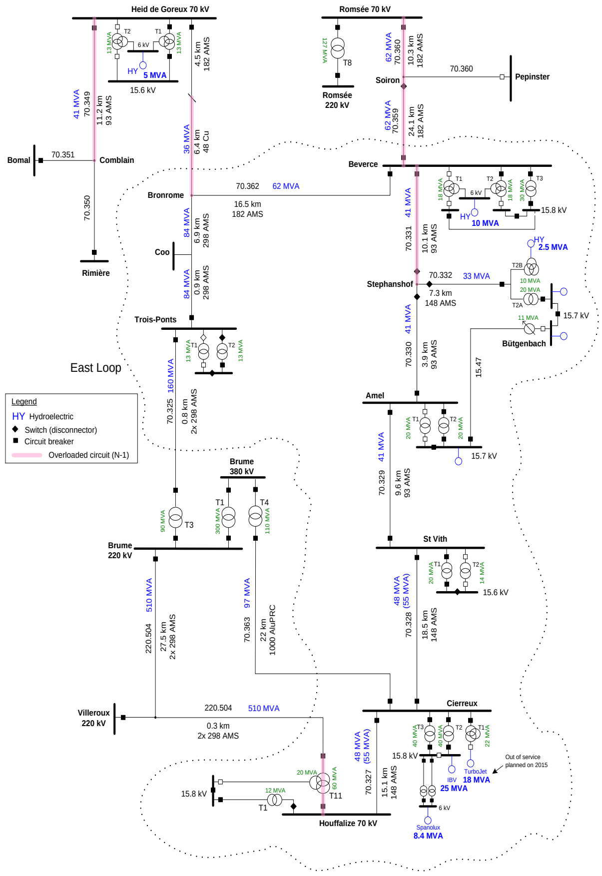

Figure 2: Schematic representation of the East Loop network [3]

The PoA will specify how curtailment is assigned to multiple generators. Examples include "last in first off" (LIFO), proportional to capacity, according to the price of constraints, or some optimisation based on prevailing network conditions.

The case study demonstrated here further highlights the perspective of an ANM scheme in managing potential congestion issues on the transmission system through the control of DGs on the distribution network.

COMMERCIAL ASPECTS

When a number of generators apply for connection to a constrained location on the distribution network, then specific commercial/contractual arrangements are required. The principles of access refer to the rules DNOs offer to generators connecting to an actively managed network. Several principles of access (PoA) models have been proposed: a market-based model, a pro rata model (SHARED) and the last-in first off (LIFO) model [5]. Each model has its advantages and disadvantages from the perspective of the different stakeholders. For the sake of the ARC and Belgian East Loop case studies, the LIFO PoA has been chosen where Lower priority generators are curtailed before those of a higher priority.

The main advantage of LIFO is that it is simple for all parties to understand what their access rights are. It also offers generators a degree of certainty with regards to the levels of network access they are likely to receive and thus the revenue their generation development may generate. Generators which connect in the future cannot impact negatively on existing generators' access rights. Other methods attempt to extract addition network utilisation, allowing more generation to connect but impacting on the capacity available to all generators over time and arguably increasing the risk to the generator.

If a generator is to connect under a non-standard connection agreement, then that connection offer has to be bankable, allowing the generator to raise finance for their project on the basis of predictable export and revenue. As a result, the developers applying for actively managed connections (and their financiers) need to understand the implications of that type of connection on their future revenue. In the UK, generators connected to the distribution network that accept a non-firm connection are not compensated when they are curtailed. As a consequence, curtailment results in a reduction in the capacity factor of the plant and a reduction in revenue.

Trials of ANM in an exporting GSP should consider the interaction between distribution network, transmission network and transmission system operator constraints and what PoA mechanisms should operate for each. Such a trial may consider how they interact. Hence, in the ARC project, National Grid, Scottish Power Transmission and SP have formed a working group in order to discuss a commercial framework for ANM deployment at Grid Supply Points. They will explore an ANM-based contract arrangement between the DNP, TNO and TSO. A set of commercial arrangements will be agreed by March 2014 [2].

This working group will also address the central issue of the scale of the generation constraint in terms of number of GSPs, capacity of generation, volume of energy and ultimately value of energy affected by network constraints. The point at which this becomes material to DNOs, stakeholders and regulators (the UK Office of Gas & Electricity Markets - Ofgem in the case of the ARC project) is decisive on choosing the most suitable PoA. Addressing this issue can take consideration of the opportunities to real time control ANM participating units and the integration of the technical delivery of ANM according to a specific commercial model (the nature of which is crucial to generation bankability) and linkage to balancing and settlement processes and the Balancing and Settlement code (BSC). The principles of access (i.e. priority given for network access for different network users) implemented in ANM schemes would clearly have to reflect the market or administrative arrangements put in place for balancing and settlement.

Furthermore, a trial of ANM in an exporting GSP may not only be limited to real power control. For example, with less synchronous plant on the network the transmission system operator is known to already be experiencing increasing difficulties in managing the voltage on certain parts of the transmission network. Utilising distributed and renewable generation to help provide reactive power support to the transmission system operator would logically also require a market or payment mechanism for providing services.

CONCLUSIONS

This paper has highlighted the potential perspectives of expanding Active Network Management principles to the transmission system, accessing distribution connected resources to relieve network constraints on the transmission side. It is possible to deploy an ANM GSP solution to manage distribution connected as well as transmission connected resources by TNO/TSOs to address thermal, voltage and stability issues.

The approaches discussed in this paper for deployment of ANM in an exporting GSP are innovative solutions which could develop towards a new technology with dedicated control and communication system/software. This technology will have a direct impact on the TNO/TSO's network. Benefits include:

- Providing greater visibility on network assets and optimising them to minimise the cost of balancing the system.
- Providing an integrated control system that is coordinated across transmission and distribution, facilitating access to a range of distribution connected resources for managing transmission constraints.
- Enhancing collaboration between DNOs and the TSOs, and addressing shared challenges.
- Accelerating the development of a low carbon sector but exploiting the potential of ANM-based control of new renewable generation and new forms of electrical demand.

In future work the principles of using ANM to control distribution-connected resources to assist in transmission system operation could be extended to the control of transmission-connected resources with the commercial issues forming a key part of any new approaches.

REFERENCES

[1] C. Foote, R. Currie, F. Clifton, S. Reid, 2011, "The Shetland Island Smart Grid", *Proceedings CIRED 21st International Conference on Electricity Distribution.*

[2] E. Davidson, A. Gooding, R. Currie, 2014, "Actively Managing Distributed Connected Generation Feeding into Distribution and Transmission Constraints", *Proceedings CIGRE* 2014.

[3] O. Durieux, V. De Wilde, J-J. Lambin et al., 2011, "Smart Grid Technology Feasibility Study: Increasing Decentralized Generation Power Injection Using Global Active Network Management", *Proceedings CIRED 21st International Conference on Electricity Distribution, paper 0316.*

[4] Low Carbon Network Fund Submission from Scottish Power–ARC. Available: https://www.ofgem.gov.uk/publications-and-updates/low-carbon-networks-fund-submission-scottish-power-arc.

[5] Flexible Plug and Play: Principles of Access Report. 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.