OPERATIONAL EXPERIENCE OF USING CONSTRAINT MANAGEMENT METHODS FOR CONNECTING DISTRIBUTED GENERATION

Tim MANANDHAR	Laura Hannant	Emmanuel CERQUEIRA
UK Power Networks – UK	UK Power Networks – UK	EDF Energy R&D UK Centre – UK
Tim.manandhar@ukpowernetworks.co.uk	Laura.hannant@ukpowernetworks.co.uk	Emmanuel.cerqueira@edfenergy.com

Sotiris GEORGIOPOULOS	Graham AULT	Finlay McNICOL
UK Power Networks – UK	Smarter Grid Solutions – UK	Smarter Grid Solutions - UK
Sotiris.Geoorgiopoulos@ukpowernetworks.co.uk	gault@smartergridsolutions.com	fmnicol@smartergridsolutions.com

ABSTRACT

Flexible Plug and Play (FPP) is a UK Power Networks' innovation project funded by the GB regulator's (Ofgem) Low Carbon Network Fund (LCNF). It is a three year project which completed in December 2014. The project has connected Distributed Generation (DG) onto constrained parts of the UK Power Networks eastern region avoiding traditional reinforcement. The project implemented Active Network Management (ANM), an already familiar concept in the industry, in combination with other innovative technical and commercial solutions to enable coordinated management of various types of constraints.

The paper focusses on the operational and commercial learning gained in connecting fully commercial generation schemes to the distribution network by monitoring various constraints and managing generator output in real-time. Technical and commercial challenges encountered and the actions taken to address them are highlighted.

INTRODUCTION

The UK government is maintaining a strong commitment to cost effective renewable energy as part of diverse, low-carbon and secure energy mix as stated in the UK Renewable Energy Roadmap Update 2013 [1]. This is supported by the UK's ambitious target for 30% electricity generation from renewable energy by the year 2020.

The Flexible Plug and Play (FPP) project was an innovative initiative aiming to address this requirement in the electricity distribution network which was awarded funding by the UK energy regulator OFGEM as part of the Low Carbon Network Fund (LCNF) scheme. It is a £9.7 million project led by UK Power Networks that ran from January 2012 to December 2014 [2].

The aim of the FPP project was to facilitate cheaper and faster connection of distributed generation (DG) on to a constrained area of the electricity distribution network. The project conducted a trial in an area of approximately 700 km^2 between Peterborough and Cambridge in the East of England where it offered flexible or interruptible connections allowing generators to connect to the distribution network without extensive reinforcement that otherwise may be required. Since the introduction of these flexible connections in the trial area in March 2013 there has been significant interest, which has seen the project achieve the following:

- 48 DG connection requests;
- Issue 39 connection offers for 176MW of generation;
- Receive 14 customer connection acceptances with total capacity of 35.88MW for the flexible connection.

As of January 2014, the project has commissioned five customers connections, totaling 6.75MW, which has given the project the opportunity to generate and implement new learning for future flexible connections that are to be commissioned in the trial area and in the further roll out of the solution.

The Problem

The project trial area had been experiencing increased activity in renewable generation development over recent years, and had seen a rapid rise in connection requests. The connection of these anticipated levels of generation was expected to require costly network reinforcement to remove network constraints such as thermal, voltage and reverse power flows. The existing technical and commercial solutions were not suitable to offer flexible connections due to the following reasons:

- Limited generator control – The inter-tripping solution used previously was not capable of dynamic control of DG power export and hence would result in unnecessary disconnection of generator plants.
- Lack of a commercial framework for flexible connections – a framework was needed to enable UK Power Networks to offer flexible connections and legally support the arrangement.

Consequently, generation projects seeking connections in this constrained part of the network received expensive connection offers which made their projects economically unviable. Although these expensive offers represent a non-interruptible (i.e. firm) connection, developers have found that the high cost of connection does not necessarily ensure a profitable project for them.

The Solution

The FPP project addressed this problem by unlocking the latent capacity in this network with active generator export management and by developing smart commercial arrangements, allowing the project to offer flexible connections.

Technical solution

In order to mitigate the network constraints the project has deployed a technical solution involving a number of smart devices in the network that are centrally and actively managed by the ANM system [3]. The technical solution is designed to cater for single or a combination of constraints at a single location and is able to evolve and adapt to changes in network conditions caused by the addition of new generators.

The project also demonstrated multi-vendor interoperability by implementing IEC 61850 standard over a highly flexible and resilient RF mesh communications network. This interoperable system integration approach over a flexible communications system has created smart grid architecture with enhanced network monitoring and management capability that both protects the integrity of the distribution network and maximizes the extent to which generation can be injected onto the distribution network. Figure 1 shows the diagram of the technical architecture showing the connection of the central ANM system with the local ANM generator controller at the DG substation and the smart devices at the Distribution Network Operator (DNO) substation. This diagram is based on the use case mapping of the generator control by the ANM system using the information layer of Smart Grid Architecture Model (SGAM) framework.

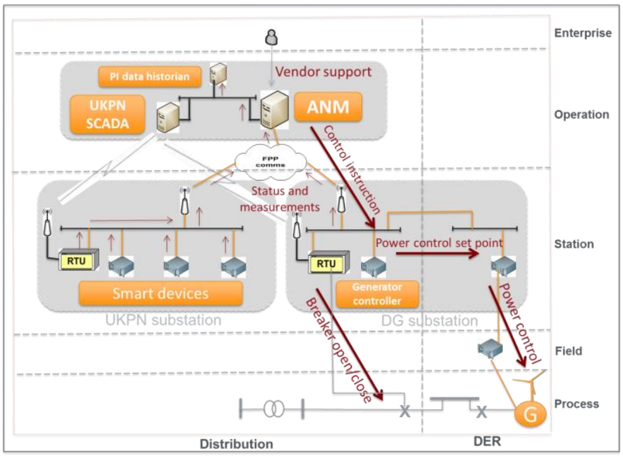

Figure 1: FPP technical architecture

The ANM system carries out real time monitoring of the network using the status and measurement information from the field devices. It is able to configure a number of application thresholds at which it can take pre-determined actions. Once the threshold is breached, the ANM solution automatically issues a power export curtailment instruction to the associated generators which is the key element of the flexible commercial agreement. The ANM system maintains an end-to-end, always-on connection to the generator equipment in order to perform this action. The ANM system also includes fail-safe mechanisms to ensure the security of the grid in case of the failure or loss of communication with any components within the solution.

Commercial solution

The commercial solution included the development of the commercial contracts with suitable Principles of Access arrangements [4]. The process began with determining the curtailment methodology and exploring an alternative method of curtailing generators using a pro-rata approach compared to the existing Last-in-First-Out (LIFO) approach commonly used in the industry. Under LIFO the customer is turned down or disconnected prior to any generators ahead of them in a queue, whereas with pro-rata the generator is curtailed by a percentage of their export, along with other generators within a capacity quota (up to a pre-set amount of capacity), which is set at the level where the cost of curtailment for the area equals the cost of reinforcement.

The two methods were assessed against five criteria: network utilisation, certainty, simplicity, fairness and learning. The project moved forward to use a pro-rata approach for the grid substation in March, where the constraint was the reverse power flow of the 132kV grid transformers. A LIFO solution was also used at another constrained location in Peterborough, due to the various constraints dependent on the area of the network the generator was being connected to.

A flexible connection offer was developed including the following key components;

- Flexible connection agreement providing clarity to the customers in the variations from conventional connection;
- Individual curtailment report for each generator;
- Capacity quota calculation methodology for relevant customers;
- Additional information booklet – detailing the project and trials.

TRIAL OUTCOME

The operational trial of these new commercial arrangements and the set of smart technical solutions faced a number of challenges generating valuable learning outcomes for the industry. This paper discusses some key challenges faced and the learning generated during the trial:

1. Configuration of the ANM system;
2. Integration of DG control systems into the ANM solution;
3. Commercial and contractual challenges.

Configuration of the ANM system

The challenge for the ANM trial was to establish the optimum system configuration parameters that ensure safety of the assets while allowing maximum possible DG export, taking into account the fact that nothing is able to happen instantaneously. The most conservative settings could be adopted in order to protect the network assets but it would not allow for the maximum possible power export from the DGs and hence, would not be the most efficient solution.

The project undertook detailed studies to (a) identify the key factors that influence the settings; and (b) establish relationships among various ANM parameters and their impact on the overall system operation.

Key factors influencing ANM settings

The key factors that directly influence the setting of parameters of a system that manages power flow constraints include:

1. **System limit:** Identification of the true system limit would be the first step as the ANM system needs to operate within this limit. This usually corresponds to the rating of the component in the system with the lowest thermal capacity such as an overhead line current flow rating, or a transformer reverse power flow rating;
2. **Ramp-up rate:** A major factor to consider is the maximum cumulative ramp-up rate which can occur at the constraint measurement point. This ramp rate depends on the amount and the combined variability effect from individual ramp rates of both firm and non-firm generations as well as the load. The faster the ramp-up rates, the greater the need to increase the separation of the ANM thresholds from the system limit;
3. **Ramp-down rate:** The ramp-down rate directly impacts on the speed of constraint management by the ANM;
4. **Network safety parameters:** Protection schemes and settings should also be studied to ensure the ANM operation cannot interfere with or trigger any protection system;
5. **Communication network:** The system needs to be configured according to the characteristics and performance of the communication network. A sensitive ANM configuration over a communication link with high amount of short term failures can lead to an unstable system with higher levels of curtailment of DG power export for communications reasons rather than due to network constraints.

ANM thresholds and operating margin

The following threshold and operating margin calculation methods were developed and applied:

- establish minimum, average and maximum figures for the variable parameters such as communication delay, generator export ramp rates and generator control response time;
- use the relevant parameter values to compute the operating margins for each;
- adjustment of the non-variable parameters such as observation times and communications timeouts to establish the most appropriate threshold settings based on the size, type, behavior and connection timescales of the expected flexible generators.

As more generators connect some parameters need to be adjusted to optimise the threshold settings in order to maximise the generation export while avoiding any possibility of a breach of the system limit.

The behavior of an ANM action can be represented by a sequence diagram showing object interactions in time sequence as per Figure 2.

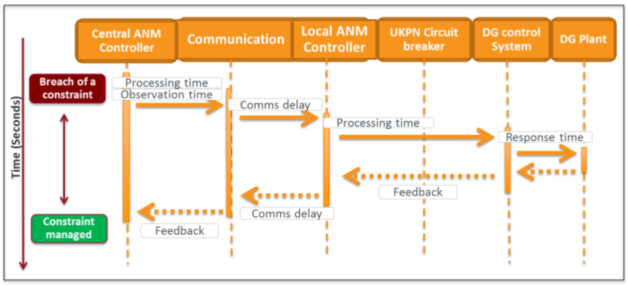

Figure 2: Example of ANM action sequence diagram

Figure shows an example of the sequence of events for a curtailment action starting from the moment when a constraint measurement point breaches a threshold until the moment it is brought back below the threshold. Every object in the sequence diagram represents one of participating components of the FPP project architecture while the time elements represent the parameters involved in the calculation of operating margins. The sequence diagram can show the minimum, maximum and average time of a particular event based on the corresponding time parameters for each participating components. Hence, this process can be used to establish the maximum time criteria for the threshold calculations.

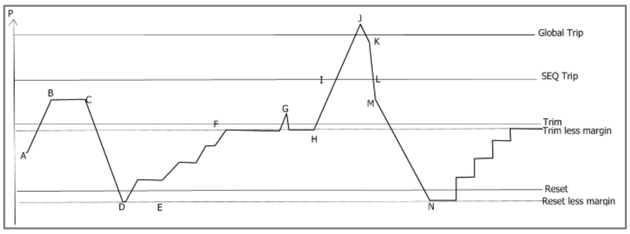

Figure 3 – Example of ANM managing constraint point

Figure 3 is a time-varying illustration of how the power flow at a constraint location varies as ANM operating thresholds are breached. The thresholds displayed on Figure 3, such as "Global Trip", are defined in the operational system after considering the "key factors influencing ANM settings".

System optimization challenges

The IEC 61850 standard is widely used in the industry for substation communications however, the project stretched the capabilities of the standard by trialing its use for network control application outside the substation and over the RF mesh network.

Numerous challenges were encountered in optimizing the overall system which required fine tuning of the parameters of the system components such as the application, the field devices and the communications network. The key challenges and corrective actions are discussed below.

- Significant reduction of the data traffic was achieved by changing the one second polling mechanism of the ANM system to reporting by exception from the field devices.
- Fine tuning of TCP/IP communication parameters such as “keep alive” timer and “keep alive” intervals reducing the level of data errors.
- Staggering the connection of devices to the ANM system reducing the “burden” on the communications network.

Integration of DG control systems into the ANM solution

Traditionally the network operator’s control system has not been required to interface with the customer’s control system. The FPP project architecture has crossed this boundary and this has presented a new set of challenges which are discussed below.

ANM and DG Interface design and commissioning

Due to the variation of the control system technologies used by DG customers, the trial encountered challenges in integrating the ANM system to these platforms. The FPP project specified the preferred protocol as DNP3 over TCP/IP for this interface but not all customers’ equipment was found to be capable of supporting this protocol. Hence, Modbus protocol and hard-wired interfaces were also implemented along with the DNP3 protocol.

The design process faced multiple challenges due to the lack of full clarity of DG control system characteristics and site-specific requirements generating significant learning outcomes as follows:

- The ANM requirement specification should be communicated to the customer at the earliest opportunity in order to allow adequate time for the necessary preparations to be made on the DG control system.
- In order to minimise the possibility of any technical issues that could affect commissioning, bench testing of all interfaces or pre-commissioning tests should be undertaken prior to final DG commissioning on site.
- There is the need to standardise the communications protocols that are used for interfacing with the generators control system. This can be achieved to a certain extent but standardisation will take time due to a large number of different control systems supporting different protocols.

Cyber security risk

As part of the cyber security assessment of the FPP technical solution, the communications interface between the ANM system and the DG control system was identified as a high risk element of the architecture. It was highlighted that there is a need of adequate isolation between the ANM system and the untrusted network (i.e. the customer’s corporate LAN and beyond which the DNO does not have visibility).

It was concluded that if the interface between the ANM system and the customer’s generator controller is via Ethernet, an additional layer of security between the ANM local controller (sgs connect) and the customer’s generator controller is required. This was achieved by the deployment of an industrial Ethernet switch with security controls designed to isolate networks and restrict traffic to specific protocols and pre-defined IP addresses.

Capacity quota performance

In setting the capacity quota for the FPP area (33.5MW), it was assumed that only wind generation would connect under the FPP project. That was the prevailing technology at the time and it was also giving the ‘worst-case’ curtailment estimate for the quota which presented a conservative position for the potential investors. The resulting curtailment was 5.3% lost output per MW of wind generated per annum.

The FPP trial area saw a significant amount of solar generation being quoted and accepted which had a positive effect in the curtailment figures due to the diversity of the solar production when compared to wind. In this instance, the position of accepted customers has become more favourable. UK Power Networks could have potentially accommodated additional generation for the same level of curtailment should there was a mechanism to flex the capacity. It is clear that there is a trade-off between ensuring optimum network utilization, offering customers certainty in their curtailment estimates and complexity of the commercial arrangements.

In addition, figure 4 shows the difference in the expected curtailment rates for the accepted generators and outstanding generation quotations in the March grid trial area, if the customer connects based on LIFO (last in, first off) or pro-rata:

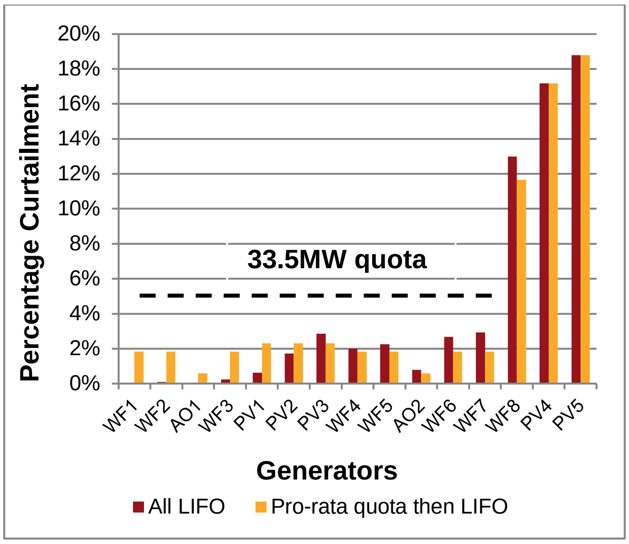

Figure 4 – LIFO vs pro-rata curtailment levels

By utilising the quota approach, the project has allowed an additional 5.8MW of generation to connect over a LIFO approach. LIFO allows 27.7MW to connect at a curtailment rate of less than 5% by using this approach. The pro-rata principle of access, allows 33.5MW of generation to connect to the network at an average curtailment of 2%, with a potential added benefit of linking generators to the potential reinforcement of the network.

Offering cheaper and faster connections

Through the trials, the project has successfully designed and implemented a methodology for offering flexible connections that have provided DG customers within the FPP trial area a cheaper and faster alternative method of connecting to a heavily constrained area of the distribution network compared to the normal business-as-usual approach. In total the project has saved accepted DG customers within the trial area approximately £38 million on their connection offers, or £32 million, when including the cost of the ANM system and curtailment.
The flexible connection has enabled an average connection cost saving of 87% for DG customers in the trial and reduced connection lead times by over 59%, or an average of 29 weeks (See Figure 5).

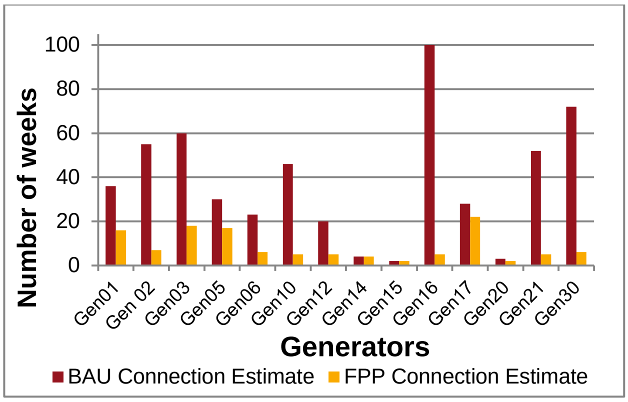

Figure 5 – Connection time of DG, comparing the business-as-usual offer and the FPP offer

CONCLUSION

The FPP project has demonstrated a simple yet a robust concept of network management by identifying only the critical constraint points in the distribution network and actively managing them using an interoperable system architecture using smart application and smart devices. The valuable operational experiences discussed in this paper contribute to the expanding knowledge in the industry to cope with the increasing penetration of distributed generation. The flexible solution gives the customer an option for a different type of connection, which is at a cheaper price, but with the likelihood of generation curtailment at peak times. The FPP project has shown that when taking account of the calculated level of curtailment, the flexible connection is a viable option for the majority of customers.

ACKNOWLEDGEMENTS

The authors would like to thank their FPP colleagues Sam Chachulski, Paul Pretlove and Gilbert Manhangwe for their work and contributions to this work.

REFERENCES

[1] Department of Energy and Climate Change, HM Government, 2013, "UK Renewable Energy Roadmap 2013"

[2] UK Power Networks, Flexible Plug and Play website www.flexibleplugandplay.co.uk

[3] UK Power Networks, 2014, SDRC 9.6 report on “Implementation of active voltage and active power flow management within FPP Trial area”

[4] L. Kane, G. Ault, L. Hannant, S. Georgiopoulos, 2014, "Analysis of Market and Non-Market Principles of Access for Wind Generation connection to Active Network Management Schemes", in *CIRED Workshop*, Rome, 2014, no.0077