UK POWER NETWORKS' EXPERIENCE OF MANAGING FLEXIBLE DISTRIBUTED GENERATION FROM PLANNING TO OPERATION

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ABSTRACT

UK Power Networks has got two live Active Network Management (ANM) systems hosting 200 MW of Flexible Distributed Generation (FDG) capacity with an additional 130 MW in the pipeline. The challenges facing the live operation of ANM schemes include; communication failure, unnecessary DG failsafe when communication is unavailable, configuration of ANM system and settings (i.e. System limits, ramp-rates and network safety parameters).

The paper focusses on the operational and technical learning gained in connecting commercial FDG schemes by monitoring various constraints and managing generator output in real-time. This paper also explains how UK Power Networks addressed the issues and optimised the performance of their ANM schemes.

INTRODUCTION

The UK energy supply system is undergoing transformation. The move towards smart grids is the most exciting change the electricity industry has seen since the days of its foundation. UK's energy policy and focus on decarbonisation has driven take up of renewable energy, such as wind farms and solar panels, which is clean and sustainable but its output is more variable. Electricity storage technology is advancing and is expected to play a major role in the next few years, along with a potential increase in the use of electric vehicles, and the completion of national smart meter roll out by 2020.

The Distribution Network Operators (DNOs) are at the forefront of enabling these changes. National Grid estimates that the system now has 10-11GW of solar generation; 90% of the solar energy alone connects directly to the distribution system. UK Power Networks has connected 8.5GW of Distributed Generation to its three networks, representing almost a third of the installed Distributed Generation across the UK [1]. In light of the pace of change, DNOs are exploring innovative solutions to manage grid capacity on their networks to maximise renewable connections without costly reinforcements. This is an influential driver in building Distribution System Operator (DSO) capabilities within the business.

UK Power Networks are the DNO in the UK with the most electricity network under active network management for generation – through the offering of Flexible Distributed Generation (FDG) connections. The offer aims to provide a point of connection within the existing network with minimal need for/or ahead of reinforcement. The customer must be willing to accept temporary reduction to their export to ensure the network is kept within operational limits. Over 20 generation sites have been connected to our distribution network through this connection offering, saving over £70m for the connectees in reinforcement costs. Although flexible connection solutions allow more Distributed Energy Resources (DER) capacity to be connected to the network, the implementation of these has created operational complexities for both DNOs and DER developers. The energy curtailment levels and network interruptions imposed on DER is influenced by foreseen and unforeseen events such as faults, maintenance outages, loss of telecommunication network and changes to network running arrangements from DNO or Transmission System Operator (TSO). As some of these events are unforeseen, mitigating their impact requires changes to communication network infrastructure and incentives amongst other changes to organisational processes.

This paper will summarise UK Power Networks' FDG connection arrangements. It will present the planning and operational experience of the last 24 months and propose learning to be incorporated.

ANM SYSTEM DESIGN

Due to the significant increase in DG connected to its networks, UK Power Networks has had extensive experience in the installation and operation of Active Network Management (ANM) systems, which are used to control DG with flexible connection agreements. These schemes allow DG to connect to constrained areas of the distribution network in reduced timescales, avoiding large connection costs by accepting curtailment when network operational limits are to be exceeded.

Prior to the deployment of an ANM system in the distribution network, power flow studies in intact, N-1 and N-2 (where necessary) arrangements under "maximum generation-minimum demand" conditions are performed to identify network constraints. Next, chronological power flow studies are carried out during a defined operational timescale (generally one year). These studies consider: expected generation profiles of flexible generators; estimated evolution of demand and existing generation's profiles over time; known alternative running arrangements, and; impact of planned maintenance schedules. The FDG schemes will be given annual energy curtailment estimates against the identified network

constraints under a given Principle of Access. To date, UK Power Networks has used "Last-in, First-off" and "Pro-rata / Quota" as Principles of Access In addition, UK Power Networks provides the customer with a breakdown of energy curtailment per hourly period. These annual energy/time of curtailment estimates are aimed to provide customers with necessary information to evaluate their commercial investment cases.

Management of multiple constraints

Constraints may be classified by their reach as global or local. Global constraints are relevant to all FDG connections in the ANM system. Local constraints are only relevant to a selection of the FDG connections in the ANM system. The possibility of constraints occurring simultaneously is considered in the ANM system design. This is required in order to ensure a consistent approach to constraint elimination and facilitate post-curtailment log analysis. The example below illustrates how two constraints that are triggered simultaneously by four generators could be managed (see Figure 1): Constraint 1 at the Grid Supply Point (132kV); Constraint 2 at Grid A (132/33kV substation).

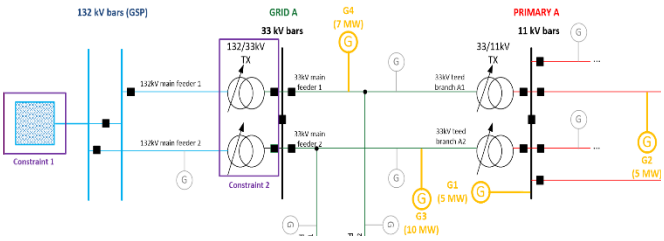
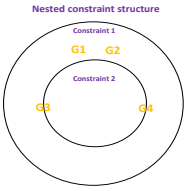


Figure 1 – ANM managing multiple constraints.

Table 1. Arrangements for Management of Multiple constraints.

Generator	Relevant to constrain
G1	Constraint 1
G2	Constraint 1
G3	Constraint 1, Constraint 2
G4	Constraint 1, Constraint 2



Generators G1 and G2 were connected first and did not trigger Constraint 2 (at Grid A). Therefore, they are only liable for curtailment for Constraint 1. Generators G3 and G4 were connected later and are thus liable for curtailment for both Constraint 1 and Constraint 2. The management of multiple constraints will then follow a "nested" structure: if both constraints are triggered, the "most local" constraint is managed first as a convention. G3 and G4 are curtailed to eliminate Constraint 2 and then, if Constraint 1 still persists, all four generators are curtailed.

ANM Configuration Settings

The ANM system deployed across UK Power Networks uses the escalating control actions philosophy presented in [2]. This is to ensure curtailment of FDGs are minimised whilst keeping the network within design limits.

The three main levels of action are considered under Trim (i.e. normally set to coincide with the Operational Margin, this corresponds to the level at which a constraint starts to be observed and curtailment actions are put in place to bring power flows to an acceptable level. Typically equal to 90% of the Global Trip Threshold), Sequential Trip (i.e. set higher than the Trim level, in this level of action generators start to be tripped one-by-one until power flow goes below "Sequential Trip" threshold. Typically equal to 96% of the Global Trip Threshold) and Global Trip (i.e. the highest level of action disconnects all generators associated with the constraint in order to maintain the network within design limits) [3].

Determining the optimum system configuration for thresholds, operating margins, ramp-rates and timers is required to avoid the following undesired impacts:

1. Frequent disconnection of DGs by the ANM scheme prior to an ANM curtailment action. This is due to inconsistency between generator ramp-rates, measurement point ramp-rates and timers.
2. Increased curtailment due to incorrect estimation of generator impact on a constraint.

Sensitivity Factors

ANM uses sensitivity factors to establish a relationship between a constraint location and a generator. It is important to make sure the most up-to-date sensitivity factors are given to the ANM system configuration. This is because the sensitivity factors are actively used to determine the necessary curtailment levels when a threshold is breached.

Ramp-rates

Generator ramp-rates define how the available capacity can be utilised in the network under ANM management. The ramp-rates of generators can influence the likelihood of the power flow at a constraint location rising at a rate that results in generators being tripped by the ANM scheme prior to an ANM curtailment action. Hence, it is important to accurately calculate and update the appropriate generator ramp-rates, in particular ensuring the stable operation of the ANM scheme. Figure 2 illustrates the process of curtailment to eliminate a thermal overload.

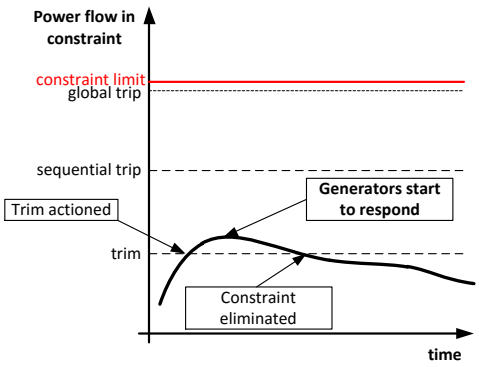


Figure 2. Sequential actions for curtailment.

In the example of Figure 2, the ANM system was able to eliminate the constraint at trim level, without escalation of

control actions. However, the ANM is at risk of occasionally tripping a generator prior to trimming if the rate of change of power flow at the constraint location is lower than the rate of change of power flow at the generator's Point of Connection (PoC). In this condition, the power flows will enter tripping levels before the trim level had time to successfully curtail generators and reduce power flow at the measurement point. Ramp-rate at the constraint location is also referred to as Measurement Point (MP) ramp-rate.

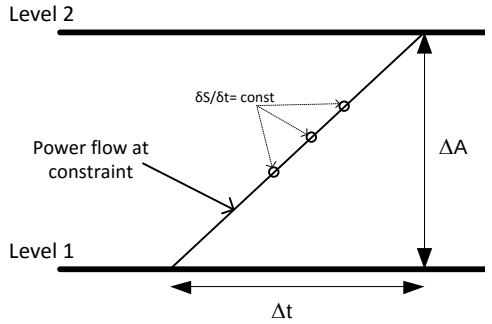


Figure 3. Rate of change of power flow at a constraint location.

The ramp-rate of a generator must not cause greater impact on the constraint location (illustrated on Figure 3) than the Amps per second value calculated for the MP ramp-rate:

$$Ramp\ rate_{Gen} \times \frac{Sensitivity}{100} \leq Ramp\ rate_{MP} \quad (1)$$

For example, a FDG generator with a ramp-rate of 16.66kW/sec (i.e. 1000 kW/min at its 33kV PoC) and a sensitivity to the constraint of 100% has the following impact at the Measurement Point:

$$\frac{16.66}{33 \times \sqrt{3}} \times 1 = 0.29\ Amps/sec. \quad (2)$$

The minimum safe ramp-rate at the measurement point that will avoid such a scenario is set as the minimum of:

$$Ramp\ rate_{MP} \leq \frac{\Delta A}{\Delta t + Latency^{Gen}} \quad (3)$$

Where

$$\Delta A = Amps^{Level\ 2} - Amps^{Level\ 1} \quad (4)$$

Rearranging equation (3) to get the Generator Response Time ($Latency^{Gen}$) in seconds will generate the following equation:

$$Latency^{Gen} \leq \frac{(Amps^{Level\ 2} - Amps^{Level\ 1}) - Ramp\ rate_{MP} \times \Delta t}{Ramp\ rate_{MP}} \quad (5)$$

The generator response time corresponds to the time it takes for the generator to respond to a signal arriving at its control system hence starting the requested turn down. Equation (5) will define the requirements for necessary control system investment to achieve the desired generator response time.

Optimising ANM settings

Performing regular operational data reviews to investigate the actual dynamic nature of power flow ramping at each measurement point would be crucial to fine tune the ANM configuration parameters and generator ramp-rates at PoC based on the following three objectives:

1. Minimise generator curtailment.
2. Minimise transient impacts on the distribution network.
3. Enhance ANM operational stability.

Generator ramp-rates are just one of many variables such as margins and communication resilience that can influence operational stability, so their setting must take account of these other variables. The ramp-rate previously calculated for generators will need to be fine-tuned.

- Analysing the historic apparent power flows through the MPs (i.e. before ANM going live) and other operational ANM behaviour (i.e. after ANM going live) to choose the most suitable values of Trim Threshold and Sequential Trip Threshold. The pattern of apparent power flows at the MPs could be analysed to calculate the maximum and minimum power flows and their frequency of occurrence. This will provide greater understanding on which Trim Threshold should be chosen to minimise curtailment level of DGs connected under FDG.
- Recalculate the sensitivity of each generator with respect to each constraint location. It is important to note that the ramp-rate of the generator must not cause greater impact on the constraint locations than the Amps per second value calculated for the MP ramp-rate.
- Analyse the pattern of individual generator responses to ANM set points and determine how long each individual generator took to achieve the set point defined by ANM. This will determine the generator response to ANM set points which also takes into account communications latencies to/from the generator site.

The relationship between generator ramp-rate and the Measurement Point ramp-rates must be investigated to make sure the generator's impact is consistent across all constraints. This will avoid undesirable triggering of those constraints which could have a lower absolute margin between thresholds.

ANM OPERATIONAL MANAGEMENT

Operational events

Failsafe is one of the key design principle of the ANM and as such, any abnormal condition leads to failsafe curtailment events which can further escalate to trip events. A pattern was observed when assessing the performance over the two years from 2015 to 2016 which followed the characteristics of a typical bathtub curve. It showed that there was a surge of issues just after March 2015 when eight generators connected under FDG to the network within a very short space of time in order to meet the deadline for the change of DG financial support incentives. This pattern repeated after March 2016 again when another batch of generators connected to the

network. However, in 2016 new types of issues were encountered as the system felt the effect of introducing additional data traffic and complexity with over 20 generators and over 10 constraint locations. This highlighted a need for a continuous optimisation of the overall system including communication infrastructure, ANM configuration and DG equipment configuration.

Issues and Challenges

Smart grid systems require DNOs ancillary infrastructure to be equipped with additional capabilities. This is observed more in the telecommunications and IT system. Most distribution networks use low bandwidth, high latency telecommunications systems for the purposes of Supervisory Control And Data Acquisition (SCADA) control systems. With the requirement for more granularity of data and higher polling rates, it can be understood that a significant step change had to be undertaken. These changes had to occur at all levels of the infrastructure since ANM generates more data and this also has an impact in other part of the shared infrastructure such as data historians, server processors, etc.

One of the complex issues was related to the ANM application handling of the comms failures. This was previously being masked as being caused by actual comms failures but it got diagnosed during an investigation of intermittent radio communications link that was unnecessarily closing Transmission Control Protocol (TCP) connection sockets between the central ANM and the local field devices. This led to the ANM triggering the failsafe action with short duration but high frequency curtailment instructions to the generators. This type of events had a greater impact to rotating machine generation due to the inertia requirements to restore to the same pre-event generation output compared to generation such as solar farms. The ANM issues that have been experienced to date can be categorised into four types:

1. **Telecommunications issues:** Communication faults have been one of the common causes of fail-safe actions for the ANM system. Radio technologies can have short term failures and if those durations exceed the observation timer, the ANM takes a failsafe action by curtailing the generator. In addition, the measurement update rate was also found to be a cause of curtailment and trip events. As the communication systems have bandwidth limitations, the update frequency of the change of measurements are throttled at the substation Remote Terminal Units (RTUs) using deadband settings. Various iterations of settings were tested to strike the right balance between update frequency and saturating the communications network.

2. **Settings issues:** Initial conservative settings made the system very sensitive to certain network conditions such as power flow spikes. As more operational experience was gained on each scheme the settings were relaxed and made more practical in order to stabilise and optimise the overall system.

3. **Generator technology specific issues:** These are malfunction issues in the customer's installation that only became apparent after commissioning. These issues usually manifest itself in form of ANM triggering generator not responding action leading to full curtailment and trip instruction.

4. **Component failures:** The system is designed with redundancy at multiple layers of the architecture. However, there are single points of failure in the measurement points on the network. The impact can be minimised by increasing the resiliency of the solution.

ORGANISATIONAL CAPABILITIES - ANM INTO BUSINESS AS USUAL

In order to run the ANM as a fully supported function in the business, all the necessary capabilities need to be in place. The capabilities need to cover the whole life cycle from planning, commissioning to operational management of an ANM scheme. These are standard and well established business functions of a network operator, that are usually extendable to support a new service transition. However, due to the novel nature of the ANM system, a whole suite of new capabilities need to be developed to wrap around this new function before progressing through the new business service introduction process.

The first step - Developing the Tools

The experience of managing the ANM system has highlighted that one of the first steps must be to identify the requirements of effective operational support tools that can further assist in shaping up other capabilities. Access to the right tools for the operational teams will help in quicker familiarisation of the new systems and will de-mystify the concept of the ANM as the new black box within the business. The following are the key areas requiring development of new tools:

Planning and Curtailment assessment

The initial stages of the flexible generation connection require efficient tools to carry out network planning with an objective of cheaper and faster connection. This also includes tools to carry out curtailment assessment of the prospective generation customers enabling them to secure necessary investment for their projects.

Visibility and Access

Fit for purpose and user friendly graphical user interfaces are required to enable relevant teams to carry out tasks such as fault diagnosis and system configuration. These interfaces need to be easily accessible, secure and reliable in order to instil confidence into the operational workforce. Apart from internal user interfaces, the project team also developed an external web portal to provide real time visibility of the ANM system to the flexible generator customers.

Monitoring and Notification

Majority of the abnormal events on the ANM system such as the communication failures lead to fail safe curtailment actions. Without effective monitoring and notification tools, such events go undetected for a long period of time causing loss of export revenues for the DG owners.

Data Analytics

The ANM system stores historic data which can be used for fault diagnosis and performance assessment. One of the operational challenges of managing ANM system has been identification of the root cause of an issue due to the lack of effective analytical and reporting tools.

Resolution and Optimisation

To address the events being experienced, the focus went on improving coverage and signal strength to reduce bottlenecks and improve the ability to more accurately discriminate against loss of communication events against normal protocol and traffic management behaviour. The application level detection had to go through several iterations as a balance between discrimination of genuine event had to be achieved. Regarding the curtailment actions being taken when no risk was posed to the safe operation of the network, further studies were carried out to realistically assess the current connected generation mix in ANM zones and determine if the same actions are required to be taken during different periods of the day. This lead to the implementation of time based failsafe values so that if an action had to be taken when the failsafe values could be higher, it would only reduce when and if it was during those periods.

System optimisation and stability

A whole system approach needs to be taken to optimise the ANM system for high degree of stability. Due to the nature of complex smart grid architecture and integration of multiple technologies, a slight variation of one component can destabilise the whole system. The optimisation process needs to strike a right balance between acceptable risk to the network assets and DG loss of export. Pushing the operational limits too much could overlap with the safety clearances and not enough could result in unnecessary curtailment of DG export.

FUTURE DEVELOPMENTS & CONCLUSION

All network operators are facing a challenge of rolling out FDG connections while preparing to cater for other smart grid technologies such as storage, electric vehicles and demand side response. The future ANM system needs to be more flexible, integrated & coordinated with other smart systems. Following are the key areas of focus for the future:

- Continuation of business adoption of FDG.
- Review and sourcing effective smart technologies.
- ANM system in areas of Transmission constraints.
- Integration of storage, demand response and electric vehicles.
- Further development in commercial area such as curtailment using market mechanisms.

Having encountered a multitude of issues as described in this paper, an end to end assessment of the overall solution was carried out in middle of 2016. This identified a number of improvement actions to stabilise the system and minimise unnecessary curtailment of the DGs, some of which are outlined below:

Measurement resilience

Loss of measurement data at the constraint location means failsafe curtailment of all associated DGs unnecessarily. There will be future logic based functionalities that allows the use of other measurement data in the network to derive an approximated measurement value at the constraint location preventing the failsafe action for certain period.

Communications resilience

Use of backup communication infrastructure would greatly increase the resilience of the ANM system. However, this will require this functionality to be developed at both the central software as well as the field devices.

Increased Intelligence

Further intelligence needs to be developed so that DGs are less curtailed due to system issues taking account of other data such as time of the day, generation profiles etc.

The ANM system is complex smart grid technology requiring integration with multiple components in the existing network. As the ANM concept is to utilise the latent capacity of the network assets without putting the network at risk, the system needs to evolve from a pre-configured logic based system to a more active and intelligence system that is able to take decisions based on dynamic power flow and real time system changes.

As UK Power Networks moves toward a Distribution System Operator (DSO), we should cater for continuous changes to network dynamics:

- Network Running Arrangements changes.
- Firm DG ramping.
- Sudden loss of demand.
- Bi-directional flows at GSP level.
- Dynamic Sensitivity factors.

UK Power Networks intend to rollout ANM across Eastern/Southern Power Networks (EPN & SPN) by 2021 and enable commercial services from DERs. ANM provides the visibility and controllability at distribution level to help DNO transition into DSO. To effectively manage the FDG connections as Business as Usual, the network operators need to build a new set of capabilities to support the new business functions from planning to operations. Due to its active nature, the system needs to be regularly assessed and optimized with a whole systems approach.

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