ACTIVE MANAGEMENT OF GENERATION IN LOW VOLTAGE NETWORKS

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ABSTRACT

SP Energy Networks (SPEN), in conjunction with Nortech Management Limited, has developed a novel active network management (ANM) system for low voltage (LV) networks. The ANM system controls the output of distributed generation (DG) in real-time, managing voltages at constraint points within the network. For the first time in the UK, the ANM system has been deployed to facilitate the connection of 200kW of generation in SPEN's LV network, as a part of the "Accelerating Renewable Connections" (ARC) project. The ANM system enables DG to be connected more quickly and cost effectively than network reinforcement. Moreover, in some cases (where network reinforcement is unviable), ANM may be the only possible solution.

INTRODUCTION

Due to UK carbon reduction targets and regulatory incentives, Distribution Network Operators (DNOs) are integrating increased levels of renewable generation into their electricity networks [1]. This is becoming a challenge for DNOs, particularly in HV (11kV/6.6kV) and LV (400V) networks where high volumes of small-scale generations are seeking connections. At times of low load and high distributed generation (DG) output, voltages in HV networks can potentially breach statutory limits, causing non-optimal operating voltages for domestic appliances downstream in the LV network. The traditional way to address this problem has been to reinforce the network by building larger capacity assets (such as overhead lines). However, this can be expensive and take a long time to deploy, due to planning permission constraints. Moreover, in some cases, network reinforcement may not be possible at all (for example, where environmental constraints restrict the construction of new overhead line circuits). In these cases, deploying an ANM solution may be the only cost-effective means by which DG can be integrated within the LV network.

This paper describes the deployment and live operation of an ANM system which, for the first time in the UK, has been deployed to facilitate the connection of 200kW of generation in the LV network, as a part of SPEN's project "Accelerating Renewable Connections" (ARC).

BACKGROUND

Accelerating Renewable Connections

Accelerating Renewable Connections (ARC) is a UK innovation project, led by SP Energy Networks (SPEN) and part-funded by Ofgem through the second tier of the Low Carbon Networks (LCN) Fund [2].

The driver for this project is that the current generation connection application process has limitations, particularly, where the volume of applications is high. This is because sub-optimal design decisions may be made due to limited information about the projection and certainty of new generation applications. ARC is helping SPEN and other DNOs to address this problem by trialling changes to the existing connections process in collaboration with stakeholders.

ARC has trialled new connections processes and supplemented this with new commercial arrangements and technology to accelerate the connection of renewable generation connections. This paper focuses on the demonstration of technology for applications in HV and LV networks (where there are high volumes of generation connections but limited ANM solutions available).

ARC has been launched in the East Lothian and Borders region of SP Energy Networks' distribution network – an area of 2,700 square kilometres stretching from North Berwick down to Holy Island, and inland as far as Hawick and Galashiels.

Development of ANM for LV Applications

Various solutions for the connection and operation of distributed generation were identified by the Distributed Generation Co-ordinating Group (as part of Workstream 3 of the DTI New & Renewable Energy Programme) in 2003 [3]. Building on this work, from 2006 to 2010, SPEN participated in a project, sponsored by the Technology Strategy Board and in collaboration with Durham University, Parsons Brinckerhoff, AREVA and iMass. In this project, a system was developed and prototyped for the active management of distributed generation based on component thermal properties [4]. The system was installed and trialled in North Wales.

Several different approaches were developed including the control of single DG schemes in discrete intervals [5] and the coordinated output control of multiple generators using power flow sensitivity factors [6].

In parallel to this, over the past decade, SPEN has been working with Nortech Management Limited on several innovative projects, harnessing Nortech's technological capability in monitoring and control systems for ground-breaking power system applications [7].

Supported by ARC project funding, SPEN has brought together its previous innovation work and Nortech's technology to demonstrate ANM solutions in LV networks.

Whilst there are several other suppliers offering ANM solutions, these are currently suited to higher voltage applications (11kV and above). A key differentiator is that the system described in this paper has been developed with an architecture and price-point that scales for high volumes of small-scale generation connected within LV networks.

HOW THE ANM SOLUTION WORKS

The ANM system manages DG power output in real time by monitoring voltages and power flows at constraint points. Critical voltages are monitored by RTUs (termed "constraint point monitors"), which report the data to Nortech's iHost management platform at regular intervals. The monitored voltages are compared to pre-determined voltage limits and set-points are calculated to reduce or increase the DG power output in discrete intervals [5]. The set-points are communicated to RTUs (termed "generator controllers"), which integrated with the generator's local control system.

USE-CASE OF THE ANM SOLUTION

Overview and Customer Engagement

Penmanshiel Piggery is located in the Berwick GSP area. The farm is fed from two distribution transformers: Penmanshiel and Penmanshiel Piggery. (For clarity, these are referred to as "Penmanshiel" and "Piggery Turbine" throughout the paper.) The customer applied for the connection of 100kW of photovoltaics (comprising two 50kW arrays) and a 100kW wind generator. Based on network planning analysis, the two transformers were identified as voltage constraint points at times of high generation and low local load demand at the pig farm. The nearest point of firm connection is Ayton, a primary substation over 10km from the farm. The cost of a firm connection was unfeasible for the customer, with a quote of £600,000 to reinforce the network.

SPEN deemed this connection suitable for further investigation. This was because the farmer already had planning permission for all the prospective generation. Through discussion with the customer, SPEN understood the practicalities of the connection better and provided an alternative connection design. Without a smart solution, this generation connection would not have gone ahead.

The driver behind the installation of this renewable energy is to have on-site generation to secure energy requirements and reduce energy bills. Pig farming is an energy-intensive process. The renewable generation allows Penmanshiel Piggery to earn additional revenue from Feed-in Tariffs and to continue to employ local people to help run the farm.

A non-firm connection offer was issued in summer 2015, the first photovoltaic (PV) array was connected in winter 2015 and the second PV array and wind turbine connected in spring 2016.

Smart Connection Design and ANM Deployment

The schematic diagram of the Penmanshiel ANM system is shown in Figure 1. 50kW of controllable PV is connected to the Penmanshiel distribution transformer and 50kW of uncontrolled PV, together with 100kW of controllable wind generation, is connected to the Piggery Turbine distribution transformer. Both constraint points are monitored using Gridkey units, which report the voltages at a 1-minute granularity to Nortech's iHost ANM system.

Prior to the deployment of the ANM system, the monitored data at the constraint points was analysed to determine the frequency of expected interventions and the available headroom for connecting generation. Monitoring of the Penmanshiel distribution transformer showed that the 50kW peak output of the PV array could cause voltage rise issues during summer months and therefore this generation scheme needed active management. Monitoring of the Piggery Turbine distribution transformer showed that there was a base load of at least 50kW, allowing a 50kW PV array to be connected unconstrained at this point. However, the additional 100kW of wind generation could lead to voltage rise issues during the summer months and therefore this generation scheme needed to be actively managed.

Due to the phased installation of the generation, initially a single constraint – single generation ANM system was deployed to control the 50kW PV connected to Penmanshiel. When the 100kW wind turbine was commissioned, a second ANM scheme was deployed to control this generation based on the voltage constraint at Piggery Turbine. Furthermore, the distribution transformer upstream of Penmanshiel (Penmanshiel South) was monitored and a single constraint – multiple generation ANM system was integrated with the existing schemes. This alleviates voltage rise issues due to the combined generation output pushing the constraint point deeper into the network.

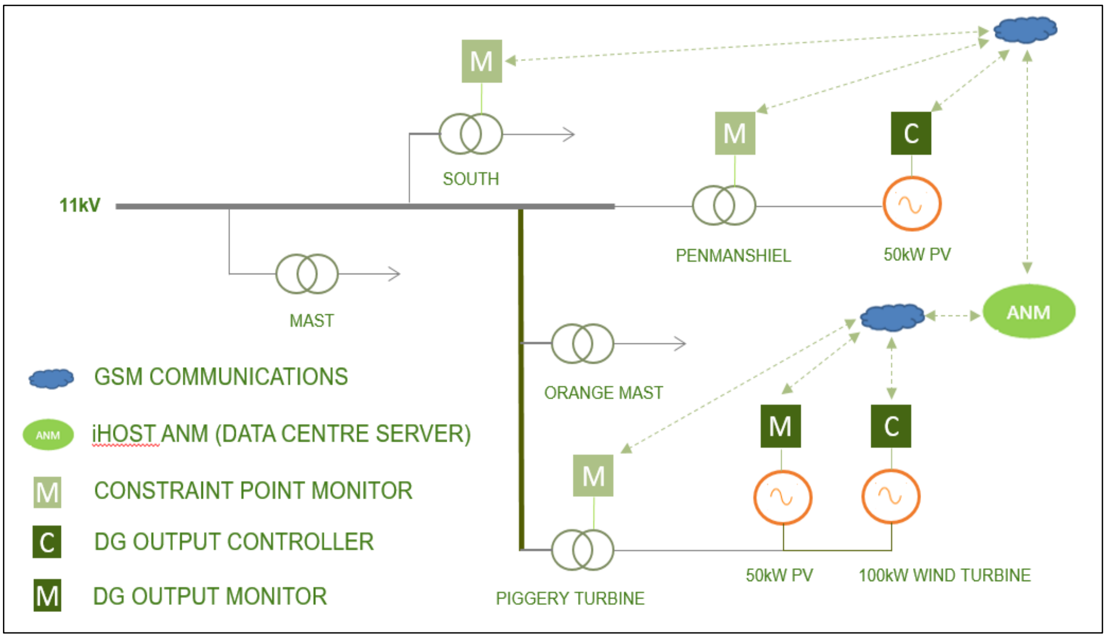

Figure 1 – Schematic diagram of the ANM system use-case

Tools and Technologies

In this particular ANM system, the voltage constraint points are monitored using Gridkey devices. Gridkeys are installed on pole-mounted transformers and allow the voltages and currents of individual LV feeders to be monitored with a 1-minute granularity. This data is reported to Nortech's iHost platform using mobile communications.

The iHost platform, hosting the ANM algorithms, can be located on substation servers, local to the generator, or in a centralised data centre location. In this case, a centralised data centre location was adopted (as the platform is already being used for remote monitoring of a number of other devices, deployed as part of SPEN's ARC project). Voltages at the constraint points are compared to pre-determined thresholds. When the voltages exceed the 'constrain threshold', a constraint signal is dispatched via Nortech's Envoy Generation Controller to the generator and the power output is reduced in discrete intervals until the voltages are brought back within limits. When the voltages fall below the 'relax threshold' the generation constraint set point is relaxed and, when the headroom allows, the generation returns to an unconstrained output.

The system is fully configurable and is accessible via a secure dashboard as shown in Figure 2. The left-hand side of the dashboard contains a single line diagram of the system. The right-hand side of the dashboard contains the control panel (allowing the ANM system to be disabled or switched between automatic and manual control modes). Figure 3 shows the three individual phase voltages against control thresholds and protection limits. Figure 4 shows the real-time power output of the generation scheme together with its real-time set point limit.

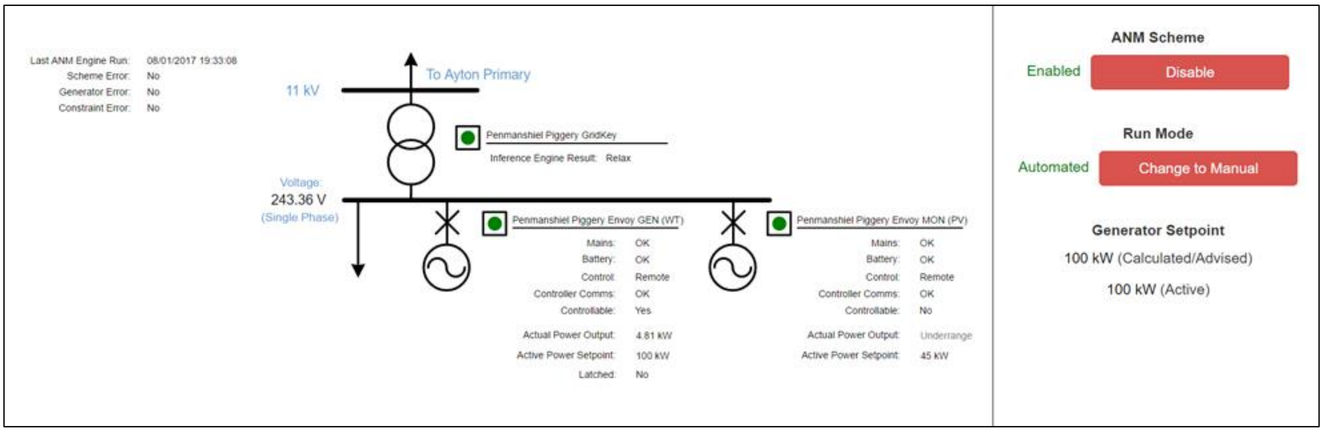

Figure 2 – Single line diagram and control panel for the ANM scheme

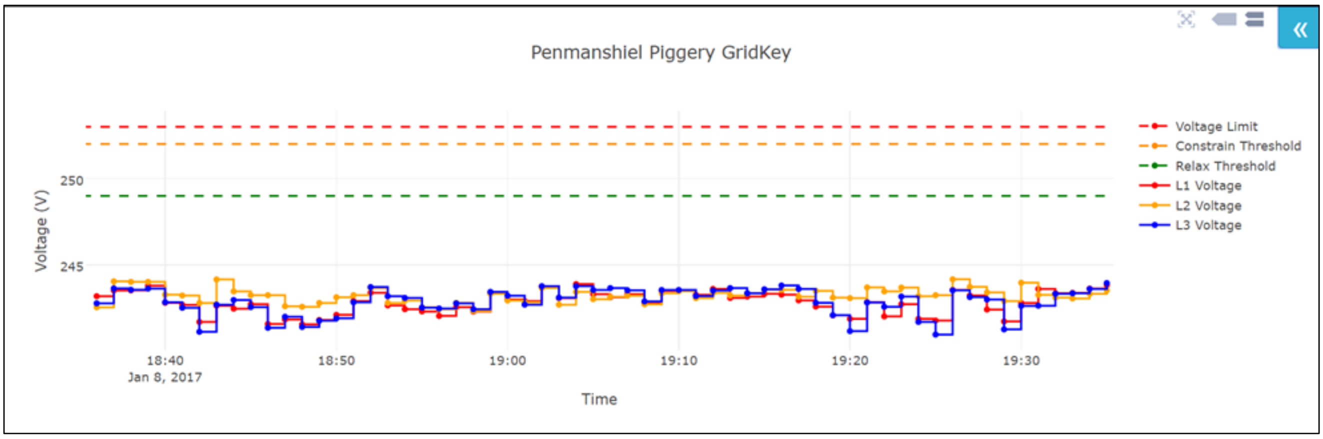

Figure 3 – Voltage monitoring at the constraint point

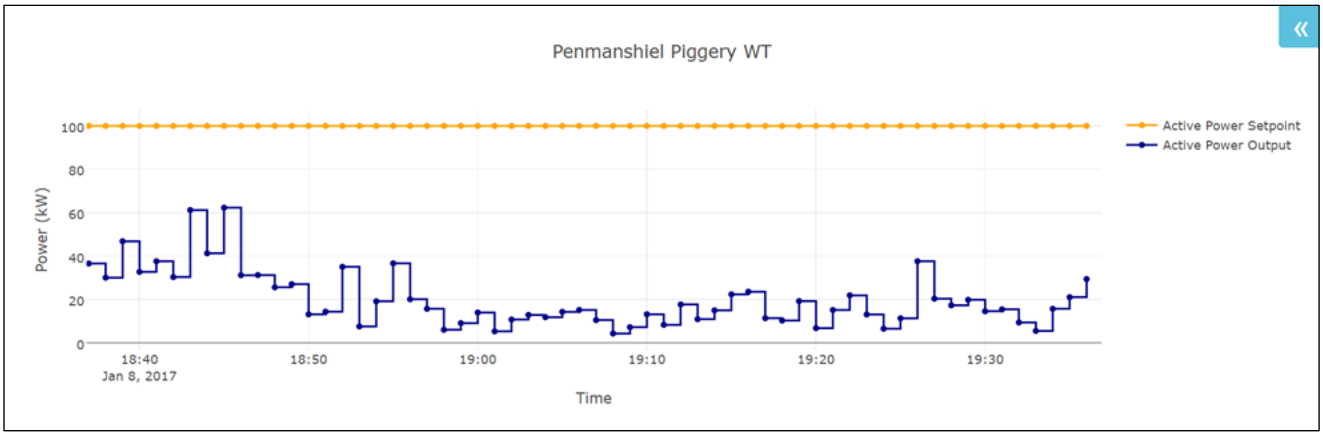

Figure 4 – Power output control of the generator via set points

FIELD TRIALS

Live operation of the system is shown in Figure 5 and described in the following steps:

1. An upstream network event causes voltages at the constraint point to increase.
2. Voltages at the constraint point breach the 'constrain' threshold.
3. The ANM system reduces the power output of the generator via set-points.
4. Voltages at the constraint point reduce to safe levels due to decreased generation output.
5. The network is restored to its previous state, decreasing the voltages below the 'relax' threshold.
6. The ANM system increases the output of the generator via updated set-points.

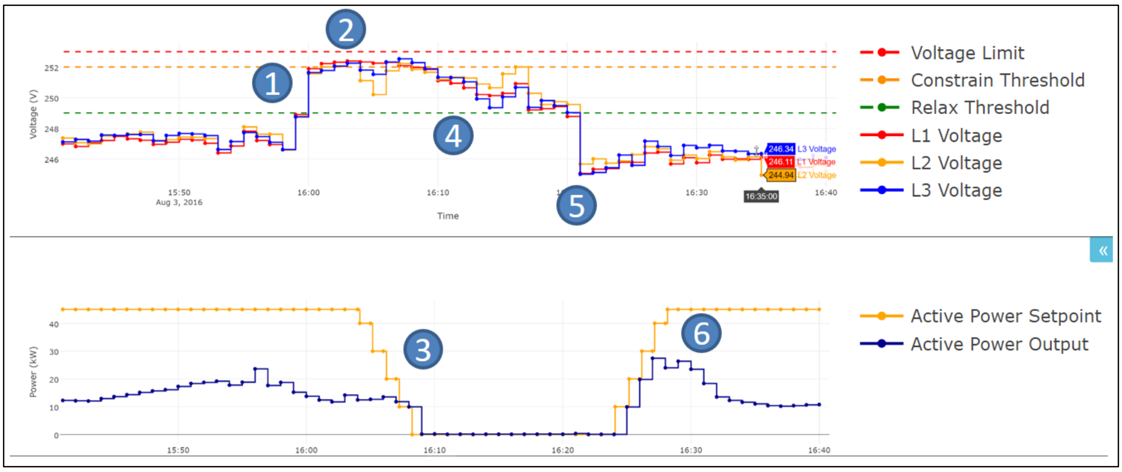

Figure 5 – Live operation of the ANM system

SYSTEM FEATURES

Alarms and Graceful Degradation

The ANM system includes intelligence to constrain DG and protect the electrical network in the case of any failure, such as loss of communications. Every component of the system is monitored and critical failure alarms are shown on the dashboard and SPEN is immediately notified.

Offline Planning Tool

Alongside the operational ANM components, a tool has been developed to allow ANM schemes to be planned and designed offline. The tool includes features such as characterisation of the constraint point to be able to quantify the expected level of constraint for different installed capacities of generation.

Constraint Reason Report

To aid SPEN with queries from the generation customer and to help quantify the actual level of constraint experienced by a particular generator, a 'Constraint Reason' reporting tool has been developed. This provides a transparent audit trail for the ANM system controls, summarising any set point changes (reductions and increases) and the reasons for the change (such as 'voltage over constraint threshold' or 'voltage under relax threshold').

CONCLUSIONS

This paper has described the development of a novel Active Network Management (ANM) system for low voltage (LV) networks. The ANM system controls the output of distributed generation (DG) in real-time, managing voltages at constraint points within the network. For the first time in the UK, the ANM system has been deployed to facilitate the connection of generation in SPEN's LV network, as a part of the "Accelerating Renewable Connections" (ARC) project. The ANM system enables DG to be connected more quickly and cost effectively than network reinforcement. Moreover, in some cases (where network reinforcement is unviable), ANM may be the only possible connection solution.

The system has successfully connected 200kW of renewable generation whilst maintaining network voltages within statutory limits. The complete system was designed, built and deployed within the first 6 months of 2016 and is continuing in live operation.

The solution saved the DG customer approximately £600,000 in network reinforcement charges. Work is continuing, as part of "ARC", to facilitate increased levels of DG connection through LV active network management.

FUTURE DEVELOPMENTS

With funding from InnovateUK (the UK's innovation agency) work is continuing in this area to develop a directional power flow sensor for overhead line networks (for ANM and fault detection applications). This work will also integrate power system analysis software into iHost and assess the feasibility of exchanging this data with third party systems in the Common Information Model (CIM) format.

Acknowledgments

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