OPERATING THE ORKNEY SMART GRID: PRACTICAL EXPERIENCE

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ABSTRACT

The Orkney project is a rare example of a fully functioning and operational smart grid based on ANM technology. The ANM solution deployed on Orkney is a result of several years' collaboration between the University of Strathclyde and Scottish Hydro Electric Power Distribution (SHEPD), resulting in the formation of Smarter Grid Solutions (SGS) in 2008. This deployed smart grid has enabled several new renewable generator connections to the existing network infrastructure. This paper provides a high-level summary of the first full year of Smart Grid operation on Orkney.

INTRODUCTION

Wind, wave and tidal energy resources are abundant in and around The Orkney Isles, which are located off the North coast of Scotland. Orkney is connected to the Scottish mainland electricity network through two 33 kV submarine cables. In 2009, Scottish Hydro Electric Power Distribution (SHEPD) and Smarter Grid Solutions (SGS) deployed an Active Network Management (ANM) scheme on the Orkney distribution network.

The goal of the Orkney smart grid is to facilitate the timely connection of further economically viable renewable generators while avoiding or postponing the requirement to reinforce the network. The operational ANM scheme manages the output of participating renewable generators in real-time, based on prevailing network constraints and has now been operating for over one year.

In this paper, the authors will summarise the lessons learned from the application of this innovative Smart Grid technology to the Orkney situation, anticipate the evolution of the Orkney smart grid and comment on the application of such technology to other distribution and transmission networks.

BACKGROUND TO ANM ON ORKNEY

The ANM scheme has been designed to be modular and scalable, supporting the addition of new renewable generators and new constraint locations as they arise on Orkney. The commercial arrangements implemented for the ANM scheme on Orkney represent a pioneering concept, with each new renewable generator accepting a constrained connection with an estimated average annual energy production figure based on securing their position within a priority stack for access to available network capacity – essentially acting as a merit order.

In [1], the authors provide an overview of ANM with particular focus on Orkney as a case study. Details of the background to the Orkney project can be found in [2], [3] and [4].

THE ORKNEY SMART GRID IN 2009

The Orkney Isles' distribution network is supplied by two subsea 33 kV feeders from the Scottish mainland, with a combined capacity of around 40 MW. The demand for electricity on Orkney varies between around 8 MW and 32 MW. Due to its large renewable resource, Orkney has a higher than UK average penetration of Distributed Generation (DG). According to conventional industry thinking, no spare capacity existed for the further connection of new DG units beyond that already connected on Orkney, as existing firm and non-firm generator connections accounted for 47 MW of installed capacity.

Extensive modelling undertaken by SHEPD, the University of Strathclyde and SGS proved that diversity in generator output and variation in demand results in an element of latent real-time capacity on the Orkney network that could be accessed by an ANM scheme.

In collaboration with SHEPD, SGS implemented the SGi ANM solution – one of the first commercially available multiple generator and multiple constraint ANM solutions. SGi is a hardware and software system that works on a zonal basis and regulates the real-time output of participating generators within the thermal constraints at multiple locations on the existing network. The ANM scheme provides a secure and reliable means of facilitating non-firm or 'interruptible' generator connections.

The first two wind generators to receive a connection through the Orkney ANM system came on-line in November 2009, representing 3.2 MW of renewable generation. It is expected that the deployment of SGi on Orkney will facilitate the connection of more than 15 MW of additional renewable generation in total. This is expected to consist of eleven extra generators connecting to the network, which without the adoption of ANM would have required around £30million in network reinforcement expenditure.

Algorithms driving the ANM system are deployed on automation controllers. New Non-Firm Generator (NNFG) controllers and network Measurement Points communicate with a Central ANM Controller using industry standard protocols. The NNFG controllers are deployed in a decentralised fashion to the Orkney network. The Central ANM Controller in SGi communicates with the SHEPD SCADA system via a DNP3.0 link. Measurement Points at constraint locations feed network measurement data back to the Central ANM Controller over both radio and private wire links. The ANM system derives the maximum real-time network capacity for export across multiple locations and issues export set points to NNFG controllers according to associated commercial connection agreements.

SGi takes a zonal approach to ANM. A zone is identified as an electrical grouping of devices and locations behind a network constraint; therefore, zones may be nested within each other. SGi solves constraints across multiple zones and nested zones according to Principles of Access. Principles of Access are the commercial rules governing the operation of an ANM scheme, as discussed in another CIRED paper by SGS [5]. The Orkney network and some of the possible ANM zone locations are provided in Figure 1.

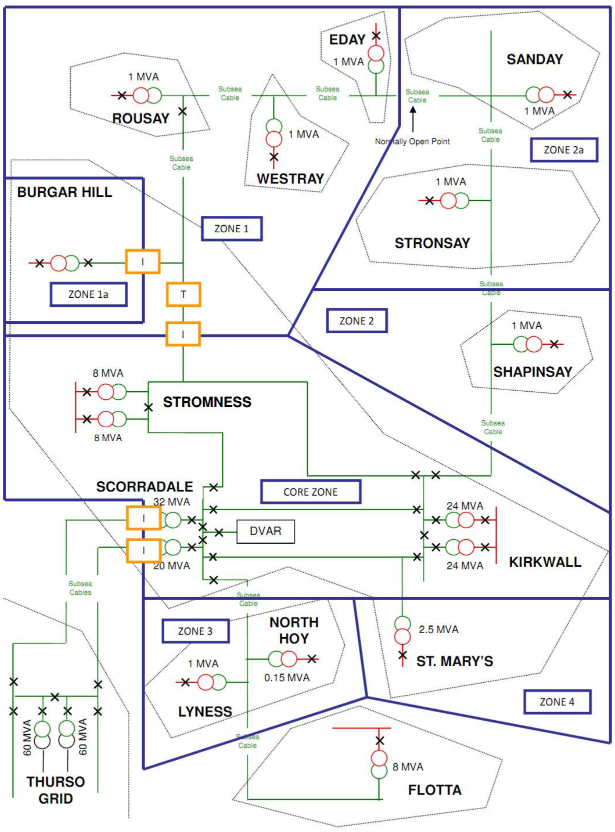

Figure 1: Orkney distribution network topology displaying potential ANM Zones and corresponding measurement locations

Curtailment studies were performed for all prospective NNFG units to provide expected curtailment values for use in financial analysis of the connection via ANM. Curtailment studies look at the network constraints a generator connection contributes to and estimates the expected frequency of curtailment based on modelling of half hourly data for an annual period and according to the Principle of Access employed. In the case of Orkney, the Principle of Access adopted was Last In First Out (LIFO).

ANM DEVELOPMENTS IN 2010

The ANM scheme deployed on Orkney experienced its first full year of continuous operation in 2010, operating autonomously and in parallel with the SHEPD SCADA system.

During 2010, SGS worked with SHEPD to support and maintain the ANM system as well as develop further functional capability. An important development was the implementation of CommsHUB, a universal communications interface developed by SGS (with funding allocated to SGS and SHEPD by the DECC Capital Grant Programme [6]) to better facilitate interaction between all ANM system components including NNFG Controllers, Measurement Points and the Central ANM Controller. Additional developments included increased redundancy, implemented using automated fail over between redundant CommsHUB modules. The implementation of the CommsHUB modules also allows data handling and processing to be separated from the core ANM algorithms. This redundancy, and the increased reliability provided, was possible because of the modular design of the ANM system. This modularity facilitates upgrades to the configuration of the installed ANM system, making the addition of more NNFG units, constraint locations and other Smart Grid technologies less onerous. Another notable ANM development of 2010 is the installation of SGcore, an improved central ANM control system that houses SGi but is also capable of supporting further future functionality. SGcore is installed in Structured Text format on an automation controller platform.

The deployed Orkney Smart grid architecture is presented in Figure 2, including the additional 4th NNFG unit to be connected early in 2011. The radio links to constraint locations three and four (MP3 and MP4) can be seen, as can the private wire links to NNFG 1-4 and to constraint locations one and two (MP1 and MP2).

At the end of 2010, the 3rd NNFG unit to connect to the ANM system came online. The renewable generation facilitated by the ANM system is 7.7 MW at the time of writing, with an additional 0.9 MW expected early in 2011. Several other connections and developments are anticipated in 2011, as discussed in the next section.

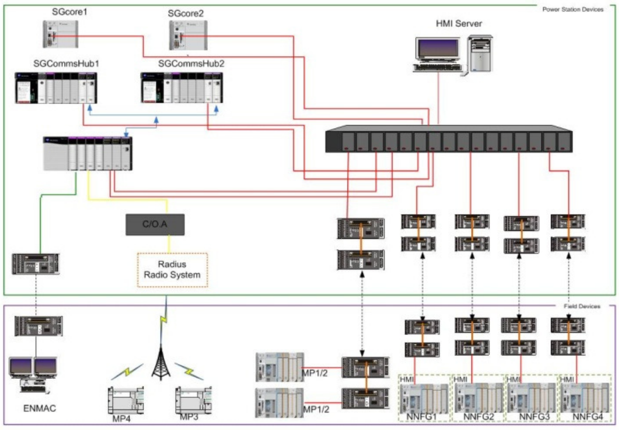

Figure 2: Deployed ANM Architecture on Orkney at the end of 2010

DEVELOPMENTS IN 2011

SGS and SHEPD plan to augment the existing ANM scheme with the deployment of a dynamic line rating (DLR) system. Conventionally, power system components are given static seasonal ratings in accordance with the maximum operating temperature that the component can endure for a continuous period. The capacity of a component to dissipate heat to its surroundings will influence its operating temperature and can be affected by various external environmental factors; such as wind speed and direction, air temperature and solar radiation. It follows that as these factors change, the effective rating of overhead lines, for example, may also be subject to variability from their nominal seasonal values. The use of DLR assists ANM schemes to further exploit latent capacity within the networks they manage by allowing additional intermittent DG to connect. Studies of the proposed arrangements are described in another CIRED paper [7].

Proposed upgrades to the Orkney ANM system include a DLR device in the form of a conductor temperature sensor and a Real Time Rating (RTR) estimation system. The PowerDonut2™, a conductor temperature measurement device, is to be installed at an existing constraint location in early 2011. The device and an accompanying weather station will report temperature readings and weather measurements to the Central ANM Controller to permit calculations of real-time rating. Information on RTR – estimating ratings across geographical and electrical areas – can be found in [8].

The total installed NNFG capacity stands at 7.7 MW at the end of 2010 and is expected to reach around 17 MW by the end of 2011. A fourth NNFG, already under construction, is due for connection early 2011. Performance reviews of the RPZ are to be commissioned annually. These will serve to evaluate the operation of the connected NNFG units. The outcomes of this work will help to inform future recommendations for the system as further sources of intermittent generation seek to connect.

ORKNEY SMART GRID PERFORMANCE

The goal of the Orkney Smart Grid has been to connect new renewable generators to the existing grid, in this respect the installation has been and continues to be a success. To calculate the CO_2 savings from this additional renewable generation, the standard conversion factor for electricity consumed from the UK grid in 2009 (0.544 kg CO_2/kWh [9]) can be used. Curtailment assessments estimated that the connection of the NNFG units in 2010 would lead to a combined 9880 MWh of energy production. Neglecting the effect of system losses, it can be inferred that the connection of these two generators has resulted in 5,375 tonnes of CO_2 being offset in the one year period during which the ANM scheme has been in operation. This figure is expected to increase annually as more renewable generation is connected to the Orkney network through the ANM scheme.

The first year of the Orkney Smart Grid has seen a number of upgrades to the ANM system to improve performance and reliability. One of the key performance issues has been concerned with communications reliability. The ANM scheme has been designed to fail safe on the loss of communications and limit access to the network for NNFG units. Loss of communication events have been temporary but nevertheless have restricted access for some NNFG units. SHEPD are investigating the implementation of redundant communications to reduce interruptions to NNFG units.

A full review of operational data is being undertaken by SHEPD and SGS and the authors expect to be able to provide more performance review data in future work, within the bounds of commercial sensitivities.

FUTURE DEVELOPMENTS OF THE ORKNEY SMART GRID

The existing ANM scheme deployed on Orkney manages the network by monitoring power flows and resolving multiple thermal constraints, in real-time, via regulation of the outputs of multiple NNFG units. In a similar manner, SGS envisages the development, and eventual deployment, of an additional module which will be interoperable with the existing scheme and seek to manage multiple voltage constraints. In addition to the curtailment of NNFG units the voltage management solution will potentially also be able to resolve voltage constraints through control of other devices such as transformer on-load tap-changer relays or reactive compensation devices. SGS and SHEPD are assessing the feasibility of deploying such a scheme to deal with voltage constraints during certain outage conditions.

SGS and SHEPD are also engaged in the development of distribution state estimation to provide further network visibility on Orkney [10]. This will become increasingly more important as low carbon technologies proliferate at the distribution level, especially for systems which are

already operating close to their performance limits.
Energy Storage Systems (ESS) have the potential to be used to reduce constraints at various zone locations on Orkney. SGS and SHEPD are in the process of completing feasibility studies of the deployment of an ESS on Orkney to reduce NNFG unit curtailment.
Developments on Orkney and elsewhere are growing. Similar schemes are being considered for deployment by other Distribution Network Operators (DNOs) and Transmission System Operators (TSOs) within the UK and abroad, as they begin to recognise the potential technical and economic benefits of ANM. SGS are working with DNOs and TSOs in the UK and Europe to assess and deploy ANM technology, examples of which are provided in other CIRED papers [5, 11].

CONCLUSIONS

Active Network Management forms one part of the Smart Grid vision; enabling the real-time management of network constraints. The Orkney Smart Grid has now been operational for one full calendar year and is operating to specification. The modular and scalable nature of the ANM scheme means that more renewable generator units will be gradually added to the network over the coming years. Facilitating these connections through ANM is saving significant network reinforcement costs and is already thought to have resulted in the saving of over 5,000 tonnes of CO_2 emissions in the UK.
The ANM solution was deployed on Orkney in 2009 and has seen several upgrades in 2010 to improve operational flexibility, redundancy and reliability. In 2011 the authors will be performing a detailed review of the operation and performance of the deployed Smart Grid and will provide an overview in future work. This review will include the addition of dynamic line ratings and real-time ratings estimation. Several other potential developments are being considered for the Orkney network and these have been identified in this paper, some are the subject of other CIRED papers.

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