THE SHETLAND ISLANDS SMART GRID

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ABSTRACT

The Shetland Islands Smart Grid will facilitate the connection of new renewable sources by implementing Active Network Management. Controlled devices will include a multi-MW electric boiler, domestic loads, new large and small wind turbines and a 1 MW battery. The architecture and main algorithms of the system are described, including system balancing, stability and constraint management. The scheme represents a new approach to network management and provides opportunities for all customers to benefit from the provision of ancillary services. The installation of new controllable devices and control systems is already underway.

INTRODUCTION

Scottish and Southern Energy (SSE) is embarking on a programme of work on Shetland that will allow more renewable sources to connect by utilising those new renewable generators, demand side management (DSM) and energy storage in system balancing, frequency control and network constraint management [1]. Approval has been granted [2] for an innovative project using active network management (ANM) supplied by Smarter Grid Solutions (SGS). The learning outcomes from this project will contribute to the understanding required to construct the sustainable low carbon electricity networks of the future. The scale and nature of ANM in this context is novel and its adoption holds promise to permit greater connection of renewable generation to the existing grid and demonstrate important technical and commercial learning for the global power industry. It is anticipated that similar schemes will be rolled out elsewhere if successful.

CHALLENGES AND OPPORTUNITIES

The network on Shetland is an isolated system with a core 33 kV network and local distribution at 11 kV and low voltage. The 33 kV network is mostly overhead lines on land with subsea cables between the islands. Demand varies between 11 and 47 MW and is concentrated in the main town of Lerwick. Lerwick Power Station (LPS) has diesel generators with sufficient capacity to meet the total system load but is reaching the end of its life. This project will inform plans for replacement of LPS. The other main generator is at Sullom Voe Oil Terminal (SVT). SVT meets its own load and exports surplus power to the public system. The SVT gas turbines are the main source of spinning reserve and while they are in service the system is relatively stable. Sudden changes in output from a 3.7 MW wind farm at Burradale can cause problems, particularly at times of low load or if SVT is not connected.

The wind resources on Shetland are excellent and there are also significant wave and tidal resources that could be exploited. However, frequency stability is a major concern and has prevented the connection of additional renewable sources. The possibility of sudden loss of power, either due to changes in wind conditions or a network fault, means that it would not be possible to keep frequency within limits. System balancing has been addressed to some degree through detailed setting of timed heating demand but still presents challenges and is exacerbated by the variability of renewable sources. Power flow and voltage constraints on parts of the network limit operational flexibility. The concentration of load around Lerwick means that a certain amount of demand must be met from LPS or Burradale, restricting the export from SVT at times. On some 11 kV and low voltage networks heating loads are timed to ensure diversity and prevent overloads. There are proposals for a very large wind farm to be built on Shetland and this would require an HVDC link to the UK mainland. If this proceeds then many existing problems would be solved. However, when the HVDC link is out of service the system must still operate in a satisfactory manner.

NEW CONTROLLABLE DEVICES

The project will see the installation of a range of new devices subject to control by the ANM scheme, from micro generation to large industrial loads. This may expand in future to encompass other types of generator, electric vehicles or different types of load.

Boiler and Thermal Store

Shetland Heat Energy and Power Ltd (SHEAP) provides district heating in Lerwick. The heat is primarily generated at a waste to energy incinerator. This is supplemented and backed up by 15 MW of oil-fired boilers. SHEAP currently has a hot water storage tank with capacity to store up to

12 MWh of excess heat during off-peak periods and provide that heat during peak loads.

It is proposed that SHEAP will install a new electric boiler and thermal store that will help to meet the growing needs of the district heating scheme but also provide a flexible and controllable demand. The new electric boiler is proposed to contain a 4 MW element and the new tank shall support the storage of up to 150 MWh of energy. The boiler will use the power generated from a new wind farm and the thermal store will allow flexible use of the boiler to match the supply of renewable power while satisfying the demand in the district heating scheme. The boiler and wind farm will be constrained as necessary by the ANM scheme and will also deliver an automatic response to changes in network frequency. The short-term operational flexibility of the boiler will depend on its power consumption and the energy level in the thermal store at any given time.

Domestic DSM

Many homes on Shetland use electric space and water heating primarily controlled by a radio teleswitch. This technology is normally used elsewhere to switch on heating loads during the night when demand is low and allows the consumer to benefit from lower energy prices. On Shetland the radio teleswitch system is already used in a more sophisticated way throughout the day to reduce demand variability and also to manage local network power flow constraints. The radio teleswitch system has been used effectively for decades but is expected to be switched off in future. The ANM scheme will replace and enhance this existing DSM functionality. Storage heaters and immersion heaters in up to 1000 homes will be replaced by new products supplied by Glen Dimplex. This represents approximately 8 MW of electrical demand and 60 MWh of thermal energy storage. The enhanced controllability of the new heaters will make possible sophisticated scheduling of power consumption, giving a significant advance over the radio teleswitch system. Their controllability will also make it possible for the heating loads to respond to changes in frequency. This new functionality makes it possible for all customers to become providers of ancillary services to the network operator and benefit through new tariffs, rewards or incentives.

A trial of new immersion and storage heaters is already underway in six homes in Lerwick [3]. Immersion heaters and controllers were installed in November 2010. Storage heaters will be installed in spring 2011. This will test the performance of the heaters and local controllers. This trial is already providing valuable information to support further development of the ANM scheme.

Wind Farms

Due to the abundant wind resources on Shetland there are already a number of applications to build new wind farms and more are expected in future but opportunities are limited by the islands' electrical isolation. The stability and security of the electrical system is already below that enjoyed by customers in mainland UK and additional wind farms, connected without ANM, would exacerbate these problems. The ANM scheme will allow new connections subject to them being actively constrained when required. Restrictions may be due to system stability, power flow or voltage constraints. Some wind farms will be linked to specific loads, either at the same connection point or somewhere else on the network, such that they can produce power only when the linked load is absorbing power. Where the generator and linked load are at the same location this can be treated as single a controlled device. Where the generator and linked load are at separate locations they will be controlled separately but the ANM scheme will co-ordinate their operation. It is anticipated that the first large generator to be connected under the auspices of the ANM scheme will be a 6.9 MW wind farm linked to the SHEAP boiler. A significant number of small and micro wind turbines shall ultimately be controlled, ranging in size from 5 to 100 kW. It is expected that the latest, most robust and flexible wind turbine technologies shall be installed exhibiting high levels of performance in terms of frequency response, voltage support, and fault ride through.

Battery

A 1 MW, 6 MWh Sodium Sulphur (NaS) battery with full power converter will be installed at LPS in spring 2011 [4]. This will provide a flexible energy storage resource that can react quickly to assist with system balancing and system stability. The installation of a battery of this type and size on a public network in the UK is a novel project in itself. A local controller will be installed to support independent operation of the battery but then allow it to be linked to the full ANM scheme when it is implemented. The ANM scheme will ensure that the battery's capabilities are exploited in co-ordination with other controllable devices.

ANM ARCHITECTURE

The ANM scheme will have an architecture based on the elements shown in Figure 1 and described below.

Central ANM Controller

The Central ANM Controller (CAC) shall interface with Local Interface Controllers, Other Systems and Measurements and will run a number of ANM algorithms as described below. The CAC will run on an appropriate hardware and software platform at LPS.

Local Interface Controllers

A Local Interface Controller (LIC) will handle communications interfaces with the CAC and with multiple Device Controllers in a single location (such as multiple heaters in a home). The LIC will receive, store and transmit schedules and instructions as appropriate, and process information fed back from controlled devices. The LIC will continue to operate when communications are not available but will adopt failsafe settings. The calculations performed in the LIC will be relatively simple and will not require significant processing power. There will be a minimum non-volatile memory requirement for its essential functions and then additional memory will be used to store device performance information. The LIC is designed in a generic fashion such that it may be used to control any type of load, generator or energy storage system. LICs will be implemented initially on programmable logic controllers (PLCs) but alternative, lower-cost solutions for mass roll-out will be identified during the project.

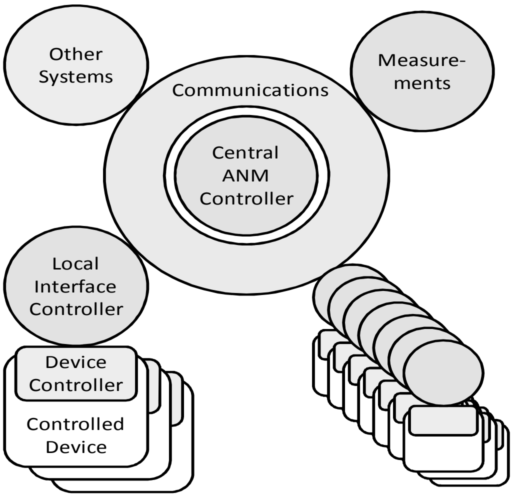

Figure 1: Basic elements in ANM Architecture

Device Controllers

All controlled devices shall be equipped with a Device Controller that is compatible with the LIC and the ANM scheme. The Device Controller will satisfy all operational constraints of the controlled device, including ensuring safe operation, but will otherwise implement control instructions received from the ANM scheme through the associated LIC. This will include schedules, set-points and frequency response characteristics as appropriate to each controlled device. It will normally be the Device Controller that implements autonomous frequency response, according to parameters set by the ANM scheme. The Device Controller shall also compile information on the operation of the device and feed this back through the LIC to the ANM scheme. The Device Controller will be implemented in different forms as appropriate to each device.

Other Systems

The ANM scheme will exchange data with a number of other systems. A bi-directional interface shall be implemented with the existing LPS SCADA system. This will provide the status of all existing generators, including LPS, SVT and Burradale. The interface shall also be used to present ANM scheme information to the LPS operators, who shall have control authority over the ANM scheme. A bi-directional interface shall be established with the ENMAC system used by SSE to monitor the status of the network and manage outages and maintenance. There shall also be uni-directional links to an OSISoft PI data historian.

Measurements

The ANM scheme will receive measurements from power flow and voltage constraint locations, identified through off-line analysis of the network. Phasor Measurement Units (PMUs) shall be installed and used to monitor the dynamic stability of the network, particularly low frequency oscillations. An on-line “Stability Analysis Application” shall feed into the ANM scheme. PMU monitoring shall also be used to improve and validate the models of the system. PMU based monitoring will help to identify any existing or future problems with oscillatory stability and support the resolution of those problems.

Communications

Communications links will be implemented by different means as appropriate to each system but using industry standard SCADA protocols, with encryption as appropriate, and within the established information management systems of SSE. Watchdog signals will be periodically transmitted and the LICs and Device Controllers will be configured to enter a failsafe mode if communications are lost. Communication between the CAC and the LICs is necessary to issue schedules, set-points and frequency response parameters. However, it is proposed that only a small fraction of LICs have a feedback capability, sufficient for the ANM scheme to assess device operation in aggregate. The physical distribution of controlled devices and the precise nature of data to be transferred to and from each device will determine the most appropriate physical link. It is anticipated that a combination of wireless and wired links will be required. The six home trial of domestic DSM is using secure GPRS communication. Each LIC must have suitable communication links to the Device Controllers with which it is associated. The LIC shall send set-points and frequency response parameters and will receive feedback information appropriate to the controlled device. This interface may be accomplished through various means dependent upon the capabilities of the device under control. For example, very simple devices may transfer commands via simple analogue signals. The LIC will be customised as necessary.

ANM ALGORITHMS

The ANM scheme will implement a number of algorithms in combination to meet the requirements of the system and manage the controlled devices.

System Balancing

The System Balancing algorithm shall produce “Day Ahead Schedules” for all controlled devices based on forecasts and current status information from all devices, and the results of the DSM-in-Hand algorithm. The algorithm will take account of the operating characteristics and limitations of controlled devices and provide for the transfer of energy according to agreed contracts and requirements, while aiming to make the fullest use of renewable generation. It shall be possible to transmit an updated schedule at any time. There will also be the facility to override the "Day Ahead Schedule" in real-time with "Active Set-points". This provides a means of responding to rapid or unforeseen changes in conditions. The algorithm shall track load and generation in real-time and thereby provide the facility to instruct certain controlled devices to follow the position of other devices or respond to the net load profile.

System Stability

System stability shall be managed by ensuring the network does not enter, or is moved away from, configurations of loads and generation that are deemed to be unsafe. An unsafe condition is one in which the network would not survive all credible disturbances or one in which the network suffers unacceptable oscillatory stability. The unsafe conditions can be defined from prior analysis. This will be supplemented by information received from the Stability Analysis Application. The algorithm will ensure the stability of the network by setting the operating limits and parameters, including frequency response characteristics, of all controlled devices. For example, new wind farms may be restricted to a MW output level deemed acceptable given the frequency response available at that time. The frequency responsive behaviour required of each controlled device will be determined. This shall include disabling the frequency response, which may be desirable when the response available from other sources, primarily SVT, is sufficient to maintain network stability. In the near to medium term, SVT shall continue to be the main source of fast-acting frequency response on Shetland. However, the new frequency responsive devices under the control of the ANM scheme shall provide a valuable contribution to frequency control in future, facilitate increased access for renewable generators, and let all customers participate in the market for ancillary services.

Power Flow and Voltage Management

The Power Flow and Voltage Management algorithms shall perform real-time control of devices as necessary to ensure power flows and voltages remain within defined limits. This shall include the facility to operate controlled devices on a "zonal" basis. The need for constraint management shall be dependent upon the connection of new controlled devices but existing constraints will also be taken into account.

DSM-in-Hand

The DSM-in-Hand algorithm shall use feedback data from a subset of controlled devices together with information from other systems and forecasts to accurately estimate the scope of controllable demand within the population of all controlled devices. In particular, it will assess the capabilities of thermal energy storage in the SHEAP boiler and domestic heaters. The results shall be probabilistic in nature due to the fact that feedback data shall only be retrieved from a subset of controlled devices. However, this subset shall be large enough to develop a sufficiently accurate estimate to perform the necessary ANM functions. The algorithm shall account for uncertainty in all feedback and shall be robust to errors in all measurements.

Forecasting

The Forecasting algorithm shall produce load and generation forecasts for use in other algorithms, primarily in System Balancing. Forecasts will take account of many factors including historic data, weather conditions, and the expected operation of large loads. Forecasts will be supplied for individual devices, like Burradale windfarm, or for a population of devices, like all small wind turbines.

CONCLUSIONS

The Shetland Islands Smart Grid will serve as a model for other areas seeking to solve the problems associated with a high penetration of intermittent renewable sources. The problems of system balancing, stability, power flow and voltage limits are being addressed together, building on existing ANM technology to implement a scalable and transferable solution. Controlled devices will extend from micro generation and domestic loads to large wind farms and multi-MW storage. The installation of new controllable devices and control systems is already underway with domestic DSM being trialled and the battery being installed. Early experience has identified communications is a crucial area for the project.

REFERENCES

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