DESIGN AND TRIAL OF AN ACTIVE POWER FLOW MANAGEMENT SCHEME ON THE NORTH-SCOTLAND NETWORK

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ABSTRACT

This paper provides an update of a collaborative project between the University of Strathclyde and Scottish and Southern Energy plc, concerned with 'active management' of the Orkney distribution network. Orkney is rich in marine and wind renewable resource, recognised by the connection of several wind farms and the establishment of the European Marine Energy Centre. The active management scheme is designed to facilitate increased connection of renewable and distributed generation and is an outcome of a previous project undertaken by the authors. Based on this work, Orkney has been designated a Registered Power Zone (RPZ) by the UK regulator Ofgem. This has paved the way for a trial of the scheme, which has been undertaken in 2006, and the anticipated full roll-out of the scheme in 2007. In the event of a successful trial and roll-out it is likely that the active management scheme will be applied to other rural distribution networks to enable increased connection of renewable and distributed generation.

INTRODUCTION

Electricity generated from renewables, such as wind and marine sources, is playing an increasingly important role in international energy policies to combat climate change. Renewable resources are often abundant in remote areas serviced by low capacity distribution networks. Accessing these resources poses a significant technical and economic challenge to generator developers and network operators. Theoretically, networks may be filled to capacity with contracted renewable generation but, due to diversity, the actual real time contribution can be significantly less than the contracted capacity. If renewable resources are to have their full potential realised than a combination of new network technologies and advances in system planning and operation are required. Active management is now emerging as the preferred solution to the connection and operation of renewable and distributed generation (DG) to UK distribution networks, as opposed to the traditional approach of capital intensive network reinforcement.

This paper presents an update on the development and deployment of an active management scheme to facilitate increased connection of renewable and distributed generation to part of the North-Scotland distribution network. The scheme is based on zonal control of the distribution network. This is facilitated by control logic installed on several Programmable Logic Controllers (PLCs). The active management scheme ensures that thermal operating limits are not violated by curtailing DG units connected under the auspices of the scheme. The scheme does not affect existing DG connections and has been designed to not impact negatively on the local quality, reliability and security of supply.

The paper presents some of the results of the closed-loop trial of the active management scheme completed in 2006. The paper will discuss the implications of the results of the trial for the design and installation of the full scheme. Discussion of the key drivers and considerations for all parties is presented. The success of this project could see this method of active management become established as an economically viable solution to the connection and operation of DG on rural distribution networks.

ACTIVE NETWORK MANAGEMENT

Active management schemes and strategies are being developed that address the main technical barriers to the connection and operation of DG: voltage control, power flow management, fault level management and network security. The authors from the University of Strathclyde recently completed a review of worldwide active management activity [1] which showed a heightened level of activity across many active management approaches. Active management has been widely discussed [2, 3, 4] and it is not the purpose of this paper to echo the extensive literature describing the requirement for active management or the solutions available. The reader is directed to the references above for more information.

REGISTERED POWER ZONES

The RPZ initiative was introduced by the UK Gas and Electricity Industry regulator – Ofgem – to encourage distribution network operators to apply technical innovation in providing a cost effective method of connecting DG. The operator receives an economic incentive within the RPZ initiative and 80% of costs are passed through. More information on the RPZ mechanism and the accompanying Innovation Funding Incentive and DG Incentive can be found at the Ofgem website [5].

BACKGROUND TO ORKNEY

The Orkney distribution network forms part of the North-Scotland network, operated by Scottish and Southern Energy plc. The north and west coasts of Scotland are rich in renewable energy and are the focus of significant interest from renewable energy developers. Orkney has a long association with wind energy in particular and was home to some of the first grid connected wind turbines in the UK in the 1970s.

Existing Infrastructure on Orkney

The Orkney electrical demand varies from around 8MW to 32MW. The Islands that comprise the Orkney Isles are connected through a combination of overhead lines and submarine cables. The network is connected to the Scottish mainland through two submarine cables with a combined import/export capability of around 40MW. 26MW of Firm Generation (FG) and 21MW of Non-Firm Generation (NFG) has already connected or has contracted to connect to the network. The FG units have priority access to network capacity and are unconstrained during normal operating conditions and N-1 contingencies. The NFG units are inter-tripped for N-1 contingencies (e.g. loss of one of the two submarine cables to the mainland) if the power export breaches a pre-defined threshold. As a result of the FG and NFG (a mixture of wind energy, marine energy and gas generation) there are times when it is possible that Orkney could export power to the mainland. A dynamic reactive compensation device and several shunt reactors have been installed to alleviate short-term and long-term voltage fluctuations [6].

The Requirement for Active Management

The installation of voltage control equipment has resulted in the thermal capacity of the Orkney network being the main network constraint on future generator connections. The active management scheme presented is concerned with extending the capacity for connection into a new tranche of DG known as New Non-Firm Generation (NNFG).

OPERATIONAL PHILOSOPHY OF ACTIVE MANAGEMENT SCHEME

The NNFG units are connected in addition to the FG and NFG and are regulated by the active management scheme according to the thermal constraints at pinch points on the network. The NNFG units are individually or collectively trimmed or tripped by the active management scheme depending on the prevailing network conditions. Figure 1 shows the main logic processes undertaken by the active management scheme. The process identified in Figure 1 is applied to several zones within the Orkney network as identified previously [7]. More zones may be identified as the location, size and nature of NNFG connections becomes apparent. The NNFG units in each zone are curtailed on a Last-In First-Off (LIFO) basis. The active management logic allows zones to be nested within one another while preserving the LIFO approach. By utilising real-time measurement of power flows on the Orkney network, the active management scheme allows the NNFG to access capacity available in real-time due to diversity in output from the FG and NFG units and from load variation. The curtailment experienced by NNFG results in an economic limit to the amount of NNFG that can connect [8].

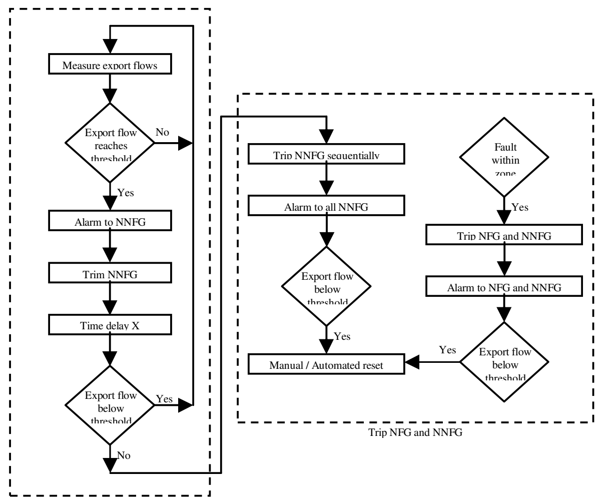

Figure 1. High-level overview of the logic processes undertaken by the Orkney active management scheme.

Operating margins for active management

Power flows are limited within the thermal capacity of the network by pre-defined margins. Power flows breaching the trim margin result in control instructions to regulate MW output (trimming). If the export power flow breaches the trip margin the active management scheme will open the customer circuit breaker (tripping) to prevent damage to network components from overloading or interruption of supply to customers by operation of circuit protection. Further discussion of these margins and their impact on the performance and economic viability of NNFG can be found in [8, 9].

NNFG CONSTRAINT ANALYSIS

Each NNFG unit will be subject to curtailment due to thermal constraints within their primary zone of location and any other measurement points as required. The curtailment experienced by the NNFG is dependent on the output of existing FG, NFG, the load demand on Orkney and the output of NNFG of higher priority. A constraint analysis tool has been developed by the authors to analyse the curtailment experienced by each NNFG connection. The estimate includes the caveat that the performance of each NNFG unit will be more accurately analysed when it is known which NNFG units will proceed with their connection application. The constraint analysis tool utilises ½ hourly historic profiles of generation and demand on Orkney to provide an indication of the MWh generated and curtailed for NNFG units. More insight into the workings of the constraint analysis tool can be found in [10].

ORKNEY ACTIVE MANAGEMENT TRIAL

A closed-loop trial of the active management scheme was completed on Orkney in 2006. An existing wind farm was regulated by the active management control logic. This was performed using a central active management PLC and a PLC located at the wind farm. The central active management PLC was used to monitor current at a critical point on the Orkney network. This PLC then initiated communications with the PLC at the generator site, which regulated the wind farm accordingly. A trace of the subsequent response of the wind farm is illustrated in Figure 2. The wind farm output was regulated to one of five set-points (0.73pu, 0.77pu, 0.8pu, 0.84pu and 0.87pu) represented by dashed lines in figure 2. The instant at which new set-points were issued is identified using arrows. No voltage problems were encountered on the Orkney distribution network during the trial.

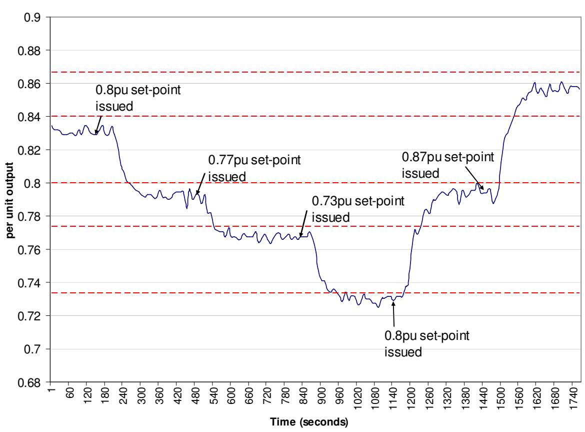

Figure 2. Snapshot of wind farm output during the trial of the Orkney active management scheme.

Results of the active management trial

In Figure 2 the wind farm is issued a set-point of 0.8pu by the active management scheme at around 120 seconds. Over the next fifteen minutes the wind farm output is reduced through set-points of 0.77pu and 0.73pu at 5-minute intervals. Output reduction instructions are sent from the central active management PLC to the wind farm in response to electrical current breaching the trim margin. It can be seen that the wind farm output remains below the set-point after reducing from the initial higher value in each case over the fifteen minute period. This holds true for the release of capacity to the wind farm towards the end of the trace when a 0.8pu set-point is issued at around 1140 seconds and a 0.84 set-point issued at around 1440 seconds.

Implications of active management trial

The trial has proven the logic approach and communications solution employed. The results of the trial have shown that the wind farm can regulate output to a satisfactory degree of accuracy. This output regulation can be initiated and dictated by the active management scheme in response to the measurement of primary system parameters at a remote site. The time taken for the wind farm to achieve the desired set-point will be taken into consideration for the full scheme design. The response of the NNFG to output regulation control instructions will have a significant impact on the configuration of the active management scheme and ultimately on the economic viability of NNFG units.

The magnitude of trim operating margin employed will be relative to expected response characteristics of the NNFG, as informed by the trial. The time taken for the active management scheme to identify an incipient overload condition, process the information, issue the control instruction to the wind farm and receive confirmation from the wind farm of the new set-point will be factored into the calculation of a secure operating margin for trim actions. In addition, the time taken for the wind farm to achieve the desired set-point will be represented in the setting of the trim operating margin, which will also be based on the characteristics of other generating units (FG, NFG and other NNFG) and the dynamic nature of the Orkney load, as described in [9].

Figure 2 shows that the output of the wind farm regularly sits just below the issued set-point. The operating margins will be set to give the NNFG adequate time to respond to the issued set-point.

Final Active Management Scheme Design

Several outcomes of the trial will influence the design of the final scheme as discussed in the previous section. Factors to be addressed within the full scheme include:

- Reconfiguring the active management scheme in response to a fault or reconfigured network.
- Coordination of multiple communications paths, measurements and NNFG units and ensuring fail safe operation of the active management scheme.
- Detailed design, testing and coordination of the logic for managing multiple NNFG units within individual zones and within nested zones.
- Defining a building block approach to scheme

implementation to account for the gradual development of the scheme and connection of NNFG units.
- Specification of communications requirements.

KEY CONCERNS FOR MAJOR PARTIES

By implementing active management, the network operator is dramatically changing the mode of operation of the distribution network. The main concern of the network operator is that the scheme does not impact on the security, quality or reliability of supply on Orkney. Indeed, much of the design of the scheme has been undertaken with this as a key consideration.

The generator developer is inclined to connect through active management due to the reduced capital outlay costs compared to a traditional connection option. The main concern of the developer is that the scheme will be robust and fair; not causing the behaviour of one NNFG unit to impact on the curtailment experienced by another. It is also crucial that the estimated levels of curtailment are representative of the reality of the connection option; therefore providing a solid economic base for appraising the connection to the active management scheme.

CONCLUSIONS

This paper has presented an update of recent developments in the design and trial of a scheme to actively manage the Orkney distribution network. The results of the trial and the subsequent implications for the design of the full active network have been introduced. The final active management solution is in development and will be ready in 2007 for deployment as generation developments are constructed to connect under the scheme. The success of the trial and the installation of the full active management scheme could see this method of active management being deployed on other rural distribution networks with the accompanying benefits of increased generation access.

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