MODELLING AND DELIVERY OF AN ACTIVE NETWORK MANAGEMENT SCHEME FOR THE NORTHERN ISLES NEW ENERGY SOLUTIONS PROJECT

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ABSTRACT

The Northern Isles New Energy Solutions (NINES) concept is an extension to existing forms of Active Network Management (ANM) and a multi-faceted demonstration of the future "smart grid". The NINES project is challenged with accommodating increased levels of renewable generation in an area where there are abundant renewable resources. However, the existing distribution network is electrically islanded and needs to operate within stringent constraints to maintain system stability. This paper discusses and presents modelling approaches to identify rule formats and parameters that can be incorporated within an ANM scheme that will facilitate these connections and maintain system stability. The paper goes on to discuss the use of these modelling outputs as criteria to inform the development of the future Shetland system.

INTRODUCTION

The geographic location of the Shetland Isles, located off the north coast of Scotland, provides a wealth of potential renewable energy resources that could be exploited [1]. However, constraints on the islanded electrical network are prohibiting the exploitation of these resources. The NINES project will deliver solutions that will allow more wind generation on to the current network through a new operating regime enabled by the installation of new frequency-responsive demand and an innovative Active Network Management (ANM) scheme running multiple applications on a robust platform. The platform builds on previous deployments by Scottish and Southern Energy Power Distribution (SSEPD), the network operator, but achieves more in terms of systems integration (to existing network management systems and corporate infrastructure) and the applications that perform constraint management or improve overall network operation. The project has had to tackle a range of systems integration problems, which will be of interest to network operators and vendors who are planning similar installations. The idea of flexible applications running on a fixed platform is commonplace but implementing this in the distribution network domain presents particular challenges. NINES demonstrates what is possible but also shows that there are many barriers to overcome in delivering the networks of the future.

The proposed ANM scheme for the Shetland Islands will comprise control functionality that will manage system balancing and scheduling operations, power flow management and voltage control in addition to transient stability management. These functions will be implemented using a number of separate algorithms that are able to operate independently or in collaboration with each other. The ANM rules and parameters are informed through system models, which must be flexible to ensure that new technology additions and power station replanting can be analysed and system responses can be accommodated within the defined format.

This paper presents three core modelling areas that are required to inform the design parameters of the ANM scheme. The *unit scheduling model* will deliver day-ahead schedules for ANM devices based upon measured and forecast data with the objective of maximizing wind generation on the network. This model requires inputs on the maximum stable wind generation, and a number of constraints have been identified. System frequency stability is a key constraint, where a *system dynamic model* is used to calculate the maximum wind penetration under all network operating conditions. In addition, a *Multi-Objective System Development Optimisation Model* is presented that can analyse and inform the future power system development.

SYSTEM STABILITY RULES

For the system to be considered stable a number of 'stability' constraints must be met. For NINES these include frequency stability, network operation stability (based on voltage constraints) and spinning reserve stability [2]. There is the possibility of adding other stability rules such as stability under fault conditions. However, the scope of this research is to define the parameters limiting the maximum wind generation due to frequency response, network operation rules and spinning reserve under normal network operation. Each stability rule is defined as a linear function of observable parameters and together the constraints define an envelope of wind generation that can be allowed for a given network configuration. An illustration is shown in Figure 1 where the maximum level of wind generation is bounded by linear functions of total system demand. The network operation constraints will only change when network operating procedures are updated, whereas the frequency stability and spinning reserve constraints will change dynamically whenever the current conventional dispatch changes.

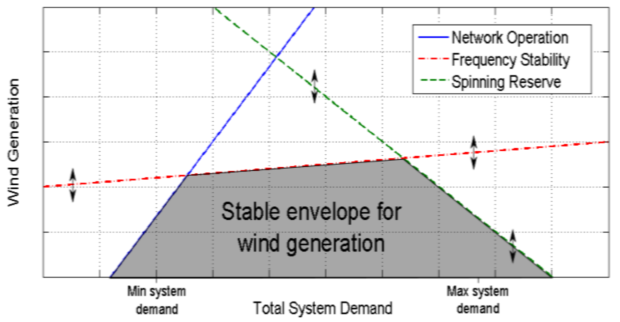

Figure 1 - Illustrates the stable operating 'envelope' for wind connections.

The introduction of distributed wind generation has the potential to disrupt the stability of an islanded distribution network. Before connecting new wind generation, the stability of the network must be defined and modelled to define, for given scenarios, the maximum allowable level of wind power production. Conventionally, islanded frequency control is carried out through the dispatch of high inertia generators with adequate governor response and under/over frequency relays that will shed load or trim/trip generation when imbalances are measured or estimated [3]. Like traditional networks the NINES frequency constraints are dependent on network loading and the dispatch of conventional generation, and as with most distribution networks, planning and design are based on worst-case conditions and very limited real-time control. However, with the availability of frequency responsive devices (frequency responsive demand (FRD) and an energy storage system) and an ANM scheme able to respond to conditions in real-time, there is potential for managing system frequency constraints without the need to remove load or generation. The frequency constraint parameters will provide the *unit scheduling model* and the ANM scheme with modelling and operational rules, respectively, to maintain system stability.

If additional constraints emerge during the NINES project, these will be formulated as additional rules, equivalent to additional lines on the Figure 1 illustration. The purpose of the system stability rules is twofold: (1) they form an input to the *unit scheduling model* allowing it to dispatch flexible demand to attempt to maintain the forecast for the system within the stable envelope; and (2) for application in real-time to be linked to ANM control actions that will curtail wind power production to maintain the real-time system within the constraints.

System Dynamic Modelling

The general format of the stability rules are discussed in [4] where the level of permissible wind, P^{Max}_{wind}, at any instance in time is a function of the dispatched conventional generation (CG) and the available frequency responsive devices (i.e. frequency responsive demand (FRD) and NaS Battery) as defined in (1) below:

$$P^{\text{Max}}_{\text{Wind}} = f_1(CG) + f_2(Battery) + f_3(FRD) \qquad (1)$$

Where the functions $f_1(CG)$, $f_2(Battery)$ and $f_3(FRD)$ determine the system inertia and response parameters for each of the connected devices. Offline dynamic simulations were carried out to provide the parameters of these functions for combinations of conventional generation dispatches that cover the full range of network demand levels. These cases were simulated in PSS/E and the frequency response recorded for the loss of various levels of connected wind. The limit is set by the power system's ability to maintain system frequency within 2% of nominal in the event of the instantaneous loss of all wind as shown in Figure 2.

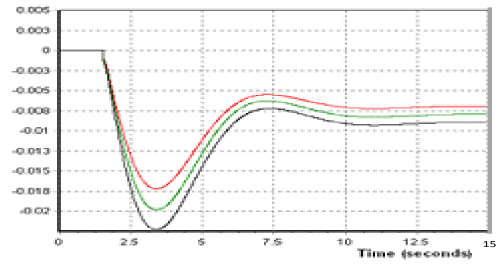

Figure 2 - Example of Frequency Response with the Loss of Different Levels of Wind

In addition to simulating the loss of wind the loss of the largest demand feeder and automatic re-instatement of that feeder was also simulated. Examples of this are shown in Figure 3. For both disturbance scenarios the network thermal limits are monitored to ensure that any conventional generation power exports do not exceed thermal protection limits.

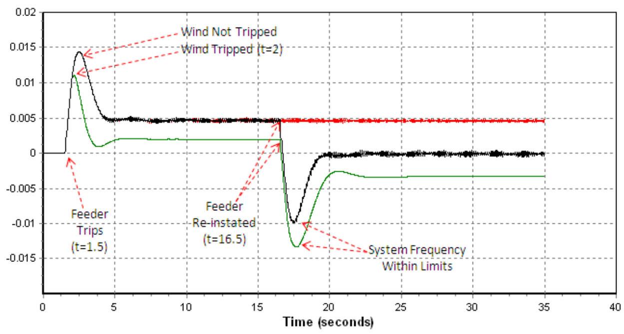

Figure 3 - Example of Frequency Response through Disconnection and Re-connection of Demand Feeder

Taking the results from these multiple scenarios enables the plotting of the limits for each case and allows linear approximations to be defined for the system frequency stability rule. Figure 4 illustrates the level of allowed wind for various conventional generation dispatches.

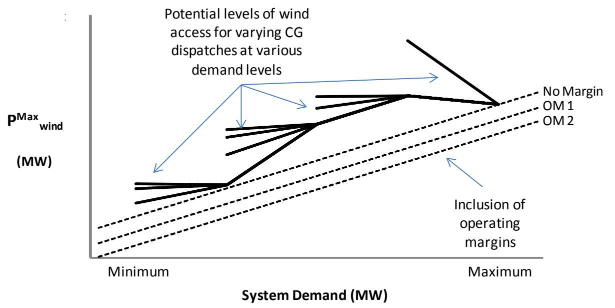

Figure 4 - Illustration of Conventional Generation Dispatches and Levels of P^{Max}_{wind} Connections that Determine Stability Rules

In the same manner, studies were conducted to evaluate the stability rules when additional frequency responsive devices are available. The levels of increased wind, for combinations of online devices/generation, can be determined by taking the same linear approximation approach as shown in Figure 5.

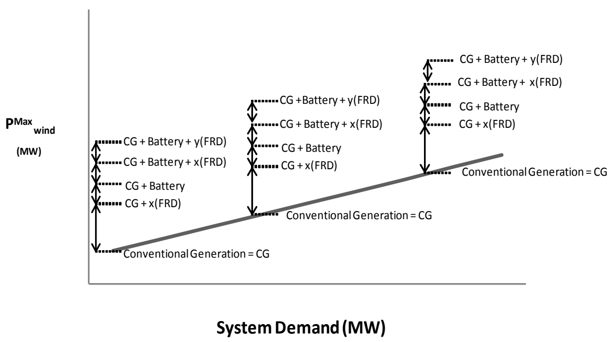

Figure 5 - Illustration of Levels of P^{Max}_{wind} with Additional Frequency Responsive Demand

Unit Scheduling Modelling

The stability rules 'envelope', Figure 1, shows the level of instantaneous wind power production that is compatible with the network remaining in a stable configuration. At times, this will be less than the installed wind generation capacity. The real-time monitoring and control components of the ANM scheme can be used to curtail wind generation when it breaches the stability envelope. In addition the scheduling component of the ANM system can be used, together with forecasts of wind generation and non-flexible demand over the coming hours, to schedule energy storage and flexible demand in an attempt to reduce the expected curtailment.

To this end, the central ANM controller contains a *scheduling engine*, a piece of software which produces schedules for flexible demand and energy storage. Inputs to the scheduling engine include: device characteristics and initial conditions; network stability rules; and forecasts for demand and generation. The scheduling engine is an important development of the ANM concept. Previous deployments such as the Orkney Smart Grid project [5] do not include intertemporal technologies and rely on real-time monitoring and control; scheduling is not required.

The design of the scheduling engine is informed through a *unit scheduling model* which is used to investigate the optimal schedule for a particular set of conditions including generation and demand across a 24 hour period. Both the unit scheduling model and scheduling engine divide the 24 hours time-horizon into 96 separate 15-minute time-steps with an average fixed demand and wind generation for each time-step. For a given 24 hour profile of fixed-demand and generation, the unit scheduling model finds the optimal schedule for the flexible demand and energy storage under the following objectives:

1. Minimise curtailment of wind generation
2. Minimise the variability in output from conventional generation

Objective 1 is the primary objective, and takes precedence over objective 2. The unit scheduling model is base on the principle of Dynamic Optimal Power Flow (DOPF) which ensures that the network constraints are observed for each time-step whilst the intertemporal constraints are applied for each flexible demand group and each energy storage unit. In addition, network stability rules are included as linear constraints on combinations of conventional and wind generators [6], [7]. An example of the optimal schedules created by the unit scheduling model is given in Figure 6. The system being modelled includes the following components:

- 1MW, 6MWh battery with round trip efficiency of 72%
- 5MW of flexible demand with a demand of 20MWh across the day
- 14MW of wind generation

Optimally scheduling the energy storage and flexible demand allows the curtailment of wind to be reduced from 44.5 MWh to 33.5 MWh.

The optimal schedules produced in this way assume perfect foresight of fixed demand and available wind generation. In reality this will not be the case and it will be forecasts, together with their inherent uncertainty, which are inputs to the scheduling engine. The next stage of the research using the unit scheduling model will be to study forecasts of wind generation and compare these with the conditions that actually developed. An important outcome will be to identify the loss of optimality which is introduced by forecasting errors and develop methods for working with these errors.

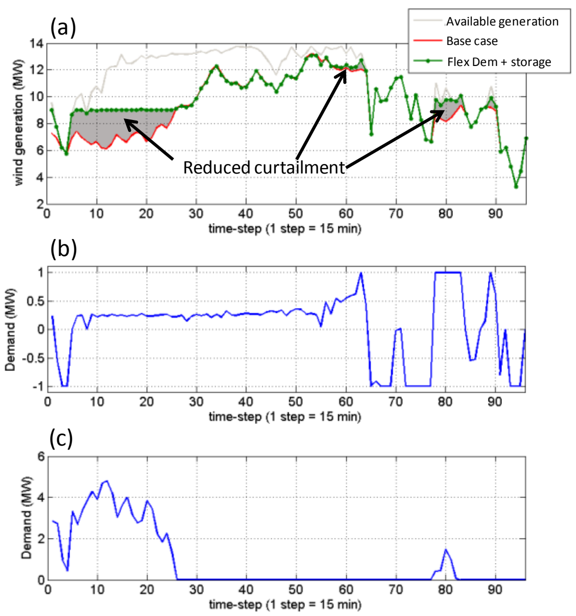

Figure 6: Example results from the DOPF unit scheduling model. (a) Available wind generation compared with the generation used with and without energy storage and flexible demand (b) energy storage optimal schedule (c) flexible demand optimal schedule.

Future Power System Modelling

The unit scheduling model developed for the NINES project is a flexible optimisation tool which can be used to study a range of scenarios. The Shetland Islands' power system is going to change quite rapidly over the next few years. The diesel-fired Lerwick Power Station (LPS) is the islands' main power plant and is coming to the end of its operating life. The future Shetland 33kV network studies take into consideration a replacement power station at Lerwick and assume that the ANM scheme is in operation. The result of this assumption is a potential reduction in the required capacity of the new LPS and also potential operating cost reductions. In order to investigate future network scenarios a *Multi-Objective System Development Optimisation Model* (*MOSDOM*) model concept is developed to extend an existing family of tools used in planning highly distributed power systems [8], to create and subsequently analyse varying generation mixes and ANM schemes (through altering locations and penetrations of generator units and ANM components). The MOSDOM determines the most desirable future energy system cases for evaluation against the following objectives:

- LPS capex and annual O&M cost (£million)
- Annual CO_2 emissions output (from all generating units)
- Annual renewable curtailment level
- Renewable penetration level
- Network reinforcement costs (£million)

The results from examining these energy system case studies will aid the decision making process behind the new LPS design and capacity requirement. The results will also confirm the future impact of the ANM scheme. The MOSDOM is linked to the generalised *unit scheduling model* which can be configured to match the particular 'future scenario'. Dynamic modelling and stability rules, as described above, are defined for each future scenario, and the *system dynamic model* is used to provide stability limits. These inputs are then used to optimise the scheduling of connected devices managed by ANM and hence maximise renewable generation output. In addition, if the case study is found to fail to adhere to thermal and voltage constraints then the *MOSDOM* calculates the network reinforcement requirement and includes the capital cost in the associated objective evaluation.

CONCLUSIONS

The development of a solution to the issue of increasing renewable generation on Shetland involves solving a range of technical challenges. The ability to model different aspects of the system is important, but equally important is the ability of those models to interact and inform each other. This paper presents the modelling methodology for three linked modelling packages analysing three different aspects of the NINES project concept. The stable operation envelope, and a standard format for stability constraints, allows the results of dynamic modelling of current and future scenarios to feed easily into the unit-scheduling model. This is designed with the flexibility required to allow the future power system model to adjust the components, such as power plant sizes, which may change in the future and assess network capacity requirements and required reinforcement.

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