Shetland Islands Smart Grid

Requirements Specification and Architecture

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1 Introduction

The Shetlands Smart Grid shall increase the proportion of electricity supplied from renewable sources by exploiting the potential for demand side management (DSM) and active control of those renewable sources to play a role in system balancing, constraint management and frequency control. Smarter Grid Solutions (SGS) shall deploy their innovative Active Network Management (ANM) system to oversee the operation of new controllable devices including new wind farms and new controllable loads at industrial and domestic levels. The scale and nature of this type of DSM is quite 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.

The essential elements of the proposed ANM scheme are as follows:

- *Central ANM Controller:* which shall include a number of algorithms that take account of the controllable resources available to balance the system and manage system stability along with network power flow constraints and voltage constraints.
- *Communications Network:* to transfer data from the central ANM controller to all controlled devices. This shall include the collection of information from a subset of controlled devices.
- *Local Interface Controllers:* which shall be installed at all controlled devices and shall function as the link between the ANM system and the controlled devices.
- *Device Controllers:* which shall manage the operation of the individual controlled devices on the network.
- *New controllable devices including:*
    - A 4 MW boiler and 150 MWh Thermal Store at Shetland Heat Energy and Power
    - Up to 1000 domestic Immersion Heaters and Storage Heaters (by Glen Dimplex)
    - A proposed 6.9 MW wind farm at Gremista
    - Numerous small-scale wind turbines
    - A 1 MW battery (likely to be situated at Lerwick Power Station)

The purpose of this document is to describe the requirements of the Shetlands Smart Grid and the high level architecture which shall be implemented in order to achieve these requirements. A conceptual overview diagram is shown in Figure 10 at the end of this document. It is suggested that the reader references the conceptual overview diagram whilst reviewing this document.

1.1 Third Party Involvement

This document has been prepared by SGS in collaboration with Scottish & Southern Energy and a number of third parties. The contribution of others is recognised as being essential to the compilation of this document. It should be noted, however, that explicit mention of third parties represents current understanding of project plans and does not signify a recommendation, guarantee or warranty from SGS on the involvement of identified third parties or the involvement of others not mentioned.

2 Requirements and Analysis

This section discusses the requirements of the Shetlands Smart Grid. An analysis is provided with each requirement suggesting the means by which each requirement shall be achieved. All requirements are compartmentalised into functional groupings.

2.1 High-Level Requirements

Requirement: *Enhance "balancing" of the system at all times based upon both real-time and forecast information.*

The SGS ANM controller shall implement a "System Balancing" ANM algorithm to perform system balancing which shall provide various features in order to coordinate the use of both generation and load assets on the network. These assets shall include the Thermal Store, domestic Immersion Heaters, domestic Storage Heaters, Energy Storage System (Battery), and New Controllable Generation.

Requirement: *Ensure the stability and security of the Shetlands electrical network at all times based upon*

- *The real-time availability and status of all generation*
- *The real-time availability and status of all controllable loads*
- *Advanced network stability measurements retrieved from an array of transducers located at strategic points on the electrical network*

The SGS ANM controller shall implement a "Stability & Security" ANM algorithm which ensures the stability and security of the network by controlling the behaviour of all controlled devices accordingly.

Requirement: *Ensure that all power flow constraints and voltage constraints are managed.*

The SGS ANM controller shall implement "Power Flow Management" and "Voltage Management" ANM algorithms in order to ensure that power flow and voltage constraints are properly managed.

Requirement: *Implement control of a newly installed Thermal Store (and boiler) to satisfy objectives in managing system balancing, system stability and network constraints.*

The SGS ANM controller shall provide demand side management of the new Lerwick Thermal Store and thereby provide a resource that can be used to satisfy objectives relating to system balancing, system stability and network constraints. Load shall be set on both a:

- *Real-Time Basis:* using the "Active Load Setpoint" features of the ANM controller
- *Day Ahead Basis:* using the "Day Ahead Schedule" generated by the ANM controller

The Thermal Store shall be equipped with a local controller which shall provide autonomous frequency responsive control capabilities. The frequency responsive capability shall operate independently of the of the SGS ANM controller. However, the ANM controller shall include the capability to modify the Droop Characteristics implemented within the Thermal Store controller at any time.

Requirement: *Implement control of thermal loads in multiple households to satisfy objectives in managing system balancing, system stability and network constraints. The thermal loads shall be composed of newly designed Dimplex Storage Heaters and Dimplex Immersion Heaters.*

The ANM controller shall provide demand side management" of the new Dimplex Storage Heaters and Immersion Heaters and thereby provide a resource that can be used to satisfy objectives relating to system balancing, system stability and network constraints. Load shall be set on both a:

- *Real-Time Basis:* using the "Active Load Setpoint" features of the ANM controller
- *Day Ahead Basis:* using the "Day Ahead Schedule" generated by the ANM controller

The Immersion Heater and Storage Heaters within each controlled home shall be equipped with a local controller (Dimplex Controller) which shall provide autonomous frequency responsive control capabilities. These capabilities shall operate independent of any real-time signals from the ANM controller. However, the ANM controller shall include the capability to modify the Droop Characteristics implemented within the Dimplex Controller at any time.

Requirement: *Implement control of the Gremista windfarm to satisfy objectives in managing system balancing, system stability and network constraints.*

The ANM controller shall provide for management of the new Gremista windfarm and thereby provide a resource that can be used to satisfy objectives relating to system balancing, system stability and network constraints. Generation shall be limited on both a:

- *Real-Time Basis:* using the "Active Generation Setpoint" features of the ANM controller
- *Day Ahead Basis:* using the "Day Ahead Schedule" generated by the ANM controller

The Gremista wind farm shall be equipped with a local controller which shall provide autonomous frequency responsive control capabilities. These capabilities shall operate independent of any real-time signals from the ANM controller. However, the ANM controller shall include the capability to modify the Droop Characteristics implemented within the Gremista wind farm controller.

Requirement: *Implement control of a number of distributed small-scale wind turbines to satisfy objectives in managing system stability.*

The ANM controller shall include features to control a number of small wind turbines on the Shetlands. These turbines shall be tripped (or curtailed) in situations when the frequency response available from all resources is insufficient and the maintenance of system stability therefore necessitates such actions.

Requirement: *Implement control of an Energy Storage System (Battery) to satisfy objectives in managing system balancing, system stability and network constraints (including optimal adjustments of the generation profile and following the instantaneous demand requirements).*

The ANM controller shall include features to control the new Energy Storage System (Battery) and thereby provide a resource that can be used to satisfy objectives relating to system balancing, system stability and network constraints. Battery real and reactive power shall be controlled on both a:

- *Real-Time Basis:* using the "Active Generation Setpoint" and "Active Load Setpoint" features of the ANM controller
- *Day Ahead Basis:* using the "Day Ahead Schedule" generated by the ANM controller

The Battery shall be equipped with a Device Controller which shall provide autonomous frequency responsive control capabilities. These capabilities shall operate independent of any real-time signals from the ANM controller. However, the ANM controller shall include the capability to modify the Droop Characteristics implemented within the Device Controller.

2.2 Detailed Requirements

2.2.1 Existing Control Systems

Requirement: *Implement an interface from the ANM controller to the existing Serck system in Lerwick Power Station. This interface must provide the power station operator with the ability to view the operation of the ANM controller and potentially control certain aspects of the operation of the ANM controller.*

A bidirectional communications interface shall be established between the ANM controller and the Serck system. Data shall be exchanged using an industry standard SCADA protocol. This interface will be used to inform the ANM controller of the status of existing generation at:

- Lerwick Power Station
- Sullom Voe Terminal
- Burradale Wind Farm

Requirement: *Implement an interface from the ANM controller to the existing ENMAC system. This interface must provide the ENMAC operator with the ability to view the operation of the ANM controller and potentially control certain aspects of the operation of the ANM controller.*

A bidirectional communications interface shall be established between the ANM controller and the ENMAC system. Data shall be exchanged using an industry standard SCADA protocol.

2.2.2 Real-Time Measurements

Requirement: *Install a number of power flow and voltage constraint measurement devices at strategic critical locations on the Shetlands electrical network and use the data from these transducers to inform power flow and voltage constraint management.*

The locations of any power flow constraints or voltage constraints shall be identified through analysis of new load and generator connections to the network. Measurement transducers shall be installed as necessary to inform power flow and voltage constraint management.

Requirement: *Install a number of Phasor Measurement Units at strategic critical locations on the Shetlands electrical network and use the data from these transducers to monitor the stability and security of the network.*

A number of PMUs shall be installed and shall be used to monitor the dynamic state of the network. These transducers shall connect to a "Stability Analysis Application".

Requirement: *Analyse the data retrieved from the Phasor Measurement Units so as to generate a simple set of network stability indicators.*

The "Stability Analysis Application" shall retrieve data from all such transducers and process and present a unified set of network stability indicators for subsequent use by the ANM controller. Data shall be streamed from the transducers in real-time and the result set shall also be provided (and updated) in real-time.

2.2.3 Core ANM Interfaces

Requirement: *Supply a Generation Management Interface to provide an interface between the central ANM controller and all generators.*

This part of the central ANM controller shall manage the interface with all generators. It shall present the data retrieved from all generators in a manner which is suitable for processing by all of the Core ANM algorithms. The status of generation shall be gathered from either direct or indirect communication links to all controlled and existing generation assets.

The Generation Management Interface shall manage the issuing of instructions from the ANM controller to all controlled generators including Day Ahead Schedules, Active Setpoints and Droop Characteristics as appropriate. It shall be used to send setpoints (or generation limits) to the generators in order to control their behaviour in accordance with the commercial terms of their connection agreement. It shall provide permission to operate at given times to non-firm contracted generators, e.g. it may be necessary to inhibit the operation of non-firm generators dependent upon various forecast conditions. Solely MW setpoints shall be sent initially. However, future developments may encompass the transmission of both MW and MVAR setpoints.

Requirement: *Supply a Load Management Interface to provide an interface between the central ANM controller and all controlled loads.*

This part of the central ANM controller shall manage the interface with all controlled loads. It shall present the data retrieved from all controlled loads in a manner which is suitable for processing by all of the Core ANM algorithms.

The Load Management Interface shall manage the issuing of instructions from the ANM controller to all controlled loads including Day Ahead Schedules, Active Setpoints and Droop Characteristics as appropriate. It shall be used to send continuously updated setpoints to controlled loads under the appropriate conditions. It shall be possible to send such setpoints to controlled loads on both a global basis (to the entire population of controlled loads) and a “zonal” basis (where a large population of loads shall be grouped into smaller individually controllable zones).

This part of the ANM controller shall also incorporate the calculation of available demand or storage capacity available which shall infer the “DSM In Hand” available from all controllable loads at any given time.

Requirement: *Supply an Energy Storage Management Interface to provide an interface between the central ANM controller and all controlled energy storage devices.*

This part of the central ANM controller shall manage the interface with all controlled energy storage devices (batteries). It shall present all data retrieved from the energy storage devices in a manner which is suitable for processing by all of the Core ANM algorithms.

It shall manage the issuing of instructions from the ANM controller to all controlled energy storage devices including Day Ahead Schedules, Active Setpoints and Droop Characteristics as appropriate. This will include the transmission of both MW and MVAR setpoints.

Requirement: *Include a "DSM In Hand" calculation within the Load Management engine which shall determine a real-time estimate of the available controllable load.*

The "DSM In Hand" calculation shall use feedback data from a subset of controlled loads (along with other information) to accurately estimate the available "DSM In Hand" within the population of all controlled loads. In particular, the "DSM In Hand" will take account of the requirements and capabilities of thermal energy storage in the Thermal Store and domestic Immersion Heaters and Storage Heaters.

Feedback data shall only be retrieved from a subset of controlled homes in order to reduce the costs of installing the requisite sensors, wiring and communications infrastructure. The retrieved data shall be used by the "DSM In Hand" calculation in order to estimate the available energy storage capacity within the population of Storage/Immersion Heaters.

This estimate shall be probabilistic in nature due to the fact that feedback data shall only be retrieved from a subset of controlled homes. However, this subset shall be large enough so as to develop an estimate which is sufficiently accurate to perform the requisite management functions with a sufficient level of certainty.

Requirement: *Include a "Total Network Load" calculation within the Generation Management engine which shall calculate the real-time network load based on the output of all (or selected) generators.*

The real-time total network load, as seen by the generators at the Sullom Voe Terminal (SVT) and Lerwick Power Station (LPS), shall be used to instruct controllable generators and thereby smooth the profile of total network load to improve overall system operation.

Requirement: *Supply a "Generation Arbitration" engine to act as an arbiter between the different instructions which shall be sent to controlled generators (and energy storage devices operating as generators) from the Core ANM algorithms.*

The "Generation Arbitration" engine shall determine which of the generator control instructions shall take precedence at any given time.

Requirement: *Supply a "Load Arbitration" engine to act as an arbiter between the different instructions which shall be sent to controlled loads (and energy storage devices operating as loads) from the Core ANM Algorithms.*

The "Load Arbitration" engine shall determine which of the load control instructions shall take precedence at any given time.

2.2.4 Core ANM Algorithms

Requirement: *Supply a number of core ANM algorithms from the SGS product range within the ANM controller to form the core elements of the control system.*

The following core SGS ANM algorithms shall be supplied:

- System Balancing
- Stability & Security
- Power Flow Management
- Voltage Management

Requirement: *Supply the "System Balancing" ANM algorithm so as to enhance the balance of load and generation, ensure the effective use of renewable generation and smooth the profile as seen by the generators at the Sullom Voe Terminal (SVT) and Lerwick Power Station (LPS).*

The "System Balancing" ANM algorithm shall coordinate the use of all controllable resources on the network to produce "Day Ahead Schedules".

The "System Balancing" ANM algorithm shall use the results from forecasting engines and current status information from all ANM Interfaces engines, including the results produced by the "DSM In Hand" calculation for controlled loads.

The "System Balancing" ANM algorithm shall track the real-time total network load, as seen by the generators at the SVT and LPS, and use this to define Active Setpoints for controlled devices to smooth the profile of total network load to improve overall system operation.

Requirement: *Supply the "Stability & Security" ANM algorithm so as to ensure the stability and security of the network by controlling both loads and generators.*

The "Stability & Security Engine" ANM algorithm shall control loads, generators and batteries in order to ensure the stability of the network. It shall have the capacity to modify the Droop Characteristics on all frequency responsive devices. It shall be capable of instructing rapid changes in the Active Setpoint of controlled devices, including switching off controlled devices if necessary.

Requirement: *Include a facility to send instructions to controllable frequency responsive devices to enable them to use differing Droop Characteristics under differing conditions (for high-speed frequency response).*

The "Stability & Security" ANM algorithm shall determine the conditions under which the use of alternate Droop Characteristics shall be desirable (in order to determine the frequency responsive characteristics of the controlled devices and ensure continued network stability). The appropriate ANM Interface shall send information to the Local Interface Controller at the controlled device to indicate the required Droop Characteristic.

Requirement: *Supply the "Power Flow Management" ANM algorithm to manage the controllable devices to ensure that power flows remain within limits at identified constraint locations.*

The "Power Flow Management" ANM algorithm shall set operating limits for controlled devices as appropriate to manage power flows at identified constraint locations. The module may implement control over generators, loads and batteries. The need for control shall be dependent upon any identified constraint locations.

Requirement: *Supply the "Voltage Management" ANM algorithm to manage the controllable devices to ensure that voltages remain within limits at identified constraint locations.*

The "Voltage Management" ANM algorithm shall set operating limits for controlled devices as appropriate to manage voltages at identified constraint locations. The module may implement real and reactive power control over generators, loads and batteries. The need for control shall be dependent upon any identified constraint locations.

2.2.5 Forecasting Systems

Requirement: *Supply a "Load Forecast" system to generate a "Day Ahead Load Forecast" for the system.*

The "Load Forecast" system shall generate a "Day Ahead Load Forecast" based upon various input data including:

- *Previous Day Load Profile:* This is ordinarily the prime input in the creation of the "Day Ahead Load Profile"
- *Forecast & Historical Temperature Data + Forecast Wind Speed:* These are generally indicative of the heating load which shall apply on the forthcoming day

Requirement: *Supply a "Generation Forecast" system to generate a "Day Ahead Generation Forecast" for all generators.*

The "Generation Forecast" module shall generate a "Day Ahead Generation Forecast" based upon the Forecast Wind Speed and other factors.

Requirement: *Supply a "Forecasting Engine" to compile and correlate historic and forecast information to generate a "Forecast Result Set".*

The "Forecasting Engine" shall receive the outputs of the "Load Forecast" and "Generation Forecast" modules. It shall use this information to generate a "Forecast Result Set" which shall be provided to the "System Balancing" ANM algorithm for the purposes of generating the "Day Ahead Schedule".

2.2.6 Thermal Store Controller

Requirement: *Specify a "Thermal Store Controller" in terms of its interface with the associated "Local Interface Controller" and capability to control the operation of the Thermal Store according to its own requirements and the requirements of the ANM scheme.*

The "Thermal Store Controller" shall be supplied by parties contracted by SHEAP to deliver the new Boiler and Thermal Store. The "Thermal Store Controller" shall have a "Controller Interface" module which shall provide for the exchange of signals with the associated "Local Interface Controller".

The "Thermal Store Controller" shall have the equivalent of an "Operational Constraints" module which shall ensure safe operation and the satisfaction of user requirements but otherwise implement control instructions received from the ANM scheme through the associated "Local Interface Controller". These instructions may be in the form of a "Day Ahead Schedule" or "Active Load Setpoint".

The "Thermal Store Controller" shall have the ability to sense the network frequency and use this in conjunction with a stored "Droop Characteristic" to perform rapid autonomous adjustment of the power level. The "Droop Characteristic" shall be modifiable by the ANM scheme through the associated "Local Interface Controller" at any time.

The "Thermal Store Controller" shall shall compile information representing the instantaneous operation of the Thermal Store and supply this through the "Controller Interface" to the associated "Local Interface Controller". This shall be transmitted back to the ANM controller for use in the Core ANM algorithms.

2.2.7 Dimplex Storage Heater Controller

Requirement: *Specify a "Dimplex Storage Heater Controller" in terms of its interface with the associated "Local Interface Controller" and capability to control the operation of the Dimplex Storage Heaters according to its own requirements and the requirements of the ANM scheme.*

The "Dimplex Storage Heater Controller" shall be supplied by Glen Dimplex.

The "Dimplex Storage Heater Controller" shall have a "Controller Interface" module which shall provide for the exchange of signals with the associated "Local Interface Controller".

The "Dimplex Storage Heater Controller" shall ensure safe operation and the satisfaction of user requirements but otherwise implement control instructions received from the ANM scheme through the associated "Local Interface Controller". These instructions may be in the form of a "Day Ahead Schedule" or "Active Load Setpoint".

The "Dimplex Storage Heater Controller" shall have a "Frequency Adjustment" module which shall sense the network frequency and use this in conjunction with a stored "Droop Characteristic" to perform rapid autonomous adjustment of the power level. The "Droop Characteristic" shall be stored in the "Dimplex Storage Heater Controller" and shall be modifiable by the ANM scheme through the associated "Local Interface Controller" at any time.

The "Dimplex Storage Heater Controller" shall have a "Feedback Interface" module which shall compile information representing the instantaneous operation of the Dimplex Storage Heaters and supply this through the "Controller Interface" to the associated "Local Interface Controller". This shall in turn convert the information as necessary and transmit it to the ANM controller for use as part of the "DSM In Hand Inference Model".

2.2.8 Dimplex Immersion Heater Controller

Requirement: *Specify a "Dimplex Immersion Heater Controller" in terms of its interface with the associated "Local Interface Controller" and capability to control the operation of the Dimplex Immersion Heaters according to its own requirements and the requirements of the ANM scheme.*

The "Dimplex Immersion Heater Controller" shall be supplied by Glen Dimplex.

The "Dimplex Immersion Heater Controller" shall have a "Controller Interface" module which shall provide for the exchange of signals with the associated "Local Interface Controller".

The "Dimplex Immersion Heater Controller" shall have an "Operational Constraints" module which shall ensure safe operation and the satisfaction of user requirements but otherwise implement control instructions received from the ANM scheme through the associated "Local Interface Controller". These instructions may be in the form of a "Day Ahead Schedule" or "Active Load Setpoint".

The "Dimplex Immersion Heater Controller" shall have a "Frequency Adjustment" module which shall sense the network frequency and use this in conjunction with a stored "Droop Characteristic" to perform rapid autonomous adjustment of the power level. The "Droop Characteristic" shall be stored in the “Dimplex Immersion Heater Controller” and shall be modifiable by the ANM scheme through the associated “Local Interface Controller” at any time.

The “Dimplex Immersion Heater Controller” shall have a “Feedback Interface” module which shall compile information representing the instantaneous operation of the Dimplex Immersion Heater and supply this through the “Controller Interface” to the associated “Local Interface Controller”. This shall in turn convert the information as necessary and transmit it to the ANM controller for use within the Core ANM algorithms.

2.2.9 New Controllable Generation

Requirement: *Specify a “Large Generator Controller” in terms of its interface with the associated “Local Interface Controller” and capability to control the operation of large generators according to their own requirements and the requirements of the ANM scheme.*

The “Large Generator Controller” shall be supplied by the parties contracted to install each large generator. The first large generator expected to be installed under the auspices of the ANM scheme on Shetland is a wind farm at Gremista.

The “Large Generator Controller” shall have a “Controller Interface” module which shall provide for the exchange of signals with the associated “Local Interface Controller”. The nature of this interface shall be determined following negotiation with the parties supplying the “Large Generator Controller”. The interface is expected to make use of standard methods and protocols.

The “Large Generator Controller” shall have the equivalent of an “Operational Constraints” module which shall ensure safe operation and the satisfaction of operational requirements but otherwise implement control instructions received from the ANM scheme through the associated “Local Interface Controller”. These instructions may be in the form of a “Day Ahead Generation Schedule” or “Active Generation Setpoint”.

The “Large Generator Controller” shall have the equivalent of a “Frequency Adjustment” module which shall respond to commands instructing the generator to provide a degree of frequency responsive control in order to help maintain the network frequency within acceptable limits.

The “Large Generator Controller” shall have the equivalent of a “Feedback Interface” module which shall compile information representing the instantaneous operation of the generator and supply this through the “Controller Interface” to the associated “Local Interface Controller”.

Requirement: *Specify a “Small* Generator *Controller” in terms of its interface with the associated “Local Interface Controller” and capability to control the operation of small generators according to their own requirements and the requirements of the ANM scheme.*

The “Small Generator Controller” shall be supplied by the parties contracted to install each small generator. The first small generators expected to be installed under the auspices of the ANM scheme on Shetland are wind turbines supported by Community Energy Scotland.

The “Small Generator Controller” shall have a “Controller Interface” module which shall provide for the exchange of signals with the associated “Local Interface Controller”. The nature of this interface shall be determined following negotiation with the parties supplying the “Small Generator Controller”. The interface is expected to make use of standard methods and protocols.

The “Small Generator Controller” shall have a module which shall respond to commands instructing the generator to be disconnected (or curtailed) in order to maintain the network frequency within acceptable limits or to ensure the system is operated in a safe condition such that it is able to withstand all credible disturbances.

The “Small Generator Controller” shall have the equivalent of a “Feedback Interface” module which shall compile information representing the instantaneous operation of the small generators and supply this through the “Controller Interface” to the associated “Local Interface Controller”.

2.2.10 Energy Storage

Requirement: *Specify a “Battery Controller” in terms of its interface with the associated “Local Interface Controller” and capability to control the operation of the Battery according to its own requirements and the requirements of the ANM scheme.*

The “Battery Controller” shall be supplied by parties contracted by SSE to deliver and install the new Battery.

The “Battery Controller” shall have a “Controller Interface” module which shall provide for the exchange of signals with the associated “Local Interface Controller”. The nature of this interface shall be determined following negotiation with the parties supplying the “Battery Controller”. The interface is expected to make use of standard methods and protocols.

The “Battery Controller” shall have the equivalent of an “Operational Constraints” module which shall ensure safe operation and the satisfaction of operational requirements but otherwise implement control instructions received from the ANM scheme through the associated “Local Interface Controller”. These instructions may be in the form of a “Day Ahead Schedule” or “Active Setpoint”.

The “Battery Controller” shall have the equivalent of a “Frequency Adjustment” module which shall sense the network frequency and use this in conjunction with a stored “Droop Characteristic” to perform rapid autonomous adjustment of the power level. The “Droop Characteristic” shall be stored in the “Battery Controller” and shall be modifiable by the ANM scheme through the associated “Local Interface Controller” at any time.

The “Battery Controller” shall have the equivalent of a “Feedback Interface” module which shall compile information representing the instantaneous operation of the Battery and supply this through the “Controller Interface” to the associated “Local Interface Controller”. This shall in turn convert the information as necessary and transmit it to the ANM controller.

2.2.11 Local Interface Controller

The Load Interface Controller (LIC) will act as the link between the central ANM controller and controlled devices.

2.2.11.1 General Functionality

Requirement: *Ability for the LIC to operate independently of the central ANM controller.*

The LIC must continue to operate when communications with the central ANM controller are not available. The LIC will continue to issue control instructions to the controlled device according to the stored instructions, or default instructions where appropriate. In some circumstances a controlled device will be installed with an LIC only for testing before being fully connected to the ANM scheme.

Requirement: *Ability for the LIC to perform minimal data processing and calculation functions.*

The LIC shall not be expected to perform any significant calculations. Data must be received, stored and transferred at the appropriate times. The most complex calculation is expected to be the derivation of energy storage or other limits based on feedback from the Device Controller. Thus, the processing capability required shall be minimal.

2.2.11.2 Day Ahead Schedule Processing

Requirement: *Ability for the LIC to store a single Day Ahead Schedule within non-volatile memory.*

The LIC shall be capable of storing the Day Ahead Schedule in non-volatile memory. Ordinarily, this schedule shall not be stored within the Device Controller as well. Rather, the LIC shall simply send a setpoint based upon the schedule to the Device Controller every half hour. Setpoints sent to the Device Controller will normally be stored within the non-volatile memory of the Device Controller and shall remain active indefinitely (until a new setpoint is sent).

Requirement: *Ability for the LIC to store a Default Day Ahead Schedule within non-volatile memory.*

A Default (or “failsafe”) Day Ahead Schedule shall be stored within the LIC. This schedule shall be used whenever the link is lost between the central ANM controller and the LIC.

Requirement: *Ability for the LIC to receive a new Day Ahead Schedule transmitted at any time from the central ANM controller.*

The LIC shall be capable of receiving a Day Ahead Schedule from the central ANM controller. An updated Day Ahead Schedule shall be transmitted from the central ANM controller to each LIC on a daily basis at a specific time each day.

Requirement: *Ability for the LIC to receive a new Default Day Ahead Schedule transmitted at any time from the central ANM controller.*

The LIC must be capable of receiving a Default Day Ahead Schedule from the central ANM controller. An updated Default Day Ahead Schedule shall only be sent under exceptional circumstances when it is determined that the existing Default Day Ahead Schedule (stored in the LIC) requires updating.

Requirement: *Ability for the LIC to issue setpoints to the Device Controller in real-time in accordance with the Day Ahead Schedule (or Default Day Ahead Schedule).*

The Day Ahead Schedule shall be composed of 48 half-hourly values for each day. The LIC shall be configured to send the appropriate setpoint to the Device Controller periodically (every half hour) according to the values stored within the Day Ahead Schedule.

2.2.11.3 Active Setpoint Processing

Requirement: *Ability for the LIC to receive an Active Setpoint Operational signal (Enabled or Disabled) which indicates whether the current Active Setpoint is to be taken into account or ignored (respectively).*

An Active Setpoint may override the current Day Ahead Schedule. However, an Active Setpoint cannot override the Day Ahead Schedule on an indefinite basis. Therefore, each Active Setpoint shall be both preceded and succeeded by an Active Setpoint Operational command. The preceding command shall ordinarily enable the transmitted Active Setpoint to be taken into account. Equivalently, the succeeding command (transmitted some time after the Active Setpoint) shall disable the previously transmitted Active Setpoint. The LIC shall then immediately revert back to the use of the appropriate setpoint from the Day Ahead Schedule for the given time of day.

In the unusual case where a device may be under active control at all times (where the device would not use a Day Ahead Schedule) then it would simply be necessary for the Active Setpoint Operational signal to remain Enabled at all times.

Requirement: *Ability for the LIC to receive Active Setpoint commands from the central ANM controller.*

Active Setpoint commands shall be sent directly from the ANM controller to the LIC. The LIC shall subsequently transmit these commands to the Device Controller. An Active Setpoint command received by the LIC shall only be transmitted to the Device Controller if the Active Setpoint Operational signal is currently “Enabled”.

Requirement: *Ability for the LIC to issue Active Setpoints to the Device Controller.*

An Active Setpoint received by the LIC shall immediately update the setpoint transmitted to the Device Controller (so long as the Active Setpoint Operational signal is currently “Enabled”). This shall override the currently active Day Ahead Schedule setpoint.

2.2.11.4 Droop Characteristic Processing

Requirement: *Ability for the LIC to store multiple sets of Droop Characteristics.*

Each stored Droop Characteristic shall comprise two integer values, namely, the Droop Characteristic Gradient and Frequency Deadband. These two values shall completely characterise each specific Droop Characteristic. Up to five (5x) unique Droop Characteristics shall be stored. The set of all Droop Characteristics shall be referenced as an “Array” with each element of the array containing a Droop Characteristic Gradient and a Frequency Deadband.

Requirement: *Ability for the LIC to store a Droop Characteristic Selection signal.*

This shall be an integer value which specifies the “index” of the Droop Characteristic which is to be used.

Requirement: *Ability for the LIC to receive Droop Characteristics from the ANM Controller.*

The ANM Controller shall send commands to the LIC at any time to update the Droop Characteristics stored within the LIC.

Requirement: *Ability for the LIC to receive a Droop Characteristic Selection signal.*

This signal shall specify the index of a specific Droop Characteristic which is to be used.

Requirement: *Ability for the LIC to update the stored Droop Characteristics in the Device Controller.*

When the LIC receives updates to the stored Droop Characteristics it shall immediately transmit these updates downstream to the Device Controller. The Device Controller shall then immediately update its stored Droop Characteristics. Thus, the Droop Characteristics shall be stored both within the LIC and within the Device Controller.

Requirement: *Ability for the LIC to send a Droop Characteristic Selection signal to the Device Controller.*

When the LIC receives a Droop Characteristic selection signal it shall immediately transmit this signal downstream to the Device Controller which shall itself immediately select the appropriate Droop Characteristic for immediate application.

2.2.11.5 LIC ↔ Device Controller Communications

Requirement: *Ability for the LIC to support a communications link with the Device Controller.*

Each implementation of an LIC and Device Controller must have a suitable communications link to facilitate the necessary exchange of information. Typically, the LIC shall send an Active Setpoint and Droop Characteristic instructions to the Device Controller. The LIC will receive feedback information appropriate to the controlled device. Ideally, these messages shall be sent via a common SCADA protocol. The LIC controller shall normally implement the SCADA master and the Device Controller shall implement the SCADA slave.

2.2.11.6 ANM Controller ↔ LIC Communications

Requirement: *Ability for the LIC to support a communications link with the ANM Controller using a common SCADA protocol.*

The ANM Controller shall send various messages to the LIC such as the Day Ahead Schedule, Active Setpoint commands and Droop Characteristics. These messages shall be sent via a common SCADA protocol. The ANM controller shall implement the SCADA master and the LIC shall implement the SCADA slave.

Requirement: *Ability to provide a communications link between the ANM Controller and the LICs which is secure against attack.*

The communications link between each LIC and the ANM Controller shall be secured using industry standard encryption algorithms.

2.2.11.7 Watchdogs and Error Handling

Requirement: *Ability to implement a "watchdog" between the central ANM controller and the LIC.*

A "watchdog" signal must be periodically transmitted between the ANM controller and the LIC in order for the LIC to determine if communications are lost with the central ANM controller. The LIC shall be configured to detect when the watchdog has failed for a pre-defined period of time. In such case, the LIC shall enter a "failsafe" mode and shall:

- Instruct the Device Controller to use the Default Droop Characteristic.
- Revert to the use of the Default Day Ahead Schedule (as opposed to the Day Ahead Schedule).

Requirement: *Ability to implement a "watchdog" between the LIC and the Device Controller.*

A "watchdog" signal must be periodically transmitted between the LIC and the Device Controller in order for the Device Controller to determine if communications are lost with the LIC. The Device Controller shall be configured to detect when the watchdog has failed for a pre-defined period of time. In such case, the Device Controller shall enter a "failsafe" mode and shall use the Default Droop Characteristic.

Requirement: *Ability for the LIC to resume normal operations following a power failure without any user intervention.*

Non-volatile memory within the LIC shall be used to ensure that all necessary data is stored in the LIC during any power outage.

Requirement: *Ability for the LIC to re-initialise all stored data within the Device Controller following a power failure without any user intervention.*

Each Device Controller is expected to have a small amount of non-volatile memory which shall be used to store all necessary data during any power outage. This memory shall be used to store the current Setpoint, Droop Characteristics, etc. The LIC shall be configured to send messages to the Device Controller to update all of this information as part of the LIC initialisation process (following a failure or power outage).

2.2.11.8 Feedback Processing

Requirement: *Ability for the LIC to retrieve feedback signals from the Device Controller and store these for subsequent analysis.*

The LIC shall include the ability to retrieve a number of feedback signals from the Device Controller. Each feedback measurement shall be transferred in a manner consistent with the chosen communications protocol.

Requirement: *Ability for the LIC to retrieve feedback signals from the Device Controller and store these for transmission to the central ANM controller.*

The LIC shall sample all available feedback signals from the Device Controller every 5 seconds and make these values available for retrieval by the ANM Controller.

2.2.11.9 Future Capabilities

Requirement: *Provide the facility for the LIC to control any type of controllable device.*

All features of the LIC shall be designed so as to permit interaction with any type of load, generation or energy storage system.

3 Functional Components

This section describes the purpose and operation of all functional components comprising the proposed Shetlands Smart Grid. The overall architecture and linkages between the function components are shown in the conceptual overview diagram in Figure 10.

3.1 Control Systems

3.1.1 Lerwick Power Station Control System (Serck)

The existing Lerwick power station includes an SCX6 SCADA control system manufactured by Serck. The status and availability of all existing generators shall be obtained through this system (including the Lerwick Diesel Generators, Sullom Voe Gas Turbines and Burradale Wind Farm).

3.1.2 ENMAC FEP

ENMAC is the existing SCADA system providing data gathering and presentation to the OSISoft PI data historian. ENMAC is used by the control room operators in Perth to monitor the status of the network and manage outages and maintenance.

3.1.3 PI North

The “PI North” instance of the OSISoft PI data historian provides the historical and data archival functions for the existing ENMAC control system.

3.1.4 PI LCNF

The “PI LCNF” instance of the OSISoft PI data historian shall be a new PI instance which shall operate independent of the existing “PI North” system. The PI LNCF historian shall provide the historical and data archival functions for the new ANM system alone.

3.2 Existing Generation

3.2.1 Lerwick Diesel Generators

This functional component represents the existing diesel generators at the Lerwick Power Station.

3.2.2 Sullom Voe Gas Turbines

The Sullom Voe gas turbines, when in service, supply a large majority of the spinning reserve capacity on the Shetlands. The status and availability of the Sullom Voe gas turbines shall be obtained via the Serck control system at Lerwick Power Station.

3.2.3 Burradale Windfarm

The existing Burradale wind farm has a rated output of 3.7 MW and is contractually regarded as a “firm” generator. i.e. there are no restrictions on the power which Burradale can produce and the times at which it may produce this power. The status and availability of the Burradale wind farm shall be obtained via the Serck control system at Lerwick Power Station.

3.3 New Controllable Generation

3.3.1 Gremista Windfarm

The Gremista windfarm shall have a rated output of 6.9 MW and shall be contractually regarded as a "non-firm" generator. The connection of this windfarm shall be subject to setpoint control by the ANM Controller.

3.3.2 CES Small Wind Farms

A significant number of small wind turbines shall ultimately be controlled as part of the Shetland Islands Smart Grid – the initial estimate is that there will be at least 40. These turbines shall range in size from 10-100 kW. The connection of these small wind turbines in export mode shall be subject to ON/OFF control by the ANM Controller based on prevailing network conditions.

3.3.3 Large Wind Farms

Further large wind farms (generally >100 kW) shall seek to connect to the Shetland Smart Grid if additional network capacity can be made available. The connection of these wind farms shall be subject to setpoint control by the ANM Controller.

3.4 Energy Storage

3.4.1 Energy Storage System (Battery)

An Energy Storage System (Battery) shall be used to enhance the capability to perform system balancing and provide other network support services. A 1 MW (6 MWh) NAS battery (with SVC functionality) shall be installed for these purposes. The battery shall ultimately be controllable for a number of potential objectives including maximising renewable generation, providing grid stability and to reduce emissions from the Lerwick Diesel Generators.

A "Local Interface Controller" shall be installed at the battery to provide control of the battery from the ANM Controller. The ANM controller shall take charge of issuing Active Setpoints, Schedules, parameter updates, etc. These commands shall be issued to the "Local Interface Controller" which shall subsequently issue the appropriate commands to the Battery Controller (as provided by the battery manufacturer).

3.5 Real-Time Measurements

The "Real-Time Measurements" functional grouping includes various functional components which provide or compile real-time data required to operate the Shetlands Smart Grid.

3.5.1 Constraint Measurements (I, V)

A number of Constraint Measurement Point Controllers shall be installed at identified constraint locations on the network in order to monitor currents and/or voltages. This information shall then be provided to the ANM Controller to manage power flow and voltage levels.

3.5.2 Phasor Measurement Units

A number of Phasor Measurement Units (PMUs) shall be used to provide raw data for the "Stability Analysis Application" to derive stability indicators. The PMUs enable a precise view of the system stability by measuring various values in real-time (including voltage and current phase angles, system frequency, low frequency oscillations, voltage magnitude and MW/MVAR flows).

PMUs shall send data to the "Stability Analysis Application" module, ideally at a rate of 50 Hz. This information may be positive sequence or 3-phase. In practice, 3-phase data at 50 Hz shall be retrieved (subject to any bandwidth limitations). This shall show the phase balancing and the fast data rate shall be useful for investigating transient events as well as oscillations. For example, a PMU sending one 3-phase voltage and three 3-phase current measurements shall require a bandwidth of 4700 bytes per second using TCP (37.6 kbits/s).

3.5.3 Stability Analysis Application

The "Stability Analysis Application" shall analyse the data received from all installed Phasor Measurement Units (PMUs) in real-time and provide a unified set of network stability indicators to the Stability and Security ANM algorithm within the ANM Controller. Based upon this information, the Stability and Security ANM algorithm shall subsequently manipulate both loads and generation in order to ensure the stability of the network.

The "Stability Analysis Application" shall analyse voltage and current phase angles in real-time. It shall also detect low frequency oscillations on the system (amongst various other potential network problems). The function of the Stability and Security ANM Algorithm shall be enhanced via the provision of the network stability indicators which shall allow for a more precise understanding and control of real time network stability.

PMU based monitoring shall be used to inform the management of stability in terms of the resources available for frequency response and the setting of control parameters. The PMU-based monitoring and real-time analysis shall also be used as an input to management of the stability in terms of the defence against multiple contingencies or common-mode disturbances.

PMU based monitoring shall also be used to improve and validate the models of the existing system and to ensure that all future changes to the network are modelled correctly. The impact of new plant on the dynamics of the system shall be assessed against a baseline of the existing network performance to ensure that there are no unintended effects, such as controller interactions or frequency stability issues. This shall provide greater confidence in all analyses and support the specification of unsafe conditions and control parameters. PMU based monitoring shall also provide a means of studying in detail the response to disturbances, thus helping to improve future responses. It shall also identify any existing or future problems with oscillatory stability and support the resolution of those problems.

The "Stability Analysis Application" shall include an interface to view raw data and dynamic analysis results. Interfaces shall also be provided for the transfer of alarms and other key indicators to the ANM Controller. Operators shall use a single primary interface to view alarms and triggers provided by the "Stability Analysis Application" in the context of the general operation of the ANM system, i.e. alarm information and other data shall be provided to the ANM Controller, but more detailed information shall be available through the "Stability Analysis Application" user interface itself – the target being that operators are provided with access to all relevant information without overloading.

It is anticipated that advanced monitoring with PMUs and the associated "Stability Analysis Application" shall be provided by Psymetrix and the PhasorPoint application.

3.6 Core ANM Interfaces

3.6.1 Generation Management Interface

The Generation Management ANM interface shall manage the interface with all generators. It shall present the data retrieved from all generators in a manner which is suitable for processing by all of the Core ANM Algorithms. It shall also handle all control signals sent to generators.

The following information will be compiled to identify the status of generation:

- The instantaneous availability of all generation, i.e. whether units are in operation, on standby, out of service, etc.
- The planned availability of all generation. A week-ahead planning schedule for all units shall be available. This shall include information regarding maintenance outages, etc.
- The instantaneous power production (MW) of all generation units.

An instantaneous measurement of the total network load shall be derived from generator outputs and used in the System Balancing ANM Algorithm. The total network load shall be indirectly determined based upon the available measurements defining the instantaneous total generation (which is equivalent to the total load plus all network losses).

3.6.2 Load Management Interface

The Load Management Interface shall manage the interface with all loads. It shall present the data retrieved from all loads in a manner which is suitable for processing by all of the Core ANM Algorithms. It shall also handle all control signals sent to loads.

The Load Management Interface shall incorporate the “DSM In Hand” calculation, which shall infer the degree of control available in all controlled loads at any given time. The “DSM In Hand” information will be used by the System Balancing ANM algorithm to determine an “Active Load Setpoint” and “Day Ahead Schedule” for all controlled loads. It will not be used for any system critical functions within the Stability and Security ANM algorithm.

The “DSM In Hand” calculation within the Load Management Interface shall take account of the characteristics of controlled loads, recent control actions, feedback from controlled loads and other information to generate an accurate estimate of the available controllable load.

3.6.2.1 Feedback Data

The “DSM In Hand” calculation shall be provided with feedback data from the Thermal Store and a subset of controlled homes (containing Immersion Heaters and Storage Heaters). The model shall account for the potential that an “Active Load Setpoint” command may be ignored by the “Operational Constraints” module in a Device Controller under certain conditions. In fact, the model shall exhibit sufficient intelligence so as to ensure that the “Active Load Setpoint” commands which are produced shall generally be taken into account (as opposed to being ignored). Note that this can never be guaranteed due to the variable operational constraints and local conditions at each storage device.

It is theoretically possible to calculate the “DSM In Hand” without having any feedback data from the field. However, such an inference would be subject to a high possibility of errors (even if the model were quite accurate). As such, feedback data shall be obtained from the Thermal Store and a subset of all controlled homes. This data shall provide the capability to accurately estimate the instantaneous controllable demand which is available. Such data shall be used to "tune" the "DSM In Hand" calculation within the Load Management Interface such that it can provide accurate results with feedback data from the minimum number of controlled homes.

The reason for this sample-based approach is because the installation of equipment required to process and transmit feedback signals from every controlled home would be complex and potentially cost prohibitive. Amongst other things, the infrastructure required in each home to be monitored would include wiring, sensors, signal processing equipment and communications equipment. Any efforts which can be made to reduce the amount of feedback required to tune the ANM calculation shall have a direct and appreciable effect upon reducing costs. The target is to achieve the greatest accuracy in the calculation whilst requiring the least possible feedback from controlled homes.

The "DSM In Hand" calculation within the Load Management Interface shall account for uncertainty in all feedback measurements and shall be robust to errors in all feedback data. Notably, even if complete feedback were received from all controlled homes then there would still be some level of uncertainty in the output of the model. This could be caused by various factors such as transducer errors, etc.

3.6.3 Energy Storage Management Interface

The Energy Storage Management Interface shall manage the interface with the Energy Storage Device (Battery). It shall present all data retrieved from the battery in a manner which is suitable for processing by all of the Core ANM Algorithms. It shall also handle all control signals sent to the battery.

3.6.4 Generation Arbitration

The Core ANM Interfaces shall implement Generation Arbitration and shall determine which of the many inputs to the module shall take precedence at any given time.

3.6.5 Load Arbitration

The Core ANM Interfaces shall implement Load Arbitration to determine which of the many inputs to the module shall take precedence at any given time.

3.7 Core ANM Algorithms

The "Core ANM Algorithms" functional grouping includes a number of ANM algorithms which provide the core infrastructure management for the Shetlands Smart Grid. Each "Core Decision Engine" shall be equipped with an understanding of the system in order to manage system operations.

Some groups within the population of controllable loads shall be treated as a single entity (a single large load) within the core engines. The controller interface shall subsequently send signals to all members of such logical groups to implement the necessary instructions. Alternately, the population of controllable devices may be controlled individually if desirable or necessary.

The Core ANM Algorithms shall be aware of both commercial and contractual rules in addition to technical rules. These commercial and contractual rules shall apply to both generators and loads and shall be used to customise the behaviour of the Core ANM Algorithms where applicable.

3.7.1 System Balancing ANM Algorithm

The System Balancing ANM Algorithm shall:

- Produce a baseline "Day Ahead Schedule" for all controllable loads based upon the output of the "Forecasting Engine" and the "DSM in Hand" calculation (within the Load Management ANM Interface). Initially, the schedule shall be created using the same methodology as already used on the Shetlands (where the "Previous Day Load Profile" is one of the principal inputs to the generation of the "Day Ahead Schedule"). Subsequently, this methodology shall be enhanced.
- Generate the "Day Ahead Schedules" so as to ensure that energy transfer over set periods is according to agreed contracts and user requirements.
- Provide the facility to actively override the "Day Ahead Schedule" stored at each controlled load in real-time via the transmission of "Active Load Setpoint" commands, e.g. if the wind increased in speed contrary to the forecast, then "Active Load Setpoint" commands may be sent to make use of the "unplanned" available renewable generation.
- Incorporate detailed knowledge regarding the operating characteristics and limitations of controlled devices and other resources. For example, the requirement to run Lerwick diesel sets above certain percentage power levels to reduce emissions and increase efficiency shall be recognised. The requirements of the Energy Storage System (Battery) shall also be reflected in the control instructions.

The System Balancing ANM Algorithm shall take account of the limits of real and reactive power for each controlled device, which define operating limits that can be illustrated with an operating chart. The capacity to absorb or release energy, or the stored energy that can be used before new power input is required, can also be illustrated with a chart. Below are some examples that demonstrate how different devices will have different operating limits, which will all be taken account of by the System Balancing ANM Algorithm in setting schedules.

The MW/MVAr charts show the region of operation possible for different devices. This will depend on the power limits of the device and the relationship between real and reactive power. The MW/t charts show the scope for different power levels to be maintained with different devices. The charts, and the information on which they are based, may be compiled for individual devices or combined to represent the scope for control of devices in aggregate.

Devices with a fixed power factor will have a clearly defined relationship between real and reactive power, such as that illustrated in Figure 1. The operational limits for this device are such that it can only be set to a position on the line.

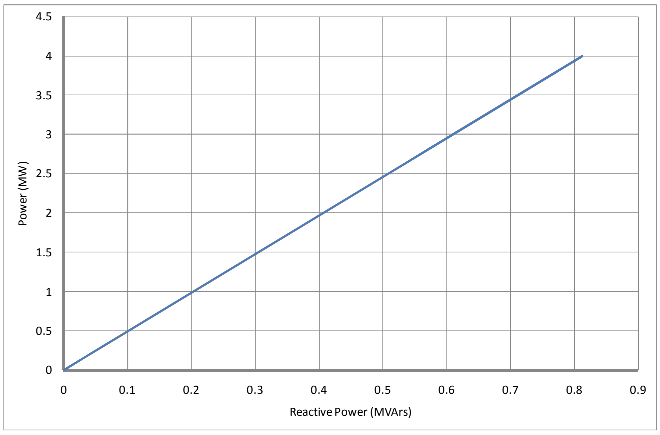

Figure 1: Example MW/MVAr Chart with Fixed Power Factor

If a device is controllable in terms of its real power but always consumes or produces a fixed amount of reactive power then its operating chart may be similar to that shown in Figure 2.

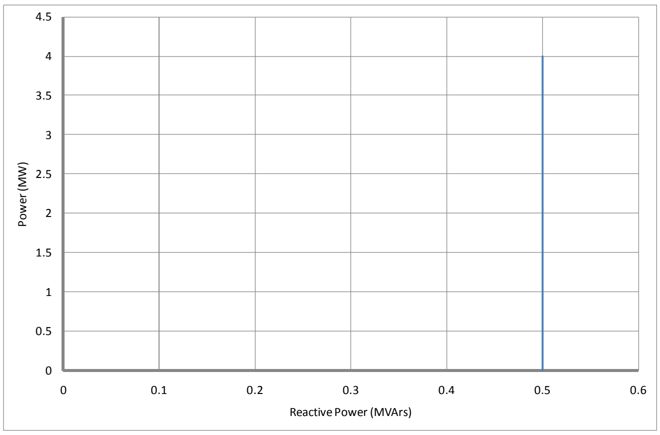

Figure 2: Example MW/MVAr Chart with Fixed Reactive Power

Devices such as batteries with power electronic interfaces may offer full four-quadrant control of real and reactive power such that any combination is possible within the MVA rating of the converter. Figure 3 shows an example operating chart where the device can be set to any position within the shaded area.

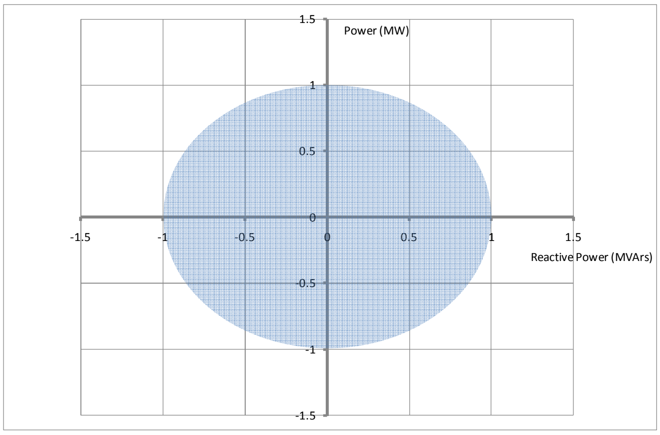

Figure 3: Example MW/MVAr Chart with Four-Quadrant Operation

For devices with stored energy and a capacity for energy to be imported or exported, e.g. batteries, it will be possible to maintain different power levels for different periods of time. Figure 4 shows a series of lines indicating the length of time that different power levels can be maintained given different starting levels of stored energy (the example assumes a battery with storage limits of 0 and 6 MWh). A given level of import can be maintained for longer than the equivalent level of export because losses in the converter mean that the impact on stored energy is different.

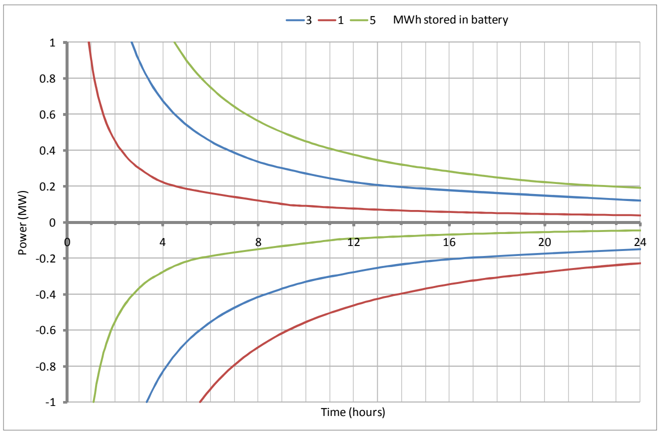

Figure 4: Example MW/t Chart for a Battery

Intermittent generators like wind turbines, or loads with variable limits, will only be able to operate at positions within their maximum feasible limits at any given time. Based on forecasts, operating charts such as that shown in Figure 5 can be produced where the shaded area indicates the possible operating points over a forthcoming period.

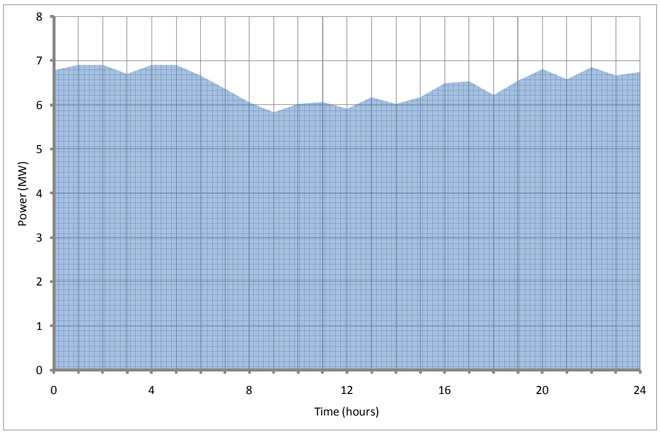

Figure 5: Example MW/t Chart for a Wind Farm

Thermal storage devices will have power limits that depend on the power limits of the devices but also the associated energy storage limits. If energy storage reaches its maximum then power input can be no more than power output. Conversely, if energy storage reaches its minimum then power input can be no less than power output. In Figure 6 the dotted line indicates the forecast power usage. The red and blue lines indicate the maximum and minimum power input respectively. The pink and green lines indicate the maximum and minimum levels of energy storage assuming a starting point of 75 MWh and limits of 0 and 100 MWh.

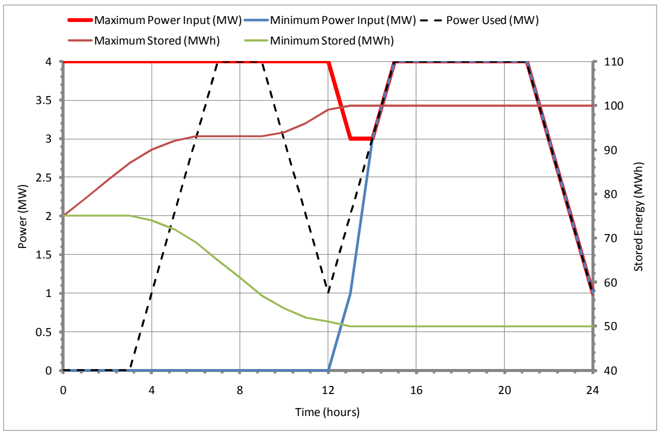

Figure 6: Example MW/t Chart for Thermal Storage

3.7.1.1 Generation Tracking

The System Balancing ANM Algorithm shall implement Generation Tracking and shall provide the facility to monitor the real-time network load, or specific loads identified for the purpose, and instruct controlled generation to track this load (insofar as possible). Accordingly, this interface has access to the real-time total network load, which shall be derived from the available generation information.

3.7.1.2 Load Tracking

The System Balancing ANM Algorithm shall implement Load Tracking to provide the facility to monitor the real-time available renewable generation and instruct controllable loads to track the available renewable generation insofar as possible (thus making the fullest use of renewable generation). Accordingly, this module has access to the real-time generation currently available on the network.

3.7.1.3 Active Generation Setpoint

The System Balancing ANM Algorithm shall send updated setpoints (or generation limits) to generators which shall override the schedule stored locally at the generator. Such setpoints shall be sent at the appropriate times according to the current system conditions as analysed by the ANM Controller. The new setpoint may apply for any given period of time (as determined by the central ANM controller).

The Active Generation Setpoint functionality shall include the facility to send signals to the operator of the Lerwick Control System (Serck) to indicate whether diesel sets should be taken online or offline according to the prevailing conditions as analysed by the ANM Controller. The Lerwick operator shall decide whether to accept or reject such suggestions based upon various additional factors which shall remain unknown to the ANM Controller, e.g. maintenance schedules, planned and unplanned outages, etc.

3.7.1.4 Active Load Setpoint

The System Balancing ANM Algorithm shall send updated setpoints to controlled loads which override the schedule stored locally at the loads. Such setpoints shall be sent at the appropriate times according to the current system conditions as analysed by the central ANM controller. The new setpoint may apply for any given period of time (as determined by the ANM Controller).

3.7.1.5 Day Ahead Generation Schedule

This System Balancing ANM Algorithm shall implement a Day Ahead Generation Schedule functionality and provide permission to operate at given times to controlled generators. For example, it may be necessary to inhibit the operation of controlled generators dependent upon various real-time and forecast conditions.

3.7.1.6 Day Ahead Load Schedule

A System Balancing ANM Algorithm shall implement a Day Ahead Load Schedule functionality to allow a schedule to be transmitted to the Local Interface Controller associated with each controlled load at a given time each day. The Day Ahead Schedule shall be stored within the Local Interface Controller at each device (such that the schedule may be followed even if communications with the central ANM controller are lost). The controlled load shall follow the stored “Day Ahead Schedule” unless it is overridden by the transmission of an Active Load Setpoint.

It shall be possible to retransmit an updated Day Ahead Schedule at any time following changes to the network, forecasts or available generation. However, it is expected that the schedule would generally only be transmitted once per day.

3.7.2 Stability & Security ANM Algorithm

The Stability & Security ANM Algorithm is used to ensure the stability and security of the network by setting the status, operating limits and operating parameters of all controlled devices. For example, it shall disable certain generators (such as small scale wind turbines) upon the loss of larger generators providing frequency control (such as SVT). Controlled devices may be assigned limits under certain circumstances, e.g. new wind farms restricted to a MW output level deemed acceptable given the frequency response available at that time. The Stability & Security ANM Algorithm will also update the frequency responsive behaviour of controlled devices by determining the desired "Droop Characteristics".

System stability shall be managed by ensuring the network does not enter, or is moved away from, configurations and combinations 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 in terms of the status and power levels of monitored devices. This will be supplemented by information received from the "Stability Analysis Application".

3.7.2.1 Inter Tripping & Rapid Load Adjustment

The Stability and Security ANM Algorithm shall implement Inter Tripping & Rapid Load Adjustment functionality to provide for the immediate disconnection of certain loads in response to the loss of specific generator(s) (in order to ensure system stability). The Inter Tripping functionality shall also provide the facility to trip (or curtail) generation in order to ensure system stability.

The Rapid Load Adjustment functionality shall detect the sudden loss of generation and rapidly adjust controllable loads accordingly. For example, if a windfarm is tripped (or SVT experiences a failure) then the Rapid Load Adjustment could immediately reduce the load in proportion in order to avoid network problems. This will supplement or provide back-up to any frequency-responsive load reductions that occur. The Stability & Security ANM Algorithm shall have access to the real-time status of all generators in order to be able to make such decisions.

3.7.2.2 Frequency Responsive Control

The Stability & Security ANM Algorithm shall implement Frequency Responsive Control functionality to provide the capability to instruct controlled devices regarding the nature of their frequency responsive behaviour. The Frequency Responsive Control instruction module shall act solely upon the instruction of the Stability & Security ANM Algorithm.

The updated Droop Characteristics shall be transmitted to the relevant controlled devices (where they shall be immediately taken into account). This module shall include the capability to entirely disable frequency responsive control in a device through the selection of a "flat" Droop Characteristic. Such an action may be taken when it is considered that the frequency response available from other sources, primarily SVT, is sufficient to maintain network stability.

Wind turbines may be operated at slightly below their potential output and thereby provide scope to "instantaneously" increase or decrease power output when required. This can be achieved either mechanically (by adjusting the pitch of the blades) or electrically (by using the power electronics to change the frequency and speed of rotation to a value that uses the available wind slightly less effectively).

The latest, most robust and flexible technologies shall be installed with any new large wind turbines. Such turbines shall impose the lowest possible perturbations on the network. This applies to frequency response, voltage support, fault ride through, etc. Indeed, such turbines shall provide positive and proactive network support through the provision of advanced control interfaces which shall used to achieve the aforementioned behaviour.

3.7.3 Power Flow Management ANM Algorithm

The Power Flow Management ANM Algorithm shall perform real-time control of generation and load as necessary to ensure power flows remain within defined limits at all constraint locations.

The Power Flow Management ANM Algorithm shall provide the facility to operate controlled loads on a “zonal” basis in order to resolve localised power flow constraints. i.e. controlled loads may be operated in groups.

3.7.4 Voltage Management ANM Algorithm

The Voltage Management ANM Algorithm shall ensure that network voltages remain within defined limits by managing controllable loads and generators.

The Voltage Management ANM Algorithm shall provide the facility to operate controlled loads on a “zonal” basis in order to provide the capability to deal with voltage constraints. i.e. controlled loads may be operated in groups.

3.8 Forecasting Systems

3.8.1 Forecasting Engine

The Forecasting Engine shall compile and correlate historic and forecast information from the Load Forecast and “Generation Forecast” modules. Based upon this data it shall produce a Forecast Result Set which shall be provided to the System Balancing ANM Algorithm for the purposes of generating the Day Ahead Schedule.

3.8.2 Forecast Result Set

The Forecast Result Set shall be produced by the Forecasting Engine. It shall contain all of the data pertaining to forecast system conditions which is required by the System Balancing ANM Algorithm in order to calculate the Day Ahead Schedule.

The Forecast Result Set shall include information which is highly specific to individual generators and loads, e.g. a specific forecast for the Burradale windfarm. Where there is a large population of devices then the Forecast Result Set may include results which apply to the whole of the population or groups within the population, e.g. groups of houses containing controllable storage and immersion heaters.

3.8.3 Load Forecast

The Load Forecast system shall generate a Day Ahead Load Forecast and shall provide this to the Forecasting Engine. The Load Forecast module shall take into account many factors in the determination of the Day Ahead Load Forecast. One of the most important of these factors is the Previous Day Load Profile (since this is generally representative of the load profile which shall be expected for the day ahead). The Load Forecast module shall also consider factors such as cold weather, holidays, the expected operation of large loads and many other factors in the determination of the Day Ahead Load Forecast.

3.8.4 Previous Day Load Profile

In the existing (manual) system, the Previous Day Load Profile is one of the principal inputs in the determination of the Day Ahead Load Forecast and the corresponding Day Ahead Schedule. Two-day load profiles may also be used to predict when loads would be expected to arise. It should be noted that there are distinct differences between the Previous Day Load Profile for weekdays and weekends.

3.8.5 Forecast Temperature Data

Forecast Temperature Data is an important input to the Load Forecast module since the forecast temperature can have a significant bearing upon the energy consumption in the Shetlands.

3.8.6 Historical Temperature Data

Historical Temperature Data is an important input to the Load Forecast module since the historical temperature records can provide direction as to the expected energy consumption during any given period.

3.8.7 Generation Forecast

The Generation Forecast module generates a Day Ahead Forecast for all generators and provides this to the Forecasting Engine. The Generation Forecast module primarily takes into account the wind speed in the determination of the Day Ahead Generation Forecast since the output of Renewable Generation is in most cases highly dependent upon the wind.

3.8.8 Forecast Wind Speed

The forecast wind speed on the Shetlands is:

- Closely correlated with the instantaneous heating requirements. Therefore, forecast wind speed is an important input to the Load Forecast module (which is required in order to generate the Day Ahead Load Profile).
- Closely correlated with the forecast output of renewable generators. Therefore, forecast wind speed is an important input to the Generation Forecast module (which is required in order to generate the Day Ahead Generation Forecast).

3.9 Local Interface Controller

The Local Interface Controller (LIC) is a hardware module which shall be physically installed at the location of all controllable devices. It shall provide the link between the ANM Controller and the controllable device:

- Commands and instructions shall be sent from the ANM Controller to the controllable devices via the LIC.
- Feedback data from the controllable devices shall be sent to the ANM Controller via the LIC.

The LIC shall be designed in a generic fashion such that it may be used to control any type of load, generation or energy storage system, e.g. not just thermal loads. A bespoke low-cost LIC shall be designed to be rolled out “en masse” for a multitude of controlled devices.

The LIC shall receive the following instructions from the control system:

- Day Ahead Schedules
- Active Setpoint instructions
- Droop Characteristic instructions

3.9.1 General Characteristics

The Local Interface Controller shall be robust to power outages and shall start up quickly.

3.9.2 ANM-LIC Interface

The ANM-LIC Interface shall provide the link between the ANM Controller and the LIC using an industry standard SCADA protocol such as OPC UA, IEC61850, IEC60870-5-104, DNP3, or Modbus. Ideally, a protocol providing native security features shall be used (or a communications medium providing a natively secured communications path). An appropriate communications channel shall be established with the LIC.

3.9.3 Day Ahead Schedule

The ANM Controller shall send a Day Ahead Schedule to the LIC via the ANM-LIC Interface. Ordinarily, an updated schedule shall be transmitted to each LIC every 24 hours (or more frequently under certain circumstances).

Under normal circumstances, the LIC shall ensure that the controlled load follows the Day Ahead Schedule by transmitting the appropriate setpoints to the load periodically throughout the day. However, the Day Ahead Schedule may be overridden at any time by the Operational Constraints within the load controller. The Day Ahead Schedule may also be overridden at any time by an Active Setpoint command.

3.9.4 Default Day Ahead Schedule

The ANM Controller shall send a Default Day Ahead Schedule to the LIC via the ANM-LIC Interface. The Default Day Ahead Schedule shall only be used when communications are lost between the central ANM controller and the LIC for a pre-defined period of time.

3.9.5 Droop Characteristics

The ANM Controller shall issue a set of Droop Characteristics to the LIC. These Droop Characteristics may be updated at any time by the ANM Controller and transmitted to the LIC. Whenever the LIC receives an updated set of Droop Characteristics it shall immediately transmit these new characteristics to the device under control (where they shall be stored for use).

3.9.6 Device Interface

The Device Interface shall provide the interface between the LIC and the actual device under control (or the controller associated with the device under control). This interface may be accomplished through various means dependent upon the capabilities of the device under control. For example, very simple devices may only include the capability to transfer commands via simple analogue signals. In such case the Device Interface would be customised to transfer signals using such a methodology.

As an example, the Dimplex Immersion Heater Controller and Dimplex Storage Heater Controller shall expose a 2-wire serial communications interface via RS485 using the Modbus RTU protocol. This interface shall be used for the bidirectional transfer of information between the LIC and the Dimplex Immersion/Storage Heater Controllers. Accordingly, the Device Interface shall be designed to support galvanically isolated 2-wire RS485 serial communications using the Modbus RTU protocol.

It should be noted that the Device Interface shall include the capability to support bidirectional communications with the device under control. However, the majority of controllable loads shall be operated on a unidirectional basis where commands are sent to the loads but feedback is not received from the loads. In such cases the response of the loads to setpoint commands shall be inferred via other mechanisms than direct feedback (and the "Device Interface" shall only support the transfer of commands to the device under control). For a small proportion of the population of controlled devices however, it shall be desirable to directly monitor the response of the device under control. In these cases feedback values from the device shall be retrieved by the "Device Interface" and returned to the central ANM controller through the "ANM-LIC Interface".

3.10 Common Characteristics of Controlled Loads

The purpose of this section is to describe a number of the common characteristics which apply to the controllers which shall be provided with all controlled loads. In some cases there are specific customisations which are required for each type of controlled load. Therefore, all of the sections herein are repeated hereafter for each type of controlled load (so as to provide the facility to describe any specific customisations).

3.10.1 General Characteristics

The controller associated with the controlled load shall be robust to power outages and shall start up quickly.

3.10.2 Operational Constraints

The Device Controller shall ensure that all operational constraints imposed by the load, independently of the ANM scheme, are respected at all times. For example:

- In the case of the Thermal Store, the Device Controller shall ensure that the tank temperature remains within acceptable limits at all times of the year.
- In the case of the Dimplex Storage Heaters, the Device Controller shall ensure that the desired room temperatures are maintained at all times.
- In the case of the Dimplex Immersion Heaters, the Device Controller shall ensure that a minimum tank temperature is maintained at all times (likely 50°C) and the maximum tanl temperature is not exceeded.

Note that in order to achieve these ends the Device Controller can potentially ignore any Active Setpoint (if this setpoint would result in the violation of the operational constraints). The Device Controller may also ignore the instructions of the Day Ahead Schedule for the same reasons.

3.10.3 Frequency Adjustment

The Frequency Adjustment module shall instantaneously adjust the power consumption of the controlled load based upon the detected instantaneous network frequency and the Droop Characteristic which is currently in use.

If the controlled load reaches its maximum frequency response (by reaching either full power or minimum power) and frequency deviates further from the target value then the controlled load shall maintain its response until such time as frequency is restored to within limits or the Device Controller instructs the controlled load to change its power level.

3.10.4 Droop Characteristics

A Droop Characteristic is a simple representation of the relationship between power and frequency. It is normally considered in the context of generators where the droop is a key characteristic of the governor, which maintains the speed of rotation, i.e. the frequency, by controlling the power of the generator. In power systems the Droop Characteristic ensures that generators respond to changes in frequency and automatically keep frequency close to the target value. Droop control is the primary means by which instantaneous supply and demand are matched. It is much less common to consider Droop Characteristics in the context of load control or DSM and there are different ways in which droop can be defined and represented. A set of example Droop Characteristics, as defined here, are shown in Figure 7. Frequency should normally be at or close to 50 Hz but deviations prompt changes in power output/input according to the Droop Characteristics as shown.

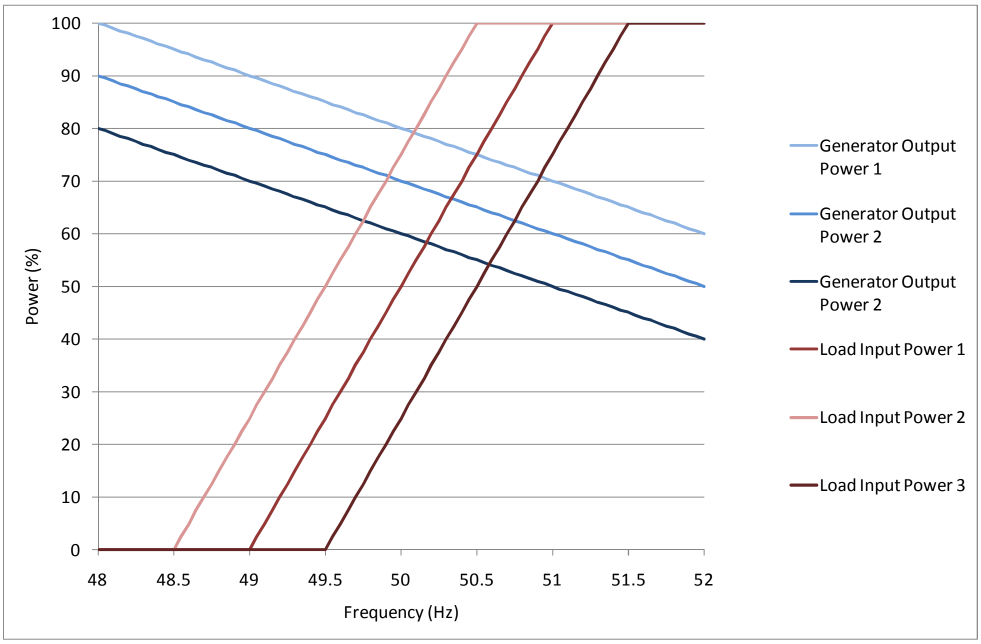

Figure 7: Typical Droop Characteristics

It is clear that generator power output and load power input must move in opposite directions when there is a change in frequency with both acting to restore the target frequency of 50 Hz. The parallel lines show how the same droop characteristic, or the same gradient of the line, can apply at different power levels. In the example above, the power input to loads reaches extreme values at different frequencies depending on the initial power level at the target frequency of 50 Hz.

Droop Characteristics need not be linear but that is the usual assumption and it is, at this time, considered sufficient for the proposed system on Shetland. The Stability & Security ANM Algorithm shall issue instructions regarding the Droop Characteristics to be applied at each controllable load. It shall be possible to disable the frequency response by selecting a "flat" Droop Characteristic. Such an action may be taken when it is considered that the frequency response provided by other devices (primarily SVT and LPS) is sufficient to maintain network stability.

A set of Droop Characteristics shall be provided by the ANM Controller to the controllable loads at any time. The provision of this set of Droop Characteristics shall allow for the real-time customisation of the frequency responsive characteristics of all controllable loads. Each Droop Characteristic shall be defined in a linear fashion with 2x equivalent slopes outside a horizontal deadband interval centred on 50 Hz. These slopes shall cater for both positive and negative frequency violations. A Droop Characteristic may thus be fully described by two parameters:

- **Gradient:** The gradient shall be the same for both positive and negative frequency violations.
- **Deadband:** The deadband shall always be centred around 50 Hz and shall cover the same extent both above and below 50 Hz. Load changes shall be triggered only if the frequency moves outside of the deadband (ordinarily between 49.98 and 50.02 Hz). This shall avoid constant variations in load for the constant variations in frequency that are an inevitable feature of any power system. The deadband shall be set according to the expected "normal" frequency variations and may be varied for the different controlled loads.

A typical Droop Characteristic is shown in Figure 8 where the following parameters apply:

- Target Frequency: 50 Hz
- Deadband (+/-): 20 mHz
- Droop: 4 kW/Hz
- Maximum Power: 3 kW
- Minimum Power: 0 kW
- Power Now: 1 kW

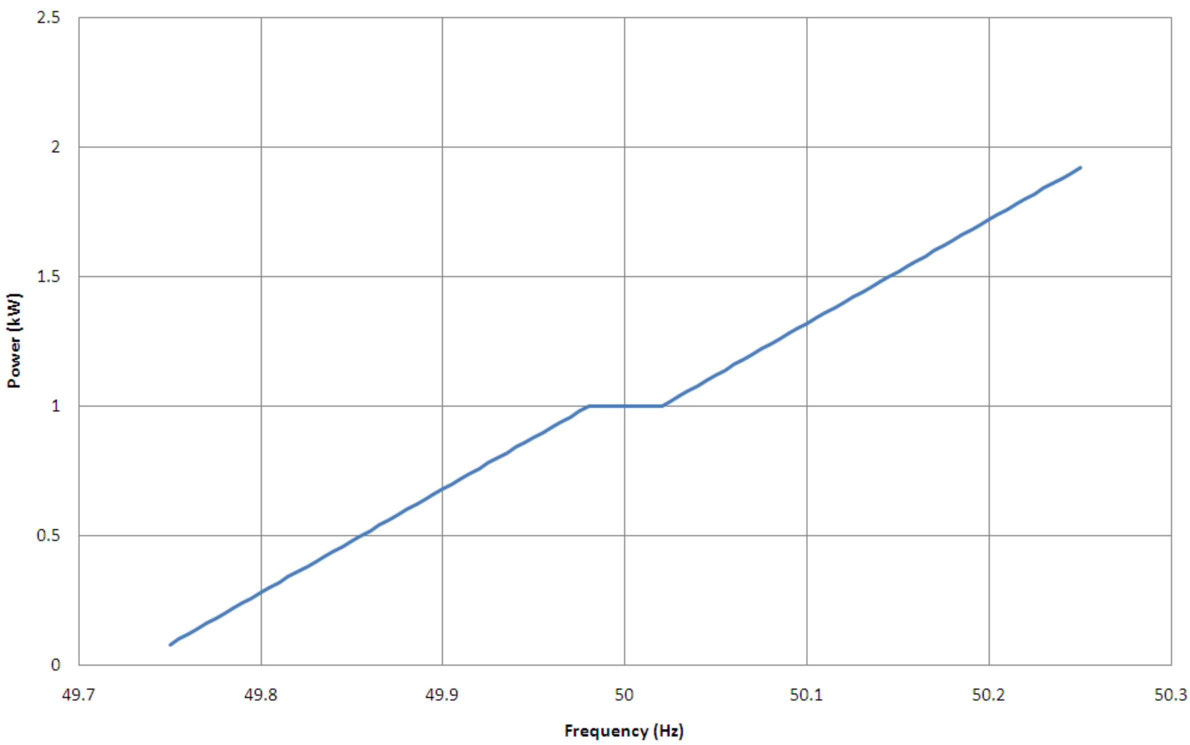

Figure 8: Typical Droop Characteristic – Zoomed In

The same Droop Characteristic is shown in Figure 9 but with a more expansive frequency range. As can be seen, for the more extreme frequency violations the controlled device shall reach the limits of its capacity (either drawing full power or no power) and shall remain at those limits for yet further extreme frequency violations.

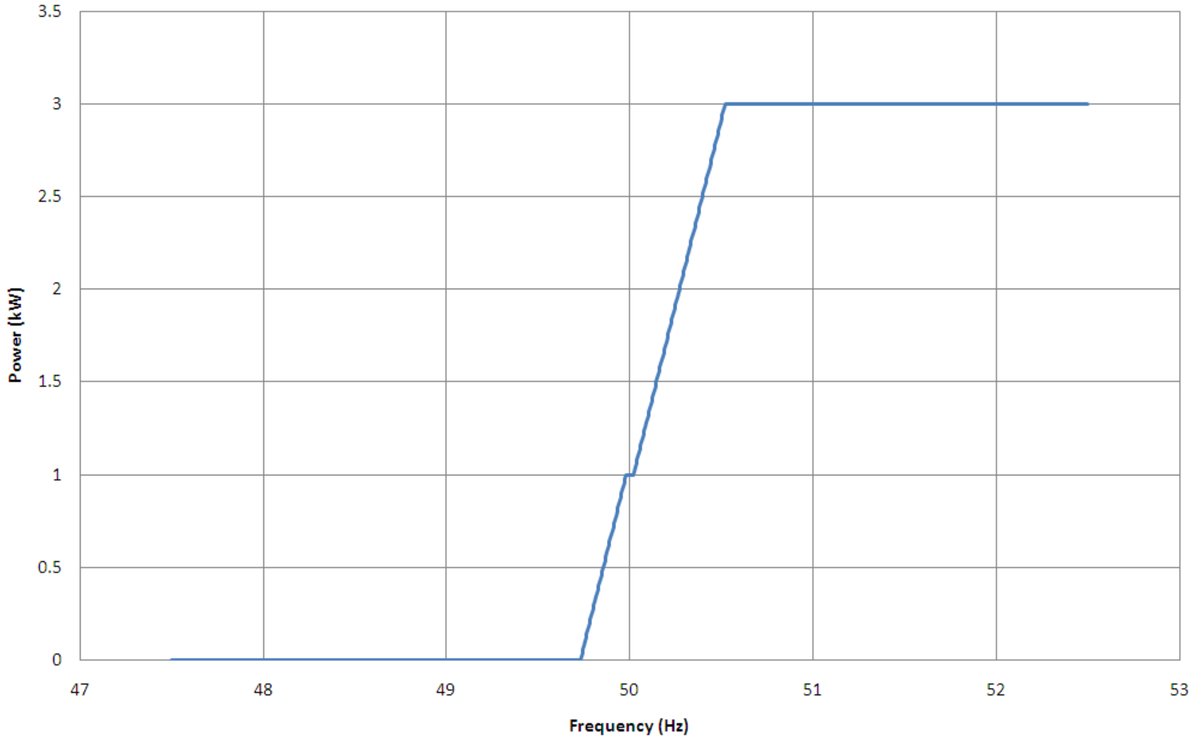

Figure 9: Typical Droop Characteristic – Zoomed Out

A Default Droop Characteristic response shall also be defined within all controlled loads. The Default Droop Characteristic shall define the frequency responsive behaviour when communications have been lost with the control system or when the selected Droop Characteristic has become stale (when the selection has not been updated for a predefined period of time).

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 loads shall provide a valuable contribution to frequency control on the Shetlands.

3.10.5 Frequency Sensor

The Frequency Sensor shall sense the frequency on the electrical network and provide this to the Frequency Adjustment module. In turn, the Frequency Adjustment module shall adjust the power of the load to compensate for frequency fluctuations according to the selected Droop Characteristic response.

All Frequency Sensors shall operate effectively under normal accepted disturbance conditions as defined in relevant standards including G5/4 and P28.

3.10.6 Feedback Interface

The Feedback Interface shall provide a set of signals representing various values known to the Device Controller. These signals shall be transmitted to the Local Interface Controller through an appropriate communications link. The feedback signals shall provide for the tuning of the DSM in Hand calculation within the Load Management Interface.

3.11 Thermal Store Controller

The Thermal Store Controller shall include various functional components which shall be used to manage the Lerwick Thermal Store on the Shetlands Smart Grid.

3.11.1 General Characteristics

Refer to Section 3.10.1.

3.11.2 Operational Constraints

Refer to Section 3.10.2.

3.11.3 Frequency Adjustment

Refer to Section 3.10.3.

Frequency responsive control for the Thermal Store shall be enabled at all times subject to the following limits:

- Power cannot be reduced below 0 and cannot be increased above 4 MW.
- Power cannot be increased if the tank temperature is at its maximum.
- Power cannot be decreased if the tank temperature is at its minimum.

The following specific frequency responsive characteristics shall be exhibited by the Thermal Store:

- A linear load response to frequency deviations outside the deadband.
- Fifty percent (50%) load response within the first 15 seconds and full load response within 30 seconds. For reference purposes, the 4 MW Thermal Store shall have a minimum load of approximately 0.6 MW when in operation, and shall be able to increase to full load within 30 seconds.
- A full load response may only be maintained for a maximum of 15 minutes (after which time it shall be replaced by secondary reserve or manual load reserve).

3.11.4 Droop Characteristics

Refer to Section 3.10.4.

3.11.5 Tank Water Temp

The Tank Water Temp is the primary sensory input to the Device Controller to manage operational constraints for the Thermal Store. The Tank Water Temp sensor is used to ensure that the temperature of the tank remains within acceptable limits at all times of the year. Note that the acceptable temperature range may vary throughout the course of the year.

3.11.6 Frequency Sensor

Refer to Section 3.10.5.

3.11.7 Feedback Interface

The following feedback signals shall be provided by this module:

- *Tank Temperature:* The Tank Temperature shall be used to undertake the DSM in Hand calculation.
- *Instantaneous Power:* The instantaneous power measured at the device shall be compared with the most recently transmitted Active Load Setpoint.

3.12 Thermal Store

The Thermal Store shall be a large water tank connected to the Lerwick district heating system. The associated boiler shall contain a 4 MW element (or equivalent) and the tank shall support the storage of up to 150 MWh of energy. An average load of 2 MW shall be used in winter (to replace oil firing) and shall therefore provide the flexibility of up to +/- 2 MW for the purposes of Active Network Management. The average winter use of 2 MW is based upon the existing customer base. Expansion of the district heating network is expected to add another 2 MW of peak load over the coming years. A boiler rated at 4 MW shall help to meet this additional demand if there is sufficient renewable energy available.

It shall be possible to use the Thermal Store during maintenance shutdowns of the waste incinerator that currently supplies the district heating scheme. Depending on the storage available (and ensuring it is full of energy before such shutdowns) it should be possible to span a four day shutdown during summer on stored energy within the Thermal Store alone.

3.13 Dimplex Storage Heater Controller

The Dimplex Storage Heater Controller shall include various functional components which shall be used to manage the Dimplex Storage Heaters in each controlled home on the Shetlands Smart Grid. There shall be a central storage heater control panel for the entire house. Comfort settings shall be set for all rooms in which there is a storage heater and temperature sensors shall be located in all rooms in which there is a storage heater.

3.13.1 General Characteristics

Refer to Section 3.10.1.

3.13.2 Operational Constraints

Refer to Section 3.10.2.

3.13.3 Frequency Adjustment

Refer to Section 3.10.3.

Frequency responsive control for the Dimplex Storage Heaters shall be enabled at <u>all</u> times subject to the following limits:

- Power cannot be reduced below 0 and cannot be increased above 5 kW.
- Power cannot be increased if the storage heater is fully “charged” (the bricks are at their maximum temperature).
- Power cannot be decreased if the storage heater is fully “discharged”.

3.13.4 Droop Characteristics

Refer to Section 3.10.4.

3.13.5 Comfort Settings

The “Comfort Settings” define the temperature which the home owner has requested for each room in which a storage heater is located. There shall be a distinct and separate “Comfort Setting” for each room in which a storage heater is located. The “Comfort Settings” shall be used by the Device Controller to manage operational constraints in order to ensure that the desired room temperatures are maintained at all times.

3.13.6 Room Temperature Sensors

The “Room Temperature Sensors” shall complete the “feedback loop” which is required by the Device Controller in order to ensure that the desired room temperatures are maintained at all times. There shall be a distinct and separate temperature sensor for each room in which a storage heater is located.

3.13.7 Frequency Sensor

Refer to Section 3.10.5.

3.13.8 Feedback Interface

The following feedback signals shall be provided by this module:

- *Storage Heater Core Temperatures:* An array of the core temperatures of each storage heater. This shall be used to in the DSM in Hand calculation.
- *Instantaneous Power:* The instantaneous power measured at the device shall be compared with the most recently transmitted “Active Load Setpoint”.

3.14 Dimplex Storage Heater

Dimplex shall supply new storage heaters as part of the Shetlands Smart Grid development. The new storage heaters shall be better insulated than the existing heaters (thus providing lower standing losses). This shall allow for heat to be stored over longer periods. The storage heaters shall be rated at 5 kW with a storage capacity of 40 kWh. The maximum permissible temperature of the bricks within the storage heaters shall be 750℃.

3.14.1 Continuously Variable Element

The storage heaters shall exhibit a “continuously variable” response from 0-5 kW. This shall be achieved via the use of one or more heating elements. The provision of a continuously variable response shall be advantageous since it shall allow for very precise control of such heating loads.

3.14.2 Fan

The new storage heaters shall contain a fan which shall provide for the more controlled release of heat. The speed of the fan shall be linearly variable and shall be controlled by the associated Dimplex Storage Heater Controller in order to optimally maintain the room temperature according to the home owners selected comfort settings (over the course of the day).

3.15 Dimplex Immersion Heater Controller

The Dimplex Immersion Heater Controller shall include various functional components which shall be used to manage the Dimplex Immersion Heaters in each controlled home on the Shetlands Smart Grid.

3.15.1 General Characteristics

Refer to Section 3.10.1.

3.15.2 Operational Constraints

Refer to Section 3.10.2.

3.15.3 Frequency Adjustment

Refer to Section 3.10.3.

Frequency responsive control within the Dimplex Immersion Heaters shall be enabled at all times subject to the following limits:

- Power cannot be reduced below 0 and cannot be increased above 3 kW.
- Power cannot be increased if the tank temperature is at its maximum.
- Power cannot be decreased if the tank temperature is at its minimum.

3.15.4 Droop Characteristics

Refer to Section 3.10.4.

3.15.5 Triac Output Module

The "Triac Output Module" is used to provide linear control of the heating elements within the Immersion Heater.

3.15.6 Tank Water Temp (Top)

Cold water shall enter at the base of the tank and hot water shall be drawn off from the top of the tank. There shall generally be an increasing temperature gradient from the base of the tank to the top of the tank. The primary heating elements shall be located at the base of the tank. An "emergency" heating element shall be located at the top of the tank.

A temperature sensor shall be located at the top of the tank in order to detect conditions in which the water being drawn off from the tank may be below acceptable limits. In such case the "emergency" element at the top of the tank may be engaged in order to quickly heat the water at the top of the tank before it is drawn off.

The "Tank Water Temp (Top)" shall be used by the Device Controller to manage the operational constraints in order to ensure that the minimum tank temperature is maintained at all times.

3.15.7 Tank Water Temp (Bottom)

A temperature sensor is located at the bottom of the tank in order to detect conditions in which the "baseline" temperature of the tank may be falling below acceptable limits. In such case the primary heating element(s) shall be engaged in order to heat the tank back up to a baseline level.

The "Tank Water Temp (Bottom)" shall be used by the Device Controller to manage the operational constraints in order to ensure that the minimum tank temperature is maintained at all times.

3.15.8 Frequency Sensor

Refer to Section 3.10.5.

3.15.9 Feedback Interface

The following feedback signals shall be provided by this module:

- *Immersion Heater Storage Capacity:* Temperature measurements in the tank will be translated into a measure of the additional energy that can be accommodated.
- *Instantaneous Power:* The instantaneous power measured at the device shall be compared with the most recently transmitted "Active Load Setpoint".

3.16 Dimplex Immersion Heater

Dimplex shall supply a new model of immersion heater as part of the Shetlands Smart Grid development. The new immersion heaters shall be highly insulated (thus providing lower standing losses). This shall allow for heat to be stored over longer periods. The immersion heaters shall be rated at 3 kW with a storage capacity of 12 kWh. The immersion heaters shall hold 200 litres of water and the typical acceptable temperature range shall be from 50-90°C. An output mixer shall be used to ensure a constant water output temperature irrespective of the internal tank temperature.

The power drawn by the Immersion Heaters shall be controllable in 37.5 W increments from 0-3 kW (thus providing 80 individual power level settings). This shall be achieved via the use of three distinct heating elements and an advanced microelectronic control system. The provision of such a small controllable power increment (37.5 W) shall be advantageous since it shall allow for very precise control of the Immersion Heater loads. If necessary, it is possible to provide yet finer granularity of control by making changes to the software on the Dimplex microcontroller (which directly controls the power supplied to the Immersion Heater elements).

Temperature control within the Immersion Heater shall operate as follows:

1. The home owner shall set a temperature they are comfortable with and this shall be delivered by the mixer valve on the Immersion Heater. This temperature would ordinarily be no higher than 45-50℃ (in order to avoid scalding).
2. The tank temperature shall be maintained between 50-90℃ with the temperature varying according to Active Setpoint, Day Ahead Schedule and Frequency Responsive control.
3. If a user requires water warmer than 50℃ then the minimum tank temperature would be increased but the basic principle of a single upper and single lower limit would remain. The

Dimplex Controller for the Immersion Heater shall be provided with a user temperature setting input which shall allow for such customisations.

3.16.1 Continuously Variable Element (750 W)

This shall be a 750 W heating element providing a response which is variable in increments of 37.5 W.

3.16.2 Continuously Variable Element (750 W)

This shall be a 750 W heating element providing a response which is variable in increments of 37.5 W.

3.16.3 Fixed Element ON/OFF (1500 W)

This shall be a 1500 W heating element providing an ON/OFF response.

4 External Communication Interfaces

This section discusses the external communication interfaces which shall be supported by the system. The Active Network Management (ANM) system shall represent the core of the Shetland Islands Smart Grid. As such, the ANM system shall provide interfaces with a number of other systems in various locations on the Shetlands. The following sections describe each of these interfaces and the intended means by which they shall be implemented. These interfaces are discussed from the perspective of the ANM controller.

Note that this section does not describe the actual data which shall be transferred across the various links. Rather, it simply describes the means by which such links shall be both physically and logically implemented.

4.1 Control Systems Interfaces

4.1.1 Lerwick Power Station Control System (Serck)

A real-time bidirectional interface providing for the transfer of status information from the Serck control system to the ANM system shall be implemented. This interface shall also support the transmission of controls and setpoints from the ANM system to the Serck control system. The interface shall be implemented using either the DNP3.0 or OPC protocol via a high bandwidth and low latency TCP/IP link.

The interface shall be used to present various information sourced from the ANM controller to the Lerwick operator. The Lerwick operator shall have limited control capabilities with regards to the operation of the ANM controller. This will include the ability to disable all ANM functions and default to an operating position that does not require the ANM controller to ensure all constraints are met.

4.1.1.1 Sullom Voe Gas Turbines

A real-time unidirectional interface providing for the transfer of status information from the Sullom Voe control system to the ANM system shall be required. However, all required information from Sullom Voe shall already be centralised in the Lerwick Serck Power Station Control System. As such, a direct link with the Sullom Voe control system shall not be required.

4.1.1.2 Burradale Windfarm

A real-time unidirectional interface providing for the transfer of status information from the Burradale windfarm to the ANM system shall be required. However, all required information from the Burradale windfarm shall already be centralised in the Lerwick Serck Power Station Control System. As such, a direct link with the Burradale windfarm shall not be required.

4.1.2 ENMAC

A real-time bidirectional link from the ANM system to the ENMAC FEP (Inverness) shall be implemented. This link shall provide for the control and monitoring of the operation of the ANM system from the Power Systems Operational Control Room in Perth. This interface shall use the DNP3.0 protocol over a serial or TCP/IP link.

4.1.3 PI North and PI LCNF

Real-time unidirectional links shall be required from the ANM system to the two distinct OSISoft PI data historians for the purposes of historical recording and logging. These interfaces shall be implemented using OPC over a high bandwidth and low latency TCP/IP link.

A link shall be implemented to the dedicated "PI LCNF" system which shall be specifically installed to record all operations of the new ANM system on the Shetlands. Additionally a link shall be implemented to the existing "PI North" system which is used as the data historian for the ENMAC SCADA system.

4.2 Forecasting Engine Interface

The Forecasting Engine shall provide the Forecast Result Set to the ANM system using a simple textual format and a simple file transfer mechanism (likely secure FTP).

4.3 Real Time Measurement Interfaces

4.3.1 Constraint Measurements (I, V)

Measurement devices shall be installed at various constraint locations on the network in order to monitor voltage, current and/or power flows. An interface between such devices and the ANM system shall be implemented. The interface with such devices shall be implemented using an industry standard SCADA protocol.

4.3.2 Stability Analysis Application

An interface between the ANM system and the Stability Analysis Application shall be implemented. This interface shall be as simple as possible (and may even be file-based).

4.4 Local Interface Controllers

Real-time bidirectional interfaces shall be implemented between the ANM system and all Local Interface Controllers (LICs) at controlled devices. These interfaces shall support the transfer of feedback information from the controlled devices to the ANM system and the transmission of controls and setpoints from the ANM system to the controlled devices (including Active Setpoints, Day Ahead Schedules and Droop Characteristics).

All interfaces shall use an industry standard SCADA protocol. 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.

5 Conclusions

This document has summarised the requirements of the Shetland Islands Smart Grid and has provided a high level architecture and technical design of an ANM system based on the products of SGS to meet these requirements. The document has also described the operation of each functional component comprising the system along with the data which must be exchanged between these components. Finally, the document has described the communication interfaces which shall be used in order to achieve the necessary data exchanges between all functional components and external systems.

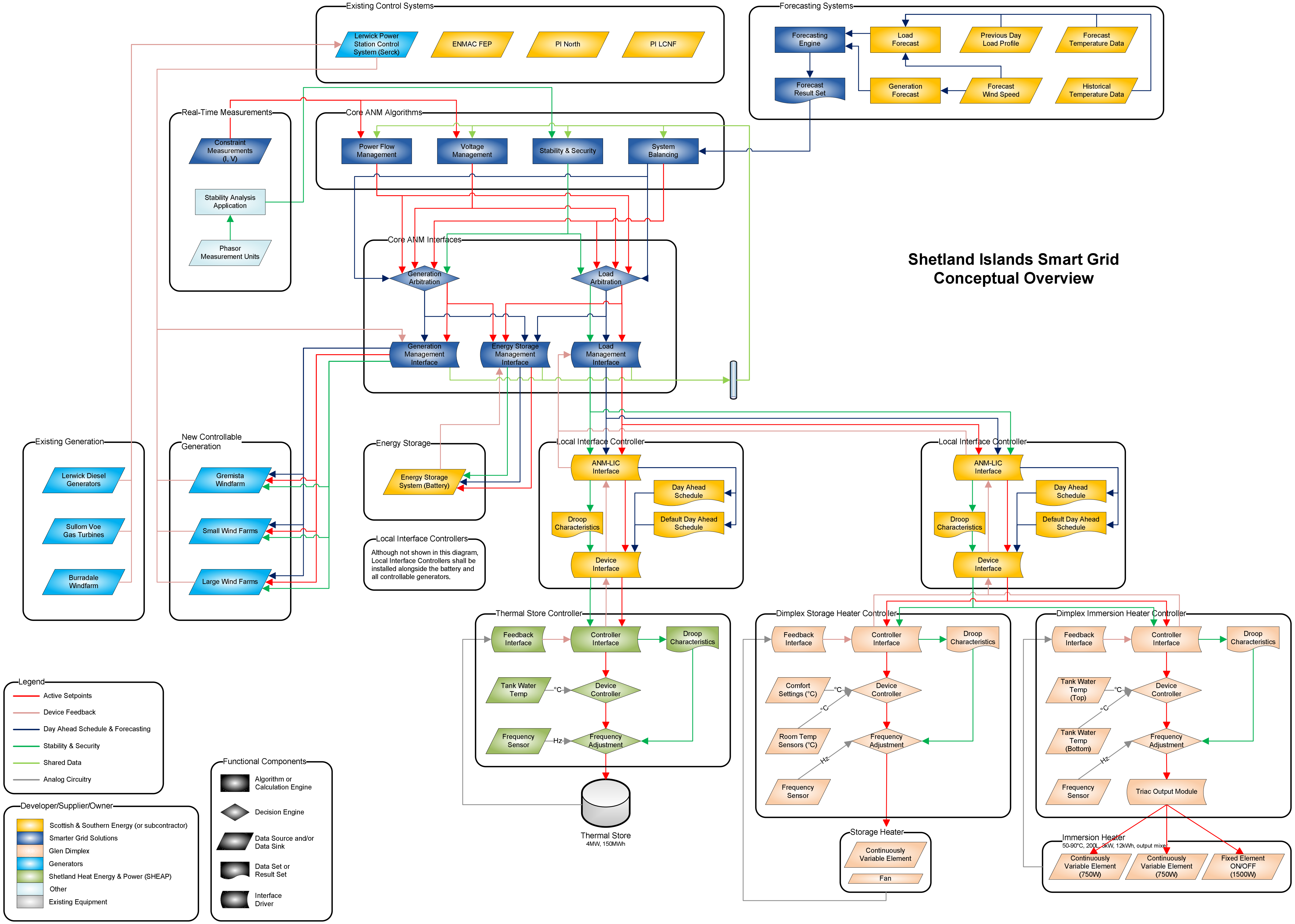

Figure 10: Shetland Islands Smart Grid Conceptual Overview