FACILITATE GENERATION CONNECTIONS ON ORKNEY BY AUTOMATIC DISTRIBUTION NETWORK MANAGEMENT

CONTRACT NUMBER: K/EL/00311/00/00

URN NUMBER: 05/514

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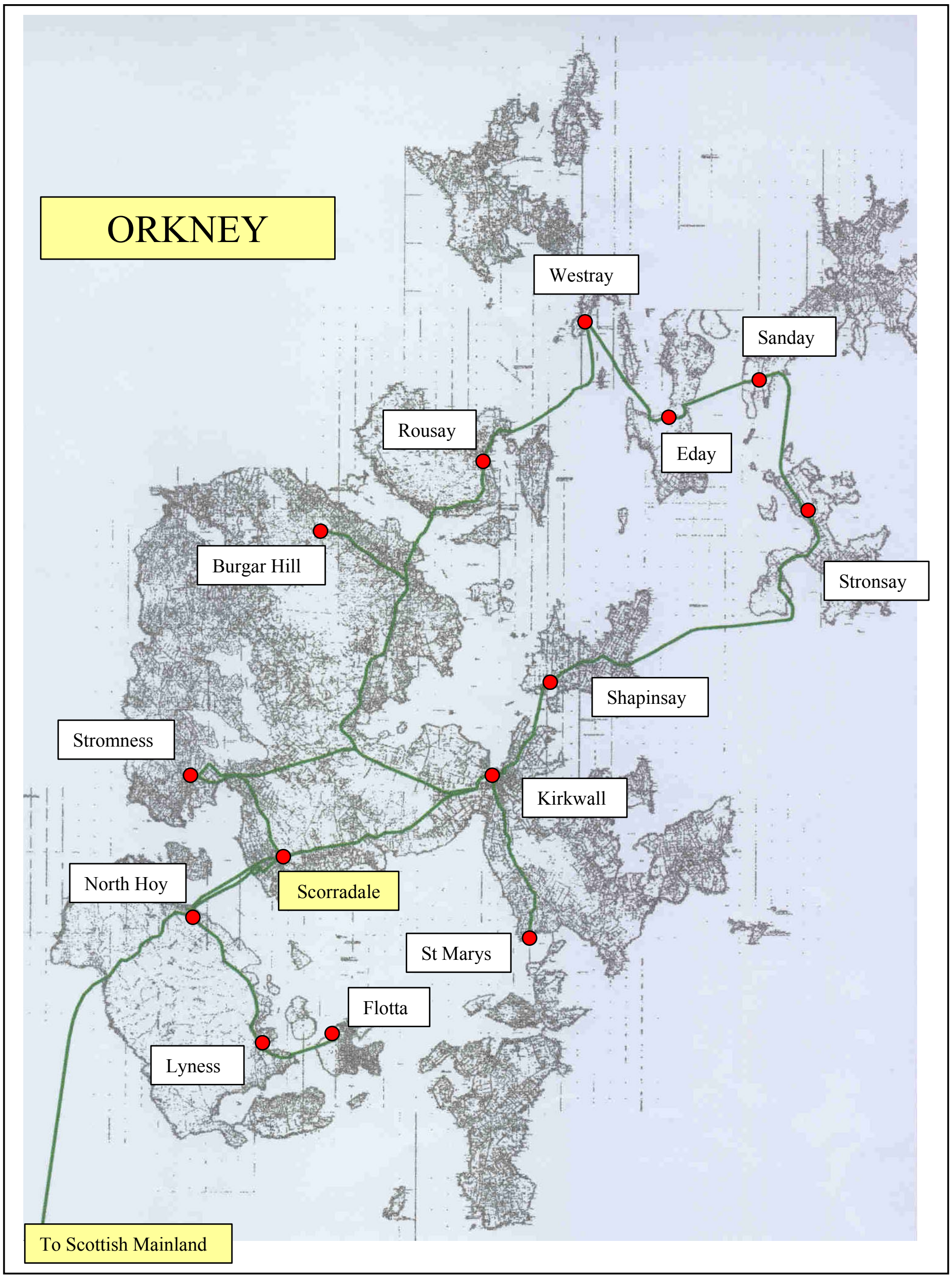
Contractor

Scottish & Southern Energy

The work described in this report was carried out under contract as part of the DTI Technology Programme: New and Renewable Energy, which is managed by Future Energy Solutions. The views and judgements expressed in this report are those of the contractor and do not necessarily reflect those of the DTI or Future Energy Solutions.

First published 2004



ORKNEY
Westray
Sanday
Rousay
Eday
Burgar Hill
Stronsay
Shapinsay
Stromness
Kirkwall
North Hoy
Scorradale
St Marys
Flotta
Lyness
To Scottish Mainland

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Executive Summary

Scottish Hydro Electric Power Distribution Limited (SHEPDL) and the University of Strathclyde undertook the project 'Facilitate Generation Connections on Orkney by Automatic Distribution Network Management' (Contract Ref. K/EL/00311/00/00) under the DTI's New and Renewable Energy Programme managed by Future Energy Solutions. The project was conducted between April 2003 and June 2004 and achieved all of its objectives. The main project outcomes are summarised below and presented in detail in the following report.

A thorough technical appraisal of the Orkney network and its capabilities and limitations under many scenarios of demand, generation connections, network configuration and reactive compensation was undertaken and the outcomes are discussed. This appraisal has provided the foundation for the subsequent active management scheme development.

A conceptual active management scheme appropriate for the specific circumstances found on Orkney is developed and evaluated. The proposed scheme increases the capacity available for new generation connections on Orkney, while providing the required network security for all customers.

A framework for the design and evaluation of future active management schemes is proposed. This framework highlights all the major considerations for designing an active management scheme, from system studies to reveal network capacity issues through to the logic behind the scheme and its implementation and integration into the existing infrastructure.

Logic control sequences are proposed for trimming and tripping managed generation units according to system requirements. These control sequences can be programmed into existing PLC devices. The logic control sequences ensure that thermal limits on key 33kV network circuits are not reached.

An evaluation method for the active management scheme is proposed. When applied to the Orkney situation this provides an indication of the capacity of additional generation enabled by the active management scheme. Use of the evaluation method showed (with caveats) that the generation portfolio on Orkney could be expanded economically from the 47 MW existing non-firm generation limit to around 75-80 MW.

A comprehensive set of implications of introducing the proposed active management scheme is presented. Some of the issues require further thought but these areas can only be taken forward when detailed design of the active management scheme is initiated. Some of the issues also require operational experience with the scheme to make a full assessment of their impact.

The adoption of the scheme has implications for SHETL, requiring detailed scheme design and then construction and operation. The costs of scheme design, testing and implementation will be recovered through connection charges. This charging will be something that developers seek to minimise by carefully selecting sites with available capacity and suitable potential for optimising communication links.

It is established that developers, already familiar with the task of assessing the network connection, now have integration with the active management scheme to consider as well as all the other aspects of connection viability. The commercial implications of active management scheme introduction affect all stages of the connection process. In addition it is shown that demand customers on Orkney are not likely to experience any drop in quality of supply as a result of active management scheme introduction. System security issues have been assessed and it is thought that the active management scheme addresses concerns over this issue.

Contents

1 INTRODUCTION

This is the final and composite report for the DTI / FES funded project entitled 'Facilitate Generation Connections on Orkney by Automatic Distribution Network Management'.

The project has been conducted at the beginning of a period of significant change in the UK power system, whereby growth trends in renewable and distributed generation are dramatic and the incentives now in place will sustain this growth rate over the next few years.

The current distribution network planning and operation methodology requires a high level of investment to reinforce networks to accommodate more renewable generation. The active management scheme developed by this project challenges this approach and proposes an alternative method of network operation that optimises existing network capacity.

The renewable energy resource in Orkney is large, with high wind speeds wind and a vast marine potential, making the renewable growth rate on Orkney much higher than that on the mainland. Furthermore, current connection activity will see the capacity of renewable generation exceed the demand for significant periods of the year, making Orkney a significant net power exporter. The configuration and operation of the Orkney network will need to be modified to meet this change from is original design purpose of importing power to meet demand.

This project explores active network management concepts and leads to a proposed solution that will maximise usage of the existing Orkney network infrastructure for the export of renewable energy. Given the relative complexity of the Orkney network, it is believed that this proposal and the experience gained will provide meaningful guidelines for other UK network areas.

1.1 This Report

This is a composite report for several stages, previously reported individually during the project programme. It starts by describing the Orkney network infrastructure (section 2) and the existing Orkney SCADA infrastructure (section 3), which are used as foundations for further analysis and discussion.

The active management concept proposed by this project is selected from a series of options described in section 4. This concept is developed into a specification in section 5 and then assessed for its contribution to renewable energy connections and production on Orkney in section 6. Further implications of the specified scheme are discussed in section 7. Finally, the report concludes with a commentary on the project outcomes and identifies the next steps towards implementation of the active management scheme proposal.

1.2 Abbreviations

FG	Firm Generation	NFG	Non-Firm Generation
NNFG	New-Non-Firm Generation	DNO	Distribution Network Operator
PLC	Programmable Logic Controller	PW	Pilot Wire
PQM	Power Quality Meter	SRS	Scanning Radio System
ROCs	Renewables Obligation Certificates	RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition		
SHEPDL	Scottish Hydro Electric Power Distribution Ltd		

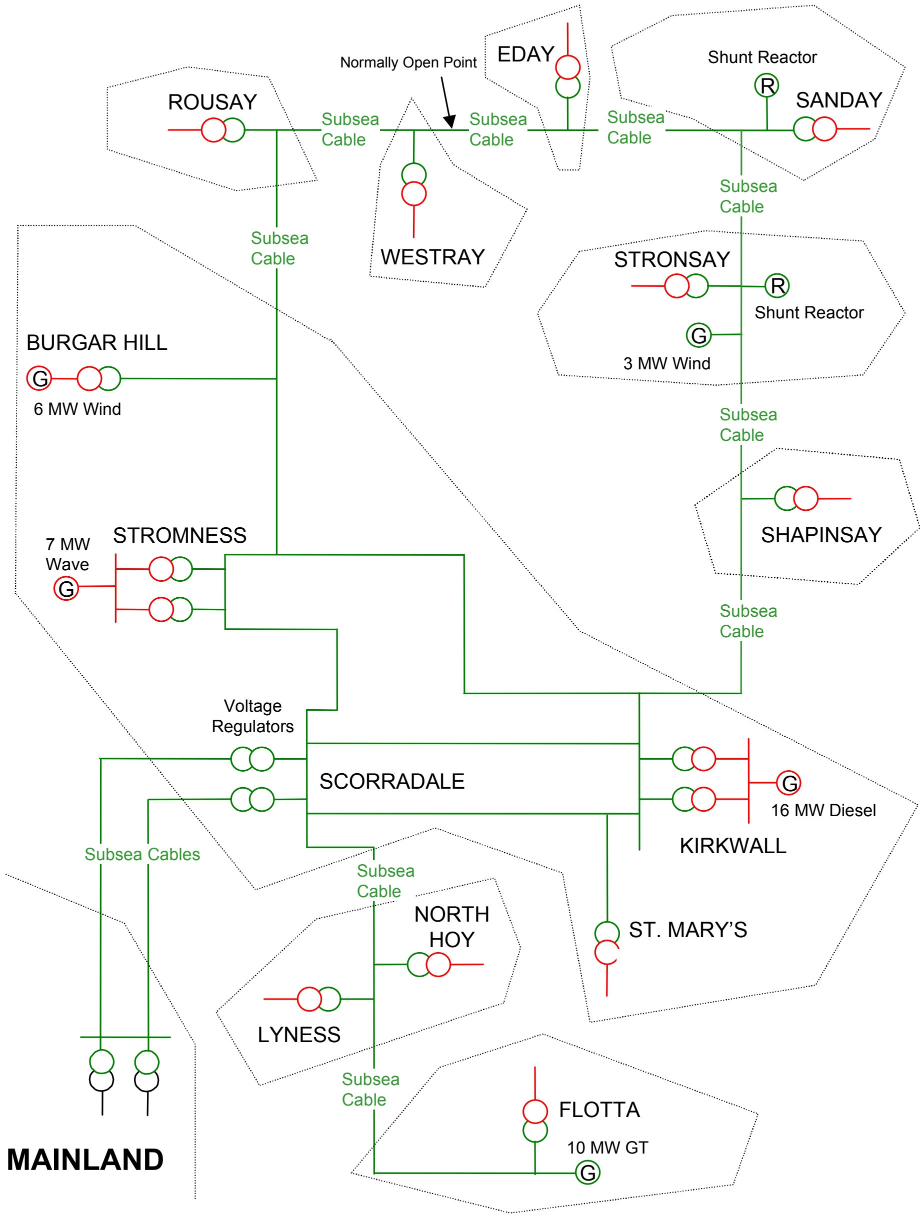
2 EXISTING ORKNEY NETWORK

This section examines the existing Orkney network, existing generation, and their operating regimes. It also identifies committed future renewable generation developments, providing the context for the design and specification of the active management scheme proposed.

2.1 Arrangement

In order to find the optimum active management solution, both technically and economically, the existing Orkney network and its operation must first be understood.

The existing network arrangement (shown below) was established to meet local demand, with the minimum of operator intervention and was not designed for the volume of generation it is presently facing. That is, it is essentially a passive network. The introduction of an active management scheme will dramatically change this position.



A geographic layout of the Orkney 33 kV network is shown on the front cover.

Orkney is connected to Thurso grid substation on the mainland by two 50 km 33 kV circuits covering the same route and operated in parallel. One circuit is rated at 20 MVA and was installed in 1982, the other circuit is rated at 30 MVA and was installed in 1998. Each circuit comprises three overland (overhead line) sections totalling 10 km and two subsea cable crossings totalling 40 km. Of note, none of the four subsea cable sections has faulted to date.

The majority of the customers on Orkney are on the main island and are served by primary substations at Kirkwall, Stromness and Burgar Hill. These substations are strongly interconned by three 17 MVA 33 kV circuits operated in parallel.

There are another nine 33 kV subsea cables linking 9 further islands, each served by its own primary substation. The subsequent 11 kV networks serve further islands.

2.2 Voltage Regulation

The terminal voltage on the mainland subsea cable circuits varies appreciably with demand and a voltage regulator on each circuit at Scorradale maintains an acceptable Orkney 33 kV system voltage profile through these changes. In sequence, the individual 11 kV network voltages are regulated by their respective on-load primary transformer tap changers.

The 33kV circuit around the northern islands is normally open at Eday and is subject to voltage rise caused by capacitive gain of the subsea cables. Shunt reactors are permanently connected to compensate for this at Stronsay and Sanday as shown. These reactors also enable network switching by cancelling the subsea cable capacitive reactance.

2.3 Demand

Orkney is presently a net energy importer and has 11,000 customers with a winter peak demand of 32 MW and a summer minimum demand of 7 MW. This minimum demand is already exceeded by the present level of connected generation and there is a regular and moderate level of export power to the mainland.

2.4 Operation with No Generation

With both mainland subsea cable circuits in service, the Orkney network can operate under any expected conditions of existing demand.

For system conditions at maximum demand with the network fully intact and no local generation, the voltage levels on the 33 kV network drop as low as 0.96 pu in some places. The voltage profile in the 11 kV system is adequately maintained by action of the primary transformer on load tap-changers.

The existing system cannot operate at maximum demand under the contingent condition of loss of the larger 30 MVA subsea cable circuit and requires the support of the Kirkwall diesel generation to top up the smaller 20 MVA subsea cable circuit. Furthermore, operation of all the other Orkney generation without Kirkwall does not stabilise the system under this contingency. The synchronous type alternators at Kirkwall provide essential reactive capability required to stabilise the Orkney voltage.

The existing system operates within acceptable limits under any normal condition, and with the support of the Kirkwall power station on the major contingency of the loss of either mainland circuit.

2.5 Demand Management

There are three examples of active demand management on Orkney.

2.5.1 Radio Teleswitching

Radio teleswitching of space and water heating is used to control the Orkney demand to within manageable levels at peak times. Individual teleswitches at customer premises respond to signals sent over public radio broadcast bands. This can be classed as active demand management but has limited potential for real time generation management, due to inherent time delays (several minutes). However, in a scheme where forward schedules for small-scale generation output were implemented, public radio would be an inexpensive communications option.

2.5.2 Low Power Radio and PLC

An example of a more dynamic demand management scheme is in operation for a large power user on Orkney and is controlled through low power radio on an unlicensed radio band. This radio link uses the bandwidth allocated to utilities and provides a communications channel over distances of up to 10 km. In this instance, the available demand is controlled to ensure the mainland-Orkney circuits do not exceed their secure power transfer limit. A programmable logic controller (PLC) at the Customer end responds to signals from a PLC at Scorradale and manages the onsite demand. In the event of an inadequate response from the demand, a trip is initiated from the Scorradale PLC through a pilot wire (PW) communications link. This scheme identifies the potential of low power radio backed up by PW.

2.5.3 PLC, Intertriping and PW

Another existing and time critical demand management scheme is installed between Scorradale and Kirkwall. This protects the mainland-Orkney and the Orkney core 33kV network from overload in the event of a fault at times of peak demand. It is based on power flow measurements on these 33 kV feeders and sequentially intertrips 11kV feeders at Kirkwall substation to bring 33kV circuit-loading levels back within limits in the event of a fault. This system uses PW for communications and identifies the use of power flow measurements to initiate tripping instructions.

2.6 Operation with Generation

The present levels of connected generation raise the Orkney 33 kV system voltages and more significantly, the subsea cable voltages at low demand times when there is a net export to the mainland. This is caused by a combination of the reverse power voltage gradient and the subsea cable capacitive gain. The Scorradale regulators have a limited 'buck' capability that can help to compensate for this voltage issue at Scorradale, but this does nothing for the mainland subsea cable voltage levels. This is a classic embedded generation issue, especially on the long feeders to Orkney and one that must be addressed to allow more generation to connect.

Generation connecting to the network peripheries such as the northern isles, Flotta and St Mary's also causes a localised voltage rise along the respective 33 kV radial feeder.

2.7 Voltage Solution

These voltage rise issues have been overcome by an integrated reactive compensation solution.

The Scorradale 33 kV bus bar and mainland subsea cable voltage levels are now being controlled by a dynamic Var compensating device (DVAr) which has been installed at Scorradale. Whereas
the more localised 33 kV radial voltage rise problem is being addressed by the installation of additional shunt reactors.

These additional shunt reactors place a heavy burden on the Orkney network, especially during periods of high demand and low generation and some are being equipped with an on load tap changer to ease this burden. Furthermore, the Scorradale DVAr compliments the operation of these shunts by providing a MVAr source local to Orkney and meets short-term voltage excursions as the generation and demand patterns change. The connecting generation also has a key voltage control role and must work in conjunction with these devices.

2.8 Connected, Contracted and Potential Future Generation

Network studies show that for the minimum demand condition of 7 MW and with both mainland subsea cables in service, the Orkney network can accommodate 47 MW of generation. However, when the demand rises to its peak of 32 MW these studies show that the permissible generation capacity rises to 72 MW (this is not the notional thermal limit which is 80 MW).

The Orkney generation can be separated into three discrete categories: Firm Generation (FG), Non-Firm Generation (NFG) and New-Non-Firm Generation (NNFG) as discussed below.

2.8.1 Firm Generation (FG)

Flotta (gas turbine)	10 MW
Burgar Hill (wind)	6 MW
Stronsay (wind)	3 MW
Stromness (wave)	7 MW

This is the initial 26 MW group of generation already connected to the Orkney system and is the FG capacity limit, based on the capacity of the smaller mainland subsea cable circuit (20 MVA) plus the minimum demand condition (6 MW). Of note, the minimum demand condition has risen to 7 MW through growth since this assessment was made.

FG is the conventional 'fit and forget' generation and is able to operate without constraint, in the event of the loss of either one of the two subsea cables to the mainland.

2.8.2 Non Firm Generation (NFG)

This is a further 21 MW group that can connect, based on both subsea circuits being in service plus the minimum demand condition (this total has been determined by network studies and includes the additional 1 MW of the revised minimum demand from above). This group will be tripped in the event of a loss of either subsea cable circuit and the power export flow exceeding 20 MVA (the capacity of the remaining subsea cable).

17 MW of this 21 MW capacity group has already contracted, as tabled below:

Burgar Hill (wind)	6 MW
Sanday (wind)	8 MW
Flotta (wind)	2 MW
St Mary's (wind)	1 MW

This NFG plus the FG above amounts to 47 MW.

2.8.3 New Non Firm Generation (NNFG)

This project focuses on the potential expansion of non-firm generation capacity beyond the 47 MW established above, which has been termed NNFG and which will be demand following. It will also benefit from the diversity (or intermittence) of the FG and NFG above.

This final tranche of generation will be able to connect, subject to implementation / approval of the active management scheme proposed in this report.

2.8.4 Kirkwall Diesel Generation

The diesel generation at Kirkwall has a capacity of 16 MW and is used to secure supplies on Orkney. This generation is for emergency purposes and does not compete for capacity on the subsea cables. It does however have priority following a mainland subsea cable circuit fault, which can take up to three months to repair.

2.9 Network Studies

The Orkney network studies were carried out using the PSS/E power system analysis tool. The results shaped the development and design of the proposed active management scheme. The key parameters for future system conditions are listed in two categories below. The first category relates to the input parameters (or simulation variables) while the second list relates to the parameters of importance in the solution of the network conditions (or output parameters).

Input Parameters	• Generation operation • Demand level • Reactive compensation scheme • Network contingency
Output Parameters	• Bus voltages (the 33 kV system planning limit is +/- 3%) • Power flows • Thermal limits on lines/cables • Reactive flows through subsea cables • Tap-changer and regulator action/position • Subsea cable terminal voltage • Voltage step on trips

The starting point was the existing infrastructure with both the FG and the NFG operating with no reactive compensation. The reactive compensation was then included. Following this, the demand level was increased in 1 MW increments from minimum to maximum to derive a value of permissible generation export capacity at each demand level. This particular result is key to assessing the generation capacity / energy output that would be enabled by an active network management scheme. The network's performance was also assessed at each of these stages.

Each of these study stages is addressed in sequence in the following sections.

2.9.1 FG & NFG with no Reactive Compensation

With the network fully intact and at maximum demand with full generation, the 33 kV network shows high voltages of up to 1.05pu at several points. There are no network thermal rating violations under this condition.

At minimum demand and full generation, the voltage rise condition is far more severe. Many more 33 kV network nodes show excessive voltages, with some network extremities rising to 1.11pu. Furthermore, some 11 kV networks show voltage levels of 1.06pu, where the on load tap changers have reached their stops. Such voltages are well outwith acceptable limits. An additional and key issue is the subsea cable voltage level on both mainland circuits, which reach the design limit of 1.05pu.

2.9.2 Mainland Circuit Outage

The next stage is to introduce the major Orkney contingency; loss of the larger (30 MVA) mainland subsea cable circuit. At the maximum generation and minimum demand, the over-voltage violations are marginally less severe. This is an interesting result as intuitively it might be expected that with more impedance on the export circuit to the mainland that voltage levels on Orkney would be higher. A possible explanation is the reduction in the capacitive effect of the subsea cables with falling voltage levels.

The most serious aspect of this condition is the violation of the thermal limits on the remaining mainland subsea circuit, as would be expected. That is, given that the generation is 43 MW and the minimum demand is 7 MW, then around 36 MW might be expected to flow through this 20 MVA circuit. This situation cannot be tolerated without immediate action, and

SHEPDL operations require that in the event of a loss of a mainland circuit and the export exceeding 20 MVA all NFG is tripped off (or intertripped).

The most severe import situation is the existing system at maximum demand of 32 MW, no available local generation and the loss of the larger mainland subsea cable. This situation is normally covered with the subsequent operation of Kirkwall power station. However, in future the dependency on Kirkwall power station may be less, depending on the nature of future renewable generation connections.

2.9.3 Reactive Compensation

The next simulation task is to include both the dynamic and shunt reactive compensation equipment with the FG and NFG operating at full output.

Starting with the worst case from above with minimum Orkney demand and the contingency of the larger subsea circuit out of service, the studies show that there are no serious over or under voltage conditions under this situation. The DVAr at Scorradale operates at 2 MVAr capacitive, while the reactor at Burgar Hill consumes 4 MVAr and the reactor at Sanday consumes 6 MVAr.

Simulations were performed at maximum and minimum demand levels with maximum generation output and with each of the two reactors switched offline in different simulations. In each case system voltages at one or more buses violated limits. This showed that the reactors are essential in maintaining acceptable system voltage levels.

2.9.4 Step Changes

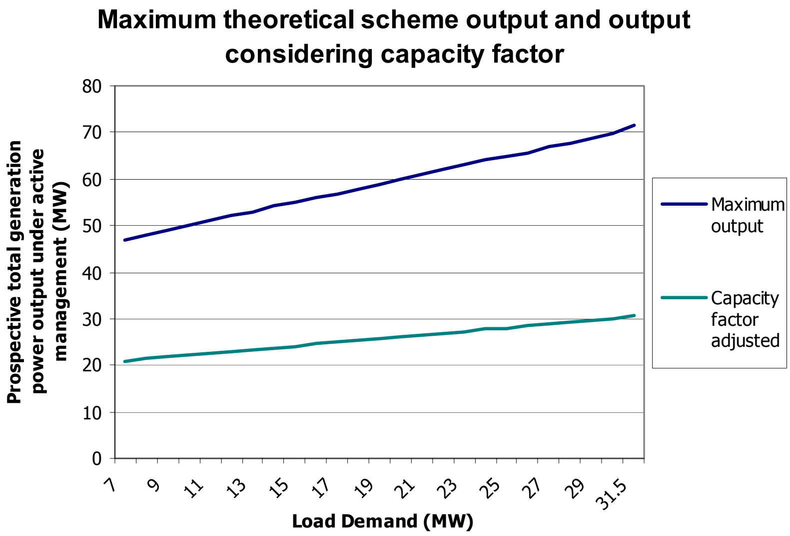
Studies were undertaken to assess the instantaneous impact of contingencies on network voltage levels. Transformer taps and switched reactors were locked to observe the network response to sudden contingencies (and the managed tripping of generation under such conditions). These studies were undertaken with the dynamic reactive compensation device at Scorradale online.

The reactor at Sanday compensates for the NFG at Sanday and is tripped off when this generation is tripped off. The time when the system is at its most vulnerable in terms of voltage is on the 30 MVA subsea cable trip. This would cause NFG to be tripped off immediately but there would be a time lag before the transformers and reactors could respond. A scenario is set up with a 32 MW demand condition and full generation output from existing and planned generation.

After tripping of the 30 MVA subsea circuit and the subsequent tripping of the associated NFG, the voltage levels do not vary by more than +/-0.5% on the 33 kV ring. At the minimum demand level of 7 MW, a voltage rise of up to 0.9% on parts of the 33 kV ring is experienced in response to the same contingency. The results lead to the conclusions that voltage step does not appear to be a constraining factor in the connection of NNFG.

2.9.5 Higher Levels of Generation and Network Capacity

Finally, further generation (NNFG) was added proportionately at the points on the network where FG and NFG capacity already exists. Initially for a full demand condition of 32 MW, NNFG was added to each feeder until thermal limits were approached for that feeder. Following this, NNFG was added to the Orkney core[1]. The near linear relationship between the available capacity for generation and the local Orkney demand is illustrated below.



This analysis results in an upper limit on generation capacity of 72 MW at maximum demand. For this condition the reactive compensation devices resolve all voltage issues. Any connections at this level of generation would be reliant on the operation of all reactors and the dynamic reactive compensation device at Scorradale.

2.10 Review

This section has outlined the characteristics of the Orkney network. The limits on generation connections due to thermal and security issues have been established. The system studies have made clear that to connect further generation beyond the planned non-firm generation (up to approximately 47 MW) then active management of the generation is required. The upper limit on any additional non-firm generation has been established at approximately 72 MW. The next section looks to identify an appropriate active management concept to achieve this extended limit on generation connection capacity.

[1] 'Core' (sometimes 'platform'): refers to the central portion of the 33kV network on Orkney between the Kirkwall, Scorradale and Stromness substations.

3 SHEPDL SCADA SYSTEM OVERVIEW

SHE transmission and distribution are both controlled by the same ENMAC (Electrical Network Management and Control) SCADA system. ENMAC is a real-time system and the information architecture embodied within it ensures that all control servers operate with the same information. The North of Scotland network control centres are connected to a real time data bus (real time network) that feeds instructions into and receives data from Front End Processors (FEPs) via a Wide Area Network (WAN).

Communications are mainly digital with analogue being used as little as possible due to its inherently lower reliability. Security is provided by duplicated radio links. Operator interface with the SCADA system is by multi-headed clients connected to the real time data bus.

An understanding of the communications and control infrastructure is essential to ensure that the proposed active network management scheme is practical from the standpoint of existing (or extensions to) the control and communications infrastructure.

3.1 Orkney Infrastructure

The Orkney control centre is at Kirkwall, where SCADA data is fed to from Scorradale, Burgar Hill and Flotta to Kirkwall, and where it enters the main SCADA system.

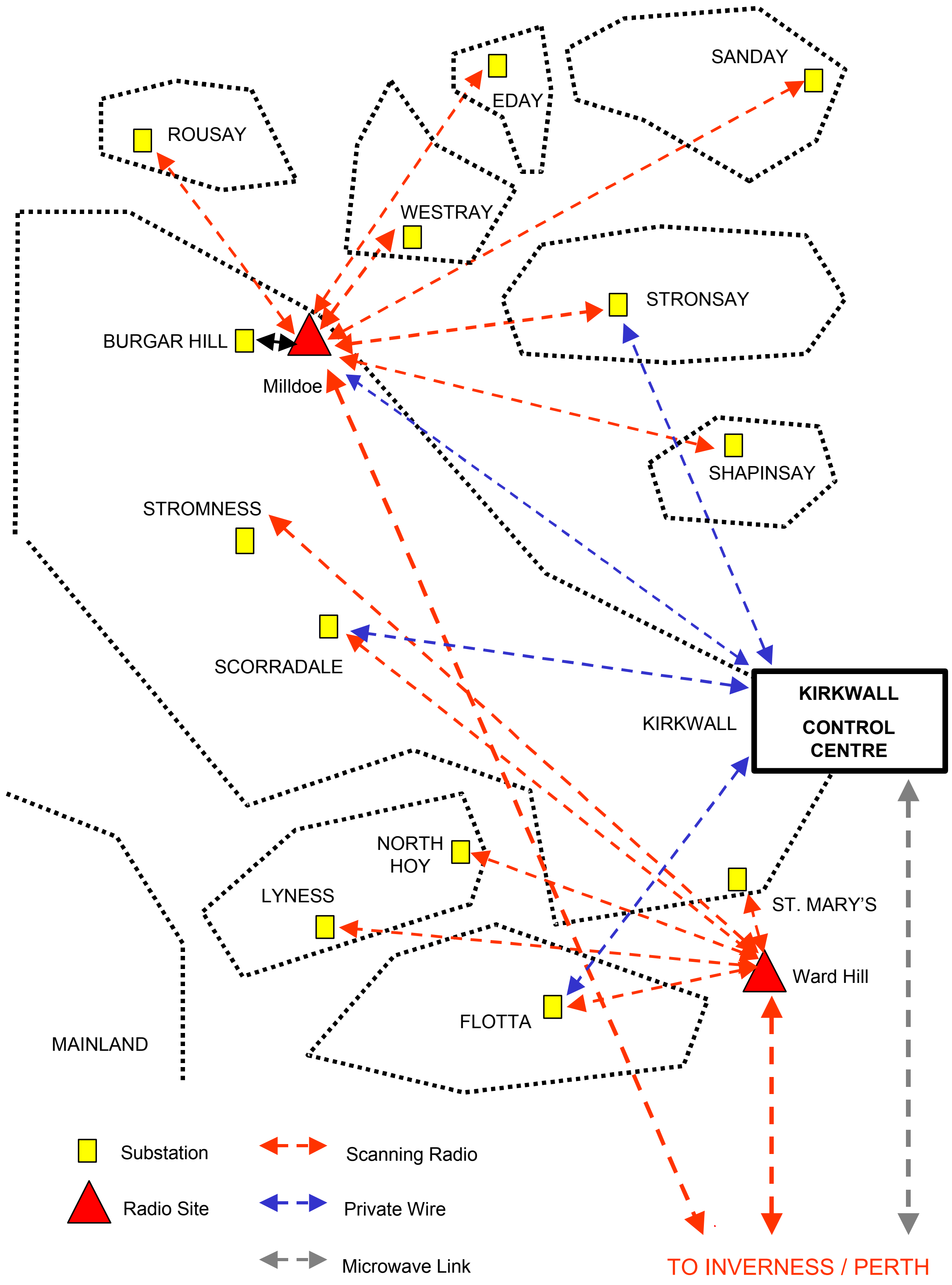
Generators must meet certain communication criteria to connect to the SHEPDL network on Orkney. In general, all generation connections greater than 1 MW will be connected to SCADA but on Orkney, because of the sensitivity of the network to smaller generation schemes, all but the smallest generating sites will be connected to the SCADA system. The control interface between the generating site and the SHEPDL control system is normally via a direct connection to a remote terminal unit (RTU).

The Orkney generators have dedicated local control systems for their individual generating units and the integration of generating units into the SHEPDL control infrastructure enables the generating units to meet their requirement to respond to control instructions from SHEPDL. SHEPDL has authority to switch generation on and off to secure operation of the whole network. This authority is moderated through issuing advance warning of imminent network control actions in the form of warnings and alerts.

3.2 Scanning Radio System

A Scanning Radio System (SRS) has already been installed on Orkney for the purposes of power system communications. Effective use might be made of this existing infrastructure within the active management scheme. With SRS one radio base station sends and receives information from several RTUs one by one, in sequence. Transmission is conducted at 450MHz in a licensed band using the MPT1411 protocol. Up to 20 RTUs can be addressed in approximately 2 seconds. Around 18 base stations have already been installed for the North Scotland network. The SRS provides a continuous feed of updated information in contrast to the dial-up approach to communications and control as used in traditional systems. However, an SRS based system itself will not provide the response necessary for quick decision-making and the turn around on control likely to be required by an active management scheme.

The drawing overleaf shows the existing SCADA links on Orkney.


SANDAY
EDAY
ROUSAY
WESTRAY
STRONSAY
BURGAR HILL
Milldoe
SHAPINSAY
STROMNESS
SCORRADALE
KIRKWALL
KIRKWALL CONTROL CENTRE
NORTH HOY
LYNESS
ST. MARY'S
Ward Hill
FLOTTA
MAINLAND
Substation
Radio Site
Scanning Radio
Private Wire
Microwave Link
TO INVERNESS / PERTH

4 ACTIVE MANAGEMENT SCHEME IDENTIFICATION and SELECTION

This section identifies active management options for Orkney and selects the preferred solution.

4.1 National Developments

The Distributed Generation Co-ordinating Group (DGCG) is developing active management schemes that will facilitate the connection of DG. A report[2] published by Work Stream 3 (Basic Active Management Project) details several active management techniques. These techniques are in three main categories according to the three main barriers presented to the connection of DG:

- Fault level management
- Voltage control
- Power flow management

The initial studies of the Orkney system indicated that power flow and voltage control, are the two key areas of interest. Fault level is a minor issue at this stage as is typical for rural networks. Furthermore, system studies show that the reactive compensation solution (Scorradale DVAr and shunt reactors) resolve all voltage issues when connecting generation up to network capacity.

This leaves power flow management as the main issue to be addressed by an active management scheme for Orkney. The solutions proposed for power flow management in the report which do not require significant network upgrading are:

- Application of *pre-fault constraints* to generators outputs to ensure that circuit thermal limits are not violated should a contingency occur.
- Application of *post-fault constraints* to generator outputs to return network within thermal limits. The implementation of this concept can be achieved by direct inter-tripping of generation, generation tripping based on power flow measurements and generator power output control based on power flow measurements.
- *Demand side management* in a pre-fault or post fault situation.

The pre-fault constraint solution will not provide opportunity for further generation to be connected, as the NFG already exploits this generation capacity to its full potential.

NFG has been connected on the basis that it will be intertripped on a contingency. This provides capacity for generation equal to the sum of the subsea cable circuit capacity plus the minimum demand (30+20+7 = 57 MW) further constrained by local thermal and voltage considerations to 47 MW. The pre-fault solution would include only the smaller subsea cable capacity plus the prevailing demand, yielding an available generation capacity between a minimum of 26 MW and a maximum of 50 MW (subject to other technical constraints). It can be seen that this does not provide capacity for additional generation connections beyond the existing NFG allowance.

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[2] DGCG WS3, 'Solutions for the Connection and Operation of Distributed Generation', produced by EA Technology Ltd., 2003.

The demand side management option is believed to be of low merit on Orkney, since both domestic and industrial demands are already managed and any generation capacity enabled by further development of demand side management is believed to be very small.

From the options listed above the application of post-fault constraints and output regulation dependent on power flow measurements is selected as the solution with the most potential. Further consideration of this solution is now presented.

4.2 Active Management Solution Operating Philosophy

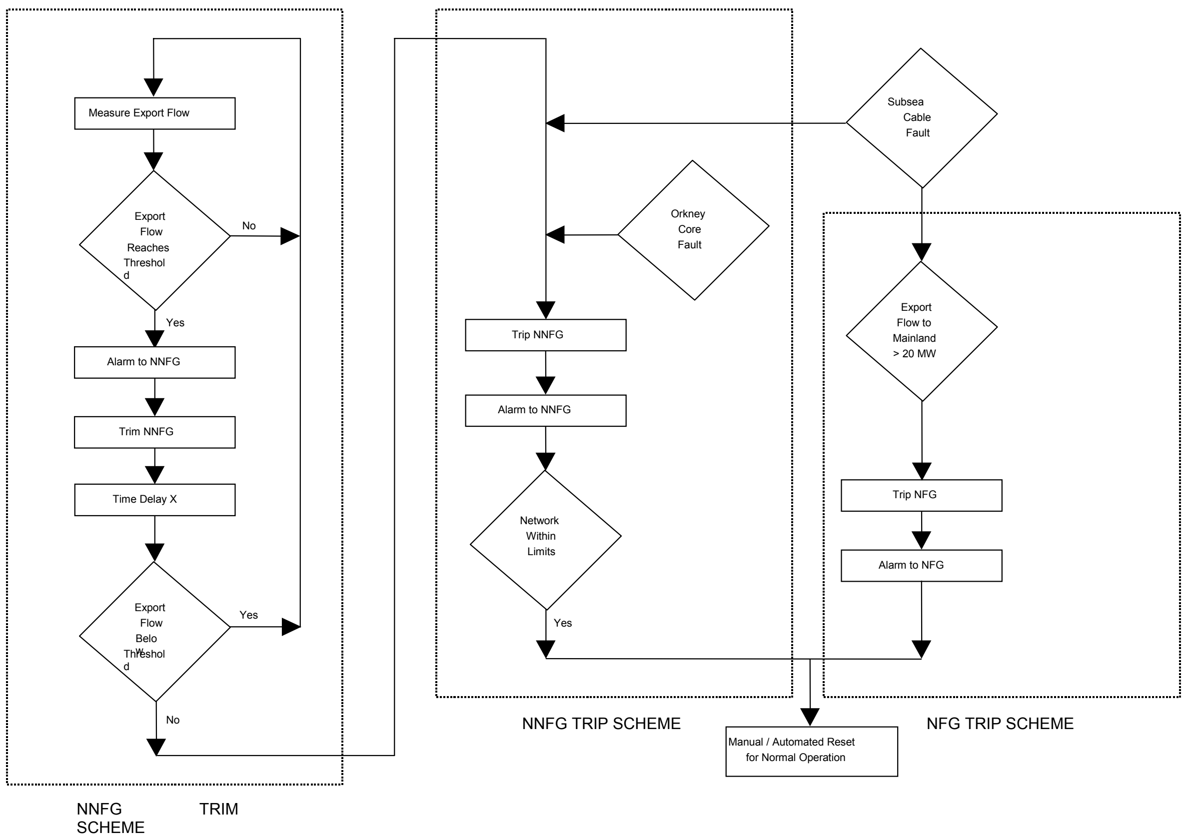
This section gives a high level description of the application of a post fault active management solution.

System studies showed that generation power output beyond the 47 MW (FG and NFG) level is possible. However, if such additional generation (NNFG) is allowed to operate on the Orkney network then the power flows must be monitored and controlled to prevent thermal overloads.

When a pre-defined power flow threshold is reached in a specific section of the network, the active management scheme will sequentially trim the appropriate NNFG to uphold the integrity of that particular section. Any failure by a generating unit to respond to such trimming instructions within a specified time lag will be tripped. Additionally, if a second, higher threshold on power flow through one of the specified sections of the network is breached, then selected NNFG units will be tripped instantaneously to maintain the integrity of the system.

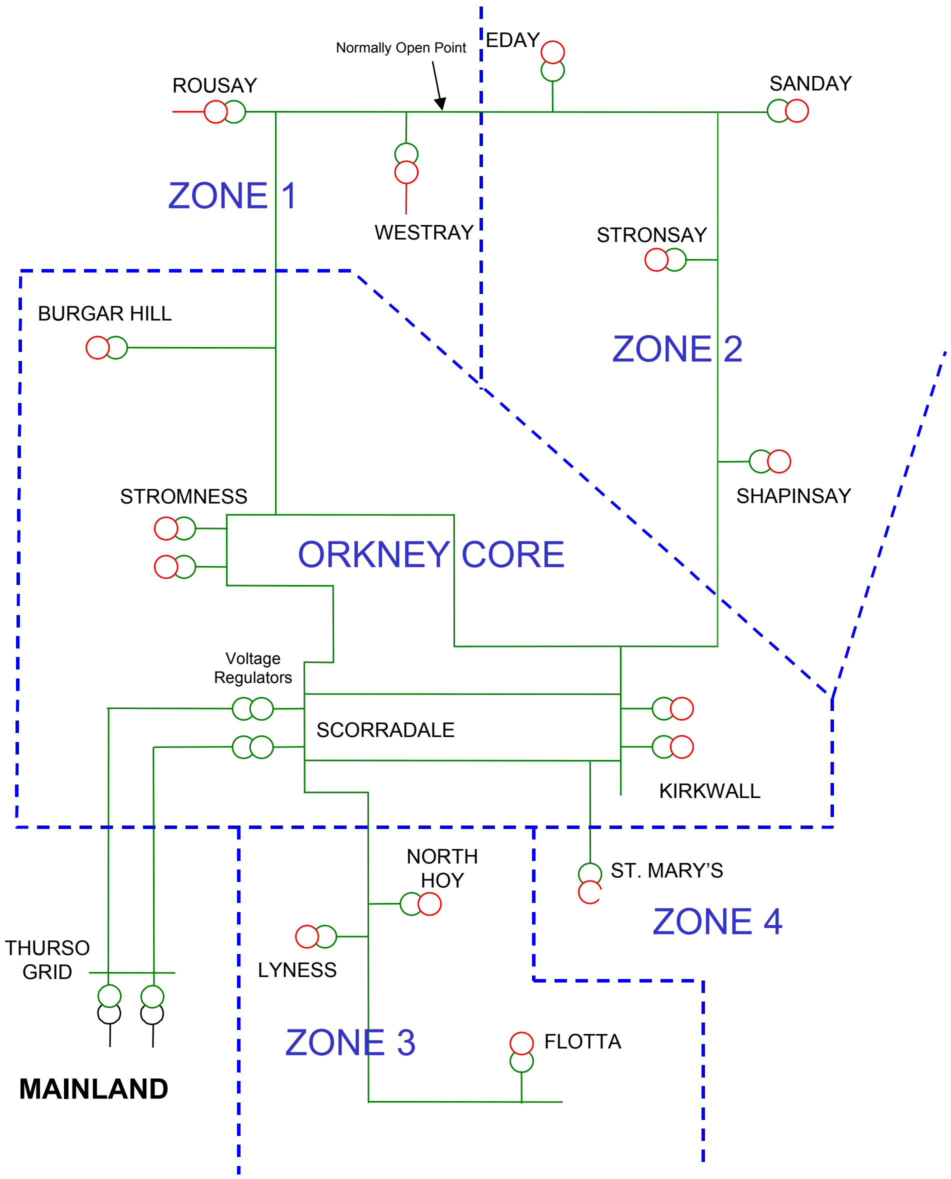
The unconstrained operation of the FG and NFG (both these generation groups could raise their output at any time) potentially threaten network security if inadequate power regulating response from NNFG was achieved. Such a sudden change in power balance requires rapid action by the active management scheme to trim (or trip) NNFG. The time-scales necessary for adequate tripping action would be too short to guarantee network security and stability and a degree of operating margin is necessary. Without such an operating margin, any minor delay in response by the active management scheme could result in circuit thermal protection acting, potentially resulting in a loss of supply.

The flowchart below shows the basic operational philosophy for the proposed NNFG active management scheme as described above. The management of the NFG units is also illustrated for completeness.


Measure Export Flow
Export Flow Reaches Threshold
No
Yes
Alarm to NNFG
Trim NNFG
Time Delay X
Export Flow Below Threshold
Yes
No
Subsea Cable Fault
Orkney Core Fault
Trip NNFG
Alarm to NNFG
Network Within Limits
Yes
Export Flow to Mainland > 20 MW
Trip NFG
Alarm to NFG
Manual / Automated Reset for Normal Operation
NNFG TRIP SCHEME
NFG TRIP SCHEME
NNFG TRIM SCHEME

4.3 Network Zones

By considering the Orkney network in zones it is possible to break down the operation of the active management scheme to maximise the utilisation of feeders into the main 'core'. Ensuring the security of these feeders allows the core to remain, on the whole, passive, with any active control pertaining to the intertripping of generators as the result of a contingency on the Orkney 33kV network. This approach facilitates a gradual progression towards active management of the network by implementing the appropriate active management system in a particular zone when there is sufficient generation connected. The zones proposed are as shown below:



- **Zone 1** is to the NW of the Orkney core and constitutes half of the 33kV northern ring up to the open point between Westray and Eday.
- **Zone 2** is to the NE of the Orkney core and constitutes the other half of the 33kV northern ring up to the open point between Westray and Eday.

- **Zone 3** is to the SW of the Orkney core and includes the 33kV feeder over Hoy to Flotta.
- **Zone 4** is to the SE of the Orkney core and includes the 33kV feeder to St Mary's.

4.4 Review

This section has outlined the thinking behind the selection of a pre-fault constraining (regulating generation output in accordance with measured network power flows) and post-fault constraint method for managing generation connections on Orkney.

Clearly more detailed consideration is required of how such a scheme would operate in practice. The following sections address this aspect of active network management concept development.

5 ACTIVE MANAGEMENT SCHEME DEVELOPMENT

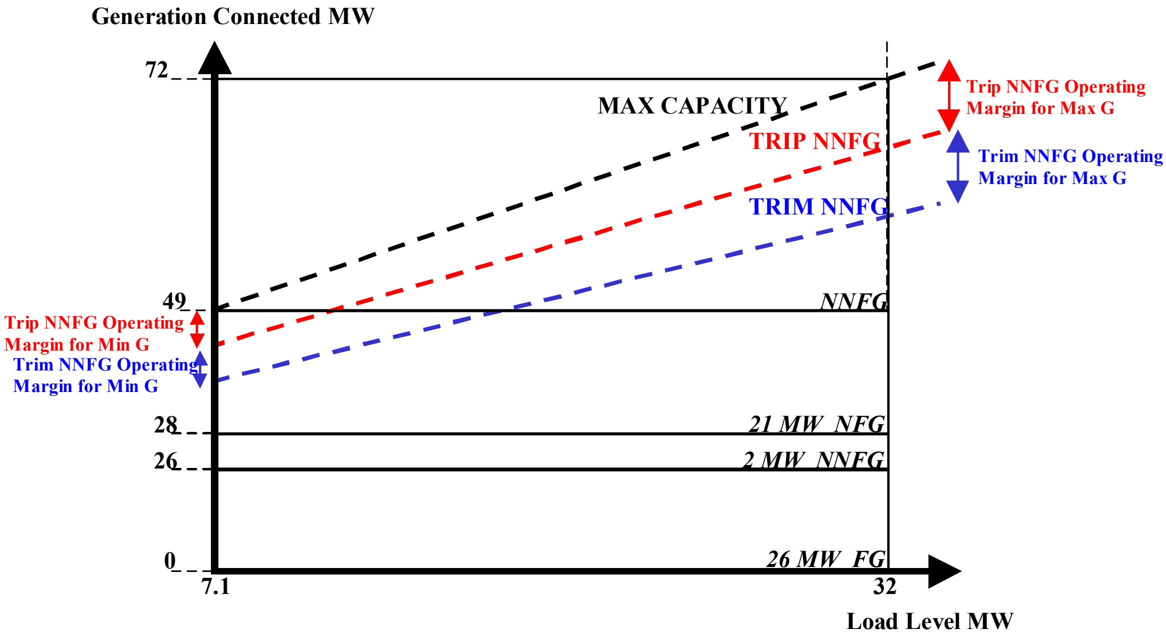
The proposed active management scheme is based on logic control integrated within, but not impacting upon the existing communications and control infrastructure serving Orkney. Logic control is ideal for the scheme due to the reactionary manner in which the active management scheme must operate. Voltage and current inputs from power quality monitors (PQMs) and other measurement devices, as well as alarm inputs / outputs and status alerts form the basis for the logic control. This logic is holistic in that it has to consider maximising the utilisation of the capacity of the subsea cables to the mainland, whilst also maximising the utilisation of the capacity of the individual 33 kV feeders into the main Orkney core. The logic associated with each of these goals is illustrated and discussed in appendices 1 and 2 of this report.

5.1 Operating Regime

The active management scheme will monitor the real-time power export level to the core from each of the 33kV feeders and from the core to the mainland through the subsea cable circuits. The scheme controls will react when power flows exceed pre-determined thresholds (encompassing an operating margin). As FG and NFG units raise their output or the demand reduces, NNFG units will have their power output trimmed to ensure that power flows are maintained within acceptable thresholds. NNFG units will be trimmed regardless of which category (FG, NFG or NNFG) of generator causes the excessive power export. The most recent NNFG units to be connected will be trimmed first and if the selected generator does not make an adequate response then it will be tripped. Following this, and if the export level continues to rise, the generator last to connect prior to the now offline generator will be given a control instruction to trim its output. If necessary the scheme will continue to instruct each NNFG unit in reverse order of connection, trimming and tripping (if necessary) to ensure system security.

5.2 Operating Margin

Operating margins are a key component of maintaining system security and are illustrated below.



The operating margins incorporated within the active management scheme will be in proportion to the amount of generation operating and the corresponding export from each zone. The operating margin ensures adequate protection for the Orkney power system and adequate time for generators to respond to scheme instructions. The 'Trim NNFG' line is the target for overall active management scheme output, but the actual output will fluctuate around this value (often sitting well below this level as a result of intermittent generation output) as generation is trimmed appropriately. Tripping of generation will only occur if the 'Trip NNFG' level is breached. It is also possible that an NNFG unit will be required to completely reduce its output over a period by a continual trimming request.

The setting of the operating margin will depend on many factors such as: ramp rates; communication and control delays; logic processing, which is related to the complexity of the scheme; capacity and type of FG and NFG on-line; deminimis NNFG (proposed to be included within the FG capacity) connected; and on-line and demand variation characteristics. For each of these factors real-time measurements, historical data, manufacturer specifications and predictions could be used. The definition of the operating margins for trimming and tripping under all conditions will need further investigation and cannot be specified exactly at this point.

5.3 Deminimus Generation Capacity Group

The allocation of a deminimis NNFG capacity group recognises the practical issues and costs of providing control schemes for the smaller generators. Deminimis generating units will be of low power capacity and it is proposed that they be allowed to connect to the power system without integrating with the control and communications infrastructure. The basis of determining a deminimis capacity level has still to be established. Local demand growth will play a part in the determination of a deminimis capacity level (since any rise in the system minimum demand will ‘release’ a small amount of firm capacity for generation connection), but the intermittency and behaviour of the FG will also have to be taken into consideration.

5.4 Trimming and Tripping

There are a number of potential approaches for the control of the generation portfolio to achieve the required response. There are also several options for selecting generators to receive trim and trip instructions. A trip instruction from the scheme could be addressed to the generation portfolio in one of the following ways:

- Trip all online NNFG
- Trip most recent NNFG connection first, then on sequential basis
- Trip all generation except FG

A trim control instruction could be addressed as follows:

- Trim most recent NNFG connection first, then on sequential basis
- Trim all online NFG with trim capability where commercial arrangements for trimming have been made

The proposed scheme centres on the control of NNFG in harmony with prevailing generation and demand conditions. Focusing on NNFG units will mean that existing connection contracts with FG and NFG are honoured, and that no control retrofit is required. In addition, future connections are more likely to have trimming capability and therefore follow the output regulation required under the active management scheme. It is proposed that NNFG units will be trimmed on a sequential basis starting with the most recent generator connection. In the event of a contingency all NNFG will be tripped off, a step necessary to ensure network security.

5.5 Proposed Logic Control

The operation of the proposed logic depends on power flow measurements from selected locations on the network. During normal operation, the main focus of the system is to ensure that the thermal limits of the subsea cables to the mainland are not breached. The communication methods employed will therefore be crucial to the success of the system and are discussed in section 5.6 of this report.

There are separate logics for each zone to optimise the flows into the core. The operation of the zonal logic will be similar to that of the core logic. Zonal logic will ensure the security and maximisaton of capacity utilisation of the feeder or zone for which they have responsibility.

The control logic system consists of four main logic groups, which work independently and collectively as necessary. The four main logic modules are:

- Loss of Communications
- Generation Output Regulation (trimming)
- Generation Tripping
- Lockouts and Enables

These logics can be seen in more detail in Appendix 2 where explanatory notes to the control logic are also provided.

5.6 Communication Requirements

The communications requirements to underpin a working active management scheme have been hinted at so far. This sub-section reviews several communications issues in some detail and outlines the options available.

One option for the essential communications links between generators and the active management scheme is Licensed Digital Radio. There is already a significant and suitable communications infrastructure in place at several locations on Orkney. The license fee and other investment associated with using this technology is minimal when compared to the installation costs for PWs. A 64K/128K 8-channel digital radio system would provide a secure link to generators and avoid the expensive and potentially unreliable use of PWs. A digital radio system has a typical range of 30km between repeater stations and is a good fit to the Orkney geographical dimensions. A single 'unrepeated' channel is adequate for the majority of routes between the generation connections being considered on Orkney (thus reducing the need for repeater stations). Digital radio has major cost advantages where no other communication link already exists.

It is possible that the communications medium may be different from generation scheme to generation scheme. The ultimate decision on communications may be based on existing infrastructure that is available, or may be due to a lack of line of sight necessary for digital radio resulting in the use of PWs. Ultimately it will be economics that will determine the communications link installed. In order to make the most of available power system capacity (viz. operating margin implications of communications and control response) a fast communications link is desirable. The implications of a slower link will need to be investigated and the capital cost weighed against the level of generation curtailment.

5.6.1 Integration with Existing Infrastructure

There is an element of flexibility when it comes to selecting the communications links required by the active management scheme, but a standard approach for the connection of NNFG will be necessary.

The control logic proposed in this report may be implemented on a PLC anywhere on the Orkney network provided the communication links are in place for secure operation. The positioning of a PLC requires careful consideration of the communications links already available, whilst also considering the new data retrieval and control requirements for active management.

The type of communications used to communicate with a generator may be dependent on its capacity. For example, the Scanning Radio System (SRS) being planned by SHEPDL will only be employed for generators of capacity 1 MW and above. If SRS was not suitable for a generation scheme then the generation developer would be required to meet the capital cost of installing a PW connection to integrate with the SHEPDL SCADA system. This same approach would likely be taken when considering the use of digital radio. If there was a problem with installing a satisfactory digital radio link then the generator would have to provide a PW link to the SCADA system. By including some small deminimis generation within the FG bracket, the problem of incorporation within the scheme, both technically and economically, can be overcome.

5.6.2 Generation and Network Monitoring

The measurements received from the PQMs and other measurement devices will allow the MVA flow of each 33kV eeder and the two subsea cable circuits to be established in real time. In addition to this, generators will be monitored by ENMAC for their status and power export.

The most recent generation connections linked into the SHEPDL SCADA system provide monitoring and control functionality including operating the circuit-breaker for the whole site, analogue readings from the site (P, Q, V, I, wind-speed, temperature, etc.), and both urgent and non-urgent alarms and set-point instruction (MW, MVAr). Clearly a similar arrangement for the Orkney generators would provide adequate data and controllability for integration within the active management scheme.

5.6.3 Control Security and Failsafe Communications

Scanning radio or digital radio will be the primary method of data retrieval for the ENMAC control system, once the communication infrastructure is fully installed. All sizeable generators will normally also have PW links to SCADA. The control instruction to trip requires a dedicated link (private wire or digital radio) from the control centre to the generator. This link will act as a back up to scanning radio should it fail, while also supporting the quick tripping of generation in the event of a contingency. In the event of a loss of communications, a 'Trim NNFG' control instruction would be initiated, followed by a 'Trip NNFG' control instruction after an appropriate time delay.

The implementation of the active management scheme requires the resolution of existing communications difficulties on Orkney. The private wire communication link into Scorradale is susceptible to lightening strikes. In addition, there is no line-of-sight from the Ward Hill base station to Scorradale for an effective radio link. One solution is to install a small digital (8-channel) radio antenna on a hill above Scorradale. This would also provide a back up to what would be a crucial communications link for the active management scheme since the monitored real time power flow on the subsea cable circuits at Scorradale plays a central role in the active management scheme operation.

5.7 Implementation Recommendation

This section concludes the discussion on effective integration of the proposed active management scheme with the Orkney control and communications infrastructure. Recommendations are made here which enable more detailed engineering design to begin.

The recommendation for the implementation of the scheme is to locate a PLC at Kirkwall. Control logic will be based on the scheme outlined in Appendix 2 (and given more detail in a previous project report[3]). Kirkwall is the site of the Orkney network control centre and the hub for the SCADA system on Orkney and, therefore, is the destination for existing communications channels with generators connected to the Orkney network. Implementing the PLC logic at Kirkwall limits the need for new communication links to be developed. As new generation is connected to the power system, the accompanying communication link would follow the normal procedure of being integrated at Kirkwall.

The active management scheme will require power flow measurements from five key areas:

- The east section of the 33kV ring
- The west section of the 33kV ring
- The southern 33kV feeder to Flotta
- The southern 33kV feeder to St Marys
- The subsea cables connecting the Orkney islands to the mainland network.

These measurements will come from PQMs installed on the network at suitable locations, and other existing network components as necessary. It is proposed the system will operate using licensed digital radio since the security provided by such a link would be high and the cost lower than comparable alternatives. Digital radio would provide an economic and reliable method of communication for the scheme that would be installed and maintained by SSE Telecoms.

Using licensed digital radio would entail the development of an antenna on the hill above Scorradale to relay signals to and from the substation. There is already a

[3] 'Specification for prototype network management scheme integrated within existing SCADA infrastructure' (SSE/ ADNM/TR/2004-001A)

PW link from Kirkwall to Scorradale and the potential use of this for the active management system needs to be considered since it provides the communications channel for the Kirkwall load shedding scheme. Too high a dependency on one communications link might not be desirable. However, the development of the digital radio link would provide redundancy in the Scorradale-Kirkwall link. The Scorradale-Kirkwall communications link is the most important as far as the management and optimisation of the power export to the mainland is concerned. Therefore having a secure link, for the continuous transfer of data is desirable for the scheme, as is having a back up communications link.

The PLC at Kirkwall would issue control instructions to the majority of connections through 8-channel digital radio. This will allow the communications system to be easily adapted for future developments and will leave channels open for other purposes as may be necessary. Digital radio technology will be able to utilise the infrastructure already in place for radio links on Orkney, which has been developed for the SRS. This means that investment in the technology will be less than for PWs making it a more flexible and economically attractive option.

Implementing the active management scheme on a PLC in an existing RTU appears to be a good solution since the use of PLCs in RTUs is a tried, tested and trusted method for applications where control turnaround is an issue.

5.8 Review

This section (and the referred appendices) presented a detailed description of the proposed conceptual design for an active management scheme to facilitate integration of further generation sources beyond normally achievable thresholds. The active management scheme operating principles and the detail of control logic provide for a ‘trimming then tripping’ approach to active power flow management.

The communications and control infrastructure requirements can be met by the use of existing or moderately expensive system extensions. The proposed communications and control development provide for security and effectiveness and it is believed that they present the best available option to generation developers.

Having proposed a conceptual design for the active management scheme, the next stage is to evaluate its benefits in terms of additional generation capacity and generated energy.

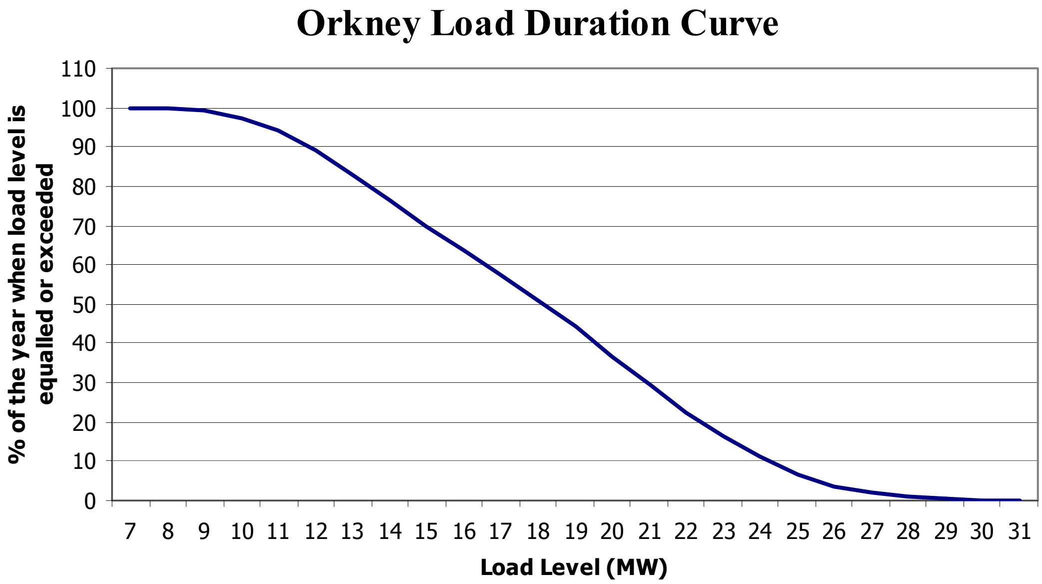
6 PROPOSED SCHEME EVALUATION

This section presents an analysis of the benefits the proposed active management scheme offers in terms of additional generation connections on Orkney and the additional generated energy enabled.

6.1 Analysis of NNFG Connections

In order to fully appraise the active management scheme it must first be understood how many generators (and of what capacity) are able to connect to the Orkney system at all demand levels. For the through year analysis presented in this report a value of total annual energy demand of 159GWh has been used. The annual load duration curve for the Orkney network is shown below. This is used in the analysis of constraints imposed on load dependent generation connections.

While demand management (through radio teleswitching of heating demands) is utilised on Orkney to reduce the peak MW demand, the energy demand remains the same. Thus there is no material effect on generation annual energy output from demand management.



The load duration curve enables new-non-firm generators (NNFG) connected dependent on a certain demand level to assess their duration online in each year. For example, a generator connected beyond the 20 MW demand level will know that for around 35% of the year the demand is either 20 MW or above, the rest of the year they might be subject to constraint depending on other generation output.

The load duration curve shows that connecting generation up to the maximum network capacity for generation exports (which is dependent on a maximum demand situation of 31.5 MW) is theoretically unattractive since the duration for demand at that level is minimal. Therefore, the generating units connected to this level will be subject to constraint by the active management system for the majority of the year. This conclusion is based on the assumption that the other generation is operational throughout the year at its full output. This is not necessarily the case, as the majority of connections are likely to be intermittent renewable generation based on wind and marine resources. Adopting the active management scheme proposed through this project will allow maximisation of the capacity online at any time subject to network thermal and security considerations and an operating margin. By examining the nature of the operating margin and considering realistic generator behaviour it will be possible to perform a more realistic analysis of annual constraint of the NNFG.

The frequency and duration of constraints will be assessed against the notional capital costs for wind generation and the expected revenues from such a constrained connection. Higher levels of power output constraints will not be economically acceptable to generation developers.

6.2 Operating Margins

The realistic performance of the scheme is difficult to predict, mainly due to the complexity involved in the specification of an appropriate operating margin. By considering two different operating margins, combined with real generator and demand data from Orkney, it is possible to give indications of expected active management scheme performance. One larger and one smaller operating margin will be considered. Both can be considered to be realistic (based on operational experience) but the actual characteristics of the operating margins will depend on the nature of future connections. The smaller operating margin might be feasible when generators have high ramp rates and fast response to control instructions. The larger operating margin would be more probable if the generation is slower to respond to control instructions and has lower power output ramp rates.

The associated values for the two operating margins at minimum and maximum demand are shown in the table below. The trim margin represents the gap between the trim generation line and the trip generation line. The trip margin corresponds to the gap between the trip line and the absolute maximum network capacity (at which stage thermal protection would be expected to operate).

Operating margin	Trim margin - minimum load (MW)	Trim margin - maximum load (MW)	Trip margin - minimum load (MW)	Trip margin - maximum load (MW)
1	2	8	2	7
2	3	10	3	10

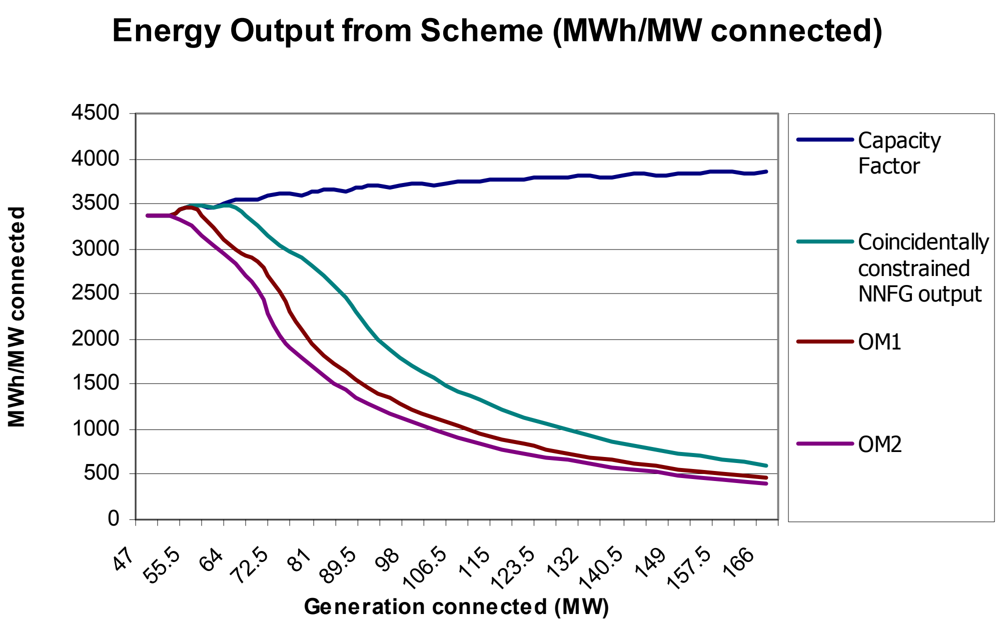
The smaller operating margin (1) increases from 2 MW at minimum demand to 8 MW at maximum demand for trimming. The corresponding trip margin increases from 2 MW at minimum demand to 7 MW at maximum demand. The larger operating margin (2) increases from 3 MW at minimum demand to 10 MW at maximum demand while the trip operating margin are the same magnitudes as the trim margins (but of course are added onto the trim margin).

6.3 NNFG Energy Output Assessment

In order to appraise the scheme and determine a realistic annual output and constraint of the NNFG, it is necessary to create a realistic portfolio of NFG and NNFG generation. Real profiles of the output of FG on Orkney can be scaled up to allow different levels of generation to be assessed. Power output data sets from the existing wind farms are used, as it is assumed the majority of new connections to the Orkney network will be wind generators. Scaling up existing data sets results in the peaks in the wind power output being compounded, but this is realistic for a geographical area such as Orkney since it is likely that peaks and troughs in wind generation will coincide to a greater degree than in more geographical diverse power systems.

The capacity factor of existing wind generation on Orkney is approximately 40%. Therefore by its very nature wind energy is constrained by the wind resource availability. This is a major factor in assessing the output of the NNFG as it is also subjected to reduction due to peak outputs coinciding with that from other generation and with troughs in the demand. The introduction of an operating margin reduces power output further but to a much lesser degree than from the (demand and generation) coincidence effects on the NNFG output.

All the factors introduced above are used to make a through year analysis of generation output under the active management scheme. Demand and generation data for 2002 are used in the analysis. The graph below illustrates the results of potential annual energy production per MW of connected NNFG with the application of these factors. There is a clear trend of decreasing energy output as more NNFG is connected to the system. This is an intuitive result as one would expect that greater constraints would be experienced by each additional generation connection beyond the NFG threshold.



Connecting generation up to the network capacity limit (72 MW) will not maximise the export to the mainland from the Orkney network because of the capacity factor and generation-generation-demand coincidence effects which allow higher ratings of generation to operate at lower output levels. In other words generating units connected beyond a total Orkney generation capacity of 72 MW could operate for a significant duration of the year because of the diversity in output of the other generating units. However, the increasing level of constraints experienced by these additional generating units will render the economics unattractive at some point.

It should be stressed that the impact of the operating margins is small compared to the effects of the coincidence of generating units output and demand that are concomitant with wind energy. Operating margins do not unduly constrain NNFG generation as shown above, but do provide security and operational flexibility for the DNO.

6.4 Economic Analysis of NNFG Capacity

It is possible to determine an economic cut off point where connection of further NNFG will become unattractive because its output is exposed to high levels of constraint. By examining the annual energy output it is possible to identify a break-even point at which the revenues for the given (constrained) energy output are equal to the annual cost of ownership. As previously, the assumption is made that the NNFG connections will be wind generating units.

The total capital cost for a generator is assumed to include only the capital cost of the generating unit, the capital cost of the electrical connection and the cost of connection to the active management scheme. The table below presents realistic examples of these costs for a wind generator connecting to the Orkney network.

Component	**Capital Cost**
Generator installation	750 £/kW
Electrical connection	£150,000 + component dependent on circumstances
Integration with active management scheme communications	£20,000 + component dependent on circumstances

The cost of electrical connection and connection to the active management scheme are specific to each individual generator. In the case of the communications equipment necessary for integration with the active management scheme there are different options (as described in section 5.6) with different associated costs. For example, in the absence of a suitable digital radio link it may be necessary to install a BT Private Wire, which might have a capital cost of around £120,000. A dedicated link is required for issuing a control instruction to trip, causing the cost of connection to go up when this facility is required as in the proposed active management scheme.

Considering the capital costs outlined above, the minimum total is approximately £920,000 for a 1 MW generating unit. The revenues received by the generator are based on energy sales and Renewables Obligation Certificates (ROCs). With this data to hand (and with the relationship of annual output to connection capacity presented graphically above), a minimum MWh annual energy production per MW of installed capacity for financial breakeven can be found if it is assumed that 10%

of total capital cost is required per annum to service the capital outlay. 10% is based on a typical capital recovery factor and normal profit at current lending interest rates.

Two levels of revenue from energy sales plus ROCs will be considered: £40 / MWh and £60 / MWh. Given that £92,000 per MW connected must be recovered for break even then the energy output required is 2,300 MWh at a revenue per unit of 40 £ / MWh and 1,533 MWh at a revenue per unit 60 £ / MWh.

Knowing the required energy output per year, the break-even capacity can be derived, which shows the energy output for marginal connection capacity for all levels of total generation portfolio capacity.

The results of this analysis are presented below.

ROCs + Energy revenue (£/MWh)	Operating margin 1 economic cut off point (MW)	Operating margin 2 economic cut off point (MW)
40	75	70
60	88	82

These results are a major outcome of the project in that they show the additional generation capacity that might be connected economically under the active management scheme. The capacity limits derived should be compared with the 47 MW limits on NFG connections. The 47 MW FG plus NFG limit is significantly less than the capacity limits achievable under the proposed active management scheme for NNFG.

The results show the significant impact on the viability of a connection uncertainty regarding the revenue accrued from ROCs and energy output. Generation developers will have to assess whether a potential generation investment on Orkney has enough merit through careful consideration of the operational constraints of the scheme and also the potential future prices for energy and ROCs.

6.5 Review

The analysis presented in this section is not an investment appraisal for a specific generation scheme, but an indicative break-even analysis for a notional generating unit connected under different conditions within the scheme. A method of defining the limits of the active management scheme and the viability of generation connected within the scheme has been presented.

The capacity limits derived for generation are a result of the assumptions made regarding operating margins and future generation on the Orkney network. A more detailed and specific economic analysis will be necessary for any generator considering connection.

7 Active Management Scheme Implications

7.1 Network Operator Implications

In introducing the proposed active management scheme on Orkney, SHEPDL would be departing from established methods of planning and operating power systems. This section details several important implications for SHEPDL as the power network operator.

7.1.1 Security and Planning standards

A major consideration for the network operator on Orkney is ensuring network security in the context of the unique network configuration. Operation of the system on the boundary of normal security limits means that the active management control system must be highly reliable. Careful design of the scheme will ensure that it is secure and failsafe – indeed the conceptual designs proposed in this project have addressed the failsafe issue. The conceptual specification of the active management scheme must be evaluated against existing planning and operating procedures to identify if revision of these procedures is necessary or desirable.

At present, networks are normally planned for security of supply in accordance with engineering recommendation P2/5. This standard, while mainly focused on demand security, has led to limits on generation connections to power distribution networks that allow operation of all units at rated output during an outage of the largest distribution circuit[4]. Actively managing the network and generators to exploit the intact network capacity challenges the approach presented in P2/5. The ability of the active management scheme to ensure security and quality of supply will be of utmost importance to SHEPDL in meeting their obligations under relevant operational standards. Meeting the specified security standards is a condition of network operators' license agreements and is also a revenue incentive/penalty issue under current regulatory mechanisms.

For any new connection applications, SHEPDL has to provide a statement of system capacity and loading, which must enable the evaluation of the opportunity by the developer[5]. This analysis will be more complicated for the connection of NNFG. SHEPDL may consider it desirable to enter into Joint Operating Agreements with NNFG units in order to outline the course of action in all eventualities.

7.1.2 Engineering Design Requirements

The active management scheme outlined in this project requires detailed engineering design before implementation. The logic forming the backbone of the scheme will require rigorous analysis in order to guarantee the

[4] Engineering Recommendation P.2/5, 'The Electricity Council Chief Engineers' Conference: Security of Supply', System Design and Development Committee, October 1978

[5] K. Jarret, J. Hedgecock, R. Gregory, T. Warham, "Technical guide to the connection of generation to the distribution network", DGCG technical Steering Group, February 2004

security required by SHEPDL. The interaction of this logic with existing management schemes on Orkney will need to be considered, as will the interaction between the 'core' and 'feeder' logic proposed in this project.

The definition of an appropriate operating margin is an area of complexity, dependent on the type of generation connected to the network, the communications employed and the export power flows from a defined zone. SHEPDL will need to define the operating margin after each new NNFG connection in light of analysis of generation portfolio response characteristics. Measurement of export power flows and generator outputs could allow the operating margin to be calculated in real-time although this would increase the complexity of the scheme further. Careful consideration of relevant measurement locations is necessary.

The communication and control requirements for generators wishing to connect to the active management scheme will require site-specific analysis (see section 7.1.3). This analysis by SHEPDL will determine the communication technologies to be used, the position of the specific generator in the generation 'stack'[6], and the impact of these issues on the necessary trim and trip facilities required. There are, therefore, many potential variables that add complexity to the definition of the operating margin for the zone in question (see section 7.1.4).

7.1.3 Additional Communications and Control Requirements

The integration of the active management scheme control devices with the existing communications and control infrastructure will require both hardware investment and engineering effort by SHEPDL.

There will be minimal impact upon the existing control centre equipment at Kirkwall. The PLC will stand separate from the existing SCADA system. However, the interaction of the scheme with the current SCADA infrastructure in Kirkwall, Inverness and Perth will need to be considered.

The siting of the main PLC at Kirkwall means the successful operation of the scheme is heavily dependent on secure communications between Kirkwall and the participating generation sites. The use of digital radio provides an effective solution, being both economically and technically attractive. Redundancy in communications through the continued use of Pilot Wires (PW) is clearly desirable, but possibly not an economically attractive option. Redundancy/security in communications links will need to be addressed further by SSE, in terms of investment and ongoing costs, and the security and performance benefits.

Available, existing power system measurements on Orkney will need to be assessed and integrated into the active management scheme as appropriate. The cost of establishing new links for vital real-time measurements will affect how the active management system is developed. The installation of Power Quality Monitors (PQMs) will provide sources for some of the required measurements. Part of the detailed design of the

[6] 'Evaluation of Network Management Solution' (SSE/ADNM/TR/2004-002)

scheme will have to analyse the number and position of voltage and current measurements and find the optimum number and position of sites. The power flow measurements required in a particular zone will be specific to that zone and this requires some further investigation.

SSE Telecoms may install and maintain the digital radio links necessary for the scheme. Any pilot wire links will be installed and operated by BT. The dedicated links required for the generator trip function may not be necessary for the generation trimming function. The issue of different communications technologies for different functions within the active management scheme requires further consideration. It may be that trimming control instructions could be issued via a multi-drop communications channel such as the scanning radio system. This may have an impact on the operating margin (possibly increasing it) but could reduce the cost associated with connecting to the active management scheme.

7.1.4 Managing Operational Complexity

The logic upon which the scheme is dependent will be modified with each new generator connection. With increasing numbers of generation schemes connecting to the network, more logic code will be required. In addition there will be added complexity in the online calculation of the operating margin, which may vary depending on which generators (with different characteristics and communication links) are online. It could also be argued that when the active management scheme is in operation (i.e. either trimming or tripping generation) then this adds another level of complexity into system operations.

The interaction of the active management scheme with existing control procedures for the Orkney network needs to be carefully considered. During the resolution of contingency events, the active management scheme trips and inhibits the reconnection of all NNFG. However, the active management scheme must not interfere with the existing intertrip scheme for NFG and must also ensure that contractual arrangements are honoured when permitting generation to reconnect after fault clearance.

The scheme (as proposed) requires manual intervention to enable NNFG reconnection after certain events to ensure network security. The potential automation of this reconnection requires further consideration.

If the network configuration were changed after a significant network event then it might be expected that the active management scheme would become invalid for this situation. The specific configuration would need to be studied in the light of the active management scheme principles. For example, if the 33kV normally open point were moved then generation that was associated with one control zone would then be in another control zone and the logic would need to be updated to reflect this. However, the overall principle of measuring circuit power flow and controlling generating unit output within the circuit ratings is still valid.

The complexity described in this section requires investment in personnel and training for staff in the control room or investment in further automation of the scheme resulting in increased complexity and detail at the planning and design stage.

7.1.5 Active Management Scheme Costs

The main costs of the active management scheme lie in the investment in the necessary communications and control equipment. The investment required relates to the detailed design of the PLC logic, the installation and operation of the PLC at Kirkwall, and a secure communications infrastructure.

The real-time data required by the scheme will, wherever possible, come from existing system measurements. Where new measurements are required this will be addressed in the most cost-effective manner. Power quality monitors will be used to monitor voltage levels and power flows at some locations. Existing pilot wire links such as that between Kirkwall and Scorradale will be used to send and receive information. Power system measurement and data administration also has a cost.

7.1.6 Commercial Considerations

It is proposed that generation will be trimmed or tripped starting with the online NNFG of lowest priority in the 'stack'[7], then proceeding in reverse order of connection date. If the response to a trim instruction from any generating unit is inadequate then a trip instruction will be issued. This is the fairest approach and also prevents generating units who do not respond or who have inadequate response characteristics from benefiting from their poor response by remaining online. In addition, network security is maintained from such a sequence.

When a generator connects or makes an application to connect they will be added to the bottom of the Orkney NNFG priority 'stack'. Generators will not be compensated for any lost output due to curtailment since this is part-and-parcel of a non-firm connection approach. SHEPDL may make available information on likely curtailment frequencies and durations based on knowledge of other connected generating units and demand profiles. This data could form the basis for analysis of the economic viability of a proposed connection.

The current connection process will need to be revised to ensure all interactions between the parties take place as necessary for full integration of generation in the active management scheme. The initial connection application period may be longer than at present. This is due to integration of the generator with the active management infrastructure involving a greater degree of complexity, as discussed in section 7.1.4. This issue may have to be raised by SHEPDL in discussions with Ofgem.

Under the active management scheme, there may be scope for additional commercial agreements between SHEPDL and one or more generators such that generating units more able to trim and trip (but not necessarily required to do so from their preferential 'stack' position) do so for some reward.

7.1.7 Reactive Power and Voltage Control Scheme

The operation of NNFG units under the proposed active management scheme requires the operation of the Orkney reactive compensation scheme. Satisfactory voltage and stability in the Orkney system can only be achieved for additional generation when the reactive compensation scheme is operational. Any operation of the active management scheme (and the generators connected under the auspices of it) when the reactive compensation scheme is fully or partially offline requires further consideration.

The active management scheme could be expanded to consider the control of generation for reactive compensation. This capability is more likely in recent wind turbine generator developments such as doubly fed induction generators (DFIGs). Reactive support may be a desirable characteristic of NNFG connections. SHEPDL would need to develop a generation reactive

[7] The lowest priority generator will normally be the one last to connect to the network – Last In First Off (LIFO).

power management approach in advance of any formal connection application by a developer on this basis.

The role of on-line tap change (OLTC) transformers and the 33kV voltage regulators and their interaction with the active management scheme in planning timescales will need to be considered fully should any change be made to the voltage control arrangements. Through further analysis and then modification of tap-change control, repetitive changing of tap position and even out of limits voltages in operational timescales should be minimised.

7.1.8 Ongoing Active Management Scheme Modifications

The active management scheme logic will need to be modified as more generation is connected to the Orkney system. In addition, the communications infrastructure will be extended to new generation sites. The communications infrastructure is likely to be a combination of different technologies dependent on the specific characteristics of each generation scheme and site location.

If further power export capacity to the mainland were installed by the introduction of further subsea cable capacity then the scheme could be modified easily to accommodate the new generation capacity. For example, if a third 33kV subsea cable were added, generating units would move up the notional priority stack. Some NFG could move up in priority to FG and some NNFG could move up in priority to NFG. Of course, the net effect would be more generation connected to the Orkney system. The communications and control systems would already be in place to accommodate this new scenario. The principles of the active management scheme could be applied equally as satisfactorily in this new situation.

If the normally open point on the 33kV ring servicing the northern islands were moved then this would impact on the generation export capacity and operating margin for each feeder on this ring. The implementation of the principles of the active management scheme would change, but not impact on the philosophy behind the scheme. Managing the effects of short-term and long-term changes to the network configuration on the active management scheme requires further thought.

As noted in section 7.1.7 above, it is likely that in future more wind turbines and other renewable generators will have some voltage control capabilities, allowing more flexible control of real and reactive power. The integration of such generators into the scheme would likely require redesign of the scheme. The commercial implications of this approach would need to be considered.

7.1.9 Future Innovation and Development in Power Networks

The potential development of the Orkney network as a Registered Power Zone (RPZ)[8] could allow SHEPDL to recover some of the expenditure in implementing the active management scheme. Pursuing this possibility might relieve some of the financial burden from NNFG developers arising from integration into the active management scheme.

7.1.10 Active Management Pilot Scheme

The principles on which the scheme is based could be tested on a smaller scale at another location or perhaps on an individual feeder on Orkney. If a pilot was sited on Orkney this would facilitate a more gradual development of the active management scheme.

The lessons learned from the pilot scheme would form the basis for the implementation of the full-scale scheme. The nature of the scheme with its zonal and core logics mean that it will be gradually built up, starting with individual zones that could potentially be used as pilot schemes for different approaches to scheme operation.

Pilot schemes are a good means of managing risks from new innovations such as the proposed active management scheme. However, the attractiveness of renewables on Orkney and the associated pressure for generators to connect to the Orkney system might not permit a gradual (and possibly more lengthy) approach to testing the active management scheme. In addition, the duties of SHEPDL as network operator may prohibit any 'experimentation' with network operation.

7.2 Generation Operator Implications

The characteristics of the generating units will directly impact upon scheme operation and the extent of generating unit power output curtailment. NNFG units wishing to connect to the Orkney network and therefore integrate with the active management scheme could benefit by developing desirable generator characteristics: quick response to control instructions and fast control over real and reactive power.

7.2.1 Communications Requirements

All generation schemes are required to provide (at their own expense) a communications connection to the SHEPDL SCADA system for general operations purposes. This also acts as an enabling step for the active management scheme. Traditionally the communication link has taken the form of a pilot wire link into the control centre in Kirkwall. This basic communications link is required for generation output trimming instructions. It may be acceptable to send instructions to trim on a less secure communications system, such as scanning radio.

[8] 'Innovation and Registered Power Zones', Ofgem, 07/2003.

Additionally, each connecting NNFG unit will require a dedicated and secure communications link to support the trip facility required by the active management scheme. It is likely that the more secure dedicated communications link for trip instructions would be provided by digital radio or pilot wire.

The nature of required communications links has to be agreed. Clearly it would be in the interest of generation developers not to be required to fund a more expensive dedicated communications link. However a likely wider-ranging effect of less secure, less dedicated or slower communications links would be an increase in the magnitude of the operating margin. This might not affect the financial outcome for a specific generator but would lead to an overall reduction of the exploitable renewable energy at a system level.

7.2.2 Desirable NNFG Control Response Characteristics

NNFG connections will be reliant on their communications link to the active management scheme to enable optimisation of their output. Responding to a power output trim instruction is essential for minimising the frequency of generator trips during normal operation. Therefore, fast control over real and reactive power outputs will help to not only reduce the size of the operating margin but also ensure a greater MWh output from individual generation units throughout the year.

7.2.3 Upper Connection Capacity Limits

Clearly, even with an active management scheme as proposed in this project, there is not unlimited capacity for generation connections to the Orkney system. In some sections of the network there still will be limited opportunity for generation connection due to existing FG and NFG. This presents the usual problems for developers of identifying and exploiting areas with high renewable resource and available network capacity. However, the network capacity available is expanded by the proposed active management scheme. After identifying a site with available local connection capacity there is now the added complexity of analysing the economic viability of the connection under the active management scheme. The results of such analysis are dependent on many location specific and generator specific characteristics. Therefore, the determination of an upper limit for generator connection capacity is not possible at this stage. However, section 6.4 showed that generation capacity in excess of 80 MW might be economically viable.

7.2.4 Potential Commercial Issues

Prior to connection it is necessary for generation developers to have made arrangements for the sale of energy exports. The revenue lost by the curtailment of the generator will not be salvageable. NNFG developers should base their financial analysis on operation with some curtailment due to the active management scheme. The level of curtailment can be estimated during the planning phase based on analysis of generator characteristics and data relating to the active management scheme.

The initiation of the active management scheme will indicate to developers that network capacity is available. This may lead to 'connection racing' which may, in turn, result in interactive connection applications. Developers will therefore have to base their initial connection appraisal on data from other prospective connections that may or may not connect to the scheme. The level of curtailment will ultimately depend on the position of the generator in the generation priority 'stack'.

When operating under constraint there is the possibility of storing the energy generated. There are many options available such as batteries, flywheels, hydrogen production and micro-hydroelectric pumped storage. All of which may be technically feasible but not necessarily economically viable. Storage could be used when the generator has been tripped or trimmed by the active management scheme despite having the capability to generate. The viability of any energy storage scheme is dependent on the initial capital required for the storage plant and the actual economic benefit resulting from its use. Stored electricity could be used to optimise available network capacity when the primary generating plant is either operating at a reduced output or is offline.

If generation schemes are developed that benefit from previous investment (e.g. in communications links) by a previous developer then the initial developer may be entitled to some compensation on their initial outlay proportionate to the use of the shared assets. Developers may seek to share the cost of relevant electrical or communications infrastructure in a manner that is financially beneficial to all.

7.2.5 Generation Connection Costs

The costs associated with the electrical connection are site dependent, but are relatively straightforward to estimate.

The costs associated with connection to the active management scheme builds upon the standard requirement for each generator to supply a dedicated communications channel to SHEPDL's SCADA system. Traditionally this has been via pilot wire and for certain situations this will continue to be the case. Each developer will be looking to minimise the costs associated with this dedicated communications link and the use of digital radio is being investigated to provide a more financially attractive solution. The development of a digital radio system for use within the active management scheme will involve the use of radio base stations at several sites on Orkney for routing and repeating signals.

Geographically grouped generators may be able to share the capital costs associated with the development of the appropriate communications and control infrastructure as part of an interactive application. Another cost saving possibility is for generation developers to utilise some of the existing and available trunk radio network capacity.

7.2.6 De-minimis Generation Capacity

The inclusion of a small capacity allowance for 'de-minimis' generation within the FG part of the priority stack will remove potential barriers for small generating unit connections to the Orkney network after the implementation of the active management scheme. The threshold capacity for individual generating units or schemes and the total allowable de-minimis capacity will require careful consideration. Ultimately, the answers to these questions depend on the characteristics of the other FG units and local demand growth on Orkney (that will naturally expand the size of the permissible FG portfolio over time). The total allowable de-minimis capacity within the FG part of the stack will also depend on the geographical zone that the connection is in - there may be limited capacity available in zones with existing FG and NFG.

The specification of the size of this de-minimis generation in the FG section of the priority stack requires investigation and cannot be stated definitively at this time. However, a total allowable de-minimis capacity of 1-2 MW made up of generating units no greater than a few hundred kW capacity looks feasible from a simple inspection of the circumstances on Orkney.

7.2.7 Future Scheme Modifications

It is in the interests of all that the scheme is adaptable to future scenarios of operation and possible network reconfiguration. Changes to the network topology, such as the moving of the normally open point, would impact on scheme operation. This would result in different trimming and tripping arrangements for certain generators, the commercial implications of which will require careful consideration. It is unlikely, however, that any individual generating unit will be disadvantaged after a network topology or active management scheme change.

Future modifications to the scheme may have an impact on existing NNFG at that time and SHEPDL will have to consider carefully what guarantees relating to operation of the scheme are given to individual NNFG developments when they first connect. The situation of essential future modification to the scheme snagging with existing commercial agreements is certainly to be avoided.

7.2.8 Developments Beyond the Active Management Scheme

Increasing the subsea cable circuits capacity will change the allocation of generation to the FG, NFG and NNFG groups as described in section 7.1.8. This would clearly benefit generators if 'promotion' within the priority stack were automatically granted. However, there may be reasons why the new NNFG and NFG capacity might be allocated to the new generation rather than existing NNFG units. There also might be good cause at the time of a future network capacity expansion for 'promotion' within the generation priority stack to be conditional on further control and communications modifications. This is yet another implication of the active management scheme that needs further consideration.

7.3 Demand Customer Implications

It is desirable that the introduction of the active management scheme should not impact on the quality of service provided by SHEPDL to their demand customers. There are several areas of concern that must be addressed and incorporated within scheme planning and operation.

7.3.1 Security of Supply

By seeking to optimise the use of network capacity through the active management scheme the network will be operated closer to its thermal limits. The incorporation of the operating margin provides a safety margin before these thermal limits are reached, provided that generation can be regulated down or tripped off within an adequate time scale. If the scheme does not provide this security then there is a danger that network thermal protection will operate leading to customers interruptions. In the worst case a cascading situation may arise, leading to the loss of supply to neighbouring generation and demand connections. Demand customers will look to SHEPDL for assurances that the implementation of the active management scheme will not lead to such circumstances (or even raise the probability of such circumstances).

7.3.2 Power Quality

The capacity of generation that might connect to the Orkney system under the active management scheme could potentially impact on the power quality on Orkney. The start-up, intermittency, output volatility, high wind shutdown and tripping of wind generators could cause step voltage and other voltage waveform problems. This will depend on the capacity and characteristics of generation connected and the response time of the switched shunt reactors at Burgar Hill and Sanday. The fast dynamic reactive compensation device employed at Scorradale will provide effective mitigation of some (but not all) voltage waveform issues.

The use of power quality monitors will provide data for offline analysis of power quality and enable operational recommendations to be made to resolve any emerging power quality issues. It could be argued that the fast response compensation device at Scorradale and the two switched reactors should lead to enhanced power quality on Orkney, leading to a higher quality of service for demand customers.

7.3.3 Social, Environmental and Local Economic Implications

The active management scheme will lead to an increase in renewable generation on Orkney. This will have an impact on the landscape as more wind and marine generation is installed. In addition, new telecommunications plant will be installed on Orkney, which will also have an impact on the landscape (dependent on the technology selected).

The concerns of local people and conservationists will need to be taken into consideration during the planning stages. The development (and then operation) of infrastructure will offer employment opportunities that might allay some local environmental concerns. This increased commercial activity will bring wealth to the local economy and benefit local businesses and eco-tourism. Most of these arguments are similar (if not the same as) for renewable energy developments elsewhere in Scotland and the UK. However, in the case of Orkney there is a strong link between the proposal of the active management scheme and the increased development of renewables and the accompanying infrastructure.

8 CONCLUSIONS

This section summarises the main project achievements and identifies areas for future investigation that stem from this work.

8.1 Summary of Achievements

The main achievements of this project are:

- A *technical appraisal* of the Orkney network and its capabilities and limitations under many scenarios of demand, generation connections, network configuration and reactive compensation. This appraisal has provided the foundation for the active management scheme development.

- The development and evaluation of a *conceptual active management scheme*. The proposed scheme will release additional capacity for new generation connections on Orkney, while maintaining network security for all connected customers.

- A *framework for the design and evaluation of future active management schemes*. This framework highlights the major considerations for designing an active management scheme, from system studies to reveal network capacity issues through to the logic behind the scheme and its implementation and integration into the existing infrastructure.

- *Logic control* sequences for trimming and tripping generation according to system requirements have been proposed. These control sequences can be programmed into PLC devices existing in the Orkney network. The logic control sequences ensure that thermal limits on key 33kV network circuits are not reached.

- An *evaluation method* for the active management scheme has been proposed. When applied to the Orkney situation this provides an indication of the capacity of additional generation enabled by the active management scheme. Use of the evaluation method showed (with caveats) that the generation portfolio on Orkney could be expanded economically from the 47 MW existing non-firm generation limit to around 75-80 MW.

- A comprehensive set of *implications* of introducing the proposed active management scheme. Some of the issues require further thought but these areas can only be taken forward when detailed design of the active management scheme is initiated. Some of the issues also require operational experience with the scheme to make a full assessment of their impact.

The adoption of the scheme proposed has implications, requiring detailed scheme design, and then construction and operation. The costs of scheme design, testing and implementation may be recovered through connection charges. Such charging will be something that developers seek to minimise by carefully selecting sites with available local capacity and suitable potential for optimising communication links.

Developers, who have the familiar task of assessing the network connection, now have integration with the active management scheme to consider as well as all the other aspects of connection viability. The commercial implications of active management scheme introduction affect all stages of the connection process.

Demand customers on Orkney are not likely to experience any drop in quality of supply as a result of active management scheme introduction. System security issues have been assessed and it is thought that the active management scheme addresses concerns over this issue.

8.2 Future Work

This project has identified the following areas for future investigation. This will lead to greater understanding of active management and also provide practical guidance for users.

- The complexity of the scheme lies in the definition of the *operating margin* based on many variables: generation characteristics, demand levels and communications links employed. The operating margin can only be defined when all of these parameters are known and assessed in the light of careful analysis of the logic behind active management scheme operation.

- The *lessons learned* from this project and the steps taken in designing and specifying the active management scheme provide a reference point for other applications. The employment of such active management schemes will enable the tapping of increased renewable resources without expensive upgrading of the distribution network. Increased connections, due to active management schemes such as the one outlined in this project, mean that active management has the potential to play an important role in meeting national renewable energy targets. Further work in this area might investigate the applicability to other areas of the principles developed for the Orkney system.

- A key consideration is the *planning of active management schemes*. Many options for active management exist but it is clear that evaluating the options and selecting then developing the best option for a particular scenario requires a new set of methods for system planners. Further work could investigate such active management planning methods.

- This project has proposed a conceptual model for active power flow management for Orkney. Further, and more *detailed, analysis* could yield enhanced insight in to the benefits and drawbacks of such approaches to active management. For example, the areas of network security evaluation, evaluation of levels of constraint and development of generic logic control sequences are believed to have further potential.

Appendix 1 - Logic Parameters and Functions for Orkney Active Management Scheme

NAME	FUNCTION
X1	Loss of communications to SCADA
X2	Export to mainland exceeds lower threshold
X3	Generator 1A online
X4	Generator 1B online
X5	Generator 1C online
X6	Generator 2A online
X7	Generator 2B online
X8	Generator 2C online
X9	Fault on 33kV network – main platform
X10	Export to mainland exceeds upper threshold
X11	Kirkwall initiate trip control instruction
X12	Kirkwall reset/enable
X13	Export above 'connection enable' level
TD1	Time delay for loss of communications. trimming initiated (19 mins)
TD2	Time delay for loss of communications. Trip after trimming initiated (1 min)
TD3	Time delay for satisfactory trimming response from generator (20 sec)
TD4	Time delay for satisfactory trimming response from scheme (1 min)
TD5	Time delay for satisfactory tripping response (45 sec)
Y1	Alarm to SCADA for loss of communications
Y2	Alarm to generation for loss of communications
Y3	Control instruction to trim all NNFG due to communications failure
Y4	Control instruction to trip all NNFG due to communications failure
Y5	Overload Alarm to generation for imminent trim
Y6	Control instruction to trim NNFG
Y7	Control instruction to trim generator 1A
Y8	Control instruction to trim generator 1B
Y9	Control instruction to trim generator 1C
Y10	Trip all NNFG
Y11	Control instruction to trip all NFG
Y12	Alarm to SCADA, NNFG tripped
Y13	Control instruction to trip generator 1A
Y14	Control instruction to trip generator 1B
Y15	Control instruction to trip generator 1C
Y16	Alarm to SCADA - Generator 1A failed to trip
Y17	Alarm to SCADA - Generator 1B failed to trip
Y18	Alarm to SCADA - Generator 1C failed to trip
Y19	Alarm to SCADA - Generation tripped
Y20	NNFG stay offline (trip or trim in progress due to fault/loss of communications)
Y21	NNFG offline stay offline, online NNFG freeze maximum output (trimming activity)
Y22	Disable trim signal

Table 1: Core Logic Signals.

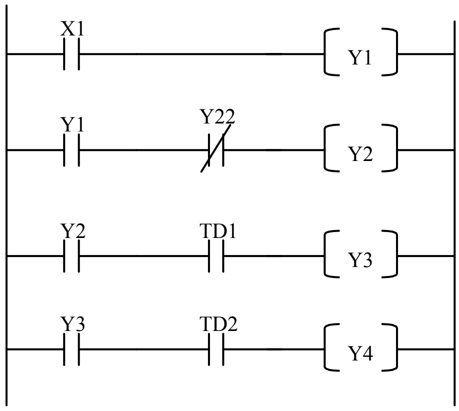
NAME	FUNCTION
X101	Export to platform exceeds lower threshold
X102	Generator A online
X103	Generator B online
X104	Fault on feeder/zone
X105	Export to platform exceeds upper threshold
TD101	Time delay – trimming imminent warning period
TD102	Time delay – inadequate trimming response period (40 Sec)
TD103	Time delay – failure to trip (45 Sec)
Y101	Alarm for imminent trim
Y102	Initiate trim NNFG
Y103	Control instruction to trim generator A
Y104	Initiate trim of generator B
Y105	Control Instruction to trim generator B
Y106	Control instruction to trip all NNFG
Y107	Control instruction to trip generator A
Y108	Control instruction to trip generator B
Y109	Alarm to SCADA - Generator A failed to trip
Y110	Alarm to SCADA - Generator B failed to trip

Table 2: Feeder/Zonal Logic Signals.

Appendix 2 – Ladder Logic for Orkney Active Management Scheme

9 Core Logic

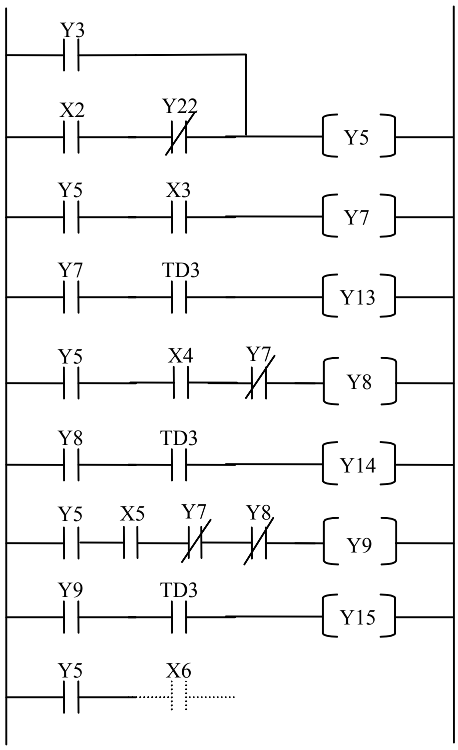
9.1 Loss of Communications



When there is a loss of communications to the SCADA system the logic gate X1 closes, resulting in an alarm Y1 being raised. This alarm also acts as an input and, as long as the disable trim contact (Y22) has not been opened, an alarm will be given to initiate the trim sequence for a loss of communications (Y2). This alarm has a delay (TD1) of 19 minutes before the control instruction is given to trim all NNFG (Y3). This control instruction is continued until either the communications issue problem is resolved or after a delay of 1 minute (TD2) an instruction to trip all NNFG (Y4) is issued.

9.2 Generation Trimming

The active management system acts to maximise the generation output on Orkney but will also trim generation when a pre-determined lower threshold for power flow is breached on the subsea cables to the mainland.



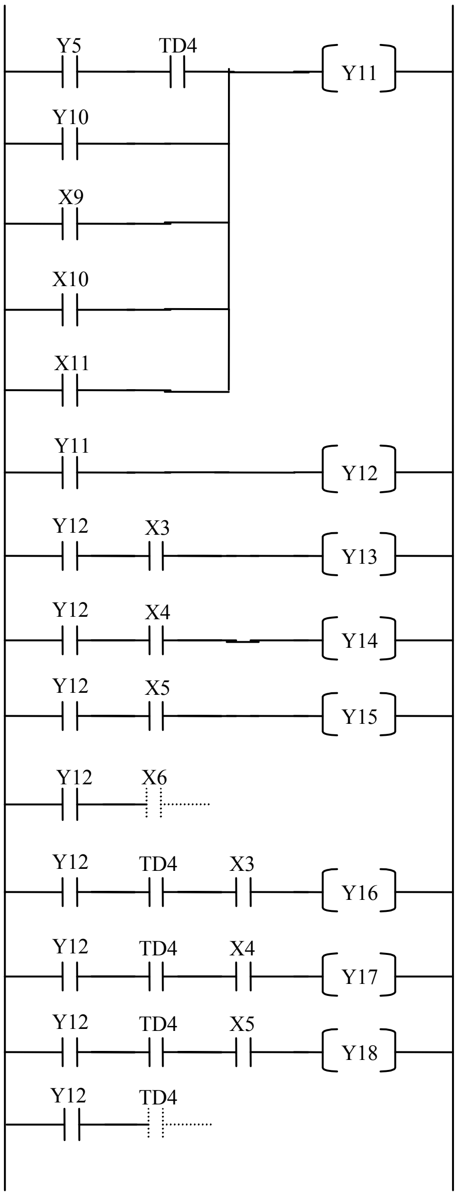
If the instruction to trim NNFG due to a loss of communications (Y3) occurs, or the lower threshold for export to the mainland is breached (X2) and providing the trim NNFG has not been disabled (Y22), then the scheme will begin sequentially trimming the NNFG. An alarm is given to the generators warning of an imminent trim (Y5).

The most recent generator to connect is approached first, generator 1A, and issued a trim control instruction (Y7), provided the generator is online (X3). After a time delay, generator 1A is tripped due to an inadequate response. Generator 1B is then approached and so on. This proceeds checking that Generator 1B is online (X4), as long as generator 1A is not being trimmed (Y7) then 1B is asked to trim and the procedure follows the same pattern as previous, eventually approaching generator 1C.

9.3 Generator Tripping

A 'global' NNFG trip is initiated from the incidence of several conditions:

- A signal to trim generation (Y5) which after a time delay of 1 minute (TD4) has still not reduced the power export below threshold
- A fault on the 33kV network on the main platform (X9)
- The export to the mainland breaches the upper power flow threshold (X10)
- The SCADA system initiates a trip of all NNFG (X11)

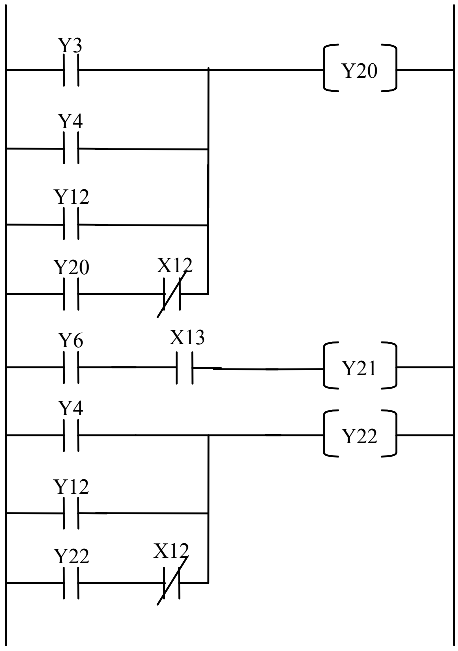


The control instruction to trip the NNFG (Y11) can be initiated through any of the actions listed previously. If there is a contingency on the 33kV network (X11) then all NNFG is tripped, at the same time the existing NFG will be intertripped in line with connection agreements made prior to this scheme. The control instruction to trip NNFG (Y11) leads to an alarm being raised to SCADA (Y12) indicating that the NNFG has been asked to trip.

The status of each generator is checked (X3-5), then they are tripped (Y13-15).

After the alarm has been raised to SCADA that a trip has been requested there is a time delay of 45 seconds (TD4) before the status of each generator is checked to indicate whether the trip has been successful. If not, then an alarm is raised to SCADA (Y16-18) which can be acted on either manually or by another automated response.

9.4 Lockouts and Enables



If a trip resulting from the breaching of a power flow threshold occurs (Y12) or a trim or trip instruction has been issued due to a loss of communications (Y3 and Y4 respectively) then a signal is sent to all offline NNFG to stay offline (Y20). This signal is put on a repeater rung via a Kirkwall reset/enable contact (X12) so that the offline NNFG will only be given permission to resume operation when the SCADA system provides this enable signal post event.

To prevent additional NNFG coming online which would immediately require trimming, a threshold for generation connection is introduced dependent on the power flow through the subsea cables (X13), which energises the NNFG connection lockout (Y21), which also acts as a signal to all online NNFG to freeze their maximum output.

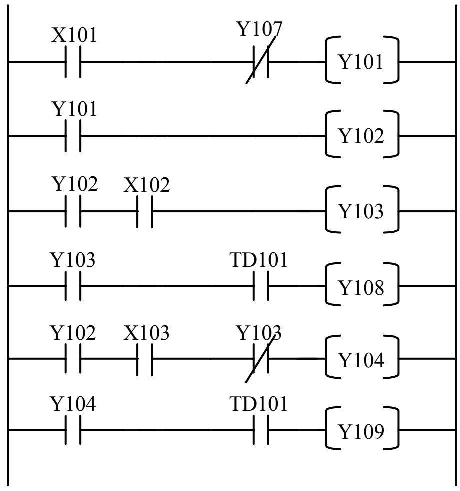
(Y4) and (Y12) are used as inputs to stop nuisance trimming signals to generation that has already been tripped through the output signal (Y22).

10 Feeder/Zonal Logic

The limits for the amount of generation are clearly dependent on the thermal capabilities of the specific zone or circuit, but the number of generators is individual to each application of the logic. A three-generator example (one FG and two NNFGs) has been chosen to illustrate the required zonal ladder logic. The approach adopted is adaptable for new connections and can be easily extended if necessary.

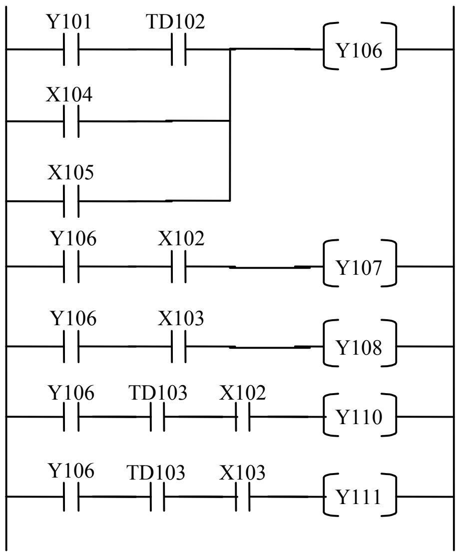
The logic for loss of communications and lockouts/enables is the same as described previously for the core logic. The generation output regulation and generation tripping logics differ from those introduced previously.

10.1 Generation Output Regulation (Trimming)



If the power flow into the platform exceeds the lower power flow threshold (X101) the signal (Y101) is energised which raises an alarm to SCADA, providing that the disable trim signal (Y107) is not energised, that there will be an imminent trim of the NNFG. The trimming of generation is then initiated (Y102).

(Y102) is used as an input to provide the control output instruction to trim generator A (Y103) after checking it is online (X102). After signal (Y103) has energised there is a time delay (TD101) after which generator A is tripped due to an inadequate response. If generator B is online, it is given the control instruction to trim as a result of either the inability of generator A to trim adequately or because generator A is offline.



10.2 Generator Tripping

As in the core logic, the tripping of NNFG can happen under several conditions. If trimming of NNFG is requested (Y101) then after a time delay of 1 minute (TD102) the NNFG will be tripped on the assumption that they cannot provide an adequate response to the trimming instruction. Tripping will also occur as the result of a fault on the feeder or within the zone (X104) or if the export to the core exceeds the upper threshold (X105). The trip signal is then sent to each NNFG, after checking that they are online using signals (X102) and (X103). After a time delay (TD103) if the generators are still online then an alarm is raised to SCADA showing that they have failed to trip.