Windcare / Infinite Renewables
Isle of Sark
Electrical Concept Report

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GLOSSARY OF TERMS & ABBREVIATIONS

The following Terms and Abbreviations have been used throughout the document:

ACRONYM	DESCRIPTION
BEMP	Brake Equivalent Mean Power
BESS	Battery Energy Storage System
BoD	Basis of Design
BS	British Standard
DNO	Distributed Network Operator
DG	Diesel Generator
E/F	Earth Fault
EN	Euro Norm
ENA	Energy Networks Association
ESQCR	Electricity Supply Quality and Continuity Regulations
FLC	Full Load Current
HV	High Voltage
IEC	International Electrotechnical Committee
ITT	Invitation To Tender
IRL	Infinite Renewables Limited
GFI	Grid Forming (Inverter)
GFL	Grid Following (Inverter)
LV	Low Voltage
NESO	National Energy System Operator
OLTC	On Load Tap Changer
PMS	Power Management System
RMU	Ring Main Unit
RTU	Remote Terminal Unit
pu	per unit
SLD	Single Line Diagram
XLPE	Cross-Linked Polyethylene

SECTION 1 - INTRODUCTION

1.1 Introduction

Aurora Power Consulting has been commissioned by Sancus Utilities Ltd. to carry out a concept study to develop an update for the HV and LV electrical network, to facilitate expansion of the island with a new generation system for the Isle of Sark. The work for Sancus is carried out on behalf of Chief Pleas, Sark.

The existing electrical network and generation facilities are at the end of their useful life and a planned upgrade of the whole island electrical infrastructure is planned by the island. The new generation requirement is being developed by Infinite Renewables Ltd.

1.2 Background

The existing network is based on a 6.6 kV distribution network, operated with a series of rings, and radial interconnections, and many step-down transformers. The existing system configuration is due to historic low demand, and a gradual evolution of the system over many decades, with an underlying strategy of adding in small Ring Main Units (RMUs) and transformers adjacent to existing loads. The existing electrical above ground network is largely past its serviceable life, however a significant portion of the below ground HV cable network is still serviceable.

The existing network is privately owned, and the current owner has indicated that they are unwilling to sell the network to the island, however it is possible that this view may change over time. The concept report assumes that the existing cable network may not be available for reuse but includes sufficient flexibility that reuse could be achieved if agreeable to the relevant parties.

1.3 Earlier Work

An early concept study was undertaken by The Energy People in 2022 [1], the report is based on a simple 11 kV, open ring distribution system, run as a loop around the network, using a main energy centre and seven (7) step-down transformers using simple RMUs and a more substantial LV distribution network, to reduce the HV costs.

The Aurora concept follows this underlying approach but alters the HV distribution design slightly to consider the HV requirements in more detail, and to provide an adequate HV protection system that is able to detect and clear faults quickly and safely.

This Concept Report is used to define the key aspects of the electrical design within the Aurora scope. The concept report develops the design concept in the initial Energy People report [1], to consider different distribution topologies to meet the planned new generation systems optimize cost, reliability, operability, losses, and expandability. The concept considers the Energy People report as the base condition, and proposes a number of alternative designs, that may offer increased performance, and lower cost.

1.4 Scope

The scope of this document is to define the electrical design concept for the HV distribution network to allow the network to proceed into the detail design stage. The LV design of the system is not fully developed at this stage of the system, due to the large volume of connections and would be developed during the detail design stages.

The concept design for the Generation systems and Energy Centre, along with all civil works are covered by 3rd party documentation. Cable routing and wayleaves / easements are to be developed and agreed by the office of Chief Pleas, Sark.

SECTION 2 - DESIGN PRINCIPLES

2.1 General Requirements

The aim of the concept study is to develop a design for the HV distribution network for the Island, to facilitate future generation plans, and provide a safe, reliable and cost-efficient design for the Island for future generations.

The HV system has been design on the assumption that it will have an operational life of 30+ years, during which the load and generation profile will change significantly, and the HV system should be able to cope with all reasonably foreseeable generation and demand changes.

The Electrical Distribution System shall be designed to provide:

- Safety to personnel
- Reliability
- High availability of supply
- Efficient operation
- Effective metering and control
- A co-ordinated system of protective devices
- Future expandability
- Possibility of provision of redundant supplies of enhanced availability to consumers with such requirements (e.g. medical centre, telecoms, island-wide emergency command/control facilities) if such consumers so request.

The design of the Electrical Distribution System shall minimise the possibility of electrical faults and reduce the consequence of any such faults to a minimum. This shall be achieved by providing:

- Equipment with adequate insulation levels for the connected voltage level
- Switchgear with adequate make duty and interrupting capacity
- Equipment with sufficient through fault capability
- Equipment and materials with sufficient continuous current carrying capacity
- Protection to detect and clear faults within the assigned ratings of the electrical equipment
- Network and protection design that, as far as possible within other constraints (e.g. cost), minimises the number of consumers impacted by a network fault
- Control and indication facilities that support safe working practice

- Facilities for maintenance

2.2 Concept Design Principles

Concept studies for whole system designs face several challenges, as engineering for future scenarios becomes increasingly difficult as longer timescales are considered. Significant events can occur on technology, climate change or social demographics that fundamentally shift current estimation techniques.

The current network design load has been specified to be 2500 kVA, to match standard equipment ratings. The network design considers two possible operational voltages of 11 kV and 6.6 kV, giving an equivalent continuous current rating as shown below.

- 2500 kVA @ 11 kV = 131 A
- 2500 kVA @ 6.6 kV = 219 A

The actual network load will depend on the planned expansion of the island in terms of electric cooking, rebound load (load suppressed due to high costs) and a move towards electric heating (heat pumps or storage), and immersion water heaters. This is discussed in detail in Section 4 of this report.

The system has been designed to be ‘generation agnostic’ i.e. capable of running any mix of generation safely and reliably. It is however noted that some additional requirements are necessary for running in 100% renewable energy mode.

2.3 Site Conditions

The design of all electrical equipment shall comply with the Project ambient conditions and shall be capable of continuous operation at peak conditions. The following general service conditions are used based on Section 4.4 of BS EN 61936 [2], considering ‘normal conditions’ and Table A-22 (UK) of BS EN 60287-3-1 [3] for cables:

- Outside
  - Maximum Ambient Air Temperature 40°C
  - Minimum Ambient Air Temperature -10°C
- Inside
  - Maximum Ambient Air Temperature 40°C
  - Minimum Ambient Air Temperature -5°C
- Wind Speed – <34ms^{-2}

- Solar Radiation – 1000 W/m^2
- Cable Installation
    - Maximum Ground Temperature 20°C
    - Minimum Ground Temperature 0°C
    - Soil Thermal Resistivity 1.2 Km/W (Damp Soil)

Note that as Sark is located to the South of the UK near France, then Table A.7 of BS EN 60287-3-1 could also apply, but the location and geography of the island make Table A.22 more appropriate.

2.4 Key Assumptions

The following assumptions are currently used within the Concept report.

1. The network design life should be 30+ years.
2. The network design load has been advised by Chief Pleas for up to 2500 kVA for initial design purposes.
3. Actual LV load details and future energy cases scenarios have been provided by Chief Pleas. Future load demand is estimated using standard UK diversity figures as a starting point.
4. The currently proposed generation is a mix of Diesel Generators (DG) and renewables including solar, wind and battery storage. The final mix and specification are within the Infinite Renewables scope and will be agreed with Chief Pleas.
5. The system design is intended to be able to run on 100% renewable generation when there is sufficient wind and solar. However Diesel Generators (DG) would always be available for black starting and low wind / solar days.
6. All cable route finding, route proving, wayleaves and easements will be managed by a 3rd party.
7. The Isle of Sark design should be considered as full island system. UK Design Standards will be followed where practical, but full alignment may not be followed, where it presents a significant cost, as small island networks have a number of additional constraints in relation to managing system voltage and frequency.

2.5 Design Standards

The electrical system design will be based on UK practice and BS EN standards, with reference to ENA practices where appropriate. However, it is recognised that the Sark Island is small and full compliance with UK practices in all areas may not be desirable or necessary, unless it concerns safety aspects.

It is noted that the IEEE 2030 series of standards provides some useful reference material and design approaches for Microgrids.

The following key standards will be followed:

- Electricity Safety, Quality and Continuity Regulations (ESQCR) 2002
- BS EN 61936 (HV Installations Exceeding 1 kV)
- BS EN 60287 (Electric cables — Calculation of the current rating)
- BS 7671 (Wiring Regs)
- BS 7430 (Earthing)
- BS EN 60909 for fault analysis
- BS EN 50160 (Voltage Characteristics)
- BS EN 50522 (HV Earthing)
- BS EN 61000 (Voltage Quality)
- IEEE 2030.7 (Microgrid Controllers)
- IEEE 2030.9 (Microgrid Design)

Note that in the above lists, BS EN standards are referenced on the basis that the main contractors are UK based. It is noted at present there is good alignment between IEC, EN and BS EN for the above standards; however if a new version of an IEC standard is released (such as IEC 60909), then the project will review and may need to adopt the newer standard.

ENA standards such as P5, P28.2, G5.5, G81, G99, TS 41-24 will generally not be followed as these are specific to mainland UK and networks operated and designed to the Distribution Code and Grid Code. However, it is recognised that these can provide useful guidance standards for assessing system performance for Sark, and may therefore be referenced.

In some cases, other international standards and practices may be followed, if there is not a suitable BS / EN / IEC equivalent.

2.6 Little Sark

Due to the location and configuration of Litte Sark, and low load and small number of residents, the design is based on a single HV connection to Little Sark. The installation method for the new HV cable will be determined and finalised during the detail design stage.

2.7 Power Demand

The design target for the new system is defined as 2500 kVA (refer to Section 2.2). The existing island power demand is discussed in Section 3.3 in general terms, and a more detailed estimate of existing and future demand is developed in Section 4.

2.8 Generation & Generation Control

2.8.1 General

The distribution system and generation systems are fundamentally linked, and therefore consideration and co-ordination will be required between all design parties at each stage of the project. For example, changes in the generation approach and control system will influence the system fault levels and protection operation.

The generation will be located the energy centre, and is currently planned for connection at LV. It will be specified and designed by Infinite Renewables Ltd. (IRL). The generation will be a mixture of wind, solar and battery storage with diesel generators to provide backup power for low wind / solar. The current proposed mixture is:

- 3 x DGs: they may be different ratings but likely to be around 320 kVA each
- 2 x Vestas V27 225 kW turbine
- 500 kWp solar
- 1x 400-500 kVA battery with 500 kWh to 600 kWh storage

The above generation is suitable for a firm load demand of circa 640 kVA, assuming the renewables are unavailable and the DGs are operated as a n-1 configuration. The DG engine must be suitably rated to deliver continuous prime power. However, as noted in Section 2.1, the overall design demand for equipment sizing is a nominal 2500 kVA. It is therefore important to note that the generation mix proposed is for the short term demand cases, rather than for the final electrical design cases.

For future design planning purposes, it is therefore assumed that if the full design load is required, additional generation would be added. The mixture and composition of this future generation would be determined at a future date.

It is also noted that most modern diesel generators need a minimum load of around 50 % to operate satisfactorily. Loadings below this are possible but can lead to degraded engine performance and requires more frequent maintenance.

The main Energy Centre LV Distribution board will be the responsibility of the generation system. Detailed configuration of the generation system is not in scope of this report; however, it shall ensure that single outages do not impact the ability to supply total system load.

2.8.2 100% Renewable Operation

The generation design intent is that at some future point the island should be able to run on 100% renewable resources, should conditions permit. The island DG sets will be available for black start, outages, high demand and unfavourable weather conditions.

To operate successfully at 100% renewable power, some additional design requirements are necessary to be agreed in the early design stages; as such operation is more challenging technically, and requires a greater degree of protection and control, than conventional generation. Typical additional requirements would include:

- The battery storage system will need to be a grid forming inverter, that can provide voltage and frequency control in conjunction with the plant controller. The BESS inverter must be sufficiently reliable and proven design.
- Due to low fault current levels more complex protection schemes are required for 100% renewable operation. This will typically require the use of specialist control schemes with adaptive settings, and/or differential protection.

It is expected that 100% renewable power generation during very low load conditions may need to be constrained (i.e. night). For example, operating purely off the BESS, during very low load is unlikely to be possible whilst achieving satisfactory fault identification and clearance (refer to Section 2.13) and operating generation may need to be constrained, or DG units required to remain on.

2.8.3 Power Management System

A key aspect of the generation system will be development of the Power Management System (PMS). This will be a complex piece of control software that must be able to manage the generation and demand in real time, to ensure voltage and frequency control and stability of the system.

The PMS scope is part of IRL package of work associated with the generation scheme.

2.8.4 Load Shedding

Load shedding may be required to maintain overall system stability and prevent blackouts in the event of a system disturbance, such as an unplanned trip of a main generator, and uses selective load tripping to maintain overall system balance. Two types of load shedding are anticipated

1) Slow Load shedding – this will be implemented in the PMS (see Section 2.8.4) and use intelligent control to disconnect flexible loads. This is intended to work for slower frequency disturbances.
2) Fast Load shedding – this will be implemented with protection functions in key protection relays within the HV switchgear. This is intended as an emergency function to quickly disconnect circuits to preserve the overall system.

2.8.5 Intelligent Demand Control

One of the project aims for the Island is use of intelligent demand control and smart devices that allow active control in response to power shortfalls / excess. These are devices that are able to come on line when there is excess generation (high wind / solar), and also curtail demand during low generation days. Typical examples of such technology include:

- Heat Pumps
- Zero emission boilers
- Electric storage heaters
- Electric immersion storage tanks
- Smart thermostats

The main approach used for this technology on the UK mainland and other countries, is to have a Centralised Smart Controller, that interfaces to compatible smart devices, via an intelligent API interface over WIFI or radio signal, and trigger load to connect / disconnect in relation to system frequency and available generation. Main suppliers in the UK all do this via their own customised API control system, so all smart devices can be controlled remotely.

The key complexity in smart controllers, is the interface API between the Central Smart Controller and the smart devices. As Sark is a small island, with limited population, this needs detailed consideration, as a custom API would be required. It has been indicated that Alderney and Guernsey are both moving to smart metering systems in the near future, and it therefore may be possible to integrate with their proposed systems and align compatibility.

An alternative approach is to use much simpler electronic timers, akin to the classic Economy 7 tariffs, where there are different day / night tariffs, and where some loads have a timer to come on at a certain time. These require either a) Smart meter that can provide 1/2 hourly data or a separate meter with the Economy 7 loads on it. If smart meters are installed on the Island this can be made as a simple flat rate discount at night time hours (this however may depend on the generation source – providing discount when running on diesel, would not be desirable) or to something more sophisticated with SMS type alerts – however this requires active user participation.

The design of such systems are within the scope of Energy Centre package. and the overall design and integration of smart technologies will need to be developed by Sark and integrated with the generation control system.

2.9 Reliability, Operability and Backup Supplies

The Sark Island distribution system reliability is of key concern, as the island relies on electricity for water supply, front line healthcare and has only boat transport, so assistance from outside can be limited / slow. Furthermore, the site has limited access to operational personnel who can be made available at short notice for switching, fault finding and operational needs. It has been stated by Chief Pleas, that routine fault finding, and operational needs can be met by island personnel, but it is assumed that more complex systems operation and maintenance would require personnel travelling over from Gurnsey.

It is therefore assumed that the network, must be designed in a way that in the event of an outage, the main power system for the island would remain largely intact, and the number of customers off supply should be limited.

In general terms, the more reliable a system is, the more expensive the system costs. This is due to increased costs of switchgear, cables and control and monitoring systems. Current UK mainland practice for distribution network is that the HV networks are ‘n-1’ redundant (i.e. can withstand a single outage), but that restoration of supply is through manual intervention by an HV authorised engineer.

In the UK mainland LV supplies are typically ‘n’ (non-redundant), due to costs, and restoration of supply is through emergency utility call out who repair the connection. This approach suffers from similar issues to the HV network, although the required level of expertise to repair an LV system, is significantly reduced compared to an HV network. In a non-redundant system, a fault on the system will typically lead to disruption / loss of power for multiple consumers, and therefore this must be mitigated by the ability to identify, clear and repair faults quickly.

It is therefore assumed that a key design goal that the main network has sufficient level of redundancy that an unplanned outage (fault) can be tolerated, and automatic switching can maintain overall electrical network security for most of the island. Network automation techniques with overall supervision from the PMS system can provide this. This requires a communications network (fibre or secure wireless) to be provided and redundant power supplies for same. This is not included for in the scope of work and is therefore discounted.

2.10 Electrical System Performance

2.10.1 General

Maintaining satisfactory electrical performance is essential in any electrical system. Consideration must be given to enabling a regulatory framework for Sark, to ensure that any connection of large disturbing loads or private generation is reviewed and managed before connecting to the network, in order to prevent unacceptable voltage disturbance to other users.

The impact of new and existing private generation must also be assessed carefully, in order to prevent nuisance behaviour and disturbance on the system – it may be necessary to impose constraints on such operation and developments.

2.10.2 Standards

The general requirements of design standards for Sark, is detailed in Section 2.5. These standards are generally suitable for most applications, but for voltage and frequency control on a small network are likely to be too restrictive. Typical voltage and frequency steady state and transient limits, from the UK mainland, BS EN 50160 and ISO 8538-1 are shown below, along with suggester limits for Sark. These limits can be reviewed and revised during detail design, when final generation sets performance details are available.

Parameter	Steady State Limits					Transient / Protection Limits		
	UK Mainland Staturory Limits (1 & 2)	IEC 60034-1 Zone A (Continious)	IEC 60034-1 Zone B (Continious)	BS EN 50160	Limits for Sark (3)	ISO 8538-1 (4)	G99 (UK Mainland)	Sark Protection Settings (ISO 8528 - G2) (5)
Under Frequency	0.996 Continious 0.99 Statutory	0.98	0.95	0.98 Continious 0.85 Transient	0.95	0.95 Continious 0.9 Transient @5s	0.95@20s 0.94@0.5s	0.95@30s 0.9@6s
Over Frequency	1.004 Continious 1.01 Statutory	1.02	1.03	1.02 continious 1.15 Transient	1.03	1.05 Continious 1.1 Transient @5s	1.04 @0.5s	1.03 @30s 1.1 @6s
Under Voltage	0.9 Continious Short Time - P28	0.95	0.9	0.85	0.9	0.9 Continious 0.8 Transient @6s	0.8 @2.5s	0.9@30s 0.8@7s
Over Voltage	1.06 Continious Short Time - P28	1.05	1.1	1.1	1.1	1.1 Continious 1.2 Transient @6s	1.1 @10s 1.13@0.5s	1.1 @30s 1.2@7s

Notes

1) Frequency Limits are set in ESQCR [4] and NESO 'Frequency Risk and Containment Report' [5]

2) Voltage Limits are set in ESQCR, transient limits are set in ENA P28.2

3) No current IEC standard for Microgrid - BS EN 50160 has some wider limits for islanded systems

4) Limits depend on class of Generator (G1, G2, G3 and G4) - G2 values shown as this is the most common type based on BMEP values

5) Stage 1 time set at continuous value for 30s. Stage 2 set at 1s above transient time limit of G2 machine limit

2.10.3 Voltage Control

The system voltage control can be implemented either through OLTCs on the step-up transformers in the Energy Centre, and used to regulate the voltage on the HV network, or via the LV generators at the Energy Centre, provided they have suitable control and regulation systems.

Regulation through OLTCs is preferable as it allows a greater degree of accuracy and management, however as noted in Section 2.12.2, OLTCs on small transformers are unusual, and generally bespoke designs, so incur additional cost. The system voltage regulation via the LV bus, is therefore preferable where possible. It will be essential for the generators to have a terminal voltage range of +/-5%.

2.10.4 Frequency Control

The system frequency control must be managed by the Power Management System, as detailed in Section 2.8.3, by balancing available demand and generation. Backup emergency load sheeting to maintain system frequency may be implemented in key HV feeder as detailed in Section 2.8.4.

2.10.5 Power Quality

Power Quality is considered in terms of voltage flicker, associated with disturbances due to intermittent loads and network load steps and network harmonics, due to disturbing loads.

- System voltage disturbances limits need further review, and development and will depend on any industrial loads. The island contains minimal disturbing loads, however consideration would be needed for any electric welding equipment at the island workshop, starting of any large compressors or large electric cookers in the hotels and cut-in associated with the wind turbines. Voltage disturbances and flicker will be assessed against P_{st} and P_{lt} limits in BS EN 50160 or ENA P28.2.
- The level of harmonics on the system are not widely understood, however as most of the island load is low level domestic loads, the values are not expected to be high. The introduction of inverter based renewable generation (solar, wind and storage) along with possible disturbing loads with heating pumps is likely to increase level of disturbance. Harmonic disturbances will be assessed against the limits in BS EN 50160 or ENA G5.5.

2.11 Network Voltage Selection

The existing island operates at a nominal system voltage of 6.6 kV. As part of the planned island upgrade consideration has been given to increasing the system voltage to 11 kV. The relative advantages of 11 kV over 6.6 kV, are primarily due to the lower equivalent current rating, and higher power transmission capacity for equivalent switchgear sizes and cable ratings.

Standard HV switchgear within the UK has a **minimum** rating of 200 A, and equipment rated at 400 A or 630 A is only fractionally more expensive. Therefore, there is no significant difference in the switchgear costs. Similarly, equipment rated for 6.6 kV is usually also capable of operation at 11 kV. The existing HV cables in the network, are of recent installation and were specified as 11 kV, although operated at 6.6 kV and could therefore be used at either voltage level (although some older ones are only rated for 6.6 kV). The network cables, apart from the Harbour supply, have a cross-sectional area of 25 mm^2. The cables are all direct buried and have a nominal continuous current rating of 140 A. As the island has no significant derating factors, the cable current carrying capacity is equivalent to:

- 140 A @ 11 kV = 2667 kVA
- 140 A @ 6.6 kV = 1600 kVA

The use of 11 kV would generally be preferred for a network with limited redundancy i.e. a single ring, as the network should be rated to carry the whole network capacity in case of an outage. The use of 6.6 kV would be suitable for networks with a higher level of redundancy, such as 3-legged ring (in the existing network).

A further consideration that is also important is the minimum load current flowing in the system. Where network load current is very low, this can cause problems with correct operation of switchgear protection operation, as self-powered relays, require a certain current flow to operate and sense disturbances. This could be a potentially significant problem in the early years of the project, where network loads are low – current minimum demand is circa 250 kW, equivalent to 23.0 A at 6.6 kV, but reduces to 13.8 A at 11 kV. This would be satisfactory for main ring feeders but would be much less for smaller network transformers.

Considering the above factors, distribution voltages of 11 kV and 6.6 kV are both considered viable; however, the use of 11 kV may create problems in the early years as the load demand will be very low, resulting in low current and potential problems with relay mal-operation. The final choice on system voltage, is therefore based on the electrical topology of the distribution system and obtaining accurate load information.

2.12 Equipment Selection and Specification

2.12.1 HV Switchgear

HV switchgear can be split into two main types 1) Primary distribution and 2) Secondary Distribution. Primary distribution switchgear has higher current carrying capacity and fault rating but can also use more sophisticated protection and control relays which allow better system operation and performance. Secondary distribution switchgear is usually much cheaper, as it has lower rating, has limited remote operability capabilities and uses relays with limited functionality.

HV switchgear circuit breakers are usually specified on the R10 series of ratings and are generally rated at: 200 A, 400 A, 630 A, 1250 A, 2000 A, 2500 A. The costs of circuit breakers increase as the current rating increases.

The suitability of different types of HV switchgear and the potential drawbacks and advantages to the proposed network configurations are detailed in the relevant section of this report.

2.12.2 Transformers

For small distribution networks transformers will usually be oil-filled, hermetically sealed units and designed to meet low loss requirements of more modern European Union Ecodesign Regulations. Whilst these are not necessarily mandatory, using low loss equipment is generally beneficial.

Transformers using Midel as the insulating agent are not considered due to cost; they may be considered where the risk to adjacent buildings in the event of a transformer fire is considered unacceptable. This risk can usually be eliminated by suitable location of the transformers. An oil-containment bund surrounding each transformer is considered normal practice to capture oil spills in the event of tank breach. Sizing of the bund is usually such that the entire oil volume of the transformer is captured by the bund.

Oil-filled transformers are not considered suitable for indoor installation due to fire risk and use of cast resin transformers is not considered suitable for the island, due to increased losses, and additional safety requirements. Specific fire risk and firefighting measures will be considered during detail design.

Step-up transformers at the Energy Centre connecting generation sources to the HV Distribution Network are planned to use YNyn0+d11, vector group to allow earthing of both the HV and LV neutral and avoid additional earthing transformers on the HV network. It may be necessary to use standard Dyn11 transformers and use zig-zag grounding transformers on the 6.6 kV system (Refer to Section 2.13.1).

The step-up transformers **may** need to be provided with on-load tap changers to control HV system voltage under the wide load variation experienced; however it may be possible to regulate the network voltage on the LV busbar, through the generators, provided they have a sufficient control functions.

Ideally, OLTCs would be avoided, as tap changing mechanisms require regular routine maintenance to avoid various failure mechanisms, although temporary operation with a tap changer stuck in one position is usually possible. It is also not common for transformers of the required rating to be so fitted with OLTCs, so these transformers may have to be new-build rather than sourced from suppliers of refurbished units.

2.12.3 LV Switchgear

LV Switchgear for the island is split into two main categories 1) Main LV distribution switchgear and 2) Local feeder distribution pillars.

Main LV distribution switchgear will be used at key substations such as the Energy Centre and will be based on the use of Air Circuit Breakers (ACBs) or Moulded Case Circuit Breakers (MCCBs) to provide main power distribution. The main LV distribution switchgear will be specified in the Electrical Basis of Design (BoD), but typically be configured in a redundant configuration with two main incomers, and a normally open bus-section with an automatic transfer capability.

LV feeder distribution pillars will be used to connect to provide distribution to smaller areas and will be based on MCCB feeder design. The use of fuses on LV pillars is not considered appropriate due to the lack of sensitivity in fault detection and clearance.

The specification and configuration of the LV Switchgear at the Energy Centre is part of a different work scope package.

2.13 Earthing

2.13.1 HV Earthing

The HV neutral points will be connected to earth via the HV star winding, of the step-up transformers at the Energy Centre (refer to 2.12.2). The neutral will be impedance earthed via Neutral Earthing Resistors (NERs), to ensure there is sufficient fault current for protection to operate, but to limit any potential Earth Potential Rise (EPR) risk. The NER rating will be determined during detail design, but typically be between 400 A and 1000 A.

The use of zig-zag grounding transformers on the HV was considered, and discounted due to the additional cost of the circuit breakers and transformers.

Depending, on the results of the soil resistivity surveys, the use of a solidly earthed HV neutral may be considered in detail design.

2.13.2 LV Earthing

The LV system earthing strategy will depend on the overall adopted strategy for upgrade of the island LV network. If the LV system is replaced entirely, then the use of a TN-C-S / PME system would be preferable for most applications (some specific island applications may be unsuitable). If the LV system is upgraded later or in a staged approach, then following a TT earthing strategy may be more suitable.

Feedback from similar systems on nearby small islands, is that TT earthing systems have been used successfully and are easier to manage and maintain than a PME system.

The final decision on LV earthing strategy will be made during detail design.

2.14 Protection, Control and Automation

2.14.1 General

The protection, control and automation scheme for any network is of critical importance to the system design as faults must be identified and cleared (isolated) quickly, to prevent unsafe operations, risks to personnel and equipment. Correct selection and operation of protection is therefore a fundamental safety requirement that must be adhered to in any scheme design.

Protection schemes for a systems that run on 100% renewables are significantly more complex than traditional network protection. This is because the generation schemes can vary significantly, and load, demand and fault levels can change depending on system operating profiles and network configuration. This is discussed in some detail in [6].

Standard protection schemes using simple time based over current and earth fault are intended for UK mainland systems, and are based on the underlying principle that there is a significant difference between load current and fault current. These relays are generally operated on a time-based inverse curve, such that should a fault occur on the system, only the relay closest to the fault will operate, so a minimum number of consumers would lose supply.

The selection of a suitable protection scheme is of critical importance for safe operation of a microgrid and can also increase cost and complexity.

2.14.2 Protection

Protection of small grids is complex, and has some fundamental challenges that can affect the overall system design and cost. The challenges faced by system with high renewable penetration and embedded generators protection are discussed extensively in a number of technical publications and journals [5] & [6]. The fundamental problem with microgrid / 100% renewable protection design, is that conventional protection (discussed above), does not generally work well. Protection schemes face a number of technical difficulties not present in conventional grid networks; for a detailed technical discussion, refer to Appendix A.

2.14.3 Protection Design & Application to Sark

In the Isle of Sark, the is no external grid reference source, to allow system stabilisation and existing load is very low and will have a low power flow on the HV network. Further there are potentially several different generation options, and some of these will not produce a comparatively high fault current, particularly if operating with only 1 x DG or in 100 % renewable mode.

A further complication arises for the Isle of Sark, as the current system demand is low (circa 350 kW), and the proposed generation mixture is only suitable for around 500 kW-750 kW.

The ultimate design is for a 2500 kVA, and the protection scheme settings are likely to need multiple updates.

The suggested approach for Sark, is to adopt a simple adaptive protection scheme based on alternate settings groups of protection relays configured in the main energy centre, based on the generation mix and the network condition (intact or outage cases). The use of the adaptive settings allows the network feeders to be set according to specific operating scenarios, and ensuring fault detection and grading is achieved with the network.

The protection settings for the system will need periodically updating (suggested every 5 years or after any major upgrade), as the network load increases and the equipment and transformers are utilised more.

Whilst, the use of adaptive overcurrent protection is the cheapest approach and uses simple standard relays, it faces some challenges. As alternate settings groups are more complex to manage and understand for operators, and managing moving between the main and alternate setting groups.

The alternative approach is to either use a large radial network, where each circuit load is substantially different to the total load, or to adopt the use of differential protection throughout the network. Radial network design is relatively simple to implement, but can result in a significant increase in costs, and a lack of redundancy Differential protection can be achieved on the main HV cables, and larger transformers, but requires the use of primary switchgear and communication links between each substation on the network, which significantly increases network cost and complexity.

The use of other protection methods is not considered suitable for Sark, and are not developed further. Refer to [5] for further information.

An adaptive protection scheme is considered the most suitable approach for the network. A possible scheme is described in Appendix A of the document, but the final decision cannot be taken until load/generation scenario over time and network configuration has been agreed.

2.14.4 Minimum Operating Current

It is also noted that standard protection relays used in an RMU, are self-powered relays and need a certain minimum current to operate. During low load / low generation / 100% renewable power condition, there may not be sufficient current to enable the relay to detect the fault and operate satisfactorily. Typically needing a minimum load current of around 5% of the CT rating. If load current falls below this value, then a minimum fault current is required and further time delays can be incurred in fault clearance.

2.14.5 Relay Automation and Control

Automation of the HV and LV electrical network is a key design aspect, due to the island location and limitation of available personnel. However, it is recognised that automation systems and SCADA can become very complex and expensive if not specified correctly. It is recommended that the system is provided with sufficient level of switching automation to ensure automatic restoration of power generation is possible, and assessment of the overall control system / PMS is carried out in detail design by IRL.

As a minimum, it will be necessary to ensure that there is there is a communication link between the generation control system and the main HV protection relays that supply the key HV feeders, and the HV protection relays will need to be provided with adaptive control systems / alternate settings groups, that are able to change settings depending on the generation mix.

Further consideration should also be given to installation of a web-based control interface where operational personnel are located remotely, could access the system and identify system behaviour, outages, and network disturbances etc.

SECTION 3 - EXISTING NETWORK

3.1 Introduction

Sark currently has an existing electrical network that consists of a 6.6 kV distribution system with a large number of transformers, RMUs and LV feeder distribution systems. The existing system is owned and operated by Sark Electricity Limited (SEL).

3.2 Existing Generation

The island is currently powered through a series of small diesel generator (DG) sets, located in the power station on the island. The exact configuration and make-up of the generators is not known, however anecdotally the following information has been obtained in relation to the existing system generation:

- 3x DG sets
    - 1 Large set (around 500 kVA)
    - 2 x Smaller sets (around 250 kVA)

The larger set is run during the day & smaller one at night, with the 2nd smaller set used in peak demands or as a backup supply.

3.3 Existing Power Demand

The island power demand has a peak operating demand of up to 400 kW, as detailed in the ITT; the same document notes that in recent years the demand has been falling to as low as 300 kW; although historically it had been as high as 870 kW [4]. The ITT document indicates that demand is expected to increase over the coming years due to increased home working, electrification of heating and cooking, electric transport and potential opening of old Hotels. The Le Fort / La Tour region is currently disconnected from the main island system but is intended to be included in the new system.

The Energy People report [1], indicated that the network was lightly loaded at around 250 kW, it is also noted that in the report demand could be suppressed significantly due to local views that electricity cost is too high. No actual site load data has been provided from the island, so an accurate load profile is not available. A plot of the expected energy demand from Alderney is shown below, which is through to be broadly similar to Sark.

The existing load demand profile is unknown, along with individual loads for each of the substations. Some estimates may be possible from the installed transformer size, but this is problematic due to the historic nature of the site, and the general uncertainty on the site.

  - 200 kW nominal load
  - 160 kW low load normal
  - 260 kW high load normal
  - 100 kW low load at night (much higher than expected)
- Stocks Hotel is the biggest single user (but also has generation)
  - 77 kWp Solar
  - 150 kWh battery storage
  - DG set (rating TBC)
- Private landowner at La Tour has a circa 22 kW solar PV and presumably some storage, but is disconnected.
- Seigneurie has been off grid for a while, and has recently come back on grid due to problems with their self-generation.
- There will be a potential future hotel & golf course near Beauregard, although this is a long term aim, rather than a firm plan.
- There are also a number of unoccupied properties that may become occupied and new buildings in production.
- Societal factors and high existing electricity demand by suppressing demand.

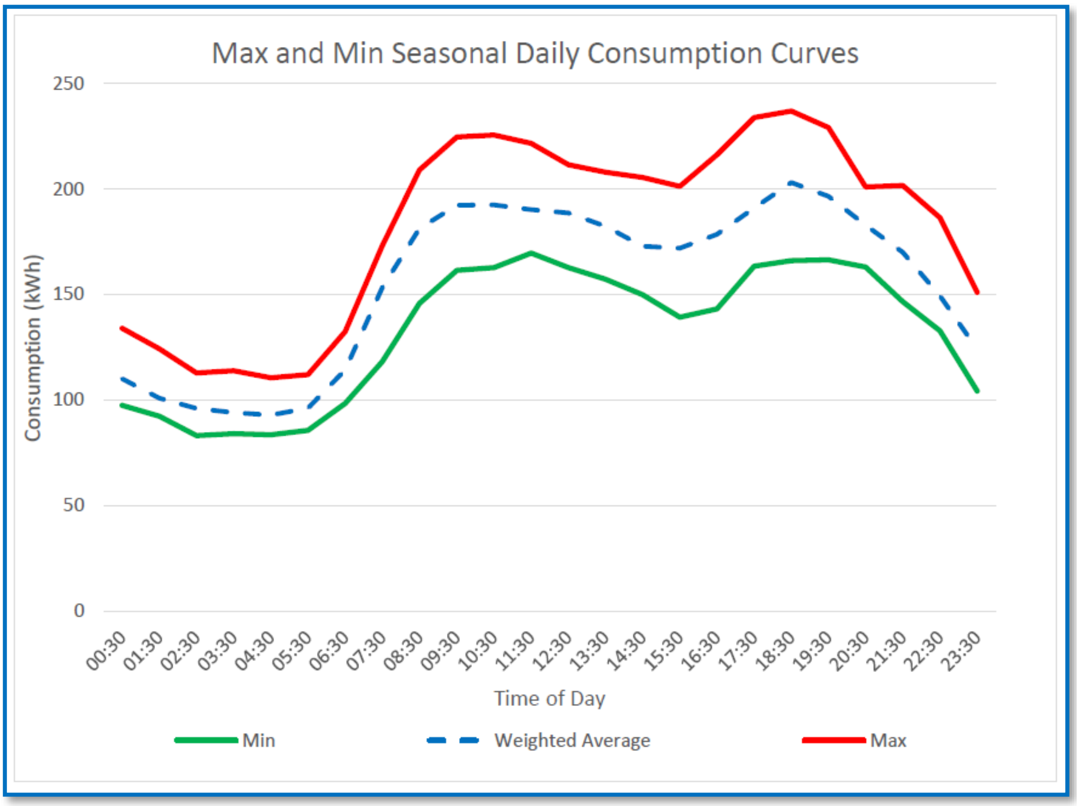

Figure 3-1: Demand Profile From Energy People Report

3.4 Existing System Configuration

Existing information of the SEL network has not been generally made available to Aurora, however a copy of the existing Sark HV network cable routes is shown in Figure 3-2 below. From this figure, and through various site visits and investigations it was possible to construct a mode of the existing power system in DIgSILENT Powerfactory, the loads at each substation were then estimated based on the information provided by the Electricity Price Commissioner. A model of the electrical system can be seen below in Figure 3-3. The HV network is configured as a ‘3-legged ring’, that is run normally closed.

The existing network contains a very large number of small substations (RMU’s and HV switches) for the relatively small size of the island; this is largely due to historic reasons, where investment has been staged over many years; the HV network has been expanded slowly but progressively over many years. The system has several dedicated radial feeders run from the network to certain locations:

- Little Sark
- La Valette

- The Harbour
- La Tour (currently disconnected)

The whole electrical network is considered to be in very poor condition, with all of the above ground HV assets (transformers and switchgear) at end of life, although the HV cables are of relatively modern design. The LV network status is largely unknown but understood to be in very poor condition. No protection is provided on the HV network, and in the event of a major fault, the whole HV network is tripped until the fault is found, isolated and repaired – this means that all consumers on the island will be without power until the fault is found and repaired. LV protection is via local LV fuses, and concerns have been raised about the system effectiveness and safety. The possibility of reuse of existing equipment is discussed in Section 3.5.

An SLD of the existing system (created by Aurora), can be seen in attachment [A1].

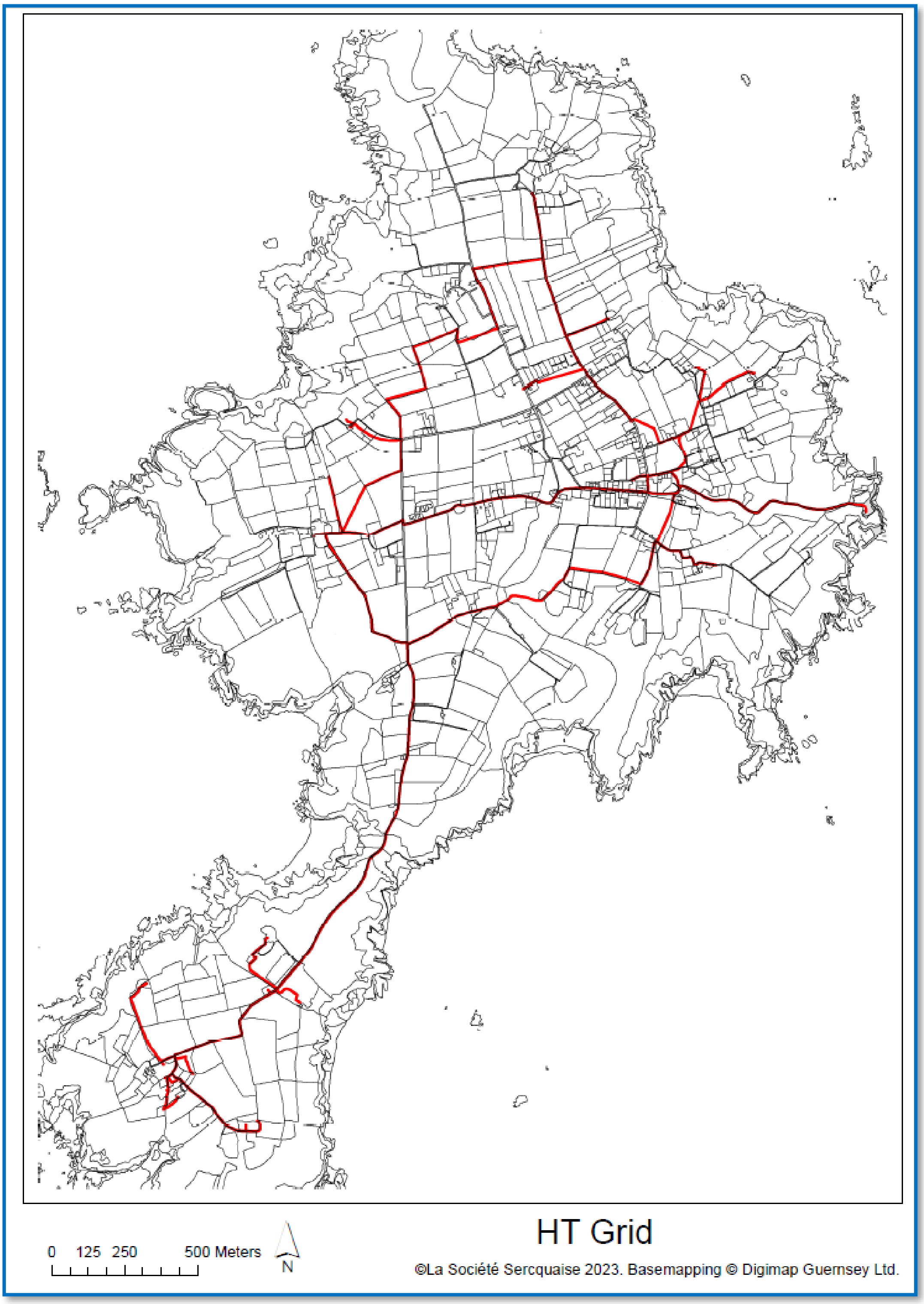

Figure 3-2: Existing HV Cable Routes

Figure 3-3: Existing Network

3.5 Reuse of Existing Infrastructure

The existing electrical HV above ground network (transformers and switchgear) is largely past its serviceable life as indicated by the report from EI Services [5]; the HV protection elements are non-existent and do not provide sufficient level of fault detection and clearance; any HV fault requires disconnection at the existing power station LV bus, with consequent widespread loss of supply to consumer. It is therefore necessary to replace the above ground HV systems.

During initial investigations, it was identified that a significant portion of the below ground HV cable network is of modern XLPE design, rated at 11 kV (but operated at 6.6 kV) and is still serviceable. The cable sizes used on the island are generally very small, with most of the network with a cross-sectional area (CSA) of 25 mm^2, equivalent to an approximate load rating of 140 A when direct buried. This cable therefore has a limited power handling capacity to cater for future loads, equivalent to 1600 kVA at an operating voltage of 6.6 kV, or 2667 kVA at an operating voltage of 11 kV. The cable to the harbour has a CSA of 35 mm^2, and the cable across the Coupee is an older style PILC cable.

Reuse of the below ground cable system is therefore possible, subject to the necessary agreements being in place. However, the small size of the buried cable network limits the overall system rating, and can cause potential voltage drop issues, which therefore may require reinforcement.

It should be noted however that whilst it should be possible to operate most of the cable at 11 kV, it is expected that when the system voltage if the voltage is increased a number of joints, terminations and cable sections may fail initially due to the increased voltage stress.

3.6 Power Quality & Performance

A key requirement of any power system is that it provides a stable and reliable supply to consumers. This is typically measured in terms of availability and reliability for uptime and outages, and for quality the system frequency and voltage flicker are measured. No island data is available to understand existing performance, and therefore it is assumed that there are no specific problems.

It is understood that there have been several significant incidents and outages on the island and fault finding can be difficult and time consuming. This is due to the lack of coordinated protection scheme or any HV protection.

SECTION 4 - LOAD DEMAND & FORECASTING

4.1 Introduction

One of the fundamental challenges in power system design for systems is correctly estimating the load demand. If the load is underestimated the HV electrical system will be unable to meet the required demand and overheat, become stressed and may fail. Conversely if the electrical load is significantly overestimated the HV electrical system will cost significantly more, be under-utilised and the lack of current flowing through the network can cause nuisance trips and disturbances.

Existing and future demand needs to be considered as an overall system value to allow sizing and configuration of the Energy Centre and HV distribution network, and also at a local level to allow estimation and sizing of transformers and switchgear.

4.2 Future Demand Scenarios

Initial discussions held during the tender stage indicated the design requirement may be for up to 2500 kVA. This represents a significant increase over current demand, which is believed to be around 250 kW to 300 kW (refer to Section 3.2 earlier in the report). Correct load forecasting is difficult on small systems where there are a lot of unknowns and the future energy scenarios are not that clear, and this is addressed and estimated within this section of the report.

Sark contains little industrial base, and the majority of the island load is either domestic or agricultural loads, along with a number of hotels. Therefore, in the case of Sark, significant complexities arise as the small size of the island mean that standard estimating approaches do not work as well, due to the small population size and additional local variables associated with supressed electricity demand due to high electricity costs, expected future growth. Typical large domestic loads are driven by consumers such as:

- Heating
- Cooking
- Washer / Dryer
- EV Charging

EV charging is not typically applicable to Sark as the island is car free, but a large number of electric bikes are present.

In relation to domestic loads, some key points advised by Chief Pleas are summarised as follows:

- Island electric load is supressed due to high electricity costs, if electricity tariffs fall there is expected to be an increased usage. This would bring demand closer to UK norms.
- The majority of cookers are gas, but there is no longer a registered gas engineer on the island and there is likely to be wholesale shift over time. It is noted that cooking loads tend to be large, but relatively short duration.
- The majority of houses of oil / gas heated, but this is expensive and there is a general desire to move to electric heating if financially viable.
- There is possibility of a shift to electric tractors and other vehicles on the island, however due to the large capital cost of these items it is not clear when these will be deployed. Some opportunity may exist in this area to use Vehicle to Grid (V2G) technology to provide bi-directional power flow and help store excess energy.

As well as domestic loads, it is also important to consider the key high demand consumers on the island, for future changes in consumption pattern and any future changes that may occur. At present, the main changes expected include:

- The hotels on the island moving to cold (electric) kitchens
- Increased commercial loads for any arc welding equipment
- Possible deployment of air conditioning

Based on the above factors, Chief Please have provided a number of different future energy scenarios, to be considered:

1) Base Case – existing network load
2) Case 1: Electric Cooking – existing network load with transition to all electric cooking and some rebound load
3) Case 2: Electric Cooking + Heat Pumps – existing network load with transition to all electric cooking, rebound load and heat pumps for all inhabited properties
4) Case 3: Electric Cooking + Heat Pumps + Water Immersion Heaters — existing network load with transition to all electric cooking, rebound load and heat pumps for all inhabited properties, and electric water immersion heaters.
5) Case 4: Electric Cooking + Storage Heater – existing network load with transition to all electric cooking, rebound load and night storage heaters for all inhabited properties.

6) Case 5: Electric Cooking + Storage Heating + Water Immersion Heaters — existing network load with transition to all electric cooking, rebound load and night storage heaters for all inhabited properties, and electric water immersion heaters.

As with any future energy scenario, overall future demand is hard to predict as it includes socio-economic factors, changes in technology and changes usage patterns and environment. Sark load in winter months, is generally expected to fall compared to summer, as many of the tourist destinations and hotels shut down.

4.3 Demand Estimation Methodology

Electrical network loads are generally split into two main types a) general residential loads and b) specific high user loads. Estimating specific high user loads is only possible if the exact makeup of the loads is known, or metering / data logger information is available. For residential loads, it is possible to estimate demands based on typical consumption patterns.

When estimating residential loads, several different design estimation methods are possible, these are known as the P-Q method and the After Diversity Maximum Demand (ADMD); other methods are also possible that contain more sophisticated analysis and estimation of house construction and socio-economic factors and Low Carbon Technology (LCT) uptake rates. These methods are defined in the ENA P5 standard [6].

It should however be noted that all of the methods for estimating residential loads are based on assumed connection size and load pattern; using a statistical averaging method to predict demand. This approach tends to work well in large / high population areas with standard consumption patterns. For small areas, and non-standard consumption (unusually high or low), then this method begins to break down as the averaging process does not work well.

ADMD estimation, is a tool used by network planners, for load estimation in areas. A number of different ADMD techniques can be used, the more complex method are based on the number of customers in a group, type of property and estimated income by areas, whilst simple methods assign a diversified kW value to a dwelling type / size, which is more appropriate to Sark, as the low volume of houses allow each property to be estimated with a reasonable level of accuracy.

Typical ADMD values for property sizes based on heating types, with a maximum cut-out rating of either 80 A or of 100 A are available in UK DNO design standards such as UKPN [7] and NGED [8]. It should be noted that within the UK mainland the ADMD figures used, generally assume that houses have electric cookers, and often have electric showers as well as some electric heating. From feedback from Chief Pleas, this is generally not the case in Sark, and as electricity costs are high, the usual figures would be expected to be depressed slightly.

Table 4-1: Typical ADMD kW Figures Based on Property Type – UK Mainland

No. Bedrooms	Gas / Oil Heated (kW)		Electric Heated (kW)	
	UKPN	NGED	UKPN	NGED
1-2	1.2	1.2	2.2	1.5
3	1.5	1.7	2.5	2.3
4	1.8	2.0	2.8	2.7
5+	2.4	2.3	3.4	3.1

Within the UK mainland, typical higher values are used for specific high demand loads such as storage heaters, heat pumps and immersion heaters, and these are typically assumed as having 100% capacity. As noted above the actual ADMD figures used are likely to be supressed slightly on Sark, and a slight reduction in overnight Storage Heater (SH) is suggested, with a more significant reduction in Heat Pumps (HP) and Immersion Heaters (IH), as these are unlikely to be used as much. As noted earlier, the use of intelligent demand control could reduce these figures further. The typical ADMD values used on the peak equipment rating are shown below.

Table 4-2: Typical ADMD Values

ADMD Figure	Typical UK DNO	Suggested Value for Sark
Gen Day ADMD	10%	10%
Gen Night ADMD	5%	5%
HP Day ADMD	100%	50%
HP Night ADMD	50%	25%
SH Day ADMD	1%	1%
SH Night ADMD	100%	90%
IH ADMD	50%	25%

4.4 Load Estimation

The Sark Electricity Price Commissioner has an overall spreadsheet that details all properties on the island, and indicates their classification as commercial with use type, high demand customers and residential properties with number of inhabitants. Each building has a Unique Building Identifier (UBI), which is in turn cross referenced with Latitude and Longitude coordinates. Chief Pleas, along with some local guidance were able to provide initial estimates of existing peak demand on a property by property basis, along with estimates of future peak demand associated with the various Future Energy Scenarios defined in Section 4.2.

To obtain some load estimates, the Excel sheet was modified by Aurora and ADMD figures were assigned to the properties assigned to each of the residential properties, as well as some measured readings for the commercial and heavy load users.

4.5 Overall Demand Results

The results of the estimation, for the Future Energy Scenarios are shown below in Table 4-3. Whilst any estimation methodology is subject to errors, when there is limited data available, the base case estimates correlate well to the anecdotal figures obtained from Chief Pleas in Section 3.3.

As would be expected, the increase to electric cooking and rebound load, brings the estimated total demand to around 750 kW during the day and 245 kW at night. If island wide roll out of Heat Pumps were to occur, this would fit within estimated maximum demand value of 2500 kVA, with a good level of headroom; however if immersion heaters were added as well, then the values become marginal against the design requirement. The use of electric storage heaters places a significant stress on the system, well in excess of the expected design target of 2500 kVA.

Table 4-3: Overall Demand Future Energy Scenarios

Scenario	Overall Network Demand kW
Base Case Day ADMD kW	381
Base Case Night ADMD kW	191
Case 1 (Kitchen) Day ADMD kW	752
Case 1 (Kitchen) Night ADMD kW	245
Case 2 (Kitchen + HP) Day ADMD kW	2183
Case 2 (Kitchen + HP) Night ADMD kW	1037
Case 3 (Kitchen + HP+IH) Day ADMD kW	2537
Case 3 (Kitchen + HP+IH) Night ADMD kW	1391
Case 4 (Kitchen +SH) Day ADMD kW	923
Case 4 (Kitchen +SH) Night ADMD	5108
Case 5 (Kitchen +SH+IH) Day ADMD kW	1276
Case 5 (Kitchen +SH+IH) Night ADMD kW	5461

As noted in Section 4.2, it should be noted that the electric heating load scenarios (either heat pump or storage heater) are the most questionable, as these are high demand users (expensive) and current kerosene based heating is likely to be cheaper. Furthermore, as the island is less populated / busy in winter, the overall demand is likely to be suppressed. It is of course noted that a wholesale shift to electric heating would occur gradually over time, and air source heat pumps are likely to become cheaper and more accessible, and conventional storage heater less popular.

A further key aspect to be considered, is that the island is planning to use Intelligent Demand Control system (refer to Section 2.8.5) to bring high load users on / off to help balance network demand (primarily heating and immersion heaters). This could also be used to regulate peak demand at night for the storage heater case.

Based on the above information, it can be concluded, that a design value of 2500 kVA is pragmatic and a sensible value that provides sufficient headroom for future demands and load growth, but may encounter some challenges if wholesale move to storage heaters on the island is a realistic possibility. Based on the information available, this does not seem likely, so pre-investing a system design to handle this scenario would not be financially sensible, but the system should instead have some basic flexibility to allow it to scale up if needed.

4.6 Area Demand Results

As part of the load analysis, properties and loads were grouped together, into local substation transformer area (based on Figure 3-3) and the building UBI details, to obtain a baseline of the load distribution. The overall results can be seen below in Table 4-4, which shows the Day / Night value for each scenario. Figure 4-1, shows the Base Case and Cases 1-3, Day values, are these are the most credible works case results.

The load by substation, as this provides the most useful grouping for planning the HV system design, to identify the geographical distribution of the load. From the data available, a large percentage of the island load is towards the centre of the Sark at The Avenue and Rue Lucas, secondary large load areas are at Carrefour Crossroads, Baytree, Plaisance, Island Hall, La Moinerie, Northfield, and the Dixcart (Stocks) Hotel.

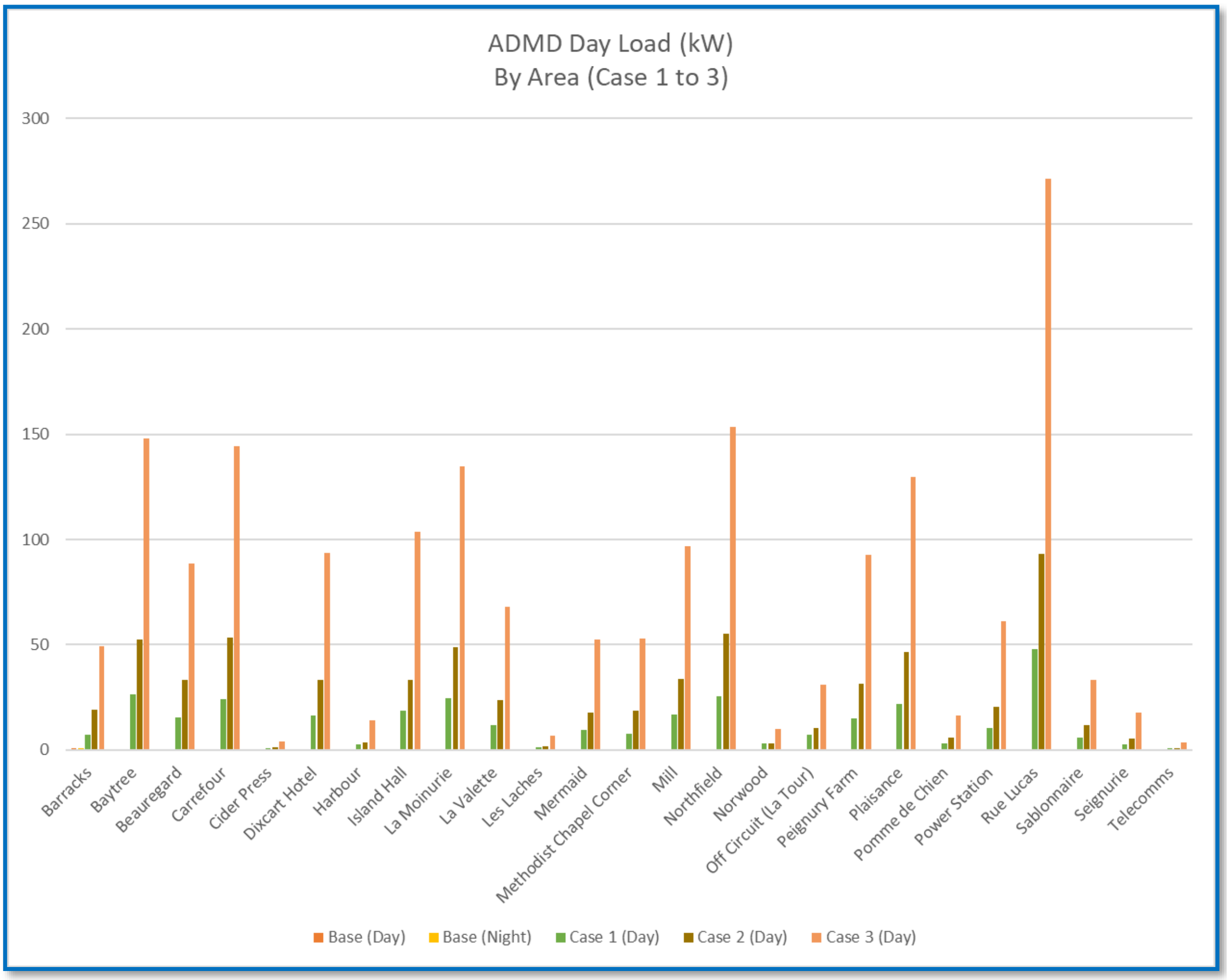

Figure 4-1: Loads By Area

It is noted that the Area Demand results are of secondary importance to the overall demand, as localized variations are expected, and some inaccuracies in the field data would be expected. Exactly which substations supply specific areas is unclear in many cases, as the HV substations are close together and there are little historical records. For example, Peingnury Farm, Norwood and Pommes de Chien are all very close to each other and / or have very low loading and could be eliminated.

During the detail design stage of the project, when further information is available, any local adjustments can be made as necessary by scaling up local transformers. This has minimal cost impact to the network and can be adapted as the network involves over time.

Table 4-4: Load Distribution by Area

Row Labels	Base (Day)	Base (Nt.)	Case 1 (Day)	Case 1 (Nt.)	Case 2 (Day)	Case 2 (Nt.)	Case 3 (Day)	Case 3 (Nt.)	Case 4 (Day)	Case 4 (Nt.)	Case 5 (Day)	Case 5 (Nt.)
Barracks	7.4	3.7	19.1	6.7	49.4	21.7	58.0	30.4	21.8	110.9	30.4	119.5
Baytree	26.5	13.2	52.6	17.7	148.0	69.6	173.9	95.5	65.2	337.0	91.1	362.9
Beauregard	15.5	7.7	33.1	11.5	88.8	40.6	103.1	55.0	40.5	196.6	54.8	211.0
Carrefour	24.0	12.0	53.4	18.3	144.4	65.9	166.0	87.5	63.9	325.8	85.5	347.4
Cider Press	0.7	0.4	1.5	0.5	4.1	1.9	4.9	2.7	1.8	9.4	2.6	10.1
Dixcart Hotel	16.1	8.1	33.3	11.2	93.6	43.7	105.8	55.9	40.7	214.5	52.9	226.7
Harbour	2.7	1.4	3.5	0.8	13.9	7.5	16.8	10.4	4.7	37.2	7.6	40.1
Island Hall	18.6	9.3	33.1	10.1	103.5	51.0	117.2	64.6	41.4	251.5	55.1	265.1
La Moinurie	24.6	12.3	48.6	16.7	134.5	62.9	156.8	85.2	60.9	300.6	83.2	322.8
La Tour (Off Circuit)	11.8	5.9	23.7	7.8	68.1	32.2	80.3	44.4	29.0	158.4	41.2	170.6
La Valette	1.5	0.7	1.6	0.3	6.9	3.9	8.3	5.3	2.3	18.7	3.7	20.2
Les Laches	9.7	4.9	17.8	5.8	52.5	25.3	61.1	33.9	22.6	121.8	31.2	130.5
Mermaid	7.6	3.8	18.7	6.0	53.1	24.4	59.6	30.8	20.9	128.3	27.4	134.8
Methodist Chapel Corner	16.9	8.5	33.8	11.2	96.7	45.7	112.5	61.5	41.5	223.9	57.3	239.7
Mill	25.6	12.8	55.2	18.5	153.7	71.1	178.1	95.6	66.3	353.4	90.7	377.8
Northfield	7.3	3.6	10.4	3.5	31.0	15.7	36.1	20.7	14.9	67.6	20.0	72.7
Norwood	15.1	7.5	31.5	10.0	92.6	43.8	108.4	59.7	37.4	222.1	53.2	237.9
Peignury Farm	21.9	11.0	46.6	15.7	129.9	60.2	150.7	81.1	56.3	297.9	77.1	318.8
Plaisance	2.9	1.5	5.9	2.0	16.5	7.7	19.4	10.6	7.3	37.4	10.2	40.3
Pomme de Chien	10.4	5.2	20.3	6.3	61.3	29.6	71.4	39.6	24.5	148.4	34.6	158.5
Power Station	47.7	23.9	93.3	30.4	271.4	129.2	315.2	173.1	115.0	634.2	158.8	678.1
Rue Lucas	5.9	2.9	11.8	4.0	33.1	15.5	38.8	21.2	14.7	74.9	20.4	80.6
Sablonnaire	2.6	1.3	5.4	1.5	17.6	8.6	19.7	10.7	6.1	45.7	8.2	47.9
Seignurie	0.7	0.4	0.8	0.2	3.4	1.9	4.2	2.7	1.1	9.4	1.9	10.1
Telecomms	50.6	25.3	86.3	24.7	284.5	142.9	334.8	193.2	107.4	714.8	157.7	765.1
The Avenue	3.7	1.8	7.4	2.5	20.7	9.7	24.3	13.3	9.2	46.8	12.8	50.4
Varoque	2.9	1.5	3.0	1.0	9.7	5.3	11.2	6.8	5.1	20.2	6.6	21.6
Total	***381***	***191***	***752***	***245***	***2183***	***1037***	***2537***	***1391***	***923***	***5108***	***1276***	***5461***

SECTION 5 - CONCEPT DESIGNS

5.1 Introduction

The Sark load is primarily based on domestic dwellings, along with a few hotels and light industrial units. The design of the system can be carried out from consumer load upwards, with the HV network designed to distribute power to the load areas and no specific high demand loads need considering. The load demand calculations given in Section 4 details the estimated overall island demand for a number of different Future Energy Cases, as these all contain a level of uncertainty, Chief Pleas agreed to use a nominal design target of 2500 kVA, as once above this value, some of the equipment costs and design increase significantly, likewise there is minimal cost difference between a system rated at 1600 kVA, 2000 kVA or 2500 kVA.

Several different concepts are presented, with some concepts being variations of earlier schemes. The viability of the different concepts is assessed initially at a higher level, as some options can be ruled out without system studies being conducted. System studies have only been conducted for concepts that remain after initial assessment of technical viability and relative cost.

5.2 Costs

The key principle in design of any future electrical system is to balance the level of performance, reliability and flexibility and future demands against costs of the system design. The installation of a new electrical system is a major capital cost and a system would be expected to last 30+ years, it is therefore necessary to have a degree of pre-investment to ensure that the system can cope with future demands, however excessive over sizing, or very ambitious design goals can lead to unnecessary cost. The use of standardized equipment is followed wherever possible.

The approach followed has therefore to be as pragmatic and low cost as reasonably possible, and only pre-invest in critical areas (pinch points), where upgrading in later years would be difficult or expensive.

5.3 Expanding Beyond 2500 kVA

As noted in earlier sections, the electrical design capacity has been targeted as 2500 kVA, as this gives a good balance between existing load and expected future load without pre-investing too far. Whilst loads are practically not expected to exceed 2500 kVA without a large move to electric heating, some consideration is necessary to provide future flexibility.

It is possible that the system could eventually increase beyond 2500 VA, and therefore the sections below give some indication of the possible upgrade paths.

In the subsections below, it is assumed that the load is evenly spread around the system – if a major upgrade were to occur at a specific location such as a Hotel and Golf Course at Beauregard, then specific generation could be added at the location to reduce network congestion, or local network reinforcement be undertaken, at the time of the development being undertaken.

5.3.1 Energy Centre

Within the proposed systems, the majority of the network constraints beyond 2500 kVA are associated with the Energy Centre, because LV generation above this value becomes complex and requires more expensive LV switchgear designs. How generation is expanded depends on many variables and outside the remit of this project to investigate in any detail. Nevertheless, as the proposed design should be capable of expanding beyond 2500 kVA capacity, two options are identified to illustrate possible approaches, as follows:

- Option 1: Installation of a 2nd Energy Centre LV switchboard, step-up transformers and associated control system.
- Option 2: Installation of an HV switchboard at the Energy Centre, and provide additional generation directly connected, or via a step-up transformer to the HV switchboard.

5.3.2 Uprating the Distribution System To 11 KV

An associated issue on the network is the consideration to move to 11 kV instead of 6.6 kV. Whilst the network demand is low (<2000 kVA) the use of 11 kV is not justified and would incur additional costs and design complexities. Where the demand is medium, between 2000 kVA and 4000 kVA, 6.6 kV would still be considered suitable, increasing the load beyond this would require consideration of 11 kV. The following approaches would therefore be followed:

- The costs of the distribution transformers on the network are relatively low, and these could be upgraded in-situ with minimal difficulty and cost. The use of dual rated transformers is unlikely to be practical. These would require bespoke special designs, which would significantly increase cost.
- The HV cables will be specified and purchased as 11 kV and run them at 6.6 kV. This allows the network to be up-rated to 11 kV at a future date if required.

5.4 Basic Principles

5.4.1 General Principles

There are many possible designs for a new electrical distribution network, and design of the system is a balance of competing technical, economic and practical issues. The underlying principle is to design a robust, practical low-cost solution that will deliver value for money to the island for the next generation, whilst retaining enough flexibility to meet future demand and generation needs.

An HV network is required to provide the ‘backbone’ to distribute power around and the island and localised LV networks provided at each substation to provide power to consumers. A fundamental trade-off with any electrical system design is achieving the correct balance between HV and LV systems; HV equipment is more expensive than equivalent LV systems, but it uses less current (amps), and thus reduces cable sizes (a key cost), and voltage drop across the network. Any electrical system therefore usually requires a mix of both HV and LV networks to operate effectively and balance costs of HV equipment with the costs and limitations of large LV cable networks.

The use of standardized transformer ratings, LV cabinet configurations and LV equipment sizes and ratings is usually desirable as this improves operability, reduces operational risks, allows commonality of spares and means that strategic spares can be held if necessary.

5.4.2 HV Cable Reuse

One of the main challenges with the Sark design is it is unclear if the existing HV cable network can be reused, this will potentially reduce the cost, but also constrains the network to follow existing routes. This issue is not considered problematic, as the existing HV cable routes follow a practical configuration, and any proposed design would have followed a broadly similar approach. If the existing HV cables can be reused, this would be ideal, if not, the concept designs would not fundamentally differ, and there would be a cost difference to consider.

Regardless of reuse of existing cable, a new main Energy Centre will be installed on the south of the island near Les Laches, which will be the main generation hub, and therefore reinforcement activities will be needed there.

5.4.3 Redundancy & Backup Supplies

The main HV distribution system is designed to be fully redundant, such that a single outage (planned or unplanned) does not impact customers. HV distribution transformers are configured to be non-redundant i.e. failure would cause loss of supply, and backup would be provided at LV into the substation by using the island temporary generator. It should be noted that the existing island generator is rated at 250 kVA, and some of the larger substation may eventually exceed this, and so localized load priority may be needed, or a larger strategic generator purchasing. Each LV substation is therefore to be provided with a spare, interlocked, circuit breaker that the temporary generator can be connected to.

The LV network is not redundant, and failures would need repair before service is resumed. During detail design stage, it is suggested that some consideration is given to backup supplies to key infrastructure, the following are suggested:

- Island Hall
- Chief Pleas Office
- Medical Centre
- Telecoms Building
- Supermarkets

The use of strategic LV interconnectors between LV substations may be possible in some locations, but this approach tends to work in high density areas, where LV feeder pillars are close to each other. For Sark, this approach is unlikely to be practical, but can be developed further in detail design, use of local UPS or a couple of smaller spare DGs could also be considered.

5.4.4 Little Sark

Due to the location of Little Sark, relatively low population and consequent cable installation difficulties across La Coupee, it is considered impractical to provide consumers on Little Sark with duplicated HV supplies. All designs considered for the HV distribution system therefore supply Little Sark consumers via a single HV cable circuit. Unavailability of this cable circuit for any reason results in consumers on Little Sark without power until the circuit is restored to use.

It should therefore be confirmed that any strategic spare temporary generator can be moved across the Coupee.

Preliminary investigations have indicated that the simplest way to install the new HV cable to Little Sark, is via cable hangers / support system off the side of the Coupee. It appears as if there is sufficient spare space to achieve this with minimal disturbance to the structure.

5.4.5 LV System

Design of the LV system is technically much simpler than the HV network as specific load locations are known, and LV equipment is cheaper. For concept design purposes the key determining factor is the location of the HV equipment and step-down transformers, as these will dictate the subsequent LV design. For this reason, the focus of the concept designs relates primarily to the HV system configuration. Selection of the concept design options is based on:

a) Technical viability
    i. Load demand & location
    ii. Voltage regulation
    iii. Reliability
    iv. Safety (protection & control)
b) Expandability / Future Requirements
c) Cost
d) Practicality
e) Re-use of existing infrastructure (if possible)

As noted in Section 4.4 existing load is unclear and future loads are estimates based on existing load information (refer to 4.2) and therefore options should take this into consideration. Further details of the LV design approach is given in Appendix B.

5.4.6 Future Loads and Expandability

It is important to note that the loads and future energy scenarios estimated in Section 4.4 of this report are, at this stage, high level estimates, and the further ahead the estimate the less accurate it will be. It is prudent to oversize key equipment such as buried HV cable for possible future loads, but oversizing all equipment such as transformers, for the future energy case is usually not pragmatic as they can be upgraded when required.

5.4.7 Protection & Control

The other key factor in the system design is safety and correct identification and clearance of faults on the network. This is a fundamental safety requirement and must not be compromised to realise cost savings. Typical Microgrid protection scheme requirements are discussed in Section 2.13. Several different options and configurations are possible for protection design, and these inevitably influence the scheme design, as more complex protection schemes require more complex switchgear (i.e. higher cost) and prohibit the use of simple RMUs at distribution substations.

5.4.8 Power Quality

As noted in Section 3.6, maintaining an acceptable level of power system quality is a key measure of the power system performance. Excessive frequency disturbance or voltage flicker will be a nuisance to consumers and must be mitigated and stay within acceptable limits. Specific issues that must be considered are:

- The new generation systems are likely to produce additional harmonics.
- Wind turbines may produce voltage flicker at cut-in and cut-out speeds.
- As the island load increases additional significant load may be added:
    - Hotel / kitchen loads
    - Electric tractors
    - Arc Welding equipment
    - Motors & compressors

Once the new system is design and installed, it will therefore be necessary to ensure that any new generation or significant demand on the island is assessed before connection, as this may affect the whole electrical network. The limiting rating of motors and harmonic-generating generation/loads , above which a specific assessment will be required prior to connection, will be identified as part of the detailed design phase. Thereafter, such calculations should be re-visited at intervals as and when the network expands.

It may be necessary for Chief Pleas to acquire regulatory powers to make this requirement enforceable

5.5 Concept 1: Modified Base Case

5.5.1 Overview

This concept is based on an upgrade of the existing island infrastructure. The existing island HV system follows a 3-legged ring system, which provides a good level of redundancy and flexibility. The existing scheme design approach is therefore reused, with a few of the existing substations consolidated into larger ones, and a new energy centre substation added into the network. The network is configured as follows:

- A new combined substation is provided at the Energy Centre to act as the main generating station. It is provided with 2x 2500 kVA step-up transformers for the HV network
- A new combined HV substation is provided at the existing Power Station (or nearby if this location is unavailable) to act as the main switching centre for the island and integrates the Rue Lucas loads.
- A new substation is added near Beauregard to allow automatic switching and reconfiguration of the network during faults, and the Beauregard switch is integrated to this substation
- Varoque and Mill substations combined
- Baytree and Baytree transformer are combined
- Norwood and Pommes de Chien substations combined
- La Tour area is supplied at LV from Northfield
- Stocks Corner switch is bypassed
- Plaisance and Little Sark are fed via a dedicated feed from Beauregard and so at single circuit risk
- Substations on Little Sark are combined
- The network is run ‘open’ with 3 radial feeders from the new Energy Centre as this allows more effective protection and control of the network in the event of a disturbance.

Overall, this scheme is viable, although not very cost effective as it still uses a large number of HV substations. It has the principal advantage that it closely follows the existing network approach, and could be upgraded over time. As the design still utilises a substantial number of HV switchgear and transformers, this is not efficient and leads to higher OPEX costs. Further simplification of the number of HV substations could be carried out as required.

If the Powerstation building is unavailable, the main HV switchboard could be located at the Energy Centre. This would not be ideal for future cases, as the HV cable networks capacity would need to be increased to allow the redundancy to be retained.

A single line diagram of the system for Concept 1 is provided in Attachment [B1a] and a Geographical Diagram is provided in Attachment [B1b]. The geographical diagram can also be seen below in Figure 5-1.

5.5.2 Cable Sizing

Cable sizing for the HV cable network can be simplified, as the 3-legged ring configuration means that the load is shared on a 2 out of 3 (2oo3) basis, and one of the main load centres (Rue Lucas) is directly supplied from the (Old) Power Station / Rue Lucas substation. In this configuration the 25 mm^2 HV cable could be reused, but the existing HV switchgear and transformers will need replacing (generally, because it is life-expired). This approach has the general advantage that it maximises reuse of the existing infrastructure, maintains continuity of design and allows the smaller distribution substations to be of simple RMU type. If the HV cable is not available for reuse, the installation of a larger size cable of 50 mm^2 would be recommended, to prevent future bottlenecks and reduce voltage drop.

5.5.3 Voltage Regulation

The network voltage is either through manipulation of the Energy Centre LV busbar by the generators, or through dedicated On Load Tap Changers (OLTC) on the Energy Centre Step Up transformers. The OLTC option is likely to be expensive, and simpler secondary control at the Energy Centre LV bus is preferred.

It is expected that voltage regulation may be more problematic at Little Sark due to the cable lengths, and it may be required to oversize the replacement HV cable for this section of the route.

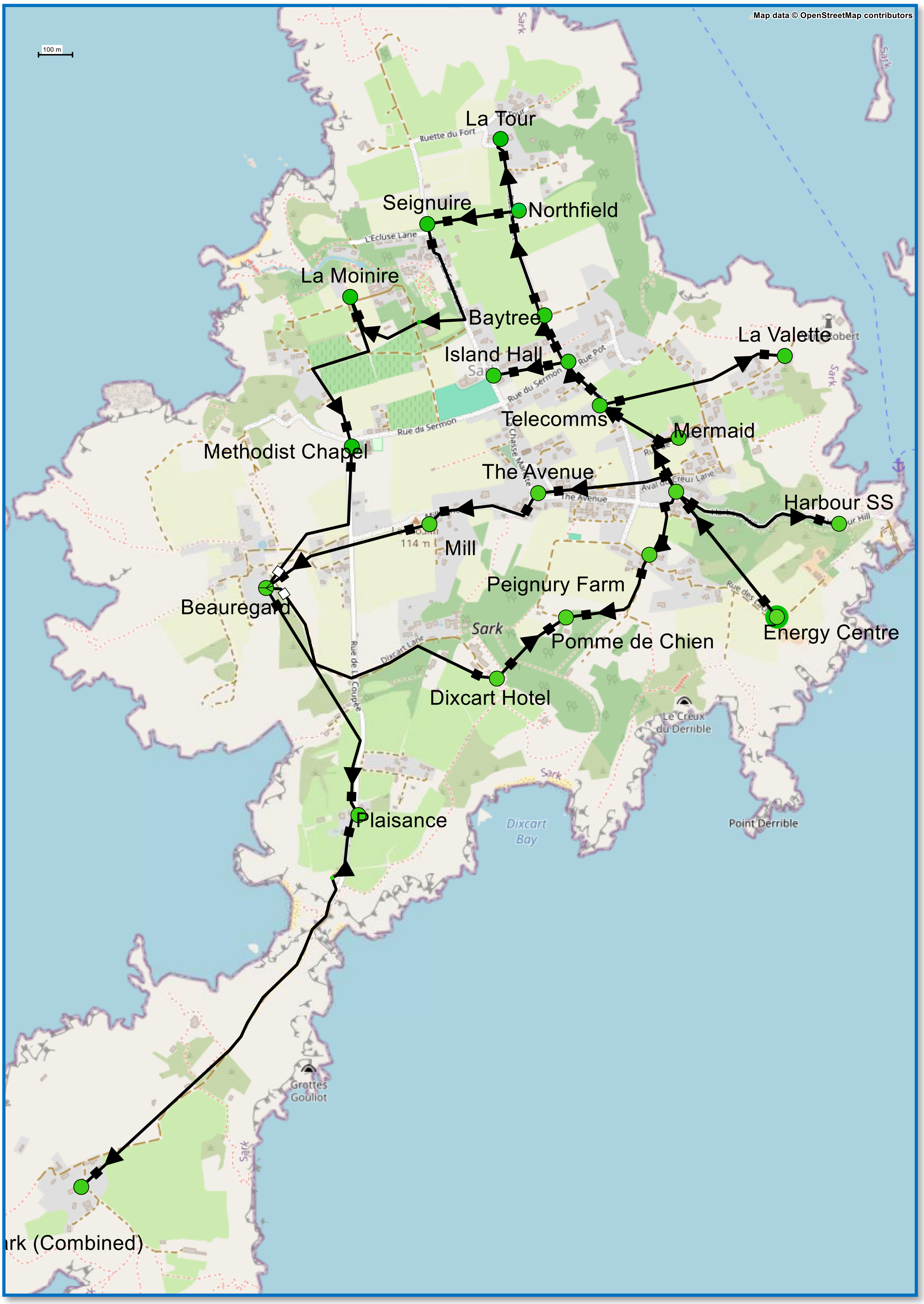

Figure 5-1: Modified Base Case

5.5.4 Protection

The new main substations located at the Energy Centre, (Old) Power Station and Beauregard are all provided with modern intelligent high-performance relays able to identify and clear faults on the network using a combination of IDMT relays (50 & 51) and directional protection relays (67) using adaptive settings for different generation configuration options as discussed in Section 2.13.

5.5.5 Summary

This configuration works well for all operating scenarios and has the advantage of following the existing island philosophy. The use of 3-legged split ring system, with more complex protection scheme at the main switching substation (Old Power Station / Rue Lucas) and the new Beauregard substation, provides sufficient protection and switching flexibility that any HV faults will be cleared quickly, and the network reconfigured with minimal disruption. Redundancy is lost at Plaisance and Little Sark, however this could be mitigated through use of a small strategic mobile emergency generator and a spare LV connection point at each substation.

The downside of the scheme is that it still uses many HV substations throughout the system, which increases costs and potential failure points, and requires more maintenance. In future energy scenarios with a very high demand, it is likely that an outage on the ring could cause significant disruption to the island and would overload the ring network.

To minimise costs in the longer term, there are options to combine further substations. This could include:

- Integrate the Village Hall & Telecoms substation to Carrefour
- Integrate Mermaid to Rue Lucas
- Combine Moinerie and Seigneurie substations
- Combine Pomme de Chien with either Peignury Farm or Stocks Hotel

The key drawback with this design approach is that in a future energy scenario where demand reaches near 2500 kVA, should an outage occur on one leg of the ring, the remaining legs of the ring would experience significant voltage drop due to the small cable size. The voltage drop might become so large as to cause undervoltage trips to occur, or damage to consumer equipment due to undervoltage operation.

The CAPEX costs of the scheme are generally higher as there are many HV substations on the network, but has the advantage that CAPEX can be deferred over many years as part of a phased upgrade. The CAPEX costs of this scheme are significantly reduced if the existing cable network can be reused, as the 25 mm^2 cable should be sufficient for almost all future energy case scenarios.

If the HV cable network is unavailable for reuse, then this approach should not be considered.

5.6 Concept 2: Energy People HV Ring

5.6.1 Overview

This concept is based on the design developed in the Energy People report and is based on an 11 kV ring system centred on the new power station. The principal followed in this concept is to significantly reduce the number of HV substations and transformers on the network (and thus reduce the cost), and transmit more power at LV, which is easier to install, repair and maintain. The proposed design uses several tap-off points formed by RMU's around the ring, feeding step-down transformers and radial LV distribution to consumers.

The Energy People design is shown in Figure 5-2 below. Note that the number and locations of ring substations might vary according to detailed analysis of load locations, to minimise LV cable lengths. The number and geographic location of substations is flexible, so can be modified, or added to in future as demand increases.

The network is configured as follows:

- A new combined HV / LV substation is provided at the Energy Centre to act as the main generating station and regulate the voltage and system.
- 8 distribution substations are located around the ring at strategic points. These would need to be primary switchgear, provided with differential protection.
- Little Sark is fed via a single radial feeder.
- Each main substation is provided with an extensive LV distribution system to feed the local surrounding area via a series of LV feeder pillars and sub-distribution panels.

A single line diagram of the system for Concept 2 is provided in Attachment [B2a] and a Geographical diagram in Attachment [B2b].

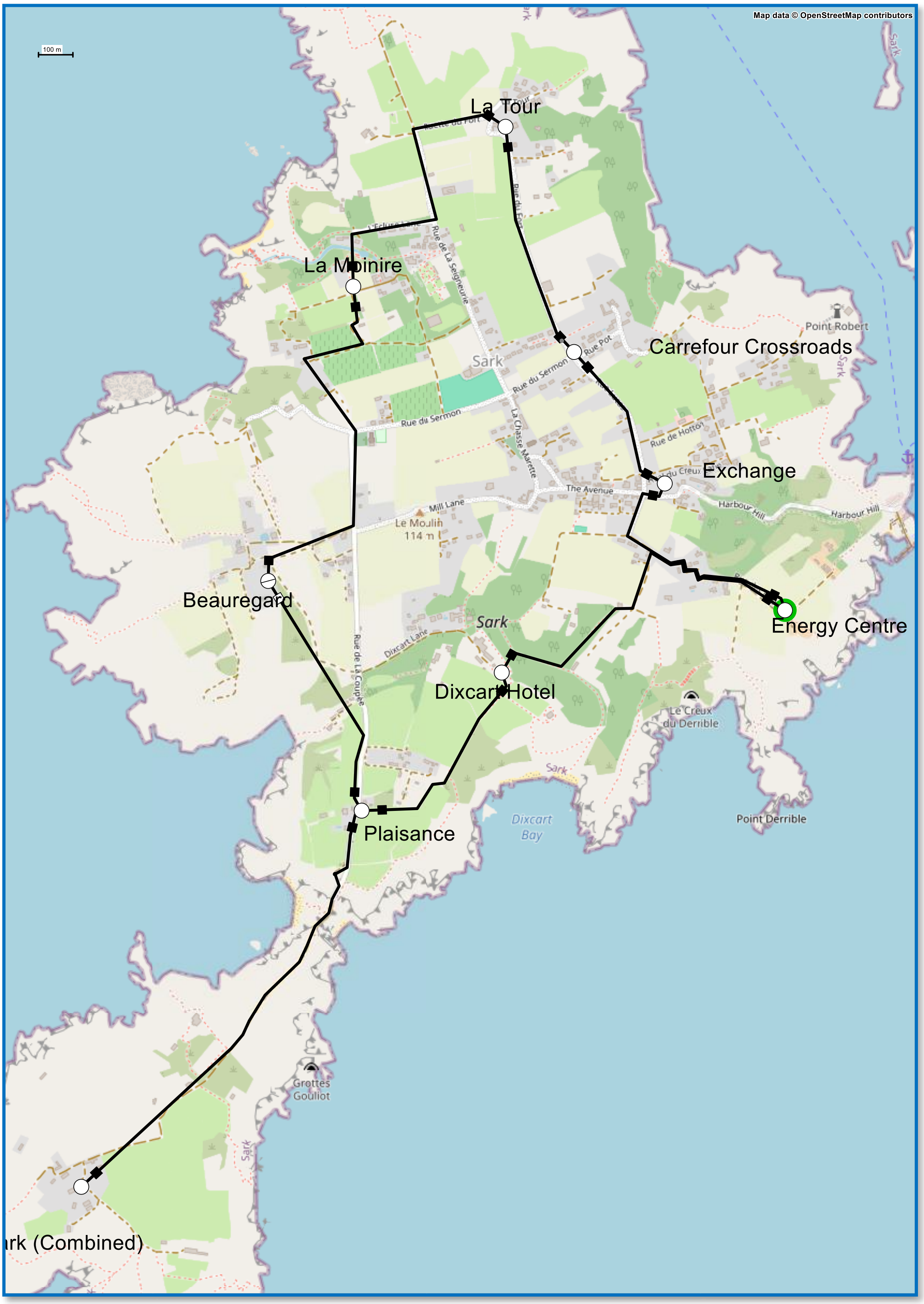

Figure 5-2: Energy People Ring

5.6.2 HV Cable Sizing

In a ring system, it is usual practice to size all the HV cables to meet the entire ring demand; it is however possible to specify the cables between the source and first substation as suitable for the full load, and the other sections of the ring to carry reduced current. In this design option, only a small part of the new route follows the existing route, and reuse of the existing cable is very limited.

For a ring operated at 11 kV, the 25 mm^2 cable has a current rating of 140 A, hence is suitable for re-use (depending on the routing of the ring). If 6.6 kV is used, some ring cables will need a larger size than 25 mm^2 – initial simulations suggest 95 mm^2 would be required to ensure cables are operated within rating.

If this design option is followed, then use of an 11 kV system voltage would be recommended.

5.6.3 Voltage Regulation

The base case Energy People ring concept did not include any specific voltage regulation control, and any management would have to be via the Energy Centre LV bus. This would give limited options for control on the HV system and may require the Energy Centre LV bus to be run ‘hot’ (i.e. intentionally high voltage up to 1.05 pu). The modified version of this scheme design uses an extra HV bus at the Energy Centre and transformers, as per Concept 1.

5.6.4 Protection

The Energy People report notes the importance of protection in ensuring network safe operation. Unfortunately, the report does not detail the proposed protection scheme. Conventional protection of a ring system using RMU’s against faults to ensure safety to personnel and physical assets requires the fault level, when open at either the start or end point, to show a significant variation, thus permitting overcurrent protection to be used. Simulations conducted unfortunately show that there is insufficient variation of fault level with location along the ring to permit application of this protection technique. The use of voltage restrained overcurrent (51V) and alternate settings groups are unlikely to be able to overcome this underlying problem.

If the ring is run closed, then a fault anywhere on the HV ring leads to total loss of supply on Sark until the fault is manually located and isolated (which might take some time if personnel are not readily available), then all the substations would need to use primary switchgear and cable differential protection on each cable between the substations, which would significantly increase the cost.

The ring could also be run as normally open, with an open point at Beauregard. This would require an adaptive IDMT protection scheme similar to the ones discussed in Section 2.13 & 5.5.4. This design helps mitigates the total system loss in the event of a fault but increases the problem of voltage drop and regulation on the system. Furthermore, faults close in to the Energy Centre will lead to a significant load loss on the network, which may cause stability problems on the system.

The conclusion is that the design may not improve the resilience of the complete network in the event of HV network faults, compared to the existing situation. This is a significant drawback of the design.

5.6.5 Summary

This concept is therefore technically viable but would need some significant modifications resulting in a high cost; as the entire HV cable network would need replacing, and the use of primary switchgear and differential protection is required around the ring to provide, to provide sufficient fault detection and clearance.

The use of an extensive LV network has the advantage of simplifying large parts of the network, making it cheaper and easier to manage, but will lead to significantly larger LV cables and challenges of voltage drop on long / large circuits. The increased LV cable cost may be a significant factor, and it is possible this may outweigh the costs of a system with additional HV substations. A particular concern is the large amount of load centred on The Avenue, as this is several hundred metres from the Exchange substation.

5.7 Concept 3: Hybrid Design

5.7.1 Overview

This configuration takes a combination of Concept 1 & 2 and combines them, the principal of this concept is to reuse the existing ring and design the system such that the load on the ring is at a manageable level. The scheme requires the network to be run at 11 kV to maintain voltage drop during outage cases.

The main HV substation for the island is provided at the Energy Centre, and three ring feeders are supplied from this location. The network is configured as follows:

- A new combined HV / LV substation is provided at the Energy Centre to act as the main generating station and regulate the voltage and system. This provides 3no ring feeders to the island.
- A new main substation is added near Beauregard to allow automatic switching and reconfiguration of the network during faults.
- The La Valette / lighthouse is fed at HV via an HV feed off Rue Lucas Substation.
- The Methodist Chapel substation could be removed, but further clarification on the local loads would be needed.
- New ring substations are provided as standard RMU configurations provided with self-powered protection relays
- The network is run ‘open’ with 3 radial feeders from the EC substation as this allows more effective protection and control of the network in the event of a disturbance.
- The Harbour supply design is to be confirmed during detail design. Two supply options are possible:
    - Supplied at HV down Harbour Hill (difficult route) via Rue Lucas substation
    - Supplied at LV via cross-country route from the Energy Centre.

A single line diagram of the system for Concept 3 is provided in Attachment [B3a] and a Geographical drawing in Attachment [B3b].

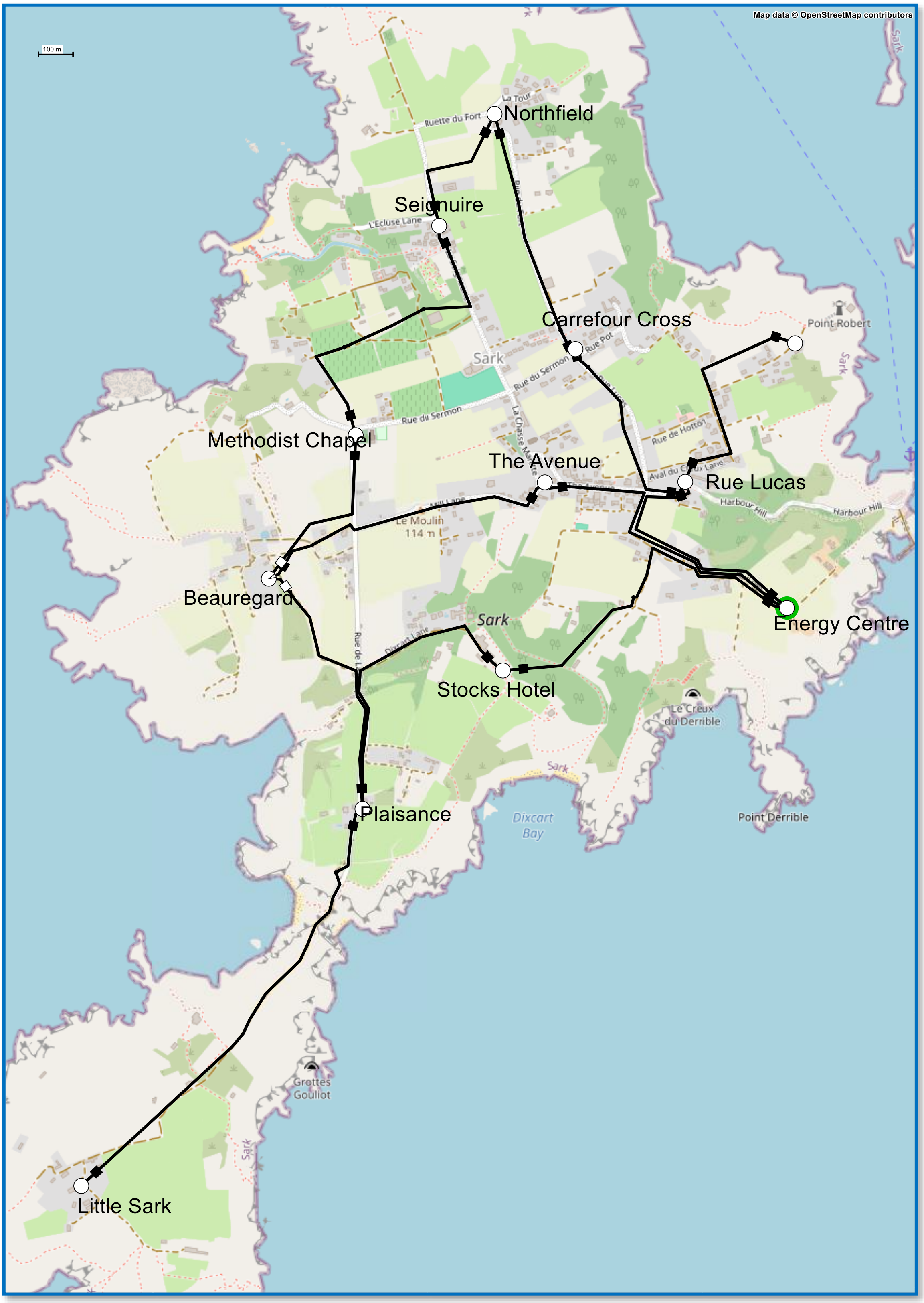

Figure 5-3: Hybrid Design

5.7.2 Cable Sizing

The Cable sizing for the HV cable network becomes constrained if the existing 25 mm^2 cable is to be reused, as although the 3-legged ring configuration means that the load is shared on a 2 out of 3 (2oo3) basis, the main load centres in the centre of the island are fed from the ring, and this may cause future bottlenecks. The system must be run at 11 kV for to meet the possible future demand of 2.5 MW if the 25mm^2 HV cable is to be reused

5.7.3 Voltage Regulation

The network voltage is regulated via On Load Tap Changers (OLTC) on the Energy Centre Step Up transformers, selected with a suitable tapping envelope and range to ensure that the 11 kV network can be regulated to the required level. Secondary control could also be applied directly at the Energy Centre LV bus if necessary.

Voltage regulation can become challenging in an outage on the ring, as a substantial amount of load remains on the remaining network ring, and the system voltages would fall significantly, although remain within limits.

It is expected that voltage regulation may be more problematic at Little Sark due to the cable lengths, and it may be required to oversize the replacement HV cable for this section of the route.

5.7.4 Protection

The new main substations located at the Energy Centre and Beauregard are all provided with modern intelligent high-performance relays able to identify and clear faults on the network using a combination of IDMT relays (50 & 51), with functionality to allow alternate settings groups for different operating conditions (adaptive control).

5.7.5 Summary

This configuration can be made to work for the various operating scenarios and has the advantage of following the existing cable routes. The use of 3-legged split ring system, helps remove some congestion, but faces problems with expandability. The design allows a more complex protection scheme at the Energy Centre and the new Beauregard substation, to be implemented and provides sufficient protection and switching flexibility that any HV faults will be cleared quickly, and the network reconfigured with minimal disruption.

Redundancy is not available at Little Sark; however, this could be mitigated through use of a small strategic mobile emergency generator and a spare LV connection point at Little Sark substation.

As with Concept 2, the scheme requires an extensive LV network. The use of an extensive LV network has the advantage of simplifying large parts of the network, making it cheaper and easier to manage, but will lead to significantly larger LV cables and challenges of voltage drop on long / large circuits. The increase LV cable cost may be a significant factor, and it is possible may outweigh the costs of a system with more HV.

The significant downside of the scheme is that it is not easily extended and will not cater to increased future network loads unless the whole HV cable network is replaced with larger cables, as all the load is on the main ring. If the existing cable network is retained, then it is expected that network congestion problems will be encountered in later years. The design meets the 2500 kVA target design but does not allow for much increase beyond this.

5.8 Concept 4: Hybrid Design with Central Switching Substation

5.8.1 Overview

This configuration takes Concept 3 and modifies it to include a key central switching substation replacing the Rue Lucas substation, this reduces the load on the ring significantly and also gives the potential to feed the large loads areas at Rue Lucas, Carrefour and the Avenue as direct radial feeders significantly reducing any future network congestion and allowing a very flexible design and redundancy of design, to cater for changes should loads increase past the expected 2500 kVA. The scheme works well at 6.6 kV.

The network is configured as follows:

- A new combined LV substation is provided at the Energy Centre to act as the main generating station and regulate the voltage and system. This provides 3no ring feeders to the island.
- A new main substation is added towards the centre of the island to provide dedicated supplies for the large load centres and reduce any future network congestion.
- A new main substation is added near Beauregard to allow automatic switching and reconfiguration of the network during faults.
- The La Valette / lighthouse is fed at HV via a feed off the central substation.
- The Methodist Chapel substation could be removed, but further clarification on the local loads would be needed.
- New ring substations are provided as standard RMU configurations provided with self-powered protection relays
- The network is run ‘open’ with 3 radial feeders from the new central substation as this allows more effective protection and control of the network in the event of a disturbance.
- The Harbour supply design is to be confirmed during detail design. Two supply options are possible:
    - Supplied at HV down Harbour Hill (difficult route) via the Central substation
    - Supplied at LV via cross-country route from the Energy Centre. This route may be easier to construct if suitable wayleaves are available.
    - If Harbour/Creux harbour load is substantial (including demand during special events), a cross-country HV supply can be used, in conjunction with a simple HV/LV substation at the Harbour.

- Fibre communication channels will be needed between the Energy Centre and the Central substation – one per feeder. As loss of a communication channel may require tripping of the applicable feeder, duplicate channels per feeder would be advantageous. Installation of these communication links can be carried out at very low additional cost at the same time and using the same routes as the new power cables required – some designs of power cables include fibre communication channels.

A single line diagram of the system for Concept 4 is provided in Attachment [B4a] and a Geographical drawings is shown in Attachment [B4b].

5.8.2 Cable Sizing

In this concept large cables are needed from the Energy Centre to the Central substation; but as a large part of the network load is located on the central substation, the significantly reduces the load on the ring, and allows the cable sizing for the ring can be minimised. The use of the 3-legged ring configuration further avoids network congestion, and means that the load is shared on a 2 out of 3 (2oo3) basis. In this configuration the 25 mm^2 HV cable can be reused if available. This approach has the general advantage that it maximises reuse of the existing infrastructure that is reusable, maintains continuity of design and allows the smaller distribution substations to be of simple RMU type.

5.8.3 Voltage Regulation

The network voltage is regulated via On Load Tap Changers (OLTC) on the Energy Centre Step Up transformers, selected with a suitable tapping envelope and range to ensure that the 6.6 kV network can be regulated to the required level. Control could also be applied directly at the Energy Centre LV bus as an alternative, to eliminate the OLTCs.

It is expected that voltage regulation may be more problematic at Little Sark due to the cable lengths, and it may be required to oversize the replacement HV cable for this section of the route.

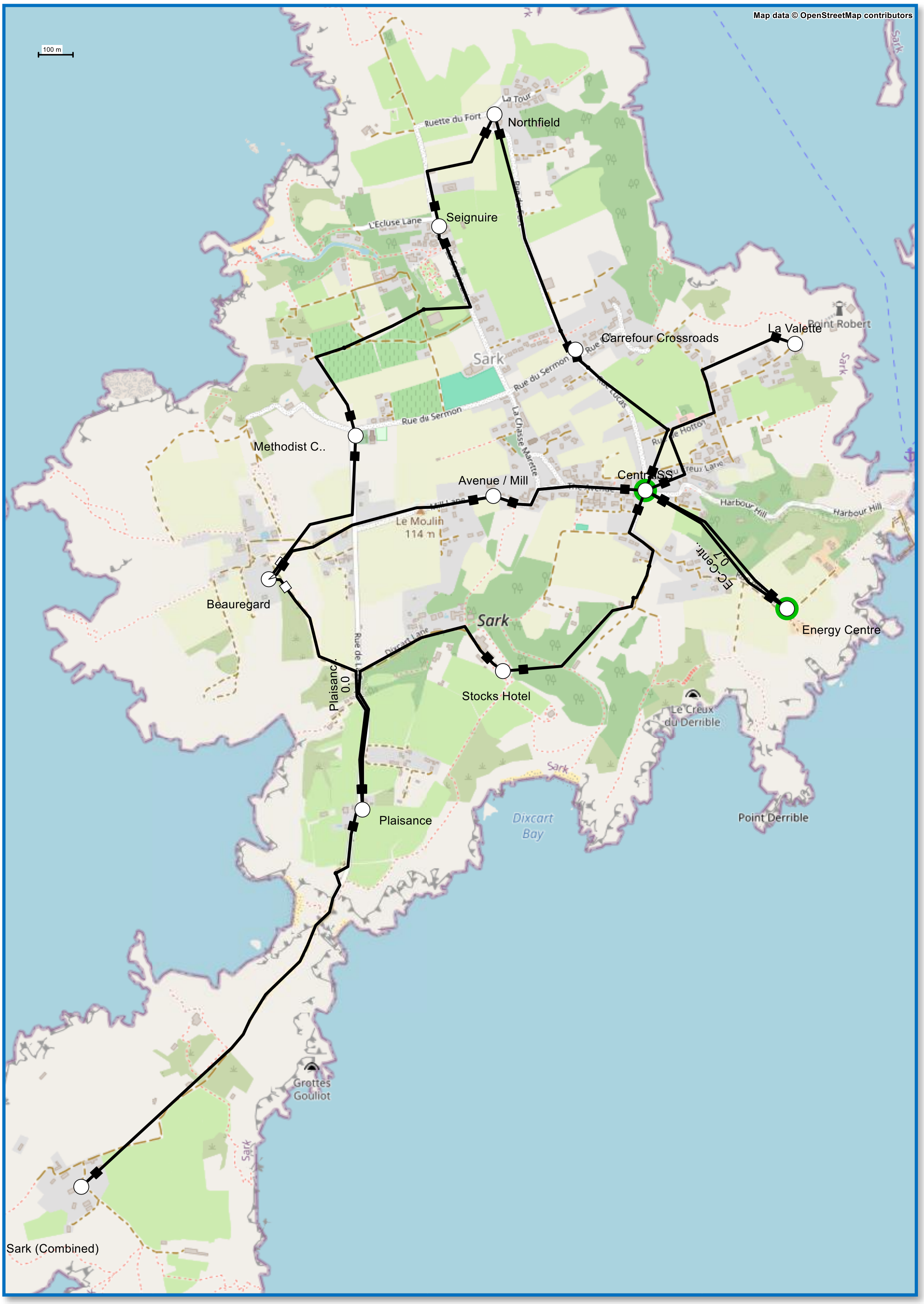

Figure 5-4: Hybrid Design with Central Substation

5.8.4 Protection

The new main substations located at the Energy Centre and Beauregard are all provided with modern intelligent high-performance relays able to identify and clear faults on the network using a combination of IDMT relays (50 & 51), with functionality to allow alternate settings groups for different operating conditions (adaptive control).

5.8.5 Summary

This configuration works well for all operating scenarios and has the advantage of following the existing island philosophy and minimising the HV substations significantly and reducing the load on the ring. The use of 3-legged split ring system, with more complex protection scheme at the Energy Centre and the new Beauregard substation, provides sufficient protection and switching flexibility that any HV faults will be cleared quickly, and the network reconfigured with minimal disruption to maintain supply continuity to the maximum possible number of consumers. The harbour is currently shown as LV, but if the HV cable network is reused, it would make sense to supply using the existing HV cable.

The only downside of the scheme is that it requires an extensive LV network (as Concept 2). The use of an extensive LV network has the advantage of simplifying large parts of the network, making it cheaper and easier to manage, but will lead to significantly larger LV cables and challenges of voltage drop on long / large circuits. The increase LV cable cost may be a significant factor, and it is possible may outweigh the costs of a system with a longer total length of HV cable and more HV/LV substations. In the event this option is chosen, the design can be developed in more detail in the next phase.

5.9 Comparison of Concepts

Each concept is technically viable and can be deployed on the island, but faces a number of limitations and constraints, these are summarised below, and a comparison of the strengths and weaknesses of the four concepts considered is provided in Table 5-1

- **Concept 1** is expensive but follows the existing strategy and is relatively simple to implement; it is also advantageous if finance for a new network is problematic, as the existing network could be upgraded in stages.
- **Concept 2** is possible, but a high-cost option, as it requires almost total replacement of the HV cable network. It also provides limited redundancy, and the

LV network costs would remain difficult to quantify until more accurate load data is available.

- **Concept 3** overcomes the technical and economic difficulties associated with Concepts 1 and 2. However, it only partially addresses the existing issue of supply availability during outage conditions, especially fault outages where repairs could take a while.
- **Concept 4** provides a hybrid combination of the other options and is the recommended approach as it is low cost as it can reuse existing HV cables and provides operational flexibility.

It is noted that all these concepts are based on assumed load profiles for each substation. Therefore, a significant amount of error may be present in the design, requiring increase in cable sizes and transformer sizes. The overall design of the system is generally robust and localized changes at a specific substation would not substantially alter the overall results or recommendations.

The concept design focus is on the HV network. The LV network is outside of the concept scope, but it is noted that it can be replaced at the same time as the HV, or alternatively replaced gradually around the system. Some details of the LV design approach are given in Appendix B.

It is Aurora's recommendation that Concept 4 is used as the most appropriate design to be taken forward into detail design stage. This design offers a relative low-cost approach, maximises reuse of existing HV cable network, and provides maximum flexibility for future operation and design changes.

Table 5-1: Concept Comparison

Concept	Advantages	Disadvantages
Modified Base Case	• Follows existing design • Good reuse of existing HV cable • Limited need for primary switchgear • Can be extended easily	• High cost if new cable needed • Uses a lot of substations • Expense will be higher for labour • HV fault would trip multiple substations • Network would struggle to cope with 2.5MW scenario during an outage condition
HV Ring	• Reduces number of HV substations • Uses large LV network which is cheaper and easier to maintain	• Difficult to add in more substations later • High cost • HV cable needs replacing • LV loads not well defined • Could face LV constraints in future energy scenarios • LV cabling could be difficult in some locations
Hybrid	• Medium cost • Follows existing design • Good reuse of existing HV cable • Limited need for primary switchgear	• Requires 11kV to work • Network congestion problems and difficulties expanding above 2.5 MW • LV cabling could be difficult in some locations • More LV load information needed to firm up LV supply
Hybrid with Central Substation	• Follows existing design • Good reuse of existing HV cable • Limited need for primary switchgear • Can be extended easily • Flexibility to adapt to uncertainty in loads	• LV cabling could be difficult in some locations • Slightly more expensive than the Hybrid option • Requires a substation in the island centre • Fibre comms needed between Energy Centre and Central substation

SECTION 6 - HYBRID WITH CENTRAL - DESIGN VALIDATION

6.1 Overview

To verify that Concept 4 results in a distribution network that performs to an acceptable standard under various scenarios, a DIgSILENT software model was developed. Generation is modelled approximately and is for illustrative purposes in the short circuit studies, as the final specification of the generation systems is not confirmed.

6.2 Load Allocation

Loads were taken from the load schedule developed to date, as detailed in Section 4.5 and attachment [A2], and assigned to the new transformer stations on the network, as indicated below in Table 6-2. It is noted that some of these groupings contain simplifications, and there may be, for example, some loads assigned to one substation that are better fed from another i.e. loads fed from Beauregard which may be better fed from Mill / Avenue – these will make minimal difference to the overall results, and should be optimised during detail design.

Table 6-1: Substation Grouping

New Substation	Existing Substation
Sablonnaire	Barracks, Cider Press, Sablonnaire
Carrefour	Baytree, Carrefour, Island Hall, Telecomms
Beauregard	Beauregard
Stocks	Dixcart Hotel, Pommes de Chien, Norwood
Energy Centre	Harbour, Les Laches
Seigneurie	La Moinurie, Seigneurie
Northfield	La Tour, Northfield, La Tour
La Valetta	La Valette
Central	Powerstation, Mermaid, Rue Lucas, Peignury Farm +50% Avenue
Methodist Corner	Methodist Corner
Avenue/Mill	Mill, Varoque + 50% of Avenue
Plaisance	Plaisance

The loads for each of the new substations are calculated, based on the existing allocation and the Future Energy Scenarios. As noted in Section 4.5, Cases 4 and 5 are discounted as non-viable. Case 2 and Case 3 are very similar, and if the Case 2 loads are increased by around 15% they would give almost identical values to Case 3. It can be seen that the majority of the load is based at the Central substation, with Carrefour being the other main load centre and containing around 50% of the whole island load.

Table 6-2: New Substation Load Allocation

Row Labels	Base (Day)	Base (Night)	Case 1 (Day)	Case 1 (Night)	Case 2 (Day)	Case 2 (Night)	Case 3 (Day)	Case 3 (Night)	Case 4 (Day)	Case 4 (Night)	Case 5 (Day)	Case 5 (Night)
Avenue/Mill	17	8	34	11	97	46	113	61	42	224	57	240
Beauregard	15	8	33	12	89	41	103	55	40	197	55	211
Carrefour	69	35	139	46	396	186	457	248	171	914	232	975
Central	107	54	194	59	605	297	706	398	241	1470	343	1572
Energy Centre	4	2	6	1	21	11	25	15	6	56	11	60
La Valette	12	6	24	8	68	32	81	45	29	159	41	171
Methodist Chapel Corner	11	6	26	9	74	34	84	44	30	175	40	185
Northfield	44	22	88	30	249	117	290	158	109	570	150	611
Plaisance	22	11	47	16	130	60	151	81	56	298	77	319
Sablonnaire	14	7	32	11	87	39	102	54	38	195	53	210
Seigneurie	27	14	54	18	152	71	177	96	67	346	91	371
Stocks	38	19	75	25	217	103	250	136	92	504	125	537
Totals	**381**	**191**	**753**	**244**	**2183**	**1037**	**2537**	**1391**	**922**	**5108**	**1276**	**5461**

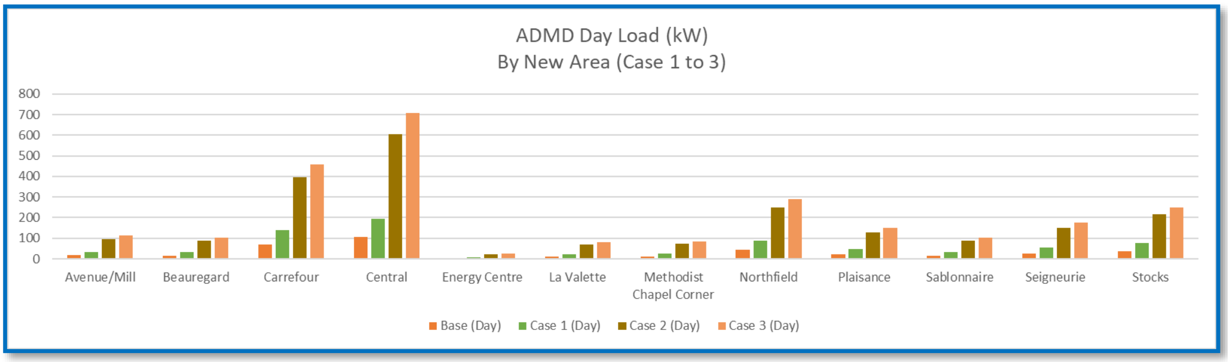

Figure 6-1: New Area Loads

6.3 Load Flow

6.3.1 Introduction and Scenarios

Load Flow studies are carried out to determine the performance of the system in steady state conditions, for normal and outage cases. In these studies, it is not necessary to check the capacity of the generation systems, as these are still unconfirmed, and the aim of the study is to validate the HV and LV network load and demand. The system is checked for the two extreme load cases of:

- Case 1: Electric Cooking & Load Rebound (752 kW)
- Case 2: Electric Cooking, Load Rebound & Heat Pump (2183 kW) + 10% spare

For each of the above load cases, further scenarios of intact and outage network conditions have been simulated. For each scenario, the network voltage profile and equipment loadings are checked. The scenarios considered are:

1) Case 1 – Intact & Mixed Generation
2) Case 1 – Outage Condition & DGs only
3) Case 2 – Intact & Mixed Generation*
4) Case 2 – Outage Condition & DGs only*

* Information is only available for base case generators. For the future cases, the generation units are ratioed up by a value of 3x.

The outage case is configured as a theoretical worst-case scenario, with one of the step-up transformers set out of service, one of the central distribution transformers out of service and an outage on the ring feeder from the Central Substation to the Avenue Substation with one of the associated normally open points on the ring at Beauregard closed. In practice multiple outages like this would not normally occur, but this case is used as a ‘stress test’ to identify weak points in the network.

6.3.2 Case 1 (Electric Cooking & Rebound)– Intact

The intact existing condition is assessed to provide a baseline for analysis. It is used to check the system performance for normal conditions, for the expected short term future network load.

Overall, the system performed well, as expected, and no areas of concern are identified for this scenario. A summary of the key results and finding is listed below, and the following tables. A copy of the output SLD can be seen in attachment [12].

- The system voltage profile remains acceptable.
- No items of equipment are indicated as overloaded.

Table 6-3: Case 1 - Network Demand Summary

Name	Generators, P	Generators, Q	Loads, P	Loads, Q	Losses, P	Losses, Q
	kW	kvar	kW	kvar	kW	kvar
Grid	773.7	162.5	755.6	142.5	18.1	20.1

Table 6-4: Case 1- Transformer Loading Summary

Name	Type	Loading	Tap 1, Current Position
	kVA	%	
Avenue Tx	630kVA Dist Tx	12.7	3
Beauregard Tx	200kVA Dist Tx	21.0	3
Carrefour Tx	630kVA Dist Tx	23.2	3
Central T1	800kVA Dist Tx	19.4	2
Central T2	800kVA Dist Tx	8.5	2
Dixcart Hotel Tx	250kVA Dist Tx	17.9	2
EC Tx 1	2500 kVA Step-Up	15.7	3
EC Tx2	2500 kVA Step-Up	15.7	3
La Valette Tx	200kVA Dist Tx	12.2	3
Little Sark Tx	200kVA Dist Tx	17.2	2
Methodist Chapel Tx	200kVA Dist Tx	9.6	3
Northfield Tx	200kVA Dist Tx	34.3	3
Plaisance Tx	200kVA Dist Tx	24.2	3
Seigneurie Tx	250kVA Dist Tx	22.0	3

HV cable loading is shown in the table below for information purposes only. It should be noted that some of the cable names are historical based on reuse of existing substations and joints, and therefore do not always directly correlate to the diagram in Figure 5-4.

Table 6-5: Case 1 - HV Cable Loading Summary

Name	Loading
	%
Avenue-Beauregard Cbl	1.9
Baytree-Northfield Cbl	8.9
ChapelCorner-Beauregard Switch	0.0
Coupee Joint to Sark	2.1
Dixcart Hotel - Pomme de Chien	7.8
EC-Central 1	7.8
EC-Central 2	7.8
Mermaid-Telecoms_a Cbl	18.0
Moinire-Chapel Corner Cbl	1.2
Moinire-JointBay Cbl	1.2
Northfield-Seigneurie Cbl	4.6
Norwood - Peignury	0.0
Norwood - Peignury_a	7.8
Plaisance - CoupeJoint	2.1
Plaisance-Beauregard	0.0
Powerstation-Mermaid Cbl	18.0
Powerstation-Peignury Farm	7.8
Rue Lucas - Powerstation	7.6
Seigneurie-JointBay Cbl	1.2
Stocks - Beauregard Cbl	5.1
Telecomms-Carrefour Cbl	18.0
Telecoms-Baytree Cbl	8.9
Telecoms-La Valette Cbl	1.5

6.3.3 Case 1 (Electric Cooking & Rebound) – Outage

The outage condition is used to check the system performance for outage conditions, at the expected short term future network load. As noted earlier, an outage is applied to one of the main step-up transformers, the ring feeder from the Energy Centre to the Central substation and the duplicated transformers at the Central substation.

Overall, the system performed well, as expected, and no areas of concern are identified for this scenario. A summary of the key results and finding is listed below, and the following tables. A copy of the output SLD can be seen in attachment [C2].

- The system voltage profile remains acceptable.
- No items of equipment are indicated as overloaded.

Table 6-6: Case 2 - Network Demand Summary

Name	Generators, P	Generators, Q	Loads, P	Loads, Q	Losses, P	Losses, Q
	kW	kvar	kW	kvar	kW	kvar
Grid	774.1	166.3	755.6	142.5	18.5	23.8

Table 6-7: Case 2 - Transformer Loading Summary

Name	Type	Loading	Tap 1, Current Position
	kVA	%	
Avenue Tx	630kVA Dist Tx	12.9	3
Beauregard Tx	200kVA Dist Tx	21.2	3
Carrefour Tx	630kVA Dist Tx	23.3	3
Central T1	800kVA Dist Tx	28.1	2
Central T2	800kVA Dist Tx	0.0	2
Dixcart Hotel Tx	250kVA Dist Tx	18.0	2
EC Tx 1	2500 kVA Step-Up	31.4	3
EC Tx2	2500 kVA Step-Up	0.0	3
La Valette Tx	200kVA Dist Tx	12.3	3
Little Sark Tx	200kVA Dist Tx	17.3	2
Methodist Chapel Tx	200kVA Dist Tx	9.7	3
Northfield Tx	200kVA Dist Tx	34.4	3
Plaisance Tx	200kVA Dist Tx	24.4	3
Seigneurie Tx	250kVA Dist Tx	22.1	3

HV cable loading is shown in the table below for information purposes only. It should be noted that some of the cable names are historical based on reuse of existing substations and joints, and therefore do not always directly correlate to the diagram in Figure 5-4.

Table 6-8: Case 2 - HV Cable Loading Summary

Name	Loading
	%
Avenue-Beauregard Cbl	3.7
Baytree-Northfield Cbl	8.9
ChapelCorner-Beauregard Switch	0.0
Coupee Joint to Sark	2.1
Dixcart Hotel - Pomme de Chien	15.6
EC-Central 1	15.7
EC-Central 2	0.0
Mermaid-Telecoms_a Cbl	18.1
Moinire-Chapel Corner Cbl	1.2
Moinire-JointBay Cbl	1.2
Northfield-Seigneurie Cbl	4.6
Norwood - Peignury	0.0
Norwood - Peignury_a	15.6
Plaisance - CoupeJoint	2.1
Plaisance-Beauregard	7.7
Powerstation-Mermaid Cbl	18.1
Powerstation-Peignury Farm	15.6
Rue Lucas - Powerstation	0.0
Seigneurie-JointBay Cbl	1.2
Stocks - Beauregard Cbl	12.8
Telecomms-Carrefour Cbl	18.1
Telecoms-Baytree Cbl	8.9
Telecoms-La Valette Cbl	1.5

6.3.4 Case 2 (Electric Cooking, Heat Pump & Rebound) – Intact

The Case 2 Scenario considers the future case with the whole island on electric cooking, some rebound load and heat pumps to provide an assessment of the worst case, future loading for analysis, and is used to evaluate system performance for future normal conditions.

Overall, the system performed well, as expected, and no areas of concern are identified for this scenario. A summary of the key results and finding is listed below, and the following tables. A summary of the key results and finding is listed below, and the following tables. A copy of the output SLD can be seen in attachment [C3].

- The system voltage profile remains acceptable.
- No items of equipment are indicated as overloaded.
- Some LV cable loading and voltage drops are a little high. This is due to simplified modelling approach. In detail design the LV system would compromise multiple smaller LV feeder circuits.
- The generation system is overloaded – this is as expected as the future generation mix is unknown, and uses the current mix, which is only rated from around circa 750 kW.

Table 6-9: Case 3 - Network Demand Summary

Name	Generators, P	Generators, Q	Loads, P	Loads, Q	Losses, P	Losses, Q
	kW	kvar	kW	kvar	kW	kvar
Grid	2524.6	674.0	2417.2	456.9	107.4	217.2

Table 6-10: Case 3 - Transformer Loading Summary

Name	Type	Loading	Tap 1, Current Position
	kVA	%	
Avenue Tx	630kVA Dist Tx	54.7	3
Beauregard Tx	200kVA Dist Tx	63.6	3
Carrefour Tx	630kVA Dist Tx	73.8	4
Central T1	800kVA Dist Tx	63.3	2
Central T2	800kVA Dist Tx	30.8	2
Dixcart Hotel Tx	250kVA Dist Tx	65.9	3
EC Tx 1	2500 kVA Step-Up	101.4	2
EC Tx2	2500 kVA Step-Up	0.2	2
La Valette Tx	200kVA Dist Tx	3.9	3
Little Sark Tx	200kVA Dist Tx	51.5	2
Methodist Chapel Tx	200kVA Dist Tx	55.9	4
Northfield Tx	200kVA Dist Tx	45.4	3
Plaisance Tx	200kVA Dist Tx	76.2	3
Seigneurie Tx	250kVA Dist Tx	69.1	4

HV cable loading is shown in the table below for information purposes only. It should be noted that some of the cable names are historical based on reuse of existing substations and joints, and therefore do not always directly correlate to the diagram in Figure 5-4.

Table 6-11: Case 3 - HV Cable Loading Summary

Name	Loading
	%
Avenue-Beauregard Cbl	5.9
Baytree-Northfield Cbl	23.4
ChapelCorner-Beauregard Switch	0.0
Coupee Joint to Sark	6.3
Dixcart Hotel - Pomme de Chien	26.1
EC-Central 1	49.6
EC-Central 2	0.1
Mermaid-Telecoms_a Cbl	52.3
Moinire-Chapel Corner Cbl	7.0
Moinire-JointBay Cbl	7.0
Northfield-Seigneurie Cbl	17.7
Norwood - Peignury	0.0
Norwood - Peignury_a	26.1
Plaisance - CoupeJoint	6.3
Plaisance-Beauregard	0.0
Powerstation-Mermaid Cbl	52.3
Powerstation-Peignury Farm	26.1
Rue Lucas - Powerstation	29.5
Seigneurie-JointBay Cbl	7.0
Stocks - Beauregard Cbl	15.8
Telecomms-Carrefour Cbl	52.3
Telecoms-Baytree Cbl	23.4
Telecoms-La Valette Cbl	0.5

6.3.5 Case 2 (Electric Cooking, Heat Pump & Rebound) – Outage

The outage existing condition is used to check the system performance for outage conditions, at the expected long term future network load. As noted earlier, an outage is applied to one of the main step-up transformers and to the ring feeder from the Energy Centre to the Central substation and the duplicated transformers at the central substation.

A summary of the key results and finding is listed below, and the following tables. A copy of the output SLD can be seen in attachment [C3].

- The system voltage profile remains acceptable.
- The EC transformers are fractionally overloaded
- The Central transformer is loaded above 90%.
- No other items of equipment are indicated as overloaded.
- Some LV cable loading and voltage drops are a little high. This is due to simplified modelling approach. In detail design the LV system would compromise multiple smaller LV feeder circuits.
- The generation system is overloaded – this is as expected as the future generation mix is unknown, and uses the current mix, which is only rated from around circa 750 kW.

Transformers generally have a significant overload capacity for up to 4 hours, and sizes are based on a 40°C ambient, so minor overloads are unlikely to be a practical issue.

Table 6-12: Case 4 - Network Demand Summary

Name	Generators, P	Generators, Q	Loads, P	Loads, Q	Losses, P	Losses, Q
	kW	Kvar	kW	kvar	kW	kvar
Grid	2539.6	685.6	2417.2	456.9	122.4	228.7

Table 6-13: Case 4 - Transformer Loading Summary

Name	Type	Loading	Tap 1, Current Position
	kVA	%	
Avenue Tx	630kVA Dist Tx	54.9	3
Beauregard Tx	200kVA Dist Tx	63.6	3
Carrefour Tx	630kVA Dist Tx	72.0	3
Central T1	800kVA Dist Tx	92.4	2
Central T2	800kVA Dist Tx	0.0	2
Dixcart Hotel Tx	250kVA Dist Tx	66.4	2
EC Tx 1	2500 kVA Step-Up	102.2	3
EC Tx2	2500 kVA Step-Up	0.0	3
La Valette Tx	200kVA Dist Tx	3.8	3
Little Sark Tx	200kVA Dist Tx	50.9	2
Methodist Chapel Tx	200kVA Dist Tx	54.6	3
Northfield Tx	200kVA Dist Tx	44.2	3
Plaisance Tx	200kVA Dist Tx	75.3	3
Seigneurie Tx	250kVA Dist Tx	67.5	3

HV cable loading is shown in the table below for information purposes only. It should be noted that some of the cable names are historical based on reuse of existing substations and joints, and therefore do not always directly correlate to the diagram in Figure 5-4.

Table 6-14: Case 4 – HV Cable Loading Summary

Name	Loading
	%
Avenue-Beauregard Cbl	16.0
Baytree-Northfield Cbl	22.8
ChapelCorner-Beauregard Switch	0.0
Coupee Joint to Sark	6.2
Dixcart Hotel - Pomme de Chien	55.3
EC-Central 1	48.9
EC-Central 2	0.0
Mermaid-Telecoms_a Cbl	51.1
Moinire-Chapel Corner Cbl	6.8
Moinire-JointBay Cbl	6.8
Northfield-Seigneurie Cbl	17.3
Norwood - Peignury	0.0
Norwood - Peignury_a	55.3
Plaisance - CoupeJoint	6.2
Plaisance-Beauregard	29.5
Powerstation-Mermaid Cbl	51.1
Powerstation-Peignury Farm	55.3
Rue Lucas - Powerstation	0.0
Seigneurie-JointBay Cbl	6.8
Stocks - Beauregard Cbl	45.1
Telecomms-Carrefour Cbl	51.1
Telecoms-Baytree Cbl	22.8
Telecoms-La Valette Cbl	0.5

6.3.6 Load Flow Summary

The system has been checked for the two main cases of short term future loads (Case 1) and a future maximum demand scenario (Case 2). For each of these cases, the network voltage profile and equipment loadings are checked for a normal (intact) condition and a worst-case outage condition.

The results for the present day indicated that the system configuration was acceptable, and no areas of concern were identified. For the future Case 2 scenario, the HV system performed well, the main EC transformers were fractionally overload, but this is considered acceptable, as it is a known constraint of the transformer rating.

A number of possible congestion points were identified in the LV network, and these were mainly related to the LV load demand and assumptions which would be developed further during detail design, and some of the loads would be split between different LV circuits.

6.4 Short Circuit Studies

6.4.1 Introduction and Scenarios

Short circuit studies are carried out to determine the maximum and minimum faults levels on the network. For standard systems, this is carried out to calculate the required switchgear fault duty, however in the case of Sark, the minimum fault levels are of key interest in determining operation of the protection systems. The system is checked for the maximum SC conditions, which can occur. In each scenario the network voltage profile and equipment loadings are checked. The cases considered are:

1) Maximum short circuit level (All generation on line)
2) Nominal short circuit level (1x DG, Solar, BESS & 2x WTGs)
3) Minimum short circuit level – 100% Renewables (Solar, BESS & 2x WTGs)

The DG sub-transient reactance X’’d have been selected as a low value (to give maximum fault current) of 10% to determine maximum fault levels on the network. Actual values may range slightly depending on the model selected but would usually be in the range of 10% to 15%.

The WTG, BESS and Solar PV, are all assumed as to have a maximum fault contribution of 150% of Full Load Current.

6.4.2 Maximum Short Circuit

The maximum short circuit study indicates the maximum fault level that can occur on the system for the existing generation mix, considering 3xDGs in service and all renewable generation online. The values are calculated using the IEC 60909 method, with the voltage c factor =1.1. Due to the small system size, the results are given in kVAsc and Amps instead of the usual MVAsc and kA.

The results indicate a very low maximum fault level, that is under 1 kA on the HV network and a maximum value of circa 12.5 kA on the EC LV switchboards. No concerns exist with the result and any standard switchgear could accommodate the fault levels. The Ph-E results are not shown for brevity.

Single Line Diagrams of the 3Ph and Phase Earth values are included in attachments [D1] and [D2].

Table 6-15: Key Busbar Maximum 3Ph Short Circuit Levels

Name	Ik"	Sk"	ip	Ib
	A	kVA	A	A
Beauregard	717	8199	1391	565
Carrefour Crossroads	728	8318	1440	568
Dixcart Hotel	742	8479	1538	571
Energy Centre HV	742	8479	1538	571
La Valette	721	8247	1403	566
Little Sark HV	655	7491	1124	553
Methodist Chapel	654	7475	1119	553
Northfield	705	8063	1318	564
Plaisance	698	7980	1285	562
Powerstation	692	7915	1260	561
Seigneurie	723	8269	1414	567
The Avenue	730	8348	1456	568
Energy Centre LV	12576	9039	26297	9264
Central LV	8886	6157	18218	7876

6.4.3 Nominal Short Circuit Level

The nominal short circuit study indicates the expected fault level that would occur on the system during routine operation, considering 1 x DG in service and all renewable generation online. The values are calculated using the IEC 60909 method, with the voltage c factor = 1.1. Due to the small system size, the results are given in kVAsc and Amps instead of the usual MVAsc and kA.

The fault level results are around 2/3 of the maximum value, and would practically dip under this slightly if some of the renewables were off line. The results indicate a very low maximum fault level, and no concerns exist. The Ph-E results are not shown for brevity.

Single Line Diagrams of the 3Ph and Phase Earth values are included in attachments [D3] and [D4].

Table 6-16: Key Busbars Nominal 3Ph Short Circuit Levels

Name	Ik"	Sk"	ip	Ib
	A	kVA	A	A
Beauregard	487	5571	922	396
Carrefour Crossroads	491	5613	939	397
Dixcart Hotel	496	5670	970	398
Energy Centre HV	496	5670	970	398
La Valette	489	5589	926	397
Little Sark HV	467	5335	823	394
Methodist Chapel	466	5330	821	394
Northfield	483	5527	897	396
Plaisance	481	5499	885	395
Powerstation	479	5478	876	395
Seigneurie	490	5596	930	397
The Avenue	492	5624	944	397
Energy Centre LV	7909	5685	15441	6253
Central LV	6661	4615	12914	5875

6.4.4 Minimum Short Circuit (100% Renewable)

The minimum short circuit study indicates the maximum fault level that can occur on the system when the DGs are out of service and the system is running on battery storage and solar or wind (battery storage and wind would be virtually identical). The values are calculated using the IEC 60909 method, with the voltage c factor = 1.1. Due to the small system size, the results are given in kVAsc and Amps instead of the usual MVAsc and kA.

The results indicate a very low fault level, around 6x smaller than the maximum fault level. For context, it can be seen that in the Case 1, outage scenario detailed in Section 6.3.3, the maximum load flowing around the heaviest part of the ring is around 240-280 kW, which would be around 21-25 A depending on power factor; and for the Case 2, outage scenario detailed in Section 6.3.5 the maximum load flowing around the heaviest part of the ring is around 820-880 kW, which would be around 71-78 A depending on power factor. The Ph-E results are not shown for brevity.

Single Line Diagrams of the 3Ph and Phase Earth values are included in attachments [D1] and [D2].

Table 6-17: Key Busbars Minimum 3Ph Short Circuit Levels

Name	Ik"	Sk"	ip	Ib
	A	kVA	A	A
Beauregard	141	1610	204	140
Carrefour Crossroads	141	1610	204	140
Dixcart Hotel	141	1610	204	140
Energy Centre HV	141	1610	204	140
La Valette	141	1610	204	140
Little Sark HV	141	1609	204	139
Methodist Chapel	141	1609	204	139
Northfield	141	1609	204	140
Plaisance	141	1609	204	140
Power Station	141	1609	204	140
Seigneurie	141	1610	204	140
The Avenue	141	1610	204	140
Energy Centre LV	2237	1608	3234	2217
Central LV	2231	1546	3226	2216

6.4.5 Summary

The short circuit studies indicated that the system has a very low short circuit level during normal operation conditions, which reduces significantly during 100% renewable operation. During 100% renewables it is noted that the fault current is above the steady state load current by a factor of around 4x during a ring outage.

The key issue with the Sark network is therefore the low short circuit levels and ensuring that the protection scheme can correctly identify and clear faults during 100% renewable operation.

6.5 Emergency Operation

The configuration of the proposed HV design is based on full redundancy at the Energy Centre and Central substations. Generation design is within the IRL scope, but currently based on an n-1 design with the DGs; the renewable generation is considered intermittent and therefore not considered for

It is proposed that these are provided with auto-changeover facilities to switch over in the event of a failure. The remaining HV substations (excluding Little Sark) on the network are provided in a ring formation with an additional switching station at Beauregard, to allow the network to be reconfigured in case of a significant outage. These substations could be configured as manual changeover or with a level of automation if required and at additional cost.

The most serious issue on the proposed design would be total failure of an RMU substation, or a distribution transformer. In this scenario it is proposed that each main LV distribution board, is provided with a spare way suitable for connection of the island owned emergency generator to be deployed.

6.6 Protection

As noted in Section 2.13, protection schemes for island microgrids can be complex and requires many factors to be considered. At the concept stage of a project, it is impossible to fully define these requirements, however the basic principles of adaptive control using alternate settings groups is possible.

Due to space limitations, a detailed explanation and example of this configuration is given in Appendix A of this report.

6.7 Black Starting

Black starting studies have not been carried out as part of the concept study validation, as these are complex studies and need accurate data to be available. The primary concern, with any black-starting of the site would be for energisation of the main step-up transformers. In a normal grid system, transformers are energised from HV, and suppliers quote inrush currents on this assumption. It is known that if energised from the LV side, the associated inrush can be significantly higher.

Energisation of the transformers would typically need multiple DG sets to be online, and it is expected that the transformers would need to be energised in a controlled manner through slowing ramping up the DG voltage, from residual voltage at rated speed, with the transformer LV winding connected to the LV generation bus before DG start-up. to limit the inrush. This requires control features that may not be present by default in the excitation control systems for such sets. Due care is therefore required in the specification of them, and any associated auxiliary and UPS supplies.

6.8 Transient Studies

Transient studies have not been carried out as part of the concept study validation, as these are complex studies and need accurate data to be available. The primary concern with transient studies is the stability of the system to disturbance events. These will need evaluating for all 3 main generation scenarios (full DG, mixed DG and renewable and 100% renewable)

- HV network faults
- Unplanned trip of generation
- Trip of main load i.e. ring feeder
- Starting / Stopping of any large loads (hotel kitchen, arc welders, compressors etc.)

It is common for such studies to reveal the need for temporary load reduction to avoid complete system blackout. The HV network and generation control systems should have such requirements included in the design specifications, noting that schemes for implementing a temporary load reduction require to be fast-acting – a requirement that can only be fulfilled by control schemes based on hard-wired (i.e. point-to-point) signals or high-speed communications protocols available when such systems are based on the IEC 61850 set of standards using fibre communications (normally in a dual redundant ring configuration).

Most modern control systems use the latter technique, which for Sark gives rise to issues of installation cost and availability of suitably trained personnel to operate and maintain such equipment. The cost of such systems is relatively high; therefore a decision may have to be made to accept the risk of temporary system blackout under certain fault scenarios.

6.9 Summary

The studies carried out for the Concept 4 design approach, indicated that the system worked well for proposed network requirements, and no significant areas of concern were identified. A few localised equipment ratings and bottlenecks were identified on the LV system, but these are relatively minor as the LV system design has not been developed in detail yet and these issues may not actually exist, or can be easily rectified.

The location of the new Central substation requires consideration in relation to available land on the Island. The exact location is not critical, and can be varied with a degree of flexibility. The size of the substation will need confirming but would typically be in the region of 6m x 4m and could either be brick built or a GRP enclosure. As this substation, and the facilities at the Energy Centre, are the most vital part of the Sark electricity grid, consideration of safety, in terms of equipment spacing, access restrictions and fire-fighting facilities. In particular, BESS units (depending on battery technology used), may represent a high fire risk as a fire in one may be very difficult to extinguish (water can ‘feed’ such a fire, rather than reduce it) and the intensity of such a fire might result in spread to other equipment nearby. The BESS would therefore need to be in a ‘sterile’ zone, or provided with suitable fire walls and fire detection system to prevent spread.

Some general high-level observations are made on the Concept 4 design, that require further development when the project moves into the detail design phase.

- Sizing for the main step-up transformer is important. These have nominally been set at 2500 kVA, to represent a credible worst-case future scenario.
- Energisation of the step-up transformer needs investigation. The larger the transformer and the more limited the available generation, the more challenging the transformer will be to energise. Typically this can be achieved using a ‘soft-magnetization’ approach from the DG sets, provided they have the correction functions in the controller.
- The distribution transformer sizing should be regarded as indicative only and it is likely that some area transformer sizes may need to increase, and others could potentially be decreased.

- The LV network would benefit from further development and investigation. Although overall loads have been estimated with a reasonable degree of accuracy, there is a significant portion of cost and uncertainty within the LV design.
- Transient studies will be needed to verify the adequacy of the generation scheme and identify any problem areas with stability and operation in 100% renewable mode. This should be carried out as a matter of priority.
- Consideration should be given to identifying any critical LV loads that need backup supplies.
- During detail design stage it may be beneficial to shift some of the substation locations around slightly, depending on available land and load details. In particular the Beauregard and Seigneurie and Carrefour substation locations could be adjusted.

SECTION 7 - DISCUSSION & CONCLUSION

The concept report has looked at the existing electrical network information and the available information from the island along with the proposed design goals and aims. As with any system design, it is necessary to trade-off the competing aspects of reliability, cost, future proofing and simplicity and find a balance between the competing requirements. In the case of Sark, several very specific island challenges are faced, due to the uncertainty in the existing load data, and the projected future loading scenarios along with some limitations in available operational personnel.

Four main concepts were presented within the report, considering different options and strategies for the island, and were analysed for suitability. The characteristics of these options are presented in Table 5-1 in the main body of the report, and briefly summarised below:

1) **Upgrade and Simplification of Existing Network** – this approach is very simplistic, faces some problems with reliability and is not cost efficient, but could be considered if funding a full network upgrade in a single round is problematic. This approach could be a stop-gap on the route to the final design.
2) **Modified Energy People Ring** – this approach utilises a simple ring network around the island. The network approach relies heavily on LV distribution, and faces a number of significant challenges to maintain an acceptable level of availability and reliability, especially to vital consumers (emergency services, etc). This approach would require 11 kV, and total replacement of the existing cable network. It is therefore relatively high cost, and cannot easily be implemented in stages.
3) **Hybrid Design** – this approach utilises a mixture of the Energy People ring and the existing network approach. The design needs 11 kV to work satisfactorily and faces potential bottleneck problems in later years, and some potential problems in the early years with low load current causing problems with protection operation.
4) **Hybrid Design with Central Substation** – this approach is the recommended solution, as it utilises modern design practices and provides a good level of design resilience and flexibility.

The Hybrid Design with a Central Substation approach was checked and validated with a number of high-level load flow and short circuit studies carried out on the HV system. No areas of significant concern were identified, and the design worked as expected.

The Hybrid Design with Central Substation approach is considered the most suitable for the island and the design approach recommended by Aurora. This approach provides a high level of reliability and scalability to meet future demands on the island. The only drawback with this approach is a new Central substation location is required.

The key findings of the concept report are:

- The Hybrid concept with a Central Substation is the most robust and flexible option. All other approaches have significant drawbacks.
- During detail design stage it may be beneficial to shift some of the substation locations around slightly, depending on available land and load details. In particular the Beauregard and Seigneurie and Carrefour substation locations could be adjusted.
- The harbour substation is assumed to be supplied at LV from the Energy Centre, if reuse of existing cable is possible, then supplying at HV from the central substation may be preferable.
- Energisation of the step-up transformers needs consideration. This should be possible with using a ‘soft magnetization’ approach within the DG sets, provided they have suitable controllers.
- Transient studies will be needed to verify the adequacy of the generation scheme and identify any problem areas with stability and operation in 100% renewable mode. This should be carried out as a matter of priority.
- The generation and its associated control systems will need careful evaluation and integration into the HV design. Any fundamental shifts in generation strategy for the island may alter the conclusions and suitability of the proposed HV concepts.
- Consideration should be given to identifying any critical LV loads (Island Hall, Medical Centre, Telecoms, supermarkets etc.) that need backup supplies.
- The LV network would benefit from further development and investigation. Although overall loads have been estimated with a reasonable degree of accuracy, there is a significant portion of cost and uncertainty within the LV design.

SECTION 8 - REFERENCES

The following specifications, documents and standards are referenced within this report:

[1] Energy People, "Report of a study on the costs of supplying electricity in Sark using a mix of wind, solar, diesel and battery storage.," 2022.

[2] "IEC 61936: Power installations exceeding 1 kV AC and 1,5 kV DC".

[3] "IEC 60287-3-1: Electric cables - Calculation of the current rating - Part 3-1: Operating conditions - Site reference conditions".

[4] HSE, "ESQCR," [Online]. Available: https://www.hse.gov.uk/esqcr/index.htm.

[5] NESO, "FRCR," [Online]. Available: https://www.neso.energy/industry-information/codes/security-and-quality-supply-standard-sqss/frequency-risk-and-control-report-frcr.

[6] Oak Ridge National Laboratry , "Methods for Microgrid Protection," 2019.

[7] NREL, "Microgrids for Energy Resilience: A Guide to Conceptual Design and Lessons from Defense Projects," 2020.

[8] "Sark Replacement Power System - Request for full proposals - Issued 28th March 2023".

[9] EI Services, "Document No: 10739 HV Assessment Report Issue No: 3.0," 2021.

[10] "ENA P5: Design methods for LV underground networks for new housing developments".

[11] "UKPN: EDS 08-2000 LV Design Standard".

[12] “NGED: SD5A/6 Design of Low Voltage Domestic Connections”.

[13] “UKPN: EDS 08-2100 Customer Supplies over 100A”.

[14] “UKPN: EDS 08-2101 Customer Supplies up to 100A”.

[15] “UKPN: EBB-08-0065 LV Network Design Mains And Services”.

APPENDIX A – PROTECTION SCHEME

A.1 Microgrid Protection

Small systems with a high percentage of renewables, and microgrids face a number of challenges over traditional protection schemes, and extra considerations need to be applied in order to successfully detect and trip faults. Challenges include:

- Low fault levels.
- Varying load demand.
- Varying fault levels due to different generation mix
- Distinguishing between load current, overloads and faults.
- Relay 'blinding' due to embedded generation and back-feeds.
- Operating quickly enough to prevent transient disturbances and system collapse.

Schemes are generally split into conventional protection schemes and non-conventional protection schemes. A summary of key scheme types with advantages and disadvantages is shown below (a direct copy of Table 4 from [5]).

Table 0-1: Conventional Microgrid Protection Scheme Concepts

Functions (Device Nº)	Advantages	Disadvantages
Undervoltage (27)	- Does not depend on fault current magnitude and direction	- Does not allow a good selectivity coordination Susceptible to transient incidents (load operations)
Overvoltage (59)	-Does not depend on fault current magnitude and direction - Protects inverters	Does not depend on fault current magnitude and direction Susceptible to transient incidents (load operations)
Voltage Balance (60)	- Detects blown voltage transformer fuses to protect generators	- Does not allow selectivity coordination
Volts per Hertz (24)	-Protects inverters	-Does not allow a good selectivity coordination -Susceptible to transient incidents (load operations)-
Frequency (81)	-Protects inverters	-Does not allow a good selectivity coordination -Susceptible to transient incidents (load operations)
Impedance (21)	- Provides solution for islanded microgrids	- Lacks sensitivity to measure apparent impedances at fault situations with distributed energy resource contributions. Needs communication

Differential (87)	- Does not depend on fault current level Does not depend on distributed energy resource type, location and size	- Does not allow a backup protection from other zones Needs communication
Instantaneous Overcurrent (50)	Allows an instantaneous trip but it is used with the inverse time and definite time overcurrent relays	-Does not allow coordination with fuse curves -Needs to be used when coordination is not required (last relay application)
Inverse Time Overcurrent (51)	-Allows coordination of relays with feeder fusses	-Needs to be complemented with directional and/or adaptive overcurrent protections -Needs communication
Directional Overcurrent (67)	- Provides proper solution to coordinate protectives devices for different microgrid circuit paths	- Needs forward and reverse coordination Needs adaptive settings

Table 0-2: Non-Conventional Protection Schemes

Functions (Device Nº)	Advantages	Disadvantages
Adaptive Protection	- Allows sensitivity and selectivity based on microgrid operation conditions	- Needs communication - Needs large amount of data for real-time adaptation of protection settings - Complicated design
Voltage Restrained	-Enhances fault detection that could not have overcurrent relays - Detects low fault currents	- Difficult Coordination - Lacks success to detect high-impedance faults
Hierarchical	- Allows to coordinate differential protection schemes at different protection levels.	- Needs communication
Symmetrical component	-Allows to detect asymmetrical faults	-Unable to Detect Types of Faults -Needs to be implemented with other protection elements

A.2 Sark IDMT Adaptive Protection Concept

The general problem with 100% renewable energy mode is that the fault contribution will be small and similar to the network load. If the recommended approach of Concept 4 is followed, the network load is split into smaller radial loads, with a large amount of the Central substation transformer and the balance split across the ring feeders. In normal operation, with the ring running normally open, this should allow a good level of coordination to be achieved, as the maximum load down any one circuit will be small compared to the overall system load.

Where challenges may occur is during network outages on the ring, or one of the central transformers. In this case the load down the ring can potentially increase significantly making discrimination harder. In order to overcome this, it is proposed that the IDMT based scheme in the Central substation HV relays are set with adaptive / alternate settings groups during network outages.

These settings are pre-defined within the relay and automatically selected, when a network outage occurs – typically using the HV circuit breaker open / close status, or if the PMS indicates that the network is operating in 100% renewable mode.

The general principal of the adaptive scheme is to set the relay pickups on actual load / generation values (i.e. deliberately low), rather than on the equipment / circuit design rating as would be usual practice. This approach is followed as in many cases the equipment is deliberately oversized for future cases, where the equipment rating far exceeds the generation / load capability.

To illustrate the point, consider the final network configuration of approximately 2500 kVA demand. Around 800 kVA would be located on the Central substation, and the remaining 1700 kVA would be spread around the ring. Assuming the ring runs open and is reasonably well balanced, the total load would be around 600 kVA in each ring feeder. This should be relatively easy to coordinate with the main incomers which would be carrying circa 2500 kVA. Should a network outage occur on one of the ring feeders, the healthy ring feeder would detect the fault via a local control signal, and change its setting group to pick-up at 1200 kVA.

A similar approach can also be used in 100% renewable operation. When in 100% renewable mode the relays use an alternate setting group, to make the relays more sensitive by lowering pickup values for overloads, lowering trip times, or using current based definite time coordination.

A.3 Protection Settings for Present vs Future

One of the other challenges faced by the protection scheme is that the current demand and is circa 350 kW and the near future case demand is 750 kW, with generation only provided up to this value. However, the overall electrical system is rated for up to 2500 kVA, and the generation mix for the future cases is unknown. It is therefore anticipated that the protection settings used in the early stages of the project may intentionally use lower pickup settings than the equipment rating, to allow coordination with the generation protection. These protection settings would then be periodically updated during each major generation expansion.

A.4 Summary

An adaptive protection scheme can be made to work with IDMT relays, provided that the relays are set to pick up against expected loads rather than circuit design ratings and the relays purchased have sufficient alternate settings groups available and communication link is available from the relays back from the Central Substation to the Energy Centre to confirm operating condition.

The testing and commissioning would be challenging, and need careful planning and oversight, with clear check / fail tests, but with suitable planning this should be manageable.

It is also suggested that the settings would need updating and revalidating at a future date as the system load and generation increased. An initial estimate would be a full review every 5 years or following any significant network changes.

APPENDIX B – LV DESIGN

B.1 Overview

As noted in Section 1.4, the LV design of the network is excluded from the main concept study. However, as the LV equipment and cabling can be a significant portion of the cost it is necessary to develop outline design requirements. To ensure a robust design approach, the general LV design principles followed will be in line with UKPN LV design standards [10], [12], [13] & [14].

The general approach followed for the new LV system design will be to:

- Install Main LV switchgear at the Energy Centre and the Central Substation.
- Install smaller LV Feeder pillars next to each transformer, with each pillar having enough circuits to supply the local area, and spare ways for future expansion and connection of a local temporary DG for emergencies.
- Install 4 core (CNE aluminium cable down all main cable LV circuits for LV mains.
- Install 4 core aluminium cable down for each high demand consumer to a meter box on the edge of the property.
- Install 4 core (3Ph) aluminium cable to domestic customers to a meter box on the outside of the house.
- Provide smart meters for consumers.
- Provide facilities for intelligent demand control.
- Provide a PME earthing system for the LV network.

Installation of 3-phase supply to all properties is suggested, as this allows a high level of flexibility for future changes to the network, as loads could be split between phases. It also allows the network phases to be rebalanced easily as the network develops over time.

B.2 LV Switchgear and Feeder Pillars

The main LV switchgear at the Energy Centre will be the responsibility of IRL scope, but is assumed to be a 3-section switchboard with 2 bus-sections operating normally closed. The switchgear should be rated at 4000 A, 50 kA, 3-phase with a fully rated neutral. The construction should be to IEC 61439, Form 4 Type 7 or similar. Consideration should be given for the assembly to be manufactured and tested in accordance with the requirements of IEC TR 61641, arcing class A or B or 1. The switchboard should be provided with spare outgoing MCCB circuits for future use.

The main LV switchgear at the Central Substation will be a 2-section switchboard with 1 bus-sections. The switchgear should be rated at 1200 A, 50 kA, 3-phase with a fully rated neutral. The LV bus-section will be operated normally open and provided with an automatic changeover facility for loss of volts on either incomer. The construction of the switchboard should be to IEC 61439, Form 4 Type 7 or similar. The switchboard will be provided with a number of spare outgoing MCCB circuits for future use.

For general LV distribution, each transformer substation will be provided with an adjacent LV feeder pillar. The feeder pillar will be rated to match the transformer current rating and fault level, using standard sized to allow commonality of spares. Each feeder pillar will be provided with a main LV MCCB incomer, and a number of outgoing LV MCCB feeders provided with ground fault detection. The number of LV MCCB feeders will depend on the individual substation, but will include at least one spare way for future use. Each feeder pillar will be provided with a spare incomer, for use with a temporary DG set in case of transformer failure – the spare incomer, will be castell key interlocked with the main transformer incomer. Feeder pillars will be provided with MCCB protection devices equipped with LSIG protection units. The rating of the units will be selected to match the transformer rating and outgoing circuit rating.

It is noted that the above fault levels of the LV switchgear are in excess of those needed by the generation equipment but have been selected for future proofing and as standard design ratings.

B.3 LV Mains Cables & Distributions

LV power will be distributed around local areas of the island using 4 core CNE cable, laid in the road / pathways. The LV mains cables will be breach jointed at each property on alternating phases, to supply a phase and neutral to individual domestic properties. Additional earth electrodes for the PME or TT system are to be provided as appropriate. The standard cable size to be used will be 300 mm^2 Aluminium or 95 mm^2, depending on the local load density. In certain places it may be appropriate to reduce / increase this size for specific load variations.

An example of the LV distribution system configuration can be seen below. Showing the design approach, with multiple houses fed from a single LV cable circuit via breech joints, and protected via a circuit MCC, and large consumers provided with a dedicated MCCB feeder.

The number of houses per feeder will depend on location specific details; 300 mm^2 Al cable has a nominal rating of around 400 A laid direct in ground based on the ADMD figures (refer to 4.3), equivalent to a nominal rating of 277 kVA, for lower density areas, a 95mm^2 Al may be suitable. Referring to Table 4-1 approximately 80-100 houses could be connected to each LV mains.

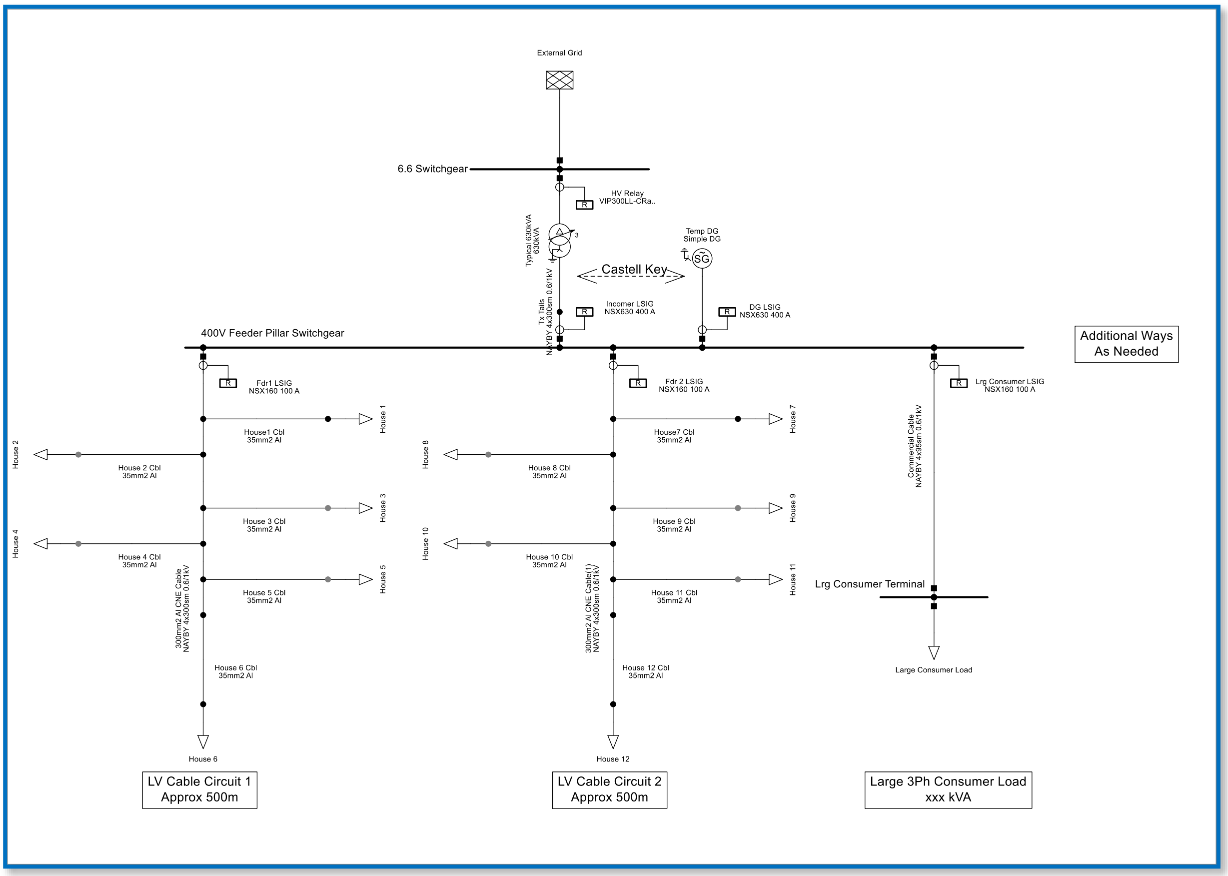

Figure B-0-1: LV Design Concept

B.4 Large Consumers

The supply to each large consumer will be designed to meet the specific installation requirements, and cable sizes will be selected to meet specific demand and volt drop requirements.

Each individual large consumer should provide a detailed summary of electrical loads at the site, and details of any disturbing loads that are switched on/off regularly.

B.5 Domestic Consumers

Domestic consumers are assumed as requiring a single phase 100 A supply, and will usually be provided with a 35 mm^2 aluminium cable to a metering point and cut-out located on the outside of the property.

For some properties it may be necessary to increase the cable size if the distance to the property from the LV cable mains exceeds the nominal distance of 40 m.

Internal property wiring will be the responsibility of the property owner.

B.6 Metering

Each property will be provided with a smart meter to allow monitoring of power demand and usage. The configuration and monitoring of power demand and tariffs are outside the scope of the system design, and are assumed as managed by the electricity price regulator.

Properties with existing generation should be provided with an export meter, and may need to be constrained during certain periods.

APPENDIX C - ATTACHMENTS

The documents listed below are embedded in the main PDF as attachments. To access them, please use the paperclip icon in Adobe or Nitro PDF. Note that if you are viewing this PDF through a web browser the attachments might not be accessible.

Base Data

[A1] Existing Network SLD

[A2] Island Load List

Concepts

[B1a] Concept 1 SLD

[B1b] Concept 1 Geographical Layout

[B2a] Concept 2 SLD

[B2b] Concept 2 Geographical Layout

[B3a] Concept 3 SLD

[B3b] Concept 3 Geographical Layout

[B4a] Concept 4 SLD

[B4b] Concept 4 Geographical Layout

Loadflow Results

[C1] Loadflow Results – Existing Load Intact

[C2] Loadflow Results – Existing Load Outage

[C3] Loadflow Results – 2.5MW Load Intact

[C4] Loadflow Results – 2.5MW Load Outage

Short Circuit Results

[D1] Maximum Short Circuit Results – 3Ph

[D2] Maximum Short Circuit Results – PhE

[D3] Nominal Short Circuit Results – 3Ph

[D4] Nominal Short Circuit Results – PhE

[D5] Minimum (100% Renewable) Short Circuit Results – 3Ph

[D6] Minimum (100% Renewable) Short Circuit Results – PhE