



NETWORK MANAGEMENT ON THE ISLES OF SCILLY

**LCN FUND TIER 1
CLOSE DOWN REPORT
NETWORK MANAGEMENT ON
THE ISLES OF SCILLY**

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1. Network Management on the Isles of Scilly

The Isles of Scilly is a small cluster of islands off the coast of Cornwall that have a stated intention of becoming energy self-sufficient. The climate afforded by its location provides a large potential for this energy to be supplied using renewable low carbon technologies, such as photovoltaic (PV) generation, wind turbines or tidal power schemes.

This project has deployed and assessed several technological solutions to form an overarching smart grid covering every substation on the Isles. On completion it has produced a platform for further low carbon related research and development activities.

Due to its islanded position, the Isles of Scilly provides a discrete platform to study the effect of low carbon technologies on an electrical network and learning from this can be applied on other electrical networks in the UK.

2. Executive Summary

This report details the work undertaken as part of the LCN funded Tier 1 project Network Management on the Isles of Scilly. The project had three aims which were covered across the project lifespan:

- Establish a real-time monitoring system on all the distribution substations
- Maximise existing generation facilities
- Control the generation using new methods

Under the project, all the substations on the Isles of Scilly were fitted with low voltage monitoring to determine the aggregate load across all phases. This has allowed the distribution of load across the network to be more accurately assessed and will aid in informing future network investment. The implemented system was a bespoke design due to limited available off-the-shelf systems when the project was initially scoped.

High Voltage automation has been installed adjacent to the off-island generation so that the load sections they supply can be altered for maximum benefit. Sequenced switching routines within the GE PowerOn Fusion Distribution Management System enable this to be an automated process and also enable routines to be configured to respond to monitored network changes. This provides flexibility for when the load and generation balance in the area changes.

Synchrophasor generator control algorithms have been developed to allow the generation sets to keep aligned to each other and the mainland without a direct electrical connection. This learning has the potential to allow the same generator control signal to be applied to multiple generator sets without the risk of dynamic stability issues. This could enable a larger amount of future low carbon generation to be accommodated, displacing the need for conventional Distribution Network Operator (DNO) owned diesel generation.

Broadband over Powerline (BPL) has been trialled on the 11kV network, allowing fast, low latency communications to be conducted over existing assets. This technology has provided some successful links within the communications structure, but has also experienced instability in other links which may limit the deployment for certain applications.

Other communication links on the Isles were completed using a mixture of low power UHF radios, enabling flexible low speed connections to be deployed with limited disruption to the electrical network. Some interference with the availability of the radios has been experienced due to atmospheric conditions, which occur more frequently on the islands, due to their position.

The original project budget was £1,287k with the project costs at closedown of £1,276k.

3. Project Suppliers

Western Power Distribution has worked with a number of companies in the deployment of the Network Management on the Isles of Scilly project.



GE Digital Energy is a major solutions provider for the global Smart Grid market integrating communications, automation and power delivery techniques. In this project, GE Digital Energy has been responsible for the design of the communications network topology and integration of the different communication technologies. GE has also designed, built and supplied the LV metering equipment.



Power Electrics

Power Electronics is one of the largest independent diesel generator specialists in the UK and provides flexible power solutions through its generator Hire, Sales, Service and Parts Divisions. Power Electronics have supplied, installed and commissioned the two off-island generators funded by Western Power Distribution and integrated the control functions funded by the LCNF.



Power Plus Communications (PPC) is a leading provider of broadband powerline communication systems, supplying utilities and distributed network operators with key technologies for smart grid communications. Within the project, PPC have been responsible for supplying the broadband over powerline technology and supporting the design, installation and commissioning of the solution.



Psymetrix provides innovative products and services that deliver significant benefits in the operation, and planning of electrical power systems. Psymetrix's solutions are used by power system operators and planners worldwide for improving power system security, securely increasing power transfer levels and tracking power system performance, including dynamics, model validation and tuning of power system stabilisers. Psymetrix have developed and supplied the PhasorPoint system used in the demonstration of synchrophasor control.



The Duchy of Cornwall is a private estate which funds the public, charitable and private activities of The Prince of Wales and his family. The Duchy consists of around 53,154 hectares of land in 24 counties, mostly in the South West of England. The Duchy owns the freehold of most of the land and nearly a third of the residential buildings on the Islands and has supported Western Power Distribution in allowing the installation works.



The Council of the Isles of Scilly provides a comprehensive range of services for those living on the islands and has aided Western Power Distribution during the installation and management of this project.



Transition Scilly is guided by the common principles of finding positive, community-led solutions to the twin threats of Peak Oil and Climate Change. Its unique approach to this challenge is in using the leverage of its social element and emphasis on community leadership.



SMART Cornwall is an EU and local council led programme to put Cornwall and the Isles of Scilly in charge of its own energy future through working with industry experts to consolidate our priorities, design and deliver a targeted programme of work. Western Power Distribution has provided advice to inform SMART Cornwall and sits on the Smart Cornwall Advisory Board.

4. Project Background

Electricity supplies to the Isles of Scilly comprise a single 33kV undersea cable from the mainland supplemented by an island based diesel generating station. There are also remote, locally controlled generators on two outer islands available for use in limited instances.

The islands provide an effective self contained microcosm of an 11kV and LV electricity distribution system that can be monitored and controlled to provide measurement of impact and capability to accommodate DG and other low carbon initiatives.

The Isles of Scilly Council has a published goal of the islands being energy self sufficient. To this end, the council is examining methods of localised generation such as waste disposal and the islanders themselves are keen to exploit PV and wave power on and off the smaller islands. WPD will work in conjunction with the islanders through this initiative to ensure the full support for their desire to be energy self sufficient. The community level interest in energy management was demonstrated in their 2009 "e-day" initiative which received national BBC TV coverage.

WPD Project partners - Duchy of Cornwall, IGE, Islanders on St. Agnes, Isles of Scilly Council, Power Electrics, PowerPlus Communications, Radius and Transition Scilly.

4.1. Electrical Network on the Isles of Scilly

The Isles of Scilly is situated around 30 miles off the west coast of Cornwall and is formed from five main inhabited islands and a number of smaller rocky islets. Electricity to the Isles is provided by a single 33kV submarine cable from the mainland to the largest island, St Mary's.

From here, an 11kV ring featuring a mix of overhead, underground and subsea cables connects St Mary's with the next two largest islands, Tresco and St Martin's. The other two inhabited islands, St Agnes and Bryher, are connected by a further two 11kV subsea cables teed off the ring.



Figure 1 - The Isles of Scilly

The 11kV circuits supply power to all 63 substations on the Isles of Scilly which comprise of a mixture of overhead and underground mounted transformers and these supply the low voltage cables connected to over 1600 customers.

Seven diesel generators feed in to the main 33/11kV Primary Substation, so that in the event of a power cut affecting the undersea cable, they can support the entire network for a sustained period. The generation is also arranged so that it can supplement the supply to the islands should demand on the isles exceed the import capacity of the cables. Conversely, if the embedded generation on the isles were ever to exceed local demand, the cables can export power back onto the mainland network.

The 11kV undersea links to St Agnes and Bryer are supported by diesel generators which operate solely to support local HV outages for faults and maintenances.

4.2. Project Overview

During 2009, the Isles of Scilly played host to E-day 2009, which attempted to co-ordinate the efforts of the islanders in reducing their electricity consumption, and record the effects in real-time. Following the sense of engagement found on the islands and the local council's aims for self-sufficiency, Western Power Distribution has undertaken a project to establish the capability to gather data on the network loadings around the islands, as well as the total aggregate loads coming in from the mainland.

In the future, the increase in visibility achieved through the collection of LV monitoring data will allow WPD planners to build more accurate models when designing connections and also share this information with strategic authorities on the islands. The potential constraint areas of the network will be able to be identified and avoided or mitigated against when planning new load connections or integrating embedded low carbon generation. By more accurately understanding the power flows within the network, the conventional generation currently securing the power supplies on the main island, St Mary's and the two electrically spurred islands, St Agnes and Bryer, can be allowed to support any future increases in load.

WPD has worked with GE and PPC to design and deploy a complete network monitoring scheme across the entire network. The network monitoring scheme has been implemented using a range of radio telecommunication technologies, as well as trialling 11kV broadband over powerline (BPL).

The combination of communication technologies has allowed comparisons between the competing technologies to be drawn, such as the differences in installation requirements, the stability of the channels and the latency of the links. By understanding these differences, future innovation projects can benefit from picking a communication method that is most suitable for the application.

The project formally registered a change in September 2012 to increase the scope of works and adjust timescales. As a result the use of phasor measurement devices has also been investigated, with a system being designed to analyse the variances in standard generation control and also 33kV submarine connections. WPD worked with Alstom and Psymetrix in order to establish real-time monitoring of phasor vectors in a number of locations across the network.

The original Project Registration pro forma is given in Appendix A1 and the amended Project Registration pro forma is included under Appendix A2.

5. Scope and Objectives

It is proposed to establish real time monitoring on all of the distribution substations on the Isles of Scilly in such a way that the use of the generation facilities on the islands can be maximised to secure supplies to the islands. The control and management of the generation on the off islands will be effected using new methods that have not been used in WPD before.

The monitoring at the substations will be supplemented by controls where appropriate to ensure that islander's and company initiatives associated with localised generation can be accommodated and managed in an effective way. The initial localised generation is expected to be by PV though the islander's themselves are actively pursuing wave power and possibly waste disposal as other sources of generation. The Scillies have the highest PV solar efficiency rating in UK and present a challenging DG/demand environment on a weakly connected rural network. The initiative will support the council's published goal of energy self sufficiency.

The scope and objectives of the project, as detailed in the original LCNF Tier-1 pro forma, were to:

- Establish a real-time monitoring system on all the distribution substations
- Maximise existing generation facilities
- Control the generation using new methods

The business case for replacement of network operator-owned generation plant follows the same methodology used for upgrading or replacing any conventional asset, in that investments are based on large step changes forecasting the required capacity over the asset's entire life.

Due to the fixed nature of the generator's output, but the changing variations in the local load connected, the generators can supply a larger area of network in times of low consumption, compared to the peak times. By changing the networks being fed at different times of the year, there can be efficiency savings gained through a reduction in losses and a reduction of generator operating hours.

The scope of this project was to monitor the network on the Isles of Scilly and allow the existing generator facilities to be controlled in order to maximise their capacity. The objective was to affect the control of the off-island generation on the Isles of Scilly using new methods. This was achieved using local generator management software instigated and coordinated by automated remote control. Adaptation of the network based upon the monitored load levels was achieved using supplementary network automation on a number of strategic devices.

By monitoring the differing load in the vicinity of the off-island generators and allowing remote changes to be made to the network topology, the generator's ability to feed different substations

can be altered flexibly. This will allow for future integration of embedded generation in the off-islands without interfering with the assumed load levels the existing generators were design for.

Six key project objectives were identified the original Tier 1 pro forma:

1. To establish real time monitoring on all of the distribution substations on the Isles of Scilly.
2. The use of the generation facilities on the islands can be maximised to secure supplies to the islands.
3. The control and management of the generation on the off islands will be effected using new methods that have not been used in WPD before.
4. Monitoring to be supplemented by controls where appropriate to manage and accommodate localised generation.
5. Support localised generation (including Photovoltaic)
6. Initiative will support the council's published goal of energy self-sufficiency.

6. Success criteria

The effective management of off island generation and monitoring & control of various PV installations on a weakly connected network.

Use of Power Line Carrier techniques on higher voltage networks

Demonstration of Synchrophasor Generator Control

From the original Tier 1 Project Registration Form, two success criteria were identified:

- The effective management of off island generation and monitoring & control of various PV installations on a weakly connected network.
- Use of Power Line Carrier techniques on higher voltage networks

Following an amendment to the originally submitted Tier 1 Project Registration Form, an additional success criterion was identified:

- Demonstration of Synchrophasor Generator Control

The WPD internal change mandates associated with this amendment are included in Appendix A3.

7. Details of the work carried out

The project design was carried out by GE Digital Energy including the design of the LV monitoring and communication methodology. Their brief was to develop a system capable of responding to new network requirements that arise from a low carbon economy and to encourage low carbon solutions.

The design recommended by GE Digital Energy also recognised DECC's key principles for a Smart Grid, which include the following four characteristics:

- **Observable** – it is possible to measure, quantify and visualise a wide range of operating values in real time
- **Controllable** – it is possible to manipulate, manage and optimise the power system to a far greater extent than is possible today.
- **Automated** – the network has a certain level of 'intelligence', being able to make, for example, certain unaided demand response decisions. It can also respond to the consequences of power fluctuations or outages by, for example, being able to reconfigure itself in the event of a circuit or equipment failure
- **Fully integrated** – the components that make up or extend smart grid capabilities must work with the existing legacy systems, as well as other new smart devices.

In order to fully implement the project, a number of parallel activities had to be carried out and co-ordinated. These can be broken down into the following categories:

- LV monitoring,
- Radio Communication,
- Broadband over Powerline,
- Off-island generators,
- Synchrophasor Control and
- HV control.

7.1. LV Monitoring

The requirement for understanding the low voltage power flows on the network was achieved by installing low voltage monitoring on all the transformers which supply power to customers. This project has created a platform for WPD to more accurately measure the aggregated customer consumptions at each substation, establish annual trends and assess daily peaks and troughs. This information is fully integrated in WPD core business systems with additional interrogation of more granular data possible over the communication links. It will help planners to more accurately plan and manage the local network as customer adopt low carbon technologies.

The variety of transformers on the Isles of Scilly has historically been wide-ranging, with ground mounted units varying in size from single phase 50kVA up to three phase 800kVA and overhead mounted units from single phase 16kVA to three phase 200kVA. With this in mind, the LV monitoring equipment was designed to be modular and cover all current ranges with the use of different current transformers (CTs). The CTs were installed directly onto the outgoing transformer LV tails, which to ensure the safety of WPD technicians required an outage due to the nature and location of the CTs fitted.

This was decided as the best approach as the age and compact nature of the equipment on the Isles did not lend itself to fitting CTs on each individual LV feeder. As the majority of the data analysis from the monitoring is to be undertaken with respect to the HV network, point load information at a substation was felt to be sufficient for the application, rather than each individual LV feeder.

Analogue inputs from the CTs and fused voltage connections were taken into SM300 and KV2C smart meters supplied by GE in order to provide time-stamped measurement data for the substation consumptions. As well as being able to collect voltage, current and power factor, the smart meters are able to gather data on a number of variables such as reactive power consumed and total harmonic distortion present. These meters can be remotely configured depending on requirements, though for this project we concentrated on the recovery of voltage, current and power consumption data.

The meters for all the substations are polled by WPD's main network managements system (GE's PowerOn Fusion product used widely with GB DNOs) to retrieve the instantaneous power consumption. GE Digital Energy's smart meter allows data to be collected to IEC 62053, Class 0.5 S accuracy.

The meters and the enclosures supplied by GE also include a battery back-up which can power the meter and communications equipment for a minimum of 6 hours should there be any low voltage interruption. Figure 2 shows a photograph of a typical enclosure installed on the islands, identifying the components used.

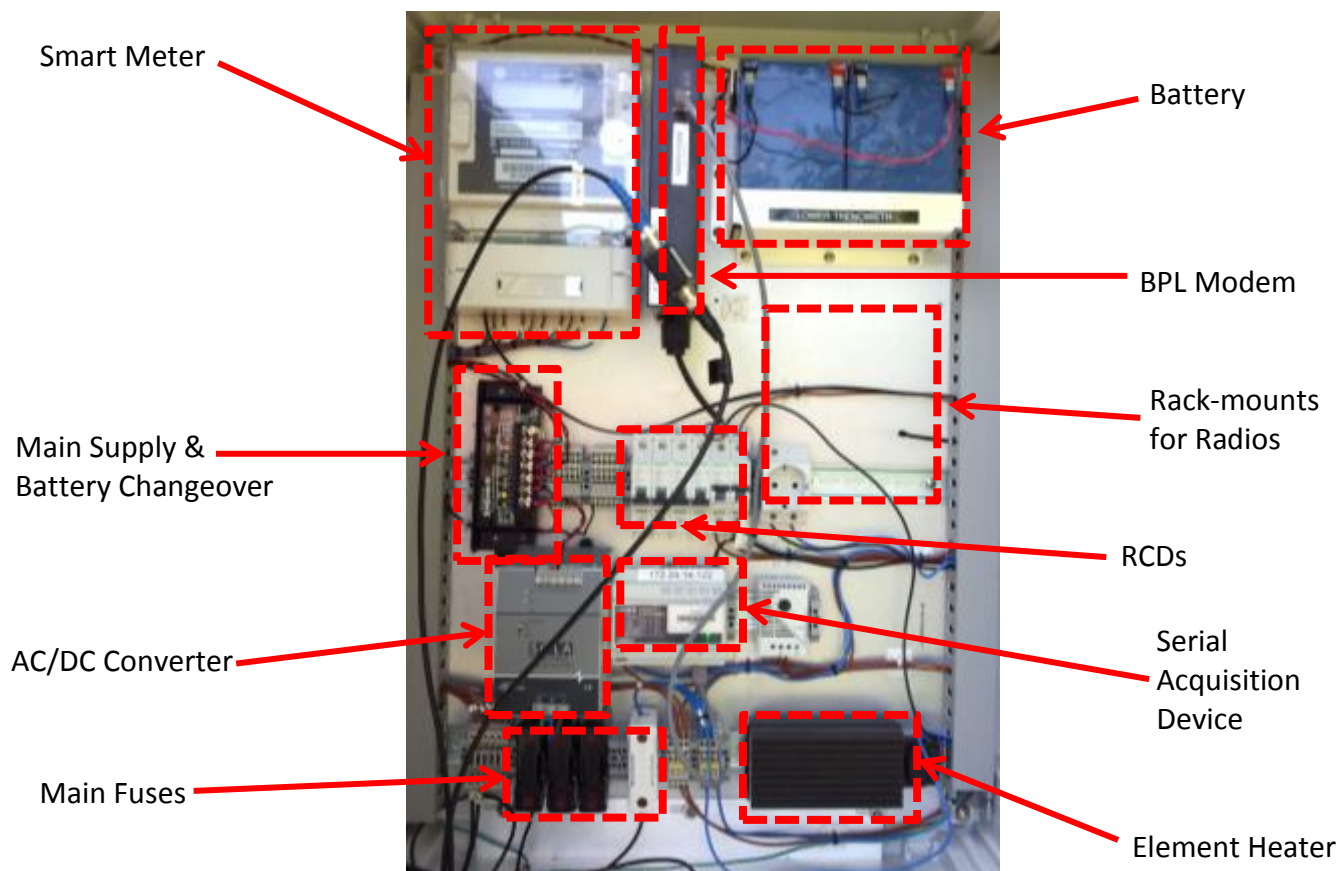


Figure 2 - Typical Metering and Communications Enclosure

The enclosures for the all the equipment are IP66 rated to provide a weatherproof and dustproof housing for both indoor and outdoor substations.

7.2. Radio Communications

The communications backhaul for this project is an IP-based hybrid comprised of two radio technologies of different frequencies and an 11kV broadband over powerline (BPL) system. These communication systems allow data to be transmitted back to a single link point on the island network, which is then taken by a series of optical fibre and microwave links back to the WPD mainland network.

GE designed the network topology after an initial site survey to determine the suitability of radio across the topology of the islands with BPL used to connect to the remaining substations not reachable by radio.

The radios supplied by GE were SD4 450MHz and EntraNet 2.4GHz units, with the SD4 devices providing long haul links between the islands at 19.2kbps and the EntraNet devices providing shorter links at a maximum of 106kbps. The two different radio systems were deployed so that the longer sections of links and the smaller hops were not competing for the same channel space or bandwidth.

Whilst a similar outcome could have been achieved through programming the same radio types to use different frequency channels, this approach allowed us to compare the two technologies within this project.

The SD4 radio technology operates within an existing spectrum secured from the JRC by WPD, whilst the EntraNet radios utilise unlicensed frequencies. This has the benefit of being able to be deployed without using valuable licensed spectrum, though does have the potential to suffer from interference. The interference risk is somewhat mitigated on the Isles of Scilly due to their remote location.

Omni-directional and directional Yagi antennae were installed at a reduced height close to the substations in order to keep visual impact to a minimum as agreed with the local authority and Duchy. As the radios only require a low voltage supply to power the electronics, there was no requirement for a supply outage to fit the communication devices.

Each substation is equipped with at least one radio or BPL device to connect to the next adjacent substation in the topology. Certain substations are installed with more than one type of communication technology dependant on how many substations they interface with. Figure 3 shows a geographic diagram depicting the communication lines and technologies used.

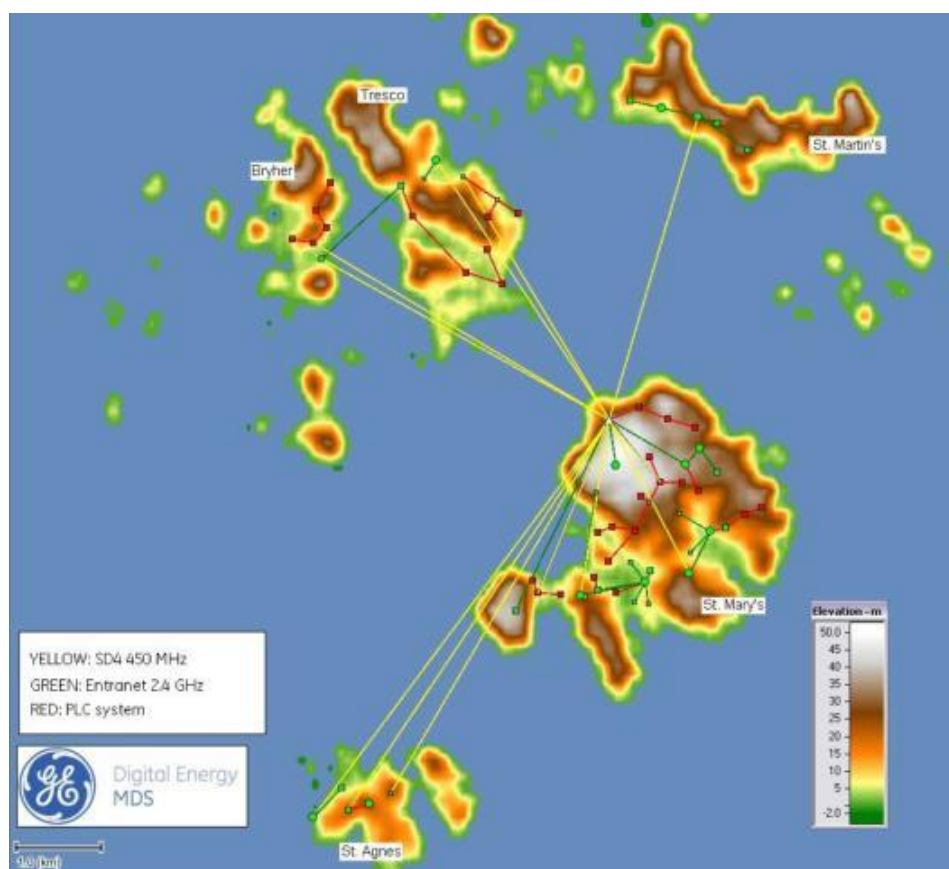


Figure 3 - The Isles of Scilly Network Management Communications Topology

7.3. Broadband over Powerline

The BPL devices supplied by PPC operate in the 2 to 30 MHz frequency band as per IEEE1901, so in addition to the 50Hz or 60Hz “signal” which is used to transmit power on the power grid, the BPL signal is modulated in several frequencies ranging from 2 to 30 MHz. The BPL system implemented in the PPC devices is named “Aranuka”.

The Aranuka uses a digital multi-carrier modulation method called Orthogonal Frequency Division Multiplexing (OFDM) to modulate the signal. In OFDM a large number of closely spaced orthogonal sub-carrier signals, also called tones, are used to carry data. The data is divided into several parallel data streams or channels, one for each sub-carrier. In OFDM each sub-carrier is modulated with a conventional modulation scheme, achieving total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. Within the frequency range of 2 to 30 MHz, the system uses up to 916 individual sub-carriers to transmit data.

Using the transmitted data, the BPL system is able to permanently determine the signal to noise ratio for each of the 916 sub-carriers and individually computes the optimal carrier for each one, out of 6 possible modulation schemes.

The sub-carrier modulation schemes differ in modulation density, with the more robust modulation schemes using a lower possible number of predefined modifications of amplitude and phase. The higher the number of predefined amplitude and phase variations, the higher the number of possible bits transmitted per time interval. However high modulation density makes the signal less robust to noise and therefore requires a higher signal to noise ratio in the sub-carrier.

The BPL system is installed in two different configurations depending on whether it is attached to an overhead or underground section of network.

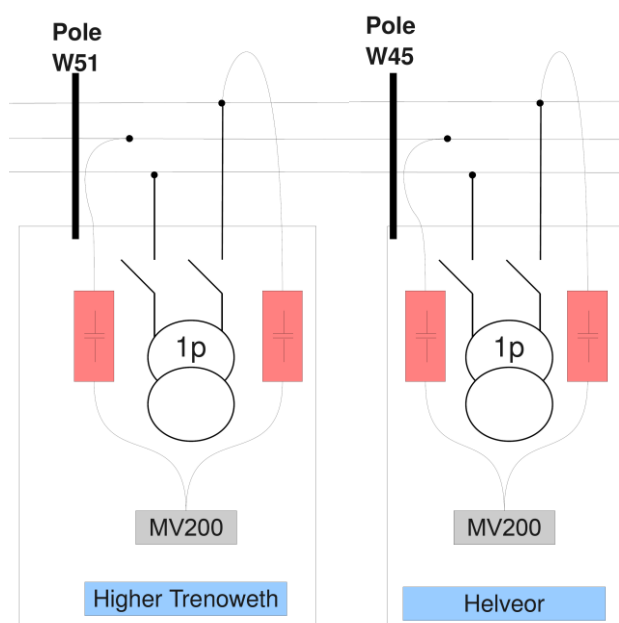


Figure 4 - Overhead BPL Configuration

The overhead implementation of BPL is shown in Figure 4 and uses two phases of the network, with a single modem attached to two couplers per site emitting a differential signal. The underground implementation uses a single modem and coupler per site attached between a phase and earth to achieve a signal (Figure 5).

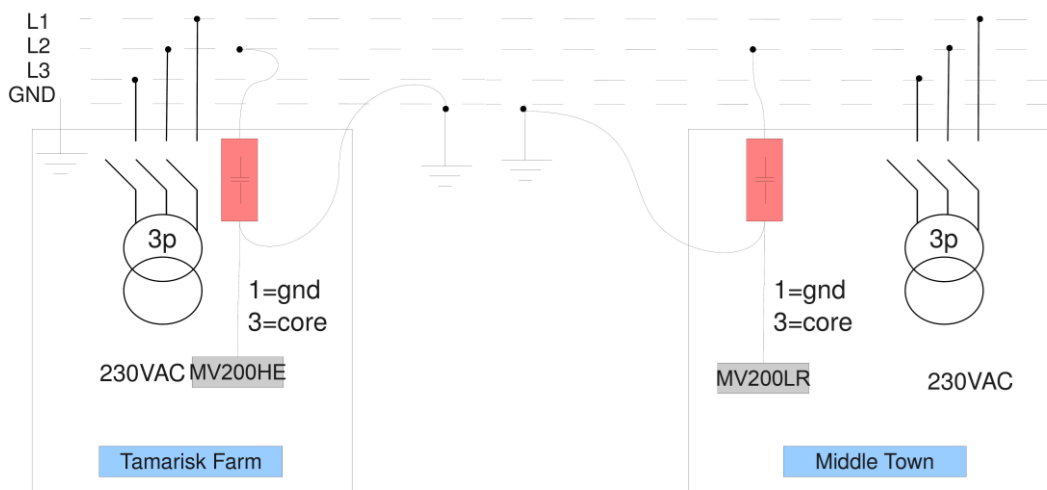


Figure 5 - Underground BPL Configuration

For the underground installations, attaching the BPL equipment to the existing HV phases was completed by breaching the flexible XLPE of the couplers into a new joint position a few metres outside of the substation. Separable connectors were used to provide an easy method of isolation should the BPL equipment need to be disconnected. For the overhead installations, the couplers were directly connected to the bare overhead conductor using wedges. For both of these types of installations, HV outages were required.

The net topology in Figure 6 shows the initial planned mixture of communication technologies used and the number of hops to each substation.

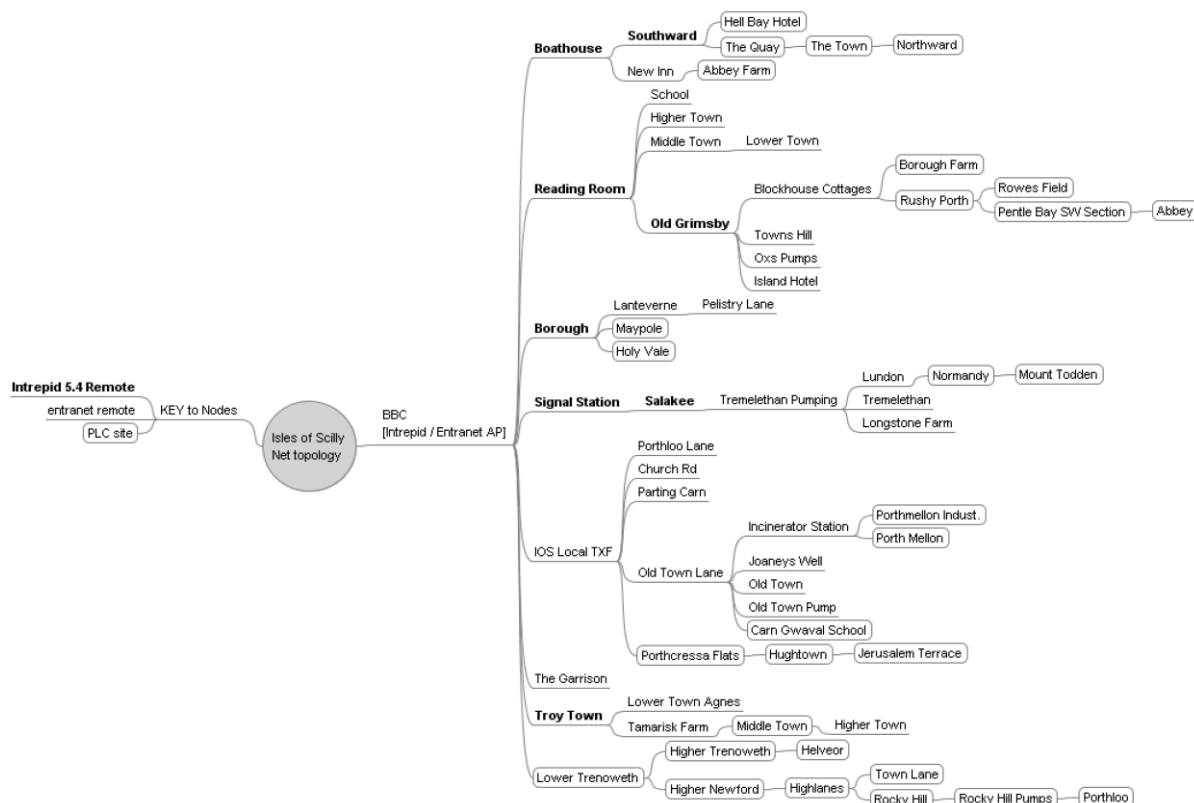


Figure 6 - Isles of Scilly Net Topology

7.4. Off-Island Generators

Off-Island generators at the The Quay substation on Bryer and at Lower Town on St Agnes have recently been replaced with two new sets, each comprising of 2 x 200kVA FG Wilson diesel generators as part of Western Power Distribution's standard asset replacement programme.



Figure 7 - 200kVA FG Wilson Gen-set

Each generator is fitted with a Comap IntelliGen controller which enables the pair of generators to be connected and share load together. The outgoing LV from the generators are connected to a 500kVA Yy11 transformer which has a removable neutral earth link in order to supply a neutral reference point for the 11kV when the system is backfeeding onto the HV network.

The generators, neutral earth link and circuit breakers are all controllable through WPD's PowerOn network management system, providing complete remote control for starting and synchronising. This removes the need for any short interruptions to the customers when changing from main supply to the generators.

7.5. HV Control

Additional automation has been installed on the HV switchgear adjacent to the generator sets in order to provide remote sectionalisation points which enable the HV network to be split up at strategic points. The extra flexibility of running arrangements afforded by this investment allow the generators to supply different amounts of HV network dependant on the customer loads and embedded generation present.

Under fault conditions, the network will be able to be split up and fed directly by the off-island generators, reducing the amount of centrally located generation required to secure supplies and also reducing the distribution losses incurred when supplying the load by diesel generation. By viewing the substation metering loads before the fault occurred, the maximum amount of network capable of being supplied by each generator set can be quickly established.

7.6. Synchrophasor Control

Phasor Measurement Units (PMUs) are traditionally used on the transmission network to provide accurate monitoring of the individual voltage and current waveforms at strategic points. These captured signals are time-stamped to a Global Positioning Satellite (GPS) time signal which enables data from different strategic points to be compared along a single time domain.

Data from the PMUs can allow more accurate monitoring of the load distribution and also aid state-estimation of network open points and switch positions.

The PhasorPoint system for the Isles of Scilly has four main functions:

- Receive phasor data streams from Phasor Measurement Units
- Provide an analogue synchronised voltage waveform to the local generation controller
- Perform synchronisation check and feedback to PowerOn
- Manage different islanding states

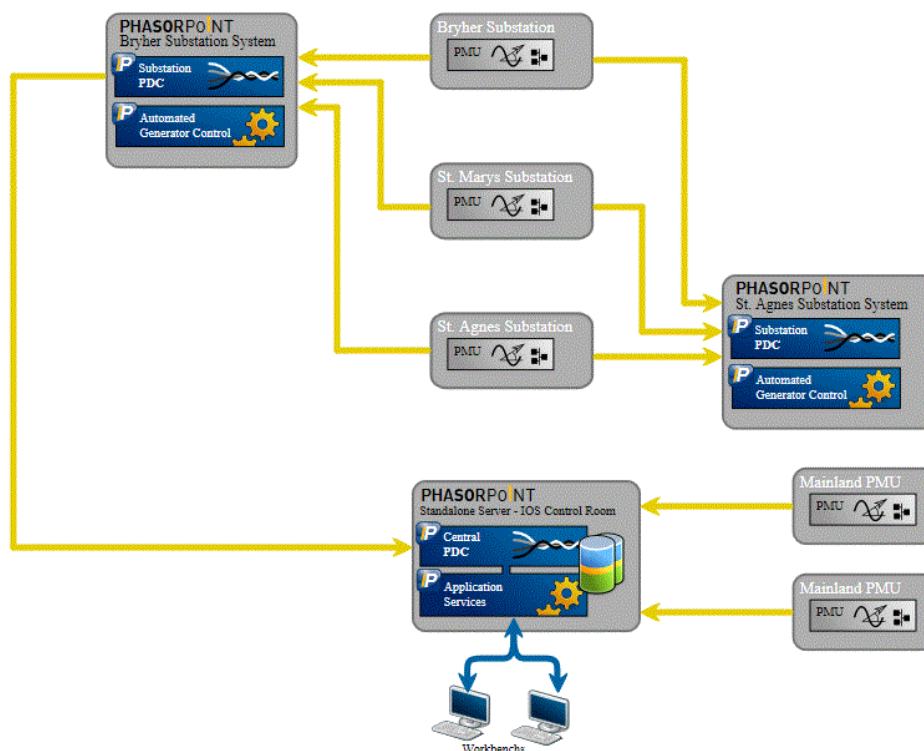


Figure 8 - PhasorPoint Topology for the Isles of Scilly

By understanding the phasor data from the PMUs that are connected to the rest of the system and comparing these to the generator phasor data, a difference in phase can be quantified and corrective action applied. The first action would be to not allow the generation to directly resynchronise to the network, with the second being to send appropriate controls to the mis-aligned generator so that it can be brought into line and ready for synchronisation.

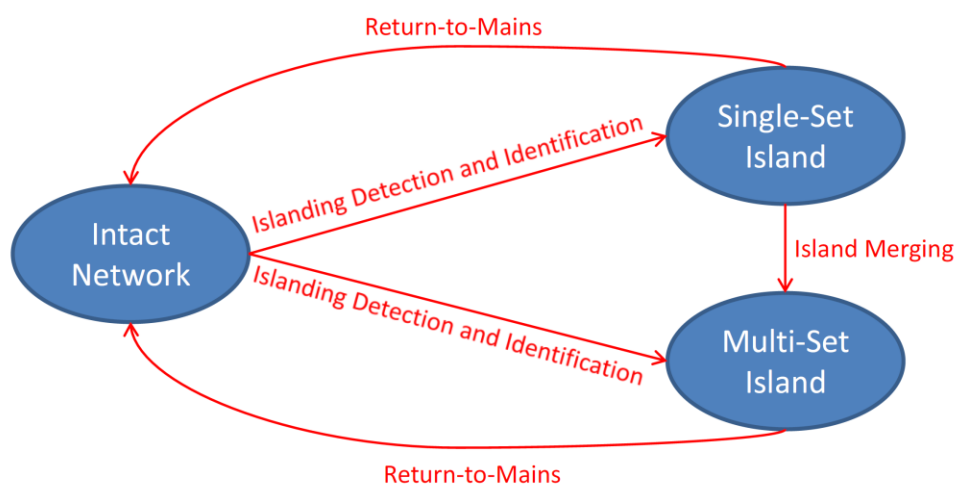


Figure 9 - Islanding states and transitions

A number of different states of network operation can be achieved using multiple generation sets and their relationships are displayed in Figure 9.

8. The outcomes of the Project

8.1. LV Monitoring Performance

The installation principles for the LV monitoring were based on established processes and off the shelf equipment. This meant fixed ring CTs were used and they were fitted onto the outgoing transformer tails, which required a shutdown of the transformer and number of staff hours to complete. This work was carried out from September 2011, with all 63 substations being installed by February 2012.

Having real-time information on the transformer load profiles will enable future initiatives on the islands to be fully informed and supported.

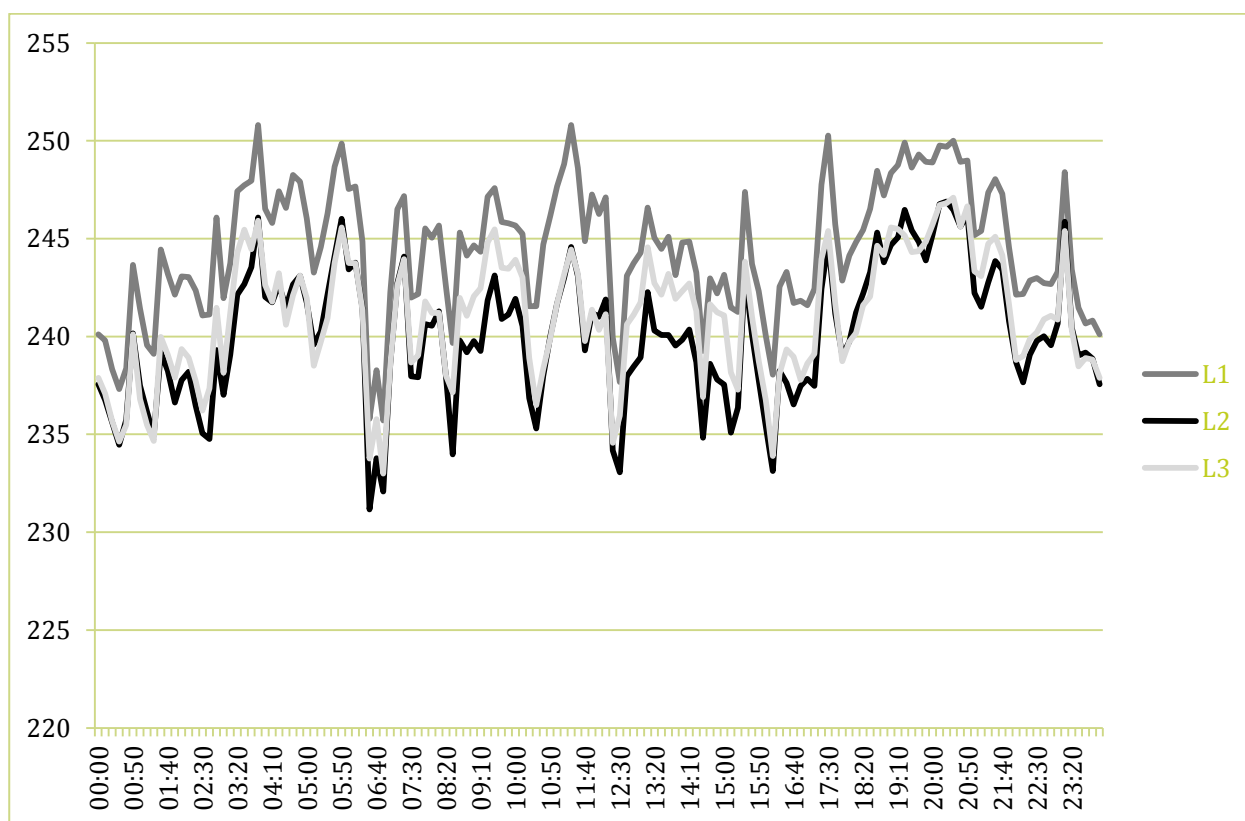


Figure 10 - Three Phase Voltage Waveform for The Garrison

The fixed ring CTs do give a high level of accuracy within the range specified by the CT ratio, but due to the fact standard stock items were used, in some instances the 400/5 CTs were over specified for the output of the smaller 16kVA single phase transformers. This mismatch between current measured and CT capability also impacted upon the reliability of the results for some of the substations, as the resolution of the meters is spread evenly over the full scale deflection of the CT output. Similar issues were encountered on the WPD Tier 2 LV Network Templates project where an amplification unit was developed to resolve any data issues encountered.

For future projects the requirement for amplification could be avoided by the specification of CT ratios on a site by site basis. However advances in other sensing technologies have, in effect,

made the use of CTs obsolete for load monitoring functions. WPD's LV Sensors project provides more information on this.

<http://www.westernpowerinnovation.co.uk/Tier-1-Projects/Low-Voltage-Current-Sensor-Technology-Evaluation.aspx>

8.2. Radio Performance

The initial radio survey completed by GE for the links used on the Isles of Scilly was completed using an assumed antennae height of 25ft, however after consultation with the local council planning officers, it was felt that this height was too great and the antennae should be installed at heights as low as possible to minimise the visual impact.

The adjustment of the anticipated antennae heights rendered the radio survey results redundant and so installation and commissioning of the links was primarily completed on location. Progress using this method was fairly quick and the heights were able to be reduced considerably in line with the council's wishes. Measured link strength was a lot higher than anticipated due to the topology of the Isles and the lack of tall, dense vegetation. Because of this, many of the links were able to be fed directly from the main transmitter at the BBC Station substation which reduced the number of hops and equipment required. For future projects WPD would still advise the use of computer based planning tools, but with additional field surveys so local conditions can be more effectively incorporated.

In some circumstances where other communication technologies were not been able to be installed as originally proposed due to the extra disruption they entail, radio has been able to fill the gap and provide backhaul communications. On Tresco, the best solution was to use radio instead of a BPL link as the outages required for BPL connection were hard to achieve during peak summer months (due to the high load experienced due to the influx of tourists). Working on the islands outside of the summer months is more costly and less flexible as the transportation services return to an off-peak schedule. The key learning is that having a range of telecommunication solutions (as in this project) allows for plans to be adapted to local conditions without impact to the project timescales or effectiveness.

The system availability of both types of radio has proved to be very good, with only limited interference from atmospheric conditions experienced. The bandwidth and latency of the devices is sufficient for metering data retrieval, but the limitation of the 9.2kbps SD4 radios mean that any further applications on the network that need mass data retrieval will lead to upgrades in the system.

Figure 11 is a table showing collected data on the performance of the SD4 radio repeaters during a single month.

Health	Device Name	Device Model	IP Address	Roundtrip Time (ms)		RSSI (dBm)		SNR (dB)		Availability (%)	Health History	Maintenance
				Current	Average	Current	Average	Current	Average			
✓	24017	4710_	172.29.14.17	144	140	-62.0	-62.0	27	27	100		
✓	24020	4710_	172.29.14.20	139	151	-68.0	-68.5	27	27	100		
✓	24027	4710_	172.29.14.27	142	139	-69.0	-68.2	23	23	100		
✓	24040	4710_	172.29.14.40	149	136	-62.0	-62.0	23	23	100		
✓	24053	4710_	172.29.14.53	147	148	-63.0	-63.0	27	27	100		
✓	24055	4710_	172.29.14.55	118	136	-62.0	-62.0	22	23	100		
✓	24063	4710_	172.29.14.63	148	148	-75.0	-74.8	24	24	100		
✓	24074	4710_	172.29.14.74	143	140	-62.0	-62.0	27	27	100		

Figure 11 - SD4 Radio Performance over 30 days

The radio showing downtime during this month locked out and required a local hard-reset before it was able to transmit data again.

The main learning points were

- That unlicensed radio is an effective solution for backhaul (noting the previous comments on the remote nature of the islands)
- That the SD4 radios using allocated power industry spectrum have limited data throughput capabilities. This learning has been fed back through ENA telecommunications groups to Ofcom.
- That whilst computer aided radio planning tools provide a good “first pass”, nothing can beat field surveys to ensure local issues are factored in

8.3. Broadband over Powerline Performance

The BPL devices required HV outages for each installation and due to the network being predominantly rural without LV backfeeds, generators were used to maintain supplies and avoid inconveniencing customers. The increased complexity and technical specialists involved in installation meant that progress was slower than the radio installation. But this would probably be reduced if the technology was deployed in a city-centre environment.

Although the BPL devices required extra civil works in order to install the couplers onto the underground HV network, the works can be hidden from view and all equipment can be housed in a standard substation kiosk. For the overhead installations, the couplers can be attached neatly to the pole and do not protrude as much as a directional Yagi antenna.

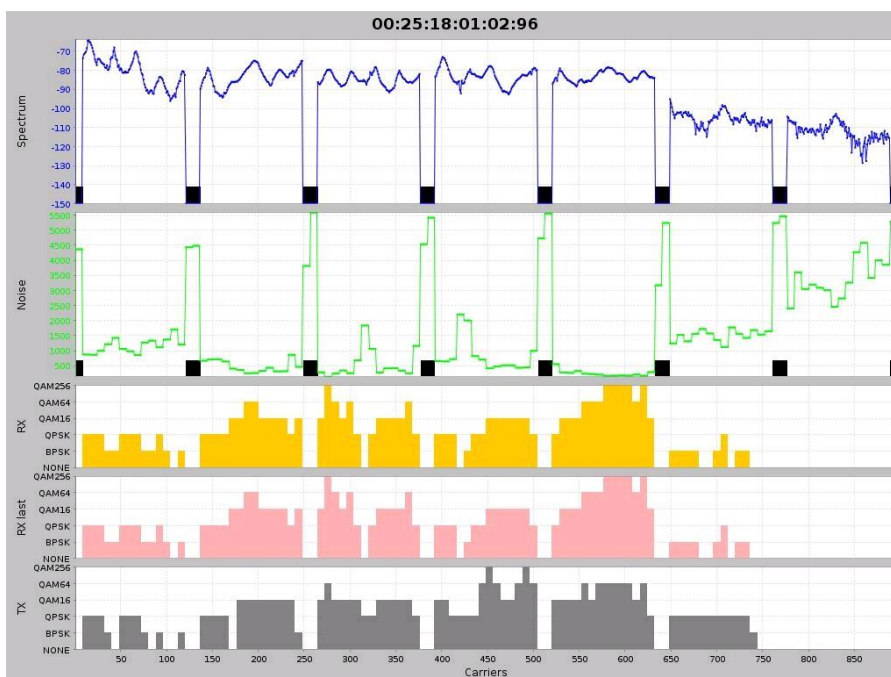


Figure 12 - BPL Link Performance – Underground Cables

There is a significant difference between the ability of certain electrical links to deliver BPL data across from node to node. Figure 12 shows a number of charts from top to bottom: the available spectrum in the cable, noise received, total received bandwidth channels, latest received bandwidth channels and sent bandwidth channels.

Underground cables tend to have more carrier paths spread across the total frequencies implemented in the BPL protocol. Overhead conductors tend to attenuate the lower frequencies and have carrier paths in the middle of the range, as observed in Figure 13.

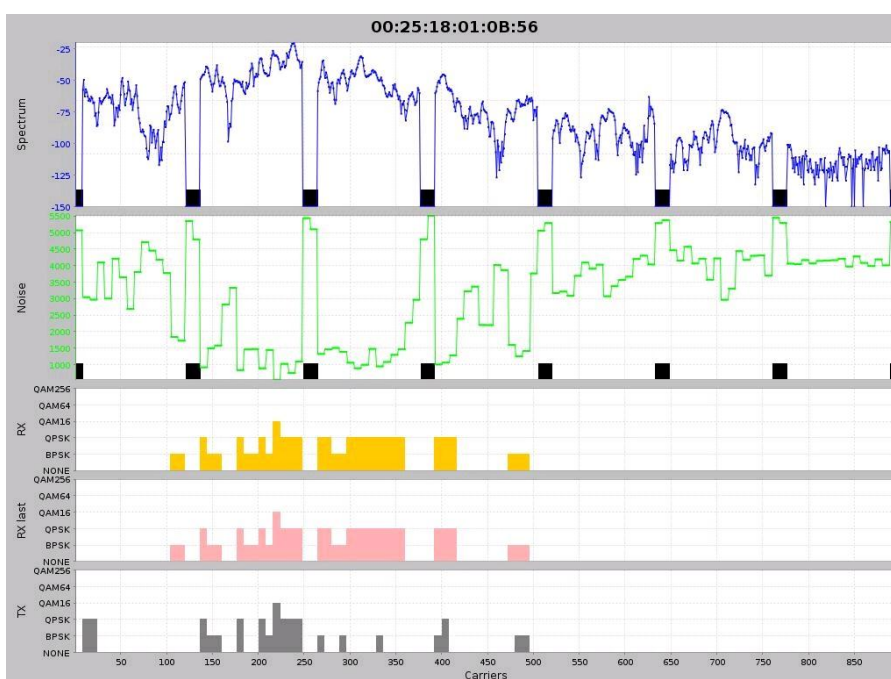


Figure 13 - BPL Link Performance – Overhead Conductors

The noise observed in the cables and conductors was also shown to change across different periods of time, however it was not possible to determine why this occurred. Presumably this was in line with the total non-resistive load or a certain type of disturbing load, but these factors are hard to isolate on a distribution network. Further analysis of these recorded results may identify certain cable types or noise signatures which preclude the use of BPL and might help pre-determine the effectiveness before installation. The learning from the project has been shared through ENA forums and through our partners with the broader PLC industry. In publishing this closedown report we invite academic or industry experts to provide additional commentary or feedback.

The results of the testing carried out show that each of the BPL links provide a latency between 5 and 35ms and bandwidths between 400kbps and 7500kbps which show a considerable improvement on the radio technology.

```
# iperf -c 172.29.14.129 -i5 -t30
-----
Client connecting to 172.29.14.129, TCP port 5001
TCP window size: 16.0 KByte (default)
-----
[ 6] local 172.29.14.137 port 1024 connected with 172.29.14.129 port 5001
[ 6] 0.0- 5.0 sec 4.25 MBytes 7.13 Mbits/sec
[ 6] 5.0-10.0 sec 4.28 MBytes 7.18 Mbits/sec
[ 6] 10.0-15.0 sec 4.76 MBytes 7.98 Mbits/sec
[ 6] 15.0-20.0 sec 4.43 MBytes 7.43 Mbits/sec
[ 6] 20.0-25.0 sec 4.71 MBytes 7.90 Mbits/sec
[ 6] 25.0-30.0 sec 4.75 MBytes 7.97 Mbits/sec
[ 6] 0.0-30.0 sec 27.2 MBytes 7.60 Mbits/sec
#
```

Figure 14 - BPL Throughput at Porthloo to Highlanes

Availability of the strongest BPL links is high, although it has been noted that their performance changes with the load connected to the HV network and harmonic disturbances within the operating frequency can affect bandwidth and connectivity.

Data detailing the performance of the installed BPL links is presented in Figure 15.

Area	Station	Station Type (UG/OH)	Modem MAC address	Modem IP 172.29.14.	Latency to NMS [ms]	Latency previous hop [ms]	Bandwidth p. Hop [Mbps/s]	Bandwidth to HE [Mbps/s]	SEW MAC address	SEW IP 172.29.14.
St. Agnes	Tamarisk Farm	UG	04AA	80	229					
	Middle Town Agnes	UG	0710	81	232	3	2,8			
Bryer	Southward	UG	07EE	90	407					
	The Quay	UG	07E4	93	n/a	n/a	n/a	n/a	22	94
	The Town	UG	05AC	95			0,7		5B	96
	Northward	UG	0538	97	n/a	n/a	n/a	n/a	4E	98
	Hell Bay Hotel	UG	07A8	91					33	92
St. Mary's	Hugh Town	UG	0488	152						
	Porthcressa Flats	UG	0BC0	150		9	1,0	1,0	28	153
	Jerusalem Terrace	UG	0752	154		8	8,4	8,4	50	155
	Incinerator Station	UG	0346	159	999					
	Porthmellon Industrial	UG	17A0	162		10	1,1	1,1	41	163
	Carn Gwaval School	UG	090A	157		10	1,1	1,1	20	158
	Lundon	OH	081A	144						
	Normandy	OH	09C0	147	536	536	4,9	4,9	2D	148
	Highlanes	OH	0A7E	129					3F	130
	Higher Newford	OH	0B3A	127		10	1,0	1,0	1E	128
	Maypole	OH	0A7A	140		10	1,5	1,5	34	141
	Town Lane	OH	0A38	131		25	0,5	0,5	4C	132
	Rocky Hill	OH	081C	133		32	0,4	0,2	1C	134
	Rocky Hill Pumps	OH	0B36	135		8,6	4,2	0,1	47	136
	Porthloo	OH	0296	137		9,5	7,3	0,1	04	138
	Lower Trenoweth	OH	0B58	120					4B	122
	Higher Trenoweth	OH	0B40	123		9	1,7	1,7	06	124
	Helveor	OH	07E0	125		9	0,9		5F	126
	Borough	OH	0B56	139	99					
	Holy Vale	OH	0B08	142	115	16	1,1	1,1	53	143

Figure 15 - Broadband over Powerline Overview

The head-end rows highlighted in yellow designate the BPL links that filter the traffic back to the radio network. The white coloured links below communicate with the other components in the network via the headends.

The key learning points were:

- BPL does provide an effective communications path where radio options are not possible
- In some circumstances the technical performance of BPL is better than radio
- For some links the performance of BPL falls below required standards for some time periods.
- Additional research is needed to understand the impact of load types on BPL performance, and in particular the impact on BPL from the connection of low carbon technologies.

WPD intends to maintain the BPL system and track performance as customers on the Isles adopt low carbon technologies. WPD invites further research on this topic.

8.4. Communications System

The communication system installed is able to retrieve the real-time instantaneous values of the installed metering, however the bandwidth is largely limited by the SD4 radios, which have a maximum capability of 9.2kbps.

The data concentrators used within the Broadband over Powerline are designed for usage on complete BPL systems, which are typically high-bandwidth systems. Consequently, the data structure is not optimised for delivery over narrow bandwidth radio devices, which further reduces the ability of the hybrid system to deliver data. Whilst the system is capable of delivering small amounts of real-time data for substation polling, the system cannot retrieve much larger daily data downloads.

Although this project was focused on technology assessment it has created a platform for further research using the data collected. However the limitations of the low bandwidth radios mean that although much data can be collected compared to the operation of a passive electricity network, the most granular data cannot be included in such analysis. The key learning point is to consider whether projects, in some cases, need to be over specified to support research beyond the initial stage.

8.5. Synchrophasor Control

Phasor Measurement Units have traditionally been deployed on EHV networks to monitor system disturbances with a high level of accuracy. Deploying PMUs on a distribution network required a ruggedised packaging to be developed so that these highly sensitive devices could be installed in the smaller spaces commonly available at distribution substation sites.

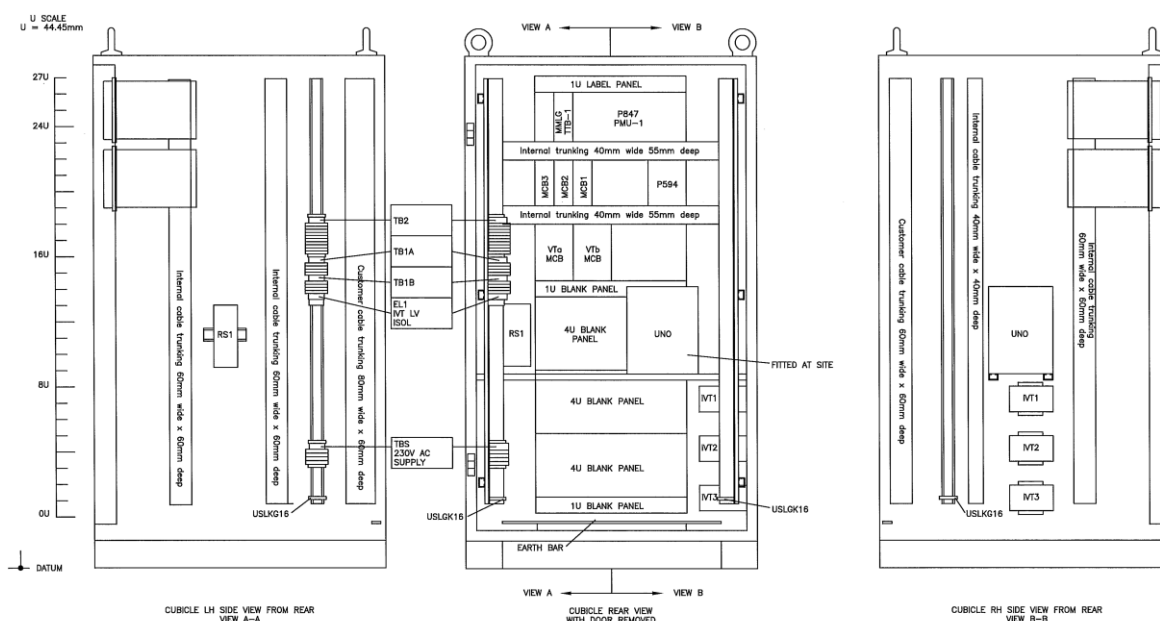


Figure 16 - PMU Cubicle

Development of this cubicle has enabled the devices to be installed in both indoor and outdoor 11kV ground mounted substations, as shown in the technical drawing of the PMU arrangement (Figure 16).

In order to demonstrate the functionality of the system, a testing scenario was designed to understand the effectiveness of the synchronisation and the stability experienced during operation.

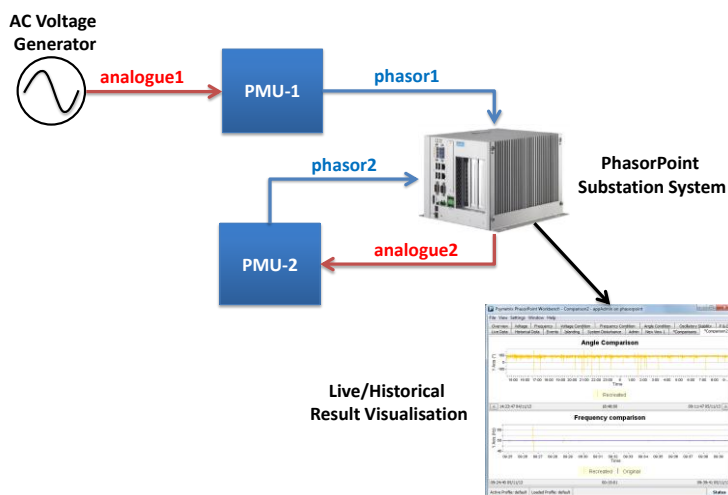


Figure 17 - Synchrophasor Demonstration Setup

A sinusoidal voltage was produced from an AC generator and measured by the first PMU (PMU-1) as a phasor. The phasor was then passed into the PhasorPoint substation system and converted back to an analogue signal. The recreated analogue signal was sent to the second PMU (PMU-2) and converted into the second phasor. The second phasor was also sent to the same PhasorPoint substation system. By altering the original sinusoidal voltage and comparing it to the second recreated phasor, the frequency and angle differences could be measured and their synchronicity calculated.

During testing, the maximum angle difference variation between the two phasors observed was about 40 degrees, as shown in the diagram below. This implies that the phase error between the original and recreated signals would be +/- 20 degree if a proper angle offset is implemented.

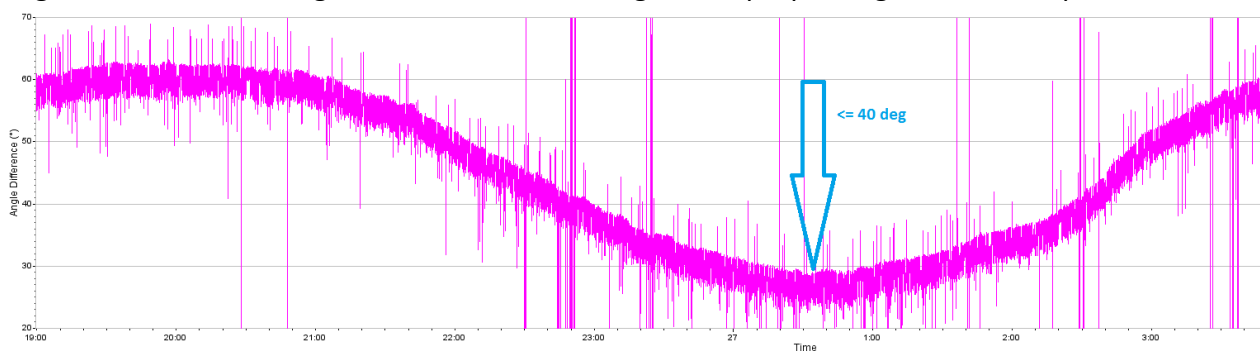


Figure 18 - Phase angle difference using NTP

Further investigation revealed that the angle variation was due to different time sources used by the PMU and the PhasorPoint substation system. The PMU time was locked into GPS, but the

PhasorPoint substation system used Network Time Protocol (NTP). The 40 degree angle variation was caused by the Nano-second time difference in one direction but lasted for a considerable time period. Thus the angle error accumulated. However, eventually the error bounced back as NTP started to correct itself.

By altering the PhasorPoint substation system to also synchronise using a GPS time signal, rather than the NTP signal, a much smaller deviation between the two signals is observed

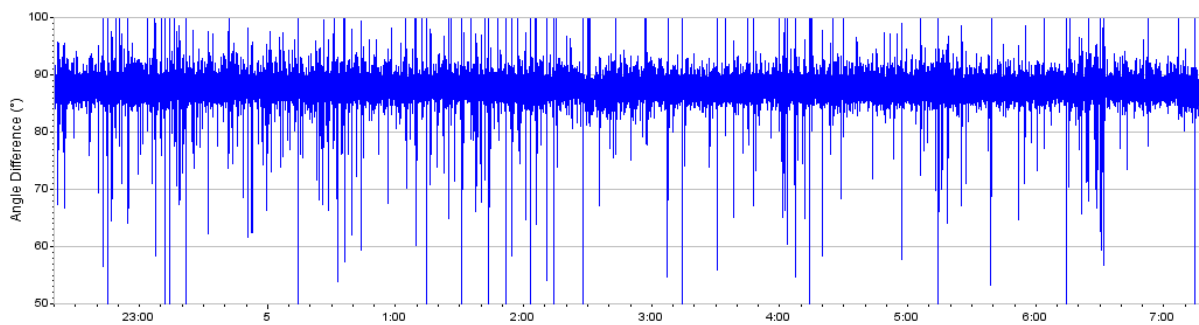


Figure 19 - Phase angle difference using GPS

The phase angle difference for an 8-hour period is shown in Figure 19 and shows that there is no obvious angle variation. The angle error was kept within ± 5 degree for most of the times, which met the IEE standard for synchronisation (± 10 degree). Further development of the algorithm used for synchronisation could reduce the noise experienced between the two signals.

The key learning points were:

- Packaging needs developing when transferring EHV technologies to distribution networks
- PMUs work on 11kV
- Accuracy of the clocking source is crucial

9. Performance compared to the original Project aims, objectives and success criteria

Objective 1: To establish real time monitoring on all of the distribution substations on the Isles of Scilly.

All 63 substations that serve customers on the Isles of Scilly are now fully monitored on the outgoing LV tails of the transformer. Each individual meter can be polled instantaneously to retrieve the real-time measurements currently being recorded.

Objective 2: The use of the generation facilities on the islands can be maximised to secure supplies to the islands.

Following the installation of the new off-island generation sets and the accompanying HV automation, sections of the network can now be remotely isolated and supplied by local

generation. This secures the supplies to the islands of Bryer and St Agnes, which are each fed by a single 11kV cable. Following a HV fault on either of those cables, the customers can now be resupplied by the local generation within 3 minutes, whereas before the customers would have had a much longer return to service time.

Objective 3: The control and management of the generation on the off islands will be effected using new methods that have not been used in WPD before.

Integration of the generation facilities into the Islands electrical network and Western Power Distribution's PowerOn Fusion network management system has been completed. The connection of the generators on the Isles of Scilly is unique as security of supply to customers is generally afforded by the addition of an alternative connection to the network. Due to the cost and complexity of laying an additional submarine cable to the two smaller inhabited islands Bryer and St Agnes, this security is created by the generators' ability to export directly onto the 11kV network.

Traditionally, the generation units would have been sized to accommodate the maximum estimated load in the area planned to be supplied, plus extra headroom to cater for any variability of load across the whole lifespan of the assets. The new monitoring installed as part of this project can determine the real-time load on the islands and allow the network to be fed in different configurations depending on whether the network is experiencing high, medium or low load conditions. This allows the generation to be utilised at its most efficient operating level and will ensure that the units do not need replacing ahead of their expected lifespan, regardless of any changes in local load.

The control and management of the 11kV primary neutral link of the Yy11 transformers allow the same transformer to be used for supplying an earth reference on the HV system when the generators are exporting, as well as allowing the transformers to be used to supply local load from the HV network when the system is running conventionally. Having this link controlled remotely by the distribution management system allows isolation from the main network and restoration from local generation to be carried out remotely and autonomously.

The addition of monitoring for local load patterns also enables any potential reverse power situations to be identified and managed. If the aggregate amount of localised embedded generation on the off-islands were to ever exceed the amount of load supplied, then it would prohibit the diesel generation from supporting it as an islanded network. The flexibility of the new HV automation installed permits other demand sections to also be supplied, which ensures there are no net reverse power conditions.

Objective 4: Monitoring to be supplemented by controls where appropriate to manage and accommodate localised generation.

The additional HV automation installed as part of this project allow the normal open points of the network to be moved depending on load conditions. Traditionally planned rural networks such as those found on the Isles tend to allow for more voltage drop than for voltage rise and this can limit the amount of generation export to be accommodated. By monitoring the voltage levels around the network and the direction and magnitude of the current, the network can be reconfigured to ensure substations with high penetrations of generation are on the same HV feeder as substations with high load take off.

Objective 5: Support localised generation (Photovoltaic)

There have been a number of photovoltaic installations on the Isles of Scilly to date, covering a mixture of public buildings and domestic dwellings and ranging in size up to 16kVA. 22 of the 63 substations have one or more photovoltaic installations connected to the low voltage network. With no large scale solar farms connected, the total installed capacity is under 150kVA.

Western Power Distribution has also supported a number of proposals which seek to develop the self-sufficiency of the islands. These have included other generation technologies such as wind, wave and power from waste.

Since the monitoring has been installed, we have connected 15 embedded low carbon generators across the isles. Whilst this proportion is significantly below the threshold which would start causing issues, the monitoring will allow any future load related reinforcement to be identified.

By using the monitoring information and the learning from the Tier 2 project LV Network Templates, an additional 20% network headroom has been identified, allowing for further distributed generation to be connected to the network without the need for reinforcement

Objective 6: Initiative will support the council's published goal of energy self-sufficiency.

The data collected by the monitoring systems is able to provide load information to the council and inform where further generation or load reduction is required for the Isles to work towards being energy self-sufficient. The data will continue to be used to support regular dialogue with representatives from the Isles.

The real-time information provided by the monitoring is only available through the internal distribution management system, however this will be interpreted and fed into the distributed generation maps available at:

<http://www.westernpower.co.uk/Connections/Generation/Generation-Capacity-Map/Distributed-Generation-Map.aspx>.

Success criterion 1: The effective management of off island generation and monitoring & control of distributed generation on a weakly connected network.

Through monitoring all the connected LV load on the Isles of Scilly, , the off-island generation is now able to be used to its fullest potential in securing customer supplies. Loads will be monitored into the future and the effects of energy efficiency and embedded LV generation (through PV or other technologies) will be identified.

Should local demand continue to reduce because of these measures, the strategic HV switching points can be altered to ensure there is always the correct balance of supporting generation and consuming load when operating as an electrical island.

Success criterion 2: Use of Power Line Carrier techniques on higher voltage networks

By working together with PPC, the implementation of 11kV Broadband over Powerline was designed, installed and commissioned within the project timescales. A number of links have been in highly successful operation throughout the trial, whilst some other links have had their availability reduced due to the reasons outlined in section 8.

The successful links have proved the technology concept for installation on both underground and overhead systems on the 11kV network. The latencies and throughput do have an advantage over comparable radio solutions, though the requirements for installation mean roll-out is not as quick. Variances in link quality would also need to be solved, potentially through pre-installation surveys, in order for this system to be considered elsewhere.

Success criterion 3: Demonstration of Synchrophasor Generator Control

Following the algorithm and system development for the synchrophasor control, initial testing has demonstrated that the principle of operation is sound and synchronisation should be within acceptable limits.

10. Required modifications to the planned approach during the course of the project

10.1. Planned Communications Topology

The initial plan for roll out of the radio and BPL was completed by GE Digital Energy following a series of site surveys during the scoping phase. On receipt of the final report, it was noted that a number of BPL links were placed either side of normal network open points and that there would be no physical connection between these two points. Whilst the BPL technology does have the ability to mesh nodes together and synchronise to the nearest head end, some secondary nodes were placed on electrical networks without an adjacent head end.

To fix this, some planning was carried out internally to site additional radio backhubs in these areas and to convert the secondary nodes to head ends in order to get the meter data back. By more careful understanding of the network running arrangements and BPL limitations, this could have been overcome in the initial planning stage.

10.2. Business As Usual Changes

Due to the changing load patterns and alterations to the low voltage network, a number of adjacent pole mounted substations were rationalised down into a single ground mounted unit. This replacement was not undertaken until the LV monitoring and communications network was designed and had entered production. Due to the monitoring solution having the flexibility to be installed in both overhead and underground substations, the equipment did not require any alterations, though the positioning and direction of the radio links did require on-site modification.

The new site established was a relatively short distance from the other substations it was replacing, so this did not require radical changes to the radio signal strengths. The other two communication and monitoring enclosures were kept for strategic spares and could be redeployed should any new substations be created.

10.3. Antennae Height

The site surveys were also carried out with a predicted aerial height of 25ft, which did not give consideration to the Isles of Scilly being an area of outstanding natural beauty. As the local planning officers required the heights to be kept to a minimum, the validity of the indicated signal strengths was also reduced, meaning many of the links had to be commissioned using signal amplitudes determined on site.

10.4. Radio Signal Strengths

During the initial site surveys and desktop studies carried out, propagation paths were analysed and signal attenuation predicted. In order to minimise the risk of interference and reduce unnecessary coverage, the output signal levels were reduced on site during the commissioning process. This enabled the levels to be fine-tuned, whilst still maintaining a good communication path between sites.

10.5. BPL Installation

The amount of HV outages required for the BPL technology proved problematic as the initial planned timetable for installation coincided with the Isles' holiday season, when occupancy is at its fullest and outages cause the greatest amount of disruption. To minimise this disruption generators have been used to maintain supplies and local staff have arranged the switchover times to fit the customers.

The results of the first survey indicated that the layout and existing infrastructure on Tresco would most suit a BPL installation, however, during initial discussions on implementation with local WPD staff, it soon became clear that the landowner and residents of Tresco would only allow limited works to be carried out on the island.

Due to the timing and duration of some of the excavation works required for BPL installation on this underground network, it left two options for successful project delivery; let the works proceed outside of the holiday season or change the communication links to a radio solution. To ensure the project ran as timetabled and with as little disruption as possible, communications on the island were changed to radio links, which required less obtrusive work and could be carried out in a shorter duration of time.

As this change was highlighted during the initial planning stage of the project, the amendments were able to be accommodated without any variation to the fixed price contract with GE.

11. Significant variance in expected costs and benefits

11.1. Costs

Description	Forecast (k)	Actual (k)	Variation (%)
Synchrophasor Control	£ 180,000	£ 179,330	-0.37%
Plant & Equipment	£ 347,000	£ 336,899	-2.9%
Monitoring & Communication	£ 760,000	£ 759,698	-0.03%
Total	£1,287,000	£ 1,275,927	-0.9%

Figure 20 - Cost breakdown

No significant variance was experienced across the project expenditure as the majority of the costs attributed to the project were fixed price contracts with suppliers, which allowed the project costs to be carefully controlled. In line with WPD policy at the time and as per the original budget estimation, internal labour costs were not included on the project.

11.2. Expected Benefits

No direct benefits were stated in the original registration pro forma. There were however the expected qualitative benefits from undertaking the project.

Whilst the uptake of low carbon generation in the rest of the South West has been very high, the amount of embedded generation connected on the Isles of Scilly has so far been limited to small-scale photovoltaic installation. The islanders have been developing plans for other diverse generation technologies and money from the Energy Savings Trust has been received by the Isles of Scilly Renewable Energy Cooperative (ISREC) to carry out a feasibility study into the islands' suitability for small-scale wind turbines.

Developers have also been looking at the potential for the Isles of Scilly to become a wave hub and invest in tidal or wave powered energy harvesters. Despite the interest, there has been little development of large scale renewable generation on the isles, but for the generation capacity already on the network, the measured effects have been measurable, but small and certainly below the level able to be absorbed locally. The ability for the islands to become energy self-sufficient is still apparent and the equipment installed as part of this project will enable the future uptake of low carbon technologies to be managed more effectively.

The ability of phasor measurement data to act as a real-time synchronising tool for embedded generation has been developed and demonstrated. The learning from this project can be taken forward and implemented in other applications where dynamic system stability can be a problem, and where frequency deviation might be greater influenced by the number of connected generation sets.

The use of Broadband over Powerline on the 11kV network has managed to demonstrate the functionality of this technology, particularly for high-speed and high bandwidth applications. BPL technology is strictly a different implementation than the PLC mentioned in the original pro-forma, but the medium used in transporting the data is the same. Whilst BPL has a greater available bandwidth, the signal does not travel as far on the conductors. For small networks like the Isles of Scilly, this is less of a problem.

12. Lessons learnt for future Projects

Throughout the running of this project, significant learning has been created on how low voltage networks should be monitored and how communications architectures should be developed for smart grids.

The low voltage monitoring equipment deployed on the Isles of Scilly was a bespoke solution developed specifically for the project by GE. When the original project was scoped, the LV monitoring supplier market was very immature and off-the-shelf solutions were not suitable for this application. The bespoke solution was also sought due to the requirements for housing radio or BPL communication equipment, as GPRS coverage on the islands was not deemed to be acceptable.

A more robust BPL implementation would be to have multiple headend units connected together by adjacent nodes, rather than relying on a single headend to reach multiple nodes. As the BPL nodes have the functionality to choose the nearest available headend unit to transmit back to, the system would communicate as intended, but the design would allow a greater resilience in the system.

The specification for an LV monitoring system was developed during the scoping for the solution delivered by GE. Following the installation of these units, further recommendations were made which have been incorporated into the tender specification for the LV sensors project, undertaken jointly with UK Power Networks.

This project also recognised that there is benefit in completing a full site survey before attempting installations, as potential difficulties can be highlighted before the activity is planned. This is particularly pertinent for the Isles of Scilly, as travel to and from the off-islands has to be carefully planned.

Many of our substations can be assumed to follow certain load patterns, as the LV Network Templates project showed. However, actual LV monitoring is particularly important for substations which include clusters of load which do not follow conventional trends found across the UK. The Isles of Scilly has a large percentage of electrically heated properties and a significant amount of load is also influenced by the peak tourist periods. Hence the maximum total demand experienced by the islands usually occurs around Easter, particularly if it coincides with a cold spell. Differences such as these increase the likelihood that the load patterns will not fit a standard template approach.

Having a greater visibility of the LV network enables more informed planning decisions to be made and allows networks to be optimised for specific operating conditions. This is of increasing importance when connecting a greater amount embedded generation on the lowest voltage levels. This becomes even more significant for networks that are limited in the amount of reverse power they can absorb, so ensuring that the load is always greater than the connected generation in areas that may be supplied by diesel generation is imperative.

Initial learning from the project has helped understand, define and manage the different types of traffic a distribution network orientated communication network needs to carry. The radio and BPL network for the Isles of Scilly does not rely on any third party intervention or services in order to operate and utilises both licensed and unlicensed spectrum. The level of resilience afforded by the licensed radios would be essential for high-priority traffic, such as control or protection. A slightly less robust availability could be tolerated for the monitoring traffic, particularly if the information is only polled in daily cycles. This was not chosen for this application due to the real-time requirements for the monitoring system.

The same levels of criticality applied to the communications backhaul was also applied to the power requirements of the equipment, with each monitoring unit being supported by DC battery backup. For future monitoring systems, the same level of resilience is not necessarily required.

Whilst the BPL technology has not fed directly into the smart metering model, the architecture developed for this project can help with the transition of distribution networks towards smarter networks requiring a greater reliance on communications. How the topological IP network was developed for the islands' communications system and how it relates to the physical electrical assets has fed into standard policies within the business.

This project demonstrated that it is possible to safely install BPL technology on the overhead and underground 11kV networks and that the equipment is fit for purpose for usage in a distribution network environment.

The requirements for a Phasor Measurement Unit system fit for installation on the distribution network has been investigated as part of this project and the final design implemented on the Isles of Scilly can be duplicated around the network. The finalised design is able to be deployed in both indoor and outdoor substations and can be powered using both AC and DC supplies.

The demonstration of synchrophasor control to enable advanced generator control has proved that by using GPS synchronised phasor measurement data, remote generators can be kept electrically separate, but synchronised to a high degree of accuracy, even with a variable and asynchronous communication delay.

13. Planned implementation

This project has created a platform to build an understanding of LV loadings in weakly connected areas that may be supplied by generation islanded from the main network. Levels of total aggregate load will continue to be monitored to ensure that reverse power conditions do not affect the security of the system.

The radio and Broadband over Powerline communication system that has been deployed on the network can act as an enabling technology in the future. Having this robust data infrastructure will allow any further advanced control of the network to be implemented and will facilitate any HV or LV active network management systems on the islands.

The use of UHF radios which use unregulated spectrum to deliver less-critical traffic piloted in the project has been proved successful, particularly in rural areas where there is less likely to be other applications using these frequencies. WPD is planning to use a similar approach to provide short-distance, low-cost communications to low carbon generators in order to bring back monitoring data to the distribution management system. The use of these radios to enable generators to be actively managed is also planned.

LV monitoring will continue to be rolled out to substations which are deemed to be of strategic importance or have the potential to operate load patterns which fall outside of a template approach. LV monitoring technologies will be deployed using best practise from the LV Sensors Report.

The use of synchrophasor control for the generators will continue to be monitored whilst the generators are run under standard business procedures, to build up confidence and further data on the accuracy of the developed algorithm. Further fine tuning of the software and a larger amount of tested hours is required before the system can be operated independent of other synchronicity checking equipment.

Learning from this project has already been transferred into the Tier 2 project FALCON (Flexible Approaches to Low Carbon Optimised Networks) as it has informed best practice when installing further phasor measurement units on the network.

If the technology wants to be transferred so that multiple renewable generation sets can be co-ordinated remotely from a single monitored source, then further development work will need to be carried out by the generator control manufacturers.

14. Facilitate Replication

14.1. Knowledge Required

The knowledge required to implement a platform which supports the connection of embedded generation and is able to maximise the effectiveness of any controllable generation is outlined below:

- Electrical network topology and connectivity
- Electrical network impedance data
- Load distribution
- Geographic asset locations
- Physical terrain and relief mapping
- Communication topology
- Data flows and requirements

14.2. Products/Services Required

As well as general project management and installation resources at the disposal of a distribution network operation, there are a number of separate products and services that have been identified by this project as being prerequisites required before the enabling platform can be fully operational. This section outlines these requirements:

- Overhead LV monitoring
- Underground LV monitoring
- Substation data aggregators
- Allocated licensed spectrum
- Licenced UHF radios
- Unlicensed UHF radios
- Broadband over Powerline
- Real-time data polling system
- Phasor Measurement Units
- Phasor data concentrators
- Generator Control systems

14.3. Project IPR

This project integrated a number of existing products and services as outlined in section 14.2 to enable successful delivery against the project criteria. Whilst there was no foreground IPR generated, there have been a number of learning outcomes developed and disseminated across the wider business and other projects, as described in sections 12 and 13.

Lessons learnt from this project have already helped form the WPD requirements for LV substation monitoring as used in the LV Current Sensors project and develop a standard for implementing Phasor Measurement on the distribution network, which has been used within project FALCON.

A method of connection for 11kV BPL devices for both the overhead and underground network has been developed and the technical policy documents are available on request.

This project has been reported on during both the 2012 and 2013 Low Carbon Network Fund Conferences.

Design documents and specifications for the equipment developed for this project are available on request from wpdinnovation@westernpower.co.uk.

14.4. Points of Contact

Further details on replicating the project can be made available from the following points of contact:

- Ben Godfrey, Western Power Distribution, Pegasus Business Park, East Midlands Airport, Castle Donington, Derbyshire, DE74 2TU. bgodfrey@westernpower.co.uk
- Future Networks Team, Western Power Distribution, Pegasus Business Park, East Midlands Airport, Castle Donington, Derbyshire, DE74 2TU. wpdinnovation@westernpower.co.uk

Appendix A1:

Pro forma

First Tier LCN Project Registration

DNO(s)
WPD
Registration date

Project description	
Project title	Network Management on the Isles of Scilly
Project background	<p>Electricity supplies to the Isles of Scilly comprise a single 33kV undersea cable from the mainland supplemented by an island based diesel generating station. There are also remote, locally controlled generators on two outer islands available for use in limited instances.</p> <p>The islands provide an effective self contained microcosm of an 11kV and LV electricity distribution system that can be monitored and controlled to provide measurement of impact and capability to accommodate DG and other low carbon initiatives.</p> <p>The Isles of Scilly Council has a published goal of the islands being energy self sufficient To this end, the council is examining methods of localised generation such as waste disposal and the islander's themselves are keen to exploit PV and wave power on and off the smaller islands. WPD will work in conjunction with the islanders through this initiative to ensure the full support for their desire to be energy self sufficient. The community level interest in energy management was demonstrated in their 2009 "e-day" initiative which received national BBC TV coverage.</p> <p>WPD Project partners - Duchy of Cornwall, IGE, Islanders on St. Agnes, Isles of Scilly Council, Power Electrics, PowerPlus Communications Radius, Transition Scilly</p>
Scope and objectives	<p>It is proposed to establish real time monitoring on all of the distribution substations on the Isles of Scilly in such a way that the use of the generation facilities on the islands can be maximised to secure supplies to the islands. The control and management of the generation on the off islands will be effected using new methods that have not been used in WPD before.</p> <p>The monitoring at the substations will be supplemented by controls where appropriate to ensure that islander's and company initiatives associated with localised generation can be accommodated and managed in an effective way. The initial localised generation is expected to be by PV though the islander's themselves are actively pursuing wave power and possibly waste disposal as other sources of generation. The Scillies have the highest PV solar efficiency rating in UK and present a challenging DG/demand environment on a weakly connected rural network.</p> <p>The initiative will support the council's published goal of energy self sufficiency.</p>
Success criteria	<p>The effective management of off island generation and monitoring & control of various PV installations on a weakly connected network.</p> <p>Use of Power Line Carrier techniques on higher voltage networks</p>
TRL(s)	Between 6 and 8
Predicted end date	Quarter 3, 2012
External Collaborators and external funding	None within LCNF Governance definition - Partners as stated above

Solutions	<p>It is proposed to monitor all of the distribution substations on the islands with demands etc. being subsumed into WPD's company wide SCADA system. The loading details can be made available to local groups on the islands if required.</p> <p>Communications between the sites and the SCADA system will be achieved by the use of mesh radio or power line carrier techniques. The power line carrier will operate over both the LV and 11kV networks.</p> <p>Controls will be achieved over the same communications infrastructure supplemented where necessary by unregulated frequency radios.</p>
Potential for new learning	<p>How PV and other low carbon generation initiatives can be managed and measured in a controlled way on a weakly connected network. The use of PLC on HV networks together with the use of concentrators and substation locations and how this might influence the design and use of the current DCC model proposed to support smart metering. Dissemination will be via reporting, seminars and submission of papers</p>
Risks	<p>The successful use of Power Line Carrier on the higher voltage network may be prohibitively costly meaning that more radio solutions may be necessary.</p> <p>The islands may develop their initiatives over a time frame from that does not match WPD's.</p>
Scale of Project	The whole of the electricity distribution network on the Isles of Scilly.
Geographic area	The Isles of Scilly
Does the Project involve customer engagement?	No.

Funding	
Revenue allowed for within the DPCR5 settlement (£)	None
Indication of the total Allowable First Tier Project Expenditure (£)	£1,125,000

Publication	
Does the DNO provide Ofgem with consent to publish its First Tier LCN Project Registration Pro-forma in full?	Yes
If not, please justify which parts the DNO considers to be confidential	

Related Undertakings	
Payments to Related Undertakings (£)	None
If a payment is to be made to any Related Undertaking that is a Distribution System User, have the same terms been offered to similar Distribution System Users of the part of the network that is within the project boundary?	
Has the DNO used reasonable endeavours to make the opportunity available to similar Distribution System Users of the part of the network that is within the project boundary?	

IPR arrangements	
If IPRs are generated, will they conform to the default IPR arrangements set out in the LCN Fund Governance Document?	Yes
If no, then please provide a compelling justification for the project being approved	

First Tier LCN Project Changes

DNO(s)
WPD
Change date

Project description	Registration details	Updated details	Reason for changes
Project title	Network Management on the Isles of Scilly		
Project background	Electricity supplies to the Isles of Scilly comprise a single 33kV undersea cable from the mainland supplemented by an island based diesel generating station. There are also remote, locally controlled generators on two outer islands available for use in limited instances. The islands provide an effective self contained		
Scope and objectives	It is proposed to establish real time monitoring on all of the distribution substations on the Isles of Scilly in such a way that the use of the generation facilities on the islands can be maximised to secure supplies to the islands. The control and management of the generation on the off islands will be effected using new methods that have not		
Success criteria	The effective management of off island generation and monitoring & control of various PV installations on a weakly connected network. Use of Power Line Carrier techniques on higher voltage networks		
TRL(s)	Between 6 and 8		
Predicted end date	Quarter 3, 2012		
External Collaborators and external funding	None within LCNF Governance definition - Partners as stated above		
Solutions	It is proposed to monitor all of the distribution substations on the islands with demands etc. being subsumed into WPD's company wide SCADA system. The loading details can be made available to local groups on the islands if required. Communications between the sites and the SCADA system will be achieved by the use of mesh radio.		
Potential for new learning	How PV and other low carbon generation initiatives can be managed and measured in a controlled way on a weakly connected network. The use of PLC on HV networks together with the use of concentrators and substation locations and how this might influence the design and use of the current DCC model proposed to support smart metering. Dissemination will be via reporting, seminars and submission of papers		
Risks	The successful use of Power Line Carrier on the higher voltage network may be prohibitively costly meaning that more radio solutions may be necessary. The islands may develop their initiatives over a time frame from that does not match WPD's.		
Scale of Project	The whole of the electricity distribution network on the Isles of Scilly.		
Geographic area	The Isles of Scilly		
Does the Project involve customer engagement?	No.		
Funding	Registration details	Updated details	Reason for changes
Revenue allowed for within the DPCR5 settlement (£)	None	None	N/A
Indication of the total Allowable First Tier Project Expenditure (£)	1125000	1125000	N/A
Publication	Registration details	Updated details	Reason for changes
Does the DNO provide Ofgem with consent to publish its First Tier LCN Project Changes Pro-forma in full?	Yes		
If not, please justify which parts the DNO considers to be confidential			
Related Undertakings	Registration details	Updated details	Reason for changes
Payments to Related Undertakings (£)	None		
If a payment is to be made to any Related Undertaking that is a Distribution System User, have the same terms been offered to similar Distribution System Users of the part of the network that is within the project boundary?			
Has the DNO used reasonable endeavours to make the opportunity available to similar Distribution System Users of the part of the network that is within the project boundary?			
IPR arrangements	Registration details	Updated details	Reason for changes
If IPRs are generated, will they conform to the default IPR arrangements set out in the LCN Fund Governance Document?	Yes	Yes	N/A
If no, then please provide a compelling justification for the project being approved			N/A

Appendix A2: **Amended pro forma**

First Tier LCN Project Changes

DNO(s)
WPD
Change date
25/09/2012

Project description	Registration details	Updated details	Reason for changes
<p>Project title</p> <p>Project background</p>	<p>Network Management on the Isles of Scilly</p> <p>Electricity supplies to the Isles of Scilly comprise a single 33kV undersea cable from the mainland supplemented by an island based diesel generating station. There are also remote, locally controlled generators on two outer islands available for use in limited instances.</p> <p>The islands provide an effective self contained microcosm of an 11kV and LV electricity distribution system that can be monitored and controlled to provide measurement of impact and capability to accommodate DG and other low carbon initiatives.</p> <p>The Isles of Scilly Council has a published goal of the islands being energy self sufficient. To this end, the council is examining methods of localised generation such as waste disposal and the islanders themselves are keen to exploit PV and wave power on and off the smaller islands. WPD will work in conjunction with the islanders through this initiative to ensure the full support for their desire to be energy self sufficient. The community level interest in energy management was demonstrated in their 2009 "e-day" initiative which received national BBC TV coverage.</p> <p>WPD Project partners - Duchy of Cornwall, IGE, Islanders on St. Agnes, Isles of Scilly Council, Power Electrics, PowerPlus Communications Radius, Transition Scilly</p>		<p>N/A</p> <p>N/A</p>
<p>Scope and objectives</p>	<p>It is proposed to establish real time monitoring on all of the distribution substations on the Isles of Scilly in such a way that the use of the generation facilities on the islands can be maximised to secure supplies to the islands. The control and management of the generation on the off islands will be effected using new methods that have not been used in WPD before.</p> <p>The monitoring at the substations will be supplemented by controls where appropriate to ensure that islander's and company initiatives associated with localised generation can be accommodated and managed in an effective way. The initial localised generation is expected to be by PV though the islanders themselves are actively pursuing wave power and possibly waste disposal as other sources of generation. The Scillies have the highest PV solar efficiency rating in UK and present a challenging DG/demand environment on a weakly connected rural network.</p> <p>The initiative will support the council's published goal of energy self sufficiency.</p>		N/A
<p>Success criteria</p>	<p>The effective management of off island generation and monitoring & control of various PV installations on a weakly connected network.</p> <p>Use of Power Line Carrier techniques on higher voltage networks</p>	<p>The effective management of off island generation and monitoring & control of various PV installations on a weakly connected network.</p> <p>Use of Power Line Carrier techniques on higher voltage networks</p> <p>Demonstration of Synchrophasor Generator Control</p>	<p>Inclusion of Synchrophasor Generator Control</p>
<p>TRL(s)</p> <p>Predicted end date</p>	<p>Between 6 and 8</p> <p>Quarter 3, 2012</p>		<p>N/A</p> <p>31-Aug-13</p> <p>Project end date extended to include further acquisition of data to provide quantifiable results on project performance. Without gathering sufficient data following the installation, the benefits realised from the LV monitoring will not be able to quantified in full confidence.</p>
<p>External Collaborators and external funding</p>	<p>None within LCNF Governance definition - Partners as stated above</p>		N/A
<p>Solutions</p>	<p>It is proposed to monitor all of the distribution substations on the islands with demands etc. being subsumed into WPD's company wide SCADA system. The loading details can be made available to local groups on the islands if required.</p> <p>Communications between the sites and the SCADA system will be achieved by the use of mesh radio or power line carrier techniques. The power line carrier will operate over both the LV and 11kV networks.</p> <p>Controls will be achieved over the same communications infrastructure supplemented where necessary by unregulated frequency radios.</p>	<p>It is proposed to monitor all of the distribution substations on the islands with demands etc. being subsumed into WPD's company wide SCADA system. The loading details can be made available to local groups on the islands if required.</p> <p>Communications between the sites and the SCADA system will be achieved by the use of point-to-point radio or power line carrier techniques. The power line carrier will operate over the 11kV network.</p> <p>Controls will be achieved over the same communications infrastructure supplemented where necessary by unregulated frequency radios.</p> <p>Phasor Measurement Units will be installed on the network to manage the off-island generation and analyse the effects of increased generation on weakly connected networks.</p>	<p>To install a number of phasor measurement units (PMUs) on the 10s Generators and 33kV mainland intake in order to trial synchrophasor control of remote generators without a direct electrical connection.</p> <p>Extension of project to include full demonstration and testing of HV BPL and removal of LV BPL from scope - The TRL of BPL on the 11kV network seems to be lower than anticipated and more time is required to report on the performance of the system and applications for the technology.</p>
<p>Potential for new learning</p>	<p>How PV and other low carbon generation initiatives can be managed and measured in a controlled way on a weakly connected network. The use of PLC on HV networks together with the use of concentrators and substation locations and how this might influence the design and use of the current DCC model proposed to support smart metering. Dissemination will be via reporting, seminars and submission of papers</p>	<p>How PV and other low carbon generation initiatives can be managed and measured in a controlled way on a weakly connected network. How Synchrophasor Generator Control can be used to reduce the likelihood of phasor shift on electrically separate networks. How Phasor Measurement Unit data can be used in the management of weakly connected networks. The use of PLC on HV networks together with the use of concentrators and substation locations and how this might influence the design and use of the current DCC model proposed to support smart metering. Dissemination will be via reporting, seminars and submission of papers.</p>	<p>By measuring synchrophasor data at each generation location, the electrical output of the generators can be accurately controlled and the units can be switched in and out within any supply interruptions to customers and without extra synchronisation equipment being installed out on the network. This trial will also demonstrate the ability of synchrophasor control to allow a network to be sustained from multiple small distributed generators on a weakly connected network without risk of electrical islanding or frequency oscillation.</p>
<p>Risks</p>	<p>The successful use of Power Line Carrier on the higher voltage network may be prohibitively costly meaning that more radio solutions may be necessary.</p> <p>The islands may develop their initiatives over a time frame from that does not match WPD's.</p>	<p>The islands may develop their initiatives over a time frame from that does not match WPD's.</p>	<p>Updated to match current project risks</p>
<p>Scale of Project</p> <p>Geographic area</p> <p>Does the Project involve customer engagement?</p>	<p>The whole of the electricity distribution network on the Isles of Scilly.</p> <p>The Isles of Scilly</p> <p>No</p>		<p>N/A</p> <p>N/A</p> <p>N/A</p>
Funding	Registration details	Updated details	Reason for changes
<p>Revenue allowed for within the DPCR5 settlement (£)</p> <p>Indication of the total Allowable First Tier Project Expenditure (£)</p>	<p>None</p> <p>1125000</p>	<p>None</p> <p>1287000</p>	<p>N/A</p> <p>Removal of LV PLC - £18k</p> <p>Addition of Synchrophasor Generator Control - £180k</p>
Publication	Registration details	Updated details	Reason for changes
<p>Does the DNO provide Ofgem with consent to publish its First Tier LCN Project Changes Pro-forma in full?</p> <p>If not, please justify which parts the DNO considers to be confidential</p>	<p>Yes</p>		<p>N/A</p> <p>N/A</p>
Related Undertakings	Registration details	Updated details	Reason for changes
<p>Payments to Related Undertakings (£)</p> <p>If a payment is to be made to any Related Undertaking that is a Distribution System User, have the same terms been offered to similar Distribution System Users of the part of the network that is within the project boundary?</p> <p>Has the DNO used reasonable endeavours to make the opportunity available to similar Distribution System Users of the part of the network that is within the project boundary?</p>	<p>None</p>		<p>N/A</p> <p>N/A</p>
IPR arrangements	Registration details	Updated details	Reason for changes
<p>If IPRs are generated, will they conform to the default IPR arrangements set out in the LCN Fund Governance Document?</p> <p>If no, then please provide a compelling justification for the project being approved</p>	<p>Yes</p>	<p>Yes</p>	<p>N/A</p> <p>N/A</p>

Appendix A3:

Change mandates

WPD Future Networks Programme Change Mandate

Project Number WPDT10002

Change Number IOSCM1

Originator: Ben Godfrey		Tel: 07894258687	Date: 24/09/12
Project Manager: Ben Godfrey		Project: Network Management on the Isles of Scilly	
Change Title: Change in Ofgem Project Registration			
Change Type:			
Resource	<input type="checkbox"/>	New Requirement	<input type="checkbox"/>
Change in Scope	<input type="checkbox"/>	Budget Change	<input type="checkbox"/>
Milestone Change	<input checked="" type="checkbox"/>		
Other dependent projects affected: NA			
Proposed change: Extension of project for 12 months up to end of September 2013			
Reason for change: To gather 12 months' worth of LV monitoring data and report on how the data influences network visibility and uptake of low carbon technologies.			
Effect of NOT making change: Without gathering sufficient data following the installation, the benefits realised from the LV monitoring will not be able to quantified in full confidence.			
Impacts of Change:			
Milestones	<input checked="" type="checkbox"/>	Deliverables	<input type="checkbox"/>
Resources	<input type="checkbox"/>	Project End Date	<input checked="" type="checkbox"/>
Costs	<input type="checkbox"/>	Benefits	<input checked="" type="checkbox"/>
Project Scope	<input type="checkbox"/>	Learning Outcomes	<input checked="" type="checkbox"/>
Describe the impacts on the project for the categories above : The last milestone, the project end date will be extended. Benefits will include more available data to analyse and a complete year cycle for load curves on the Isles of Scilly. A report will be produced on recommendations of where low carbon technologies can be implemented.			
Cost of making the change (and justification): £0k No additional spend forecast for the analysis of the data. Report to be written for project closeout.			
Supporting Information:			
Signed: Project Manager Future Networks Manager Project Sponsor			Date : 24/09/12

WPD Future Networks Programme Change Mandate

Project Number WPDT10002

Change Number IOSCM2

Originator: Ben Godfrey		Tel: 07894258687	Date: 24/09/12
Project Manager: Ben Godfrey		Project: Network Management on the Isles of Scilly	
Change Title: Change in OFGEM Project Registration			
Change Type:			
Resource	<input type="checkbox"/>	New Requirement	<input type="checkbox"/>
Change in Scope	<input checked="" type="checkbox"/>	Budget Change	<input checked="" type="checkbox"/>
Milestone Change	<input type="checkbox"/>		
Other dependent projects affected: NA			
Proposed change: Inclusion of Synchrophasor Control element for IoS Generators			
Reason for change: To install a number of phasor measurement units (PMUs) on the IoS Generators and 33kV mainland intake in order to trial synchrophasor control of remote generators without a direct electrical connection. By measuring synchrophasor data at each generation location, the electrical output of the generators can be accurately controlled and the units can be switched in and out within any supply interruptions to customers and without extra synchronisation equipment being installed out on the network. This trial will also demonstrate the ability of synchrophasor control to allow a network to be sustained from multiple small distributed generators on a weakly connected network without risk of electrical islanding or frequency oscillation.			
Effect of NOT making change: A short 11kV interruption will be required for Bryer and St Agnes when restoring to the main network supply from being locally fed by the generators			
Impacts of Change:			
Milestones	<input type="checkbox"/>	Deliverables	<input type="checkbox"/>
Resources	<input type="checkbox"/>	Project End Date	<input checked="" type="checkbox"/>
Costs	<input checked="" type="checkbox"/>	Benefits	<input checked="" type="checkbox"/>
Project Scope	<input checked="" type="checkbox"/>	Learning Outcomes	<input checked="" type="checkbox"/>
Describe the impacts on the project for the categories above : Project will be extended to September 2013 and the PMU/control will be installed before end of 2012. This will enable testing to be carried out and effects of the novel control technique to be observed and disseminated			
Cost of making the change (and justification): £180k Psymetrix quote to be paid for plus installation time by local delivery staff. Some comms upgrading also required			
Supporting Information:			
Signed: Project Manager Future Networks Manager Project Sponsor			Date : 24/09/12

WPD Future Networks Programme Change Mandate

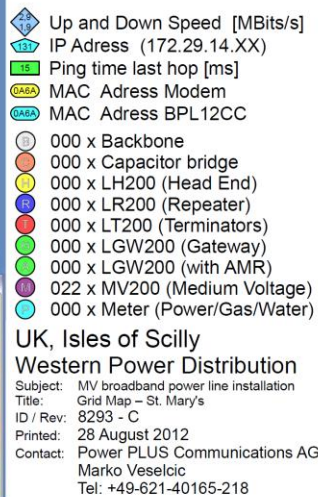
Project Number WPDT10002

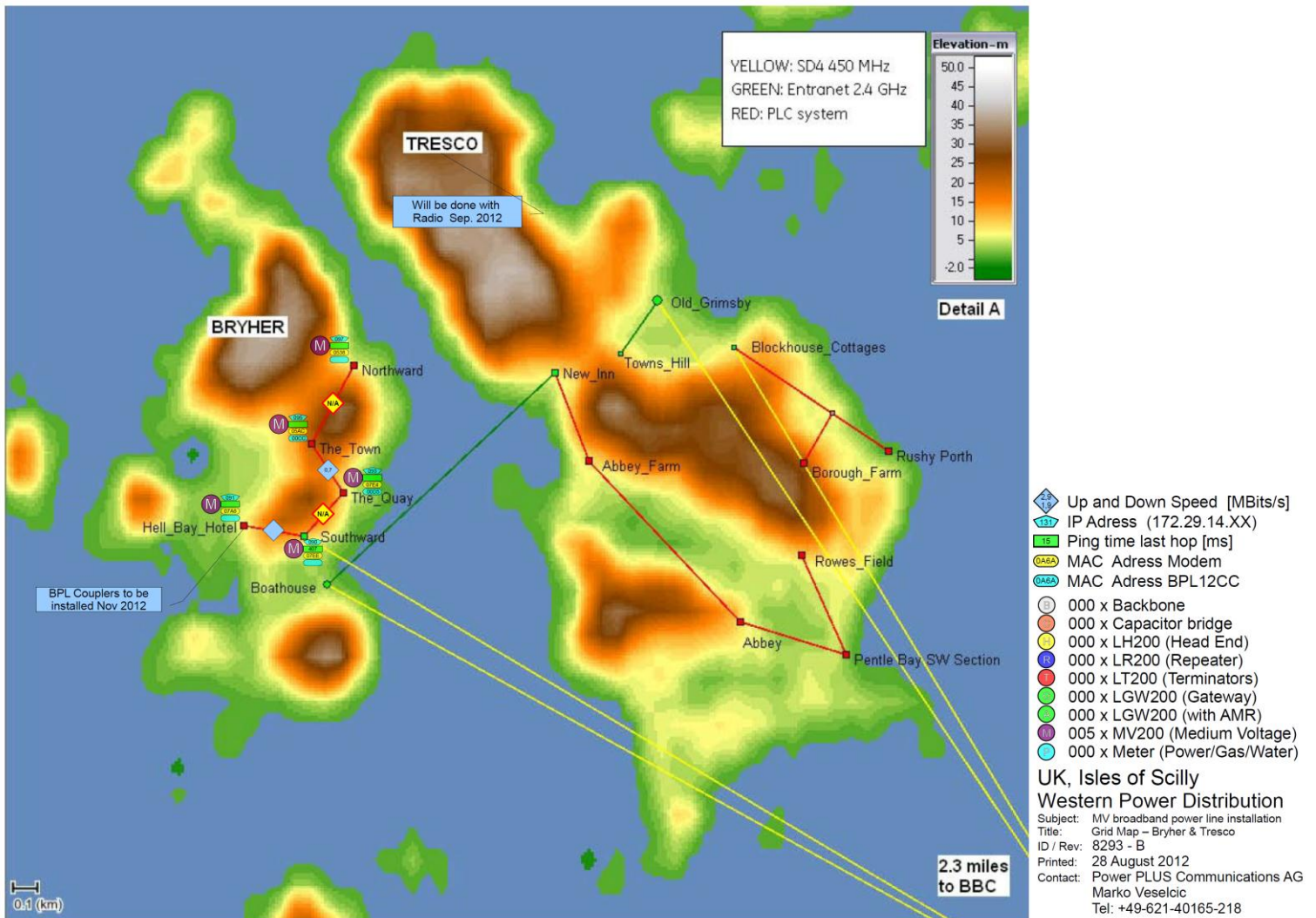
Change Number IOSCM3

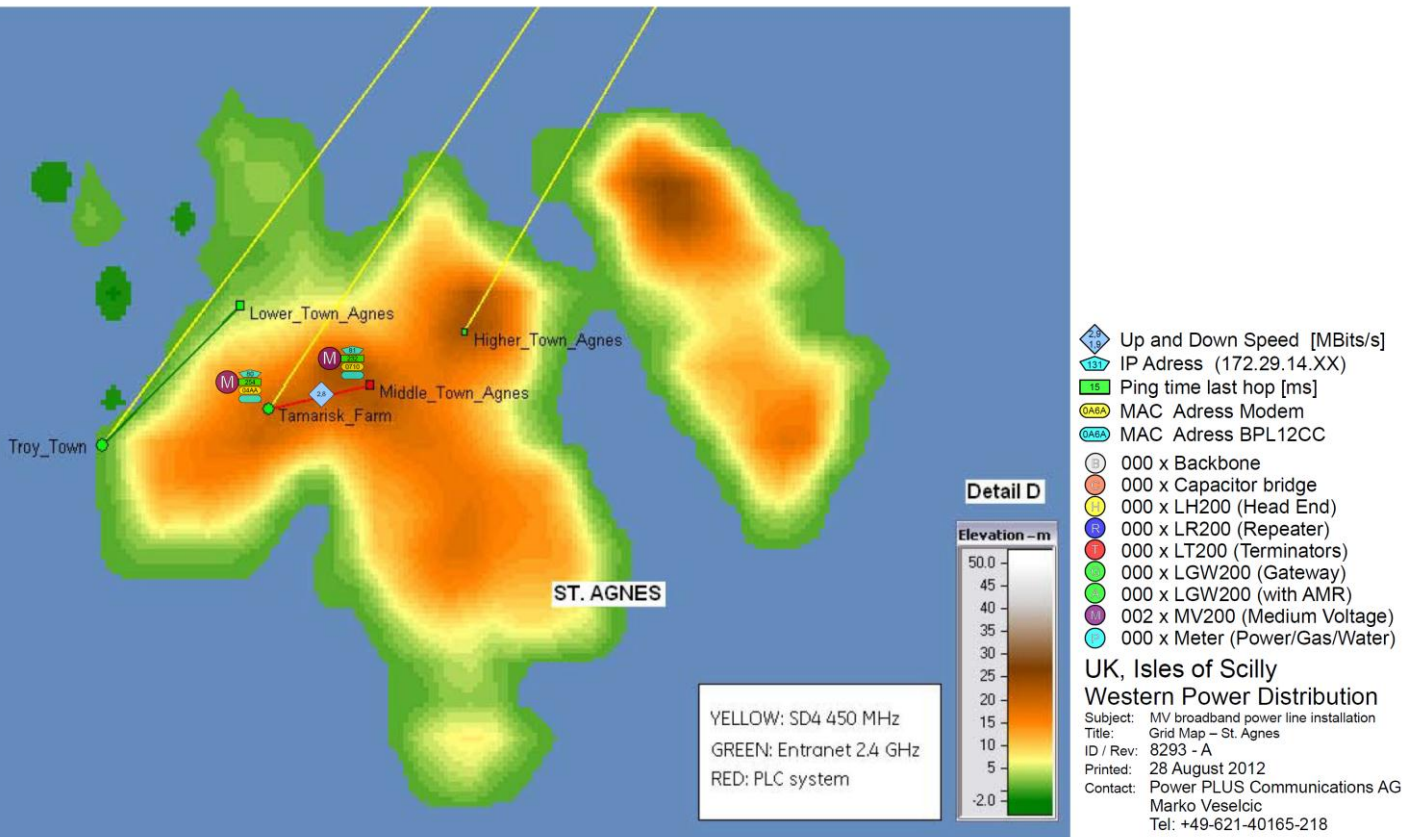
Originator: Ben Godfrey		Tel: 07894258687	Date: 24/09/12
Project Manager: Ben Godfrey		Project: Network Management on the Isles of Scilly	
Change Title: Change in OFGEM Project Registration			
Change Type:			
Resource	<input type="checkbox"/>	New Requirement	<input type="checkbox"/>
Change in Scope	<input checked="" type="checkbox"/>	Budget Change	<input type="checkbox"/>
Milestone Change	<input checked="" type="checkbox"/>		
Other dependent projects affected: NA			
Proposed change: Extension of project to include full demonstration and testing of HV BPL and removal of LV BPL from scope			
Reason for change: <i>The TRL of BPL on the 11kV network seems to be lower than anticipated and more time is required to report on the performance of the system and applications for the technology.</i>			
Effect of NOT making change: Learning of the installation will be reduced as the recommendations for applications is not backed up by quantifiable data			
Impacts of Change:			
Milestones	<input checked="" type="checkbox"/>	Deliverables	<input type="checkbox"/>
Resources	<input type="checkbox"/>	Project End Date	<input checked="" type="checkbox"/>
Costs	<input type="checkbox"/>	Benefits	<input checked="" type="checkbox"/>
Project Scope	<input type="checkbox"/>	Learning Outcomes	<input checked="" type="checkbox"/>
Describe the impacts on the project for the categories above : Project will be extended to September 2013 and more data on reliability, latency and availability will be captured.			
Cost of making the change (and justification): £ -18k for LV BPL removal No additional spend anticipated for extension.			
Supporting Information:			
Signed: Project Manager Future Networks Manager Project Sponsor			Date : 24/09/12

Appendix A4:

BPL topology







Appendix A4:

Substations on the Isles of Scilly

Island	Substation Name	OH / UG Site	Customers
St Mary's	BBC Station	UG	31
	Borough	OH	4
	Carn Gwaval School	UG	5
	Church Road	UG	64
	Helveor	OH	2
	Higher Newford	OH	4
	Higher Trenoweth	OH	20
	Highlanes	OH	13
	Holy Vale	OH	1
	Hughtown	UG	304
	Incinerator Station	OH	1
	IOS Local Txf	UG	0
	Jerusalem Terrace	UG	113
	Joaneys Well	OH	1
	Lanteverne	OH	5
	Longstone Farm	OH	3
	Lower Trenoweth	OH	3
	Lundon	OH	6
	Maypole	OH	14
	Mount Todden	UG	1
	Normandy	OH	32

Island	Substation Name	OH / UG Site	Customers
St Mary's	Old Town	UG	111
	Old Town Lane	OH	18
	Old Town Pump	OH	27
	Parting Carn	OH	9
	Pelistry Lane	OH	13
	Porth Mellon	OH	28
	Porthcress Flats	UG	220
	Porthloo	OH	31
	Porthloo Lane	OH	15
	Porthmellon Industrial	UG	110
	Rocky Hill	OH	28
	Rocky Hill Pumps	OH	1
	Salakee	OH	11
	Signal Station	OH	38
	The Garrison	UG	21
	Town Lane	OH	1
	Tremelethan	OH	4
	Tremelethan Pumping	OH	1
Tresco	Abbey	UG	7
	Abbey Farm	UG	25
	Blockhouse Cottages	UG	7

Island	Substation Name	OH / UG Site	Customers
Tresco	Borough Farm	UG	14
	New Inn	OH	29
	Old Grimsby	UG	28
	Rowes Field	UG	5
	Towns Hill	OH	17
St Martin's	Higher Town	UG	63
	Lower Town	UG	24
	Middle Town	UG	15
	Reading Room	UG	3
	School	UG	5
Bryher	Boathouse	UG	3
	Hell Bay Hotel	UG	16
	Northward	UG	14
	Southward	UG	5
	The Quay	UG	7
	The Town	UG	18
St. Agnes	Higher Town Agnes	UG	12
	Lower Town Agnes	UG	11
	Middle Town Agnes	UG	19
	Tamarisk Farm	UG	12
	Troy Town	UG	5

Appendix A5:

Typical overhead installations





Appendix A4:

Typical underground substation



