MODERN COMMUNICATIONS INFRASTRUCTURE TO ENABLE FLEXIBLE MANAGEMENT OF NETWORK CONSTRAINTS AND INCREASED LEVELS OF DISTRIBUTED GENERATION

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ABSTRACT

The 'Flexible Plug and Play Low Carbon Networks' (FPP) project aims to facilitate the acceleration, growth and expansion of distributed generation connections onto the distribution electricity network without the need for conventional network reinforcement. Rather, the approach seeks to achieve this by, managing network constraints and maximising network utilisation. The project will do this through the integration of smart devices, smart applications and smart commercial arrangements.

This paper encapsulates and presents the associated work carried out to design and deploy a modern communications infrastructure: the IP communications platform that is capable of carrying the open standard protocol defined by the International Electrotechnical Commission, IEC 61850. Also discussed is the functional verification tests undertaken on the communications network equipment, using IEC 61850 simulators, to demonstrate its ability to successfully pass IEC 61850 traffic. Furthermore, further work to be performed is outlined.

1. INTRODUCTION

The UK Renewable Energy Strategy outlines a clear commitment for an increase in the nation's use of renewable electricity, with the UK government setting an ambitious target for 30% of the UK's electricity to be generated from renewable energy sources by 2020 [1]. Onshore wind is an identified and proven technology that will be a leading contributor to the achievement of the target and help transition the UK to a low carbon economy.

One area of focus that has emerged is the requirement for Distribution Network Operators (DNOs) to explore innovative technical and commercial solutions to enable an accelerated and cost-efficient connection of distributed generation.

UK Power Networks was awarded funding under Ofgem's (GB Energy Regulator) Low Carbon Networks Fund (LCNF) scheme, for the FPP project that will look to address this requirement. It is a £10 million project, which commenced in January 2012 and will conclude in December 2014.

1.1 The Problem

UK Power Networks' Eastern Power Network (EPN) distribution network serves an area of 700km^2 between Peterborough and Cambridge in the East of England, UK. This is an area that has experienced an increased activity in distributed generation development; existing onshore wind connections total 120MW, with 200MW of distributed generation capacity currently at various stages of the planning process seeking to connect.

The connection of this anticipated growth in distributed generation is expected to require significant network reinforcement to manage network thermal and voltage constraints and reverse power flow issues.

For this reason, the area between Peterborough and Cambridge serves as an ideal trial area for the FPP project to trial alternative smart connection solutions.

1.2 The Solution

The FPP solution will deploy smart devices from various vendors (Quadrature Booster, Dynamic Line Ratings, advanced protection systems, Active Voltage Control and Frequent Use Switches) to manage specific network constraints. A smart application will be installed providing an Active Network Management (ANM) solution to coordinate and manage the smart devices. The ANM will also manage the generators' output using coordinated controllers.

Instrumental to the successful integration of each smart component is the deployment an IEC 61850 based communications system over an Internet Protocol (IP) platform.

This IP communications infrastructure will enable the wide range of vendor smart devices to be integrated onto the distribution network to resolve specific network constraints and to demonstrate interoperability. Additionally, it will facilitate the data exchange and control capability of ANM to implement the technical and commercial solutions in real time to manage network constraints. This will allow for the distribution network to accept increased levels of distributed generation and for an increase in the generators' export onto the distribution network.

2. THE PARTNERS

The FPP project is led by UK Power Networks in partnership with ten partners. The IP communications infrastructure is in partnership with Cable & Wireless Worldwide and Silver Spring Networks (Figure 1).

Figure 1: Two of the FPP Project Partners

3. CONNECTIVITY AND COVERAGE

The IP communications infrastructure was developed to provide:

(i) Connectivity between:

- Two 132/33kV Grid substations
- Ten 33/11kV Primary substations
- Two 33kV poles

  The existing onshore wind farm connections were excluded as a point of connectivity as the generators are not controllable by ANM.

(ii) Connectivity to the ANM solution.

(iii) A canopy approach to provide coverage to sixteen potential generator locations (33kV or 11kV Interfacing generator substation) within the trial area.

(iv) Extension using Low Voltage (LV) distribution poles as Relay sites.

(v) The ability to transport DNP3 and IEC 61850 traffic.

4. IP COMMUNICATIONS INFRASTRUCTURE

Cable & Wireless Worldwide will provide a fully managed service based on their Multi Service Platform (MSP) for local loop backhaul access, and Managed Customer Edge (CE) routers in conjunction with Silver Spring Networks' technology to form a resilient, scalable and secure wireless Radio Frequency (RF) Mesh network. The end-to-end solution will be capable of IP encapsulation and termination of the IP protocols, DNP3 and IEC 61850.

The IP communications infrastructure solution is comprised of the following components:

- Wide Area Network (WAN)
- Wireless Radio Frequency (RF) Mesh Network
- Local Area Network (LAN)

4.1 Wide Area Network

Two new IP back-haul sites will be established at the Grid substations, each connected to a Provider Edge (PE) node via an access circuit with 2Mbit/s usable bandwidth; one using a throttled 10 Mbits/s Ethernet fibre service and the other 2 Mbit/s Copper Partial Private Circuit (PPC) service. Both services are terminated on a CISCO 2901 Managed CE router housed within a router cabinet, presenting Ethernet to the RF Mesh Network equipment within the substation.

The new WAN comprises two Virtual Routing and Forwarding (VRF) networks that integrate securely with UK Power Networks' existing WAN. One VRF carries DNP3 and IEC 61850 data between devices on the RF Mesh and UK Power Networks' main network control centre. The other VRF enables the RF Mesh to be monitored and controlled from a remote network operations centre.

4.2 RF Mesh Network Tools and Equipment

Design Tool

The FFP RF Mesh Network was designed using the tool *Radio Mobile* [2] that uses the Irregular Terrain Model (ITM), also referred to as the Longley-Rice terrain-based path loss model. This identifies three modes of variability (expressed as a percentile) to categorise and account for variations in measured median signal levels.

Two propagation case studies were run for each of the design phases with retries set to zero:

Mode of Variability	**Study 1:** Conservative Parameters	**Study 2:** Less Conservative Parameters
% of Time	80	50
% of Locations	70	50
% of Situations	70	70

Table 1: Propagation Case Studies

RF Mesh Equipment

The Silver Spring Networks equipment will operate within the 870 – 876 MHz RF spectrum and will use omni-directional antennae. The equipment includes:

- **eBridges:** Wireless routers for secure IP, two-way, real time communications. They are manufactured to perform one of two roles, Master or Remote. A Master eBridge is the take-out point for Remote eBridges to the ANM system.
- **Access Points:** Serve as a take-out point for the network management traffic.
- **Relays:** Extend the reach of the RF Mesh Network; particularly when spanning over longer distances and around topographical obstacles. Relays are designated to be: strategic - for those to be installed in support of the design; or, tactical - for unforeseen optimisation/remediation if required.

4.3 RF Mesh Network Design

The process to design the RF Mesh Network is in three parts:

Phase 1: Initial Field Network Design

Location data (asset name and grid reference) of the various endpoints were collated using UK Power Networks' electrical asset catalogue, Ellipse.

Relay locations were determined by applying the extrapolated location data and sixteen generic generators' locations in to the *Radio Mobile* tool. The preliminary quantity of the required Silver Spring Networks equipment (eBridges, Access Points and Relays) for the trial area is captured below:

Device Type	Qty	Install Location
Remote eBridges	12	10x 33/11kV Primary substation 2x 132/33kV Grid substation
Remote eBridges	16	Interfacing generator substation
Remote eBridges	2	33kV poles
Master eBridges	4	132/ 33kV Grid substation
Access Points	2	132/ 33kV Grid substation
Strategic Relays	14	LV distribution pole
Tactical Relays	6	LV distribution pole

Table 2: Initial Design - Equipment Quantity & Location

Phase 2: Enhanced Field Network Design
Building upon the Initial Field Network Design, site surveys at the preliminary LV distribution poles were undertaken for the fourteen strategic Relays. The primary purpose of the site surveys are to determine if there was an alternative optimal LV distribution pole that would avoid/mitigate the following local environmental conditions that may affect the RF Mesh Networks performance, which would not have been apparent during the initial selection process:

- **Foliage** – especially troublesome when in close proximity (2-3 metres) to antenna or if extremely dense.
- **Obstructions** – examples would include nearby buildings and terrain.
- **Potential interference sources** – close proximity to other RF transmission sites operating in or near the same frequencies.

The site surveys resulted in thirteen of the fourteen LV distribution pole locations to be updated and for third party towers to be considered.
The final confirmed quantity and location/asset of the equipment to be installed is as follows:

Device Type	Qty	Install Location
Remote eBridges	12	10x 33/11kV Primary substation 2x 132/33kV Grid substation
Master eBridges	4	132/ 33kV Grid substation
Access Points	2	132/ 33kV Grid substation
Strategic Relays	13	LV distribution pole and one at a third party Tower
Tactical Relays	7	LV distribution pole

Table 3: Enhanced Design - Equipment Quantity & Location

The RF Mesh Network equipment for the sixteen potential generator locations and 33kV poles will only be deployed when required.
The propagation analysis identified that a previous Strategic Relay location would be used instead as a Tactical Relay in the case of remediation for improved connectivity.

Phase 3: Final Field Network Design
The Final Field Network Design will be carried out post installation of the RF Mesh Network equipment as listed in Table 3. The layout of the configuration is validated by performing connectivity tests.
As a result of such tests, the network design may be optimised by two adjustments. The adjustment may be the requirement to install additional Relays (Tactical) within the trial area to realise the connectivity required or the relocation of Relays (Strategic) to improve mesh links between end points.
The Enhanced Field Network plus required network optimisation will yield the Final Field Network Design and reflect the as-built RF Mesh Network.

4.4 Local Area Network

A LAN will be established within each of the identified substations to connect the RF Mesh Network to the smart devices using Ethernet connection.
At the Grid substations, the LAN will be achieved using an integrated Layer 3 switch module (HWIC-4ES) within the Cisco 2901 router to connect the Master eBridges and Access Point:

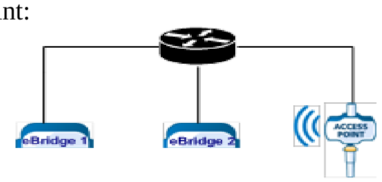

Figure 2: Grid Substation LAN

The use of an integrated module avoids the need for separate networking equipment at the Grid sites.
At the Primary substations the LAN will be established by connecting the installed Remote eBridge's Ethernet port directly to the Remote Terminal Unit (RTU). In locations requiring more devices and therefore more LAN ports, these will be provided using modular Layer 2 unmanaged industrial Ethernet switches.

4.5 End-to-End Solution

The IP communications infrastructure depicted below:

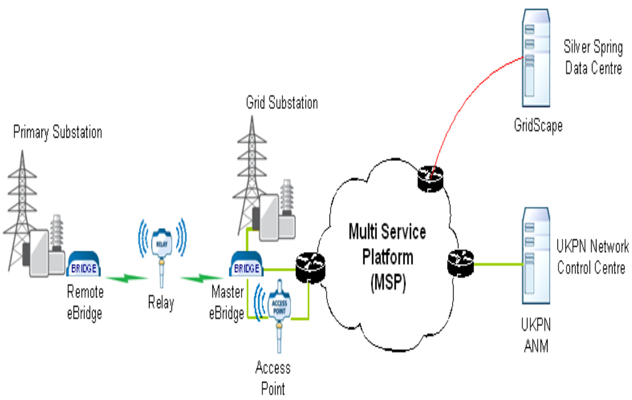

Figure 3: High Level IP communications infrastructure

To manage the wireless RF Mesh network, the project will be deploying the Silver Spring Networks web-based network management application suite, GridScape. It provides a complete grid context, with full geographical visualisations.

5. IEC 61850 LABORATORY TEST

Functional verification of the Silver Spring Networks equipments' ability to pass simulated IEC 61850 traffic was successfully performed. The lab tests were functional in nature, and explicitly did not include performance tests such as: congestion, corruption, overload or failover.
The test was performed using a simulated IEC 61850 client and server, these were implemented using two laptops, one running Triangle Microworks Version 3.1.14.0 Hammer and the other the Anvil software package. Network connectivity between the Master eBridge and Remote eBridge was through an 870.2-875.8 MHz RF Mesh link. The functional test environment consists of two eBridges (Master and Remote), two laptops, Triangle Microworks Version 3.1.14.0 Hammer and Anvil software packages, a switch, and a packet sniffer as depicted in the below configuration:

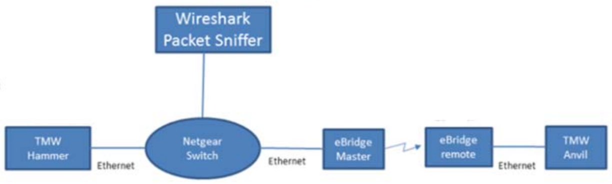

Figure 4: IEC 61850 Lab Test Configuration

Five tests were performed: GetDirectory discovery of data components on a remote server; periodic GetDataValues polling of data; progressively more rapid GetDataValues polls of data to demonstrate multiple reads per seconds; an Exception Based Report in which data was sent from the simulated IEC 61850 Server to the simulated IEC 61850 client; and finally, a combined test of polling, exception based reporting, and Standard Network Time Protocol (SNTP) Time updates of an RTU.
All tests were passed successfully, with the GetDirectory pulling back a full model of the remote server's data definition, GetDataValues correctly retrieving discrete values from the remote server, and exception based reporting demonstrating full ability to send back data across the RF Mesh to an IEC 61850 client from an IEC 61850 server. SNTP time updates also successfully occurred in parallel with several of these operations.

6. CONCLUSION

A modern communications infrastructure has been designed; IEC 61850 based communications system over an Internet Protocol (IP) platform that will enable smart devices and smart applications to be more easily and flexibly integrated on the distribution network. This will support the investigation of alternative smart connection solutions to enable an accelerated and cost-efficient connection to generators onto the distribution network and demonstration of interoperability.
The RF Mesh Network component successfully passed all functional verification lab tests to prove its ability to pass simulated IEC 61850 traffic.

7. FURTHER WORK

The IP communications infrastructure will be installed, commissioned and tested by March 2013.
The test methodology to be executed will include IEC 61850 communication trials using IEC 61850 simulators at various locations in the FPP trial area and end-to-end tests to ensure the infrastructure operates as designed.
Investigation of the RF Mesh Networks' ability to extend and connect to new end points will be undertaken. Also, failover tests will be performed to test that it is fully dynamic and self-healing; when a device comes online or another goes offline, the network adjusts and routes converge on new communication paths.
A security risk assessment will be undertaken to confirm that the design is both resilient and secure that will not introduce any additional risk to UK Power Networks' existing Supervisory Control and Data Acquisition (SCADA) system.

8. ACKNOWLEDGEMENTS

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UK Power Networks would also like to thank Ofgem for their financial support from the Low Carbon Networks Fund.

9. REFERENCES

[1] Department of Energy and Climate Change, HM Government, 2009, "The UK Renewable Energy Strategy"

[2] Roger Coudé, VE2DBE, *Radio Mobile version 10.2.1 Radio Propagation and Virtual Mapping Freeware*