FLEXIBLE PLUG AND PLAY PROJECT: SYSTEM INTEGRATION USING IEC 61850 OVER THE RADIO FREQUENCY MESH NETWORK TO ACTIVELY MANAGE DISTRIBUTION GENERATION

Tim MANANDHAR
UK Power Networks – UK
tim.manandhar@ukpowernetworks.co.uk

Emmanuel CERQUEIRA
EDF Energy R&D UK Centre – UK
emmanuel.cerqueira@edfenergy.com

Sotiris GEORGIOPOULOS
UK Power Networks – UK
sotiris.georgiopoulos@ukpowernetworks.com

ABSTRACT

The Flexible Plug and Play (FPP) project is trialling a number of innovative solutions to enable the most flexible and cost effective method of connecting renewable generation to the distribution network.

The vision of smart grid requires seamless integration of various innovative and intelligent solutions to the existing electricity grid over a reliable and flexible communications network. The network operators have been facing continuous challenges in interoperating various vendor technologies due to variety of proprietary and legacy communications protocols. This is further hindered by challenges in designing and implementing a "fit for purpose" communications system that is both secure and scalable in future.

The paper focuses on the three key aspects of the smart grid design adopted by the FPP project that aims to address the above issues.

Firstly, it describes the implementation of a deterministic Active Network Management (ANM) system that is totally independent to the existing network control system.

Secondly, the paper describes the system integration approach using open standard protocol specified by IEC 61850-8-1 to achieve multi-vendor interoperability.

Thirdly, the paper describes the implementation of IPv6 (Internet Protocol version 6) enabled radio frequency (RF) mesh communications technology to facilitate efficient integration of smart solutions onto the distribution network.

INTRODUCTION

The UK government is maintaining a strong commitment to cost effective renewable energy as part of diverse, low-carbon and secure energy mix as stated in the UK Renewable Energy Roadmap Update 2013 [1]. This is supported by UK's ambitious target for 30% electricity generation from renewable energy by the year 2020.

The Flexible Plug and Play (FPP) project is an innovation initiative looking to address this requirement in the electricity distribution network which was awarded funding by the UK energy regulator OFGEM as part of the Low Carbon Network Fund (LCNF) scheme. It is a nearly £10 million project running from January 2012 to December 2014.

The aim of the FPP project is to facilitate cheaper and faster connection of distributed generation (DG) to the constrained area of the distribution network. This approach involves offering interruptible connections which allow generators to connect to the distribution network without extensive reinforcement that otherwise may be required. As part of this interruptible connection approach, the network operator is able to actively manage the output of the distributed generators (DG) to keep the network within operating limits.

As of September 2013, the FPP project has installed and commissioned all technical solutions required to enable the integration of DG. As of March 2014, the FPP project has made **20** interruptible connection offers totalling to **77.61MW**, out of which **8** offers have been accepted totalling to **31.7 MW**. The project is currently in the trial phase until the end of 2014 where the accepted offers are going to be connected and all the technical solutions assessed to demonstrate the commercial and technical project concepts.

The problem

UK Power Networks' Eastern Power Networks (EPN) distribution network serves an area of approximately 700 km^2 between Peterborough and Cambridge in the East of England that is particularly well suited to renewable generation. UK Power Networks has experienced increased activity in renewable generation development in this area over recent years, and a rapid rise in connection applications.

The connection of these anticipated levels of generation is expected to require costly network reinforcement to mitigate network constraints relating to **thermal, voltage and reverse power flow**. Consequently, generation projects seeking connections in this constrained part of the network have received expensive connection offers which make their projects unviable. Although these expensive offers represent an un-interruptible (i.e. firm) connection, developers are unlikely to be able to afford these high connection costs.

In order for the FPP project to demonstrate the benefits it can deliver, it is paramount that both the technical solution and commercial framework being developed are adopted by distributed generators.

The Technical Solution

In order to mitigate these network constraints the project has deployed a technical solution involving a number of smart devices in the network that are centrally and actively managed by Active Network Management (ANM) system. The technical solution is designed to cater for single or combination of constraints at a single location and is able to evolve and adapt to changes in network conditions caused by addition of new generators. The project has also demonstrated multi-vendor interoperability by implementing IEC 61850 standard over a highly flexible and resilient RF mesh communications network. This interoperable system integration approach over a flexible communications system has created smart grid architecture with enhanced network monitoring and management capability that both protects the integrity of the distribution network and maximizes the extent to which generation can be injected onto the distribution network.

The project has successfully demonstrated multi-vendor interoperability using IEC 61850 standard between the ANM application provided by Smarter Grid Solutions (SGS) and the following list of smart devices:

- Dynamic Line Rating (DLR): **Alstom Micom P341 relay**
- Automatic Voltage Controller (AVC): **Fundamentals Supertapp N+ relay**
- Upgraded Remote Terminal Unit (RTU): **GE T5500**
- Quadrature-booster Control System (QBCS): **MR Tapcon 260 relay**
- Local Generator Controller: **Brodersen RTU**

Dynamic Line Rating (DLR)

The DLR technology releases additional headroom on the overhead lines for accepting power export from DG by calculating the real time thermal rating or ampacity of power lines based on local weather measurements. The DLR relay sends the calculated ampacity figure to ANM over the FPP communications platform.

Automatic Voltage Controller (AVC)

High volumes of generation connecting onto the distribution network affect the voltage profile along the feeders, and possible unacceptable voltage rise at the point of common coupling (PCC). The project is trialing innovative approach of dynamic change in voltage control setpoint in the AVC relay triggered by ANM to address the voltage issues caused by increasing generation.

Upgraded Remote Terminal Unit (RTU)

FPP project worked with GE to develop IEC 61850 server functionality in the T5500 RTU and upgraded legacy RTUs in 12 grid and primary substations within the trial area. These RTUs provide the visibility of the network status of the trial area to ANM by transmitting substation measurements and indications.

Quadrature-booster Controller System (QBCS)

The Quadrature-booster Controller System [2] is used to control an on-load tap changer connected within a Quadrature-booster, which has been deployed to adjust the phase angle within a circuit that increases the impedance of an individual line. The QBCS manages the operation of the Quadrature-booster to carry out automatic balancing of real power flow between parallel 33kV circuits and provides the real time information to ANM for network visibility.

Local Generator Controller

The local Generator Controller at the DG substation interfaces with the central ANM system and the native control system of DG. It receives set-point signals from central ANM and issues them to the DG control system in order to manage the associated network constraints.

TECHNICAL ARCHITECTURE

In context of the above constraint scenarios a technical solution is designed to enable integration of new DGs within the trial area with an autonomous and real time management of those network constraints.
The technical solution involves the implementation of a smart grid architecture based on the three key aspects, (1) system components including smart devices and ANM, (2) open standard based system integration approach, (3) fit for purpose communications infrastructure.

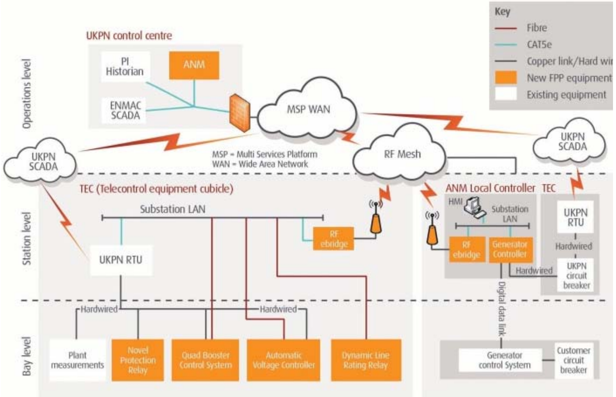

Figure 1 – Overall communications architecture

The overall communications architecture in Figure 1 describes three communications levels: operations level (control centre), station level (substation) and bay level (device). The diagram also demonstrates the integration of new FPP components depicted in orange colour with existing network components depicted in white colour.

Active Network Management

At the Operations level, the FPP project's central ANM system is installed at the UK Power Networks' Control Centre operating in parallel with existing Supervisory Control and Data Acquisition (SCADA). This approach follows the similar model to existing SCADA system with a centralised Active Network Management (ANM) system that interfaces with the SCADA system but operates independently at both functional and non-functional levels. By the virtue of this model, every design aspect ensures that no element of the FPP architecture will interfere with the existing IT and SCADA infrastructure during the FPP trial phase.
The central ANM system consists of following components

- **Communication Front End:** It performs all data handling and processing for the ANM system via a range of industry protocols
- **Application Server:** It is a modular and scalable execution environment upon which the SGS smart applications are deployed. Its platform hosts smart algorithms and schemes that are responsible for making smart decision for real time DG output management.
- **Power Flow Management Application:** It manages the power flow through chosen points on the network ensuring it remains below specific thresholds by curtailing or releasing DG power output as shown in Figure 2.

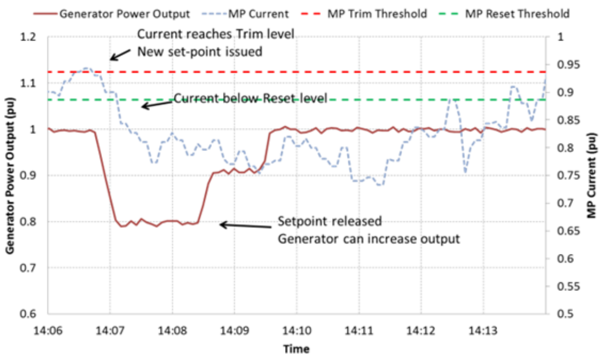

Figure 2 – Trim and release of DG

- **Voltage Management Application:** It manages voltage at chosen points on the network ensuring it remains within specific thresholds.
- **Dynamic Ratings Application):** It monitors weather and network information, and calculates ampacity ratings for entire overhead line sections in addition to DLR information for use by the Power Flow Management Application.

System Integration using IEC 61850

The IEC 61850 standard is widely used inside the electrical substation for protection scheme applications. However the project is trialing innovative approaches; (a) by using it for communication between multiple substations as well as substation to Control Centre; (b) by implementing this standard over a wireless mesh technology which has relatively lower bandwidth compared to the usual wired communication mediums such as optical fibre used for substation communication bus.
The FPP technical solution uses the following elements of IEC 61850 standard communications as defined in IEC 61850-8-1 part:

- Core Abstract Communication Server Interface (ACSI) services, which are supported via Manufacturing Message Specification **(MMS)** Protocol Suite support.
- Time synchronisation services, which are supported via **SNTP** support.

By setting a clear requirement for the conformance of each vendor solution and by undertaking a robust system integration testing process, the benefit of using the standard was realized on site with faster and simpler commissioning process. With a leading role in system integration process, UK Power Networks has developed in-house skills and learning for future projects.

Data modelling and engineering

Adopting a central management role in the architecture, ANM is designated as the IEC 61850 client to all the field devices acting as IEC 61850 servers. UK Power Networks worked closely with industry experts to execute a structured implementation of IEC 61850 standard. This involved three key stages as explained in Figure 3.

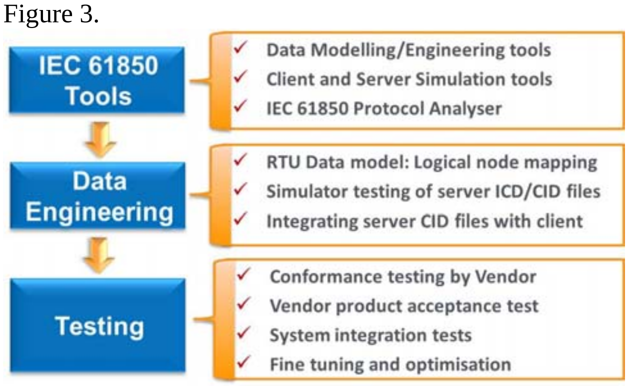

Figure 3 – FPP IEC 61850 implementation approach

As shown in Figure 3, the implementation process started with obtaining relevant testing and data engineering tools followed by data engineering process. Also all the smart devices used within the FPP solution were required to be conformance tested to facilitate the integration stage. The final step involved integrating all the configured server CID files into the ANM client application to test the end to end functionality and finalise the field commissioning of more than 20 smart devices.
One of the challenging activities was to develop a common IEC 61850 data model for existing substations.

The project did identify some gaps inside the existing Logical Nodes resulting to the use of generic nodes to map some data points (I/O). The project is now undertaking the final stage of system integration which involves integrating ANM to DG control systems using various industry protocols.

Data communications

Data communication is an integral part of the FPP solution as the FPP project concept relies on a system capable of real time interaction between its components across wide geographic area. In comparison to the widely implemented star or ring topology in power industry, the FPP project has implemented wireless mesh network topology which offers additional level of resilience and flexibility.

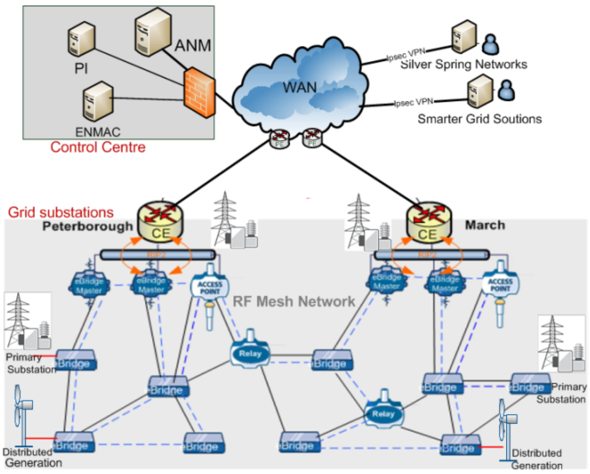

Figure 4 – FPP communications architecture

RF mesh design

The RF Mesh technology operates on sub-GHz radio spectrum, 870-876 MHz, delivering the propagation and performance levels required by the ANM system.

The RF mesh network utilises Vodafone Multi Service Platform (MSP) to connect to the central ANM network via two back-haul links as part of dual redundancy architecture. Each back-haul site has two master nodes that further increases network resilience. The RF mesh nodes including remotes and relays form a peer-to-peer mesh with each having multiple redundant routes back to a master node. This enables 'self-healing' feature so that a node can fail over to a redundant path in event of failure of a dependent node. Furthermore, dynamic routing ensures that a remote node can automatically connect to any of the master node based on the quality of the existing available link.

Remote RF mesh monitoring is done by Gridscape application using IPv6 link via the two access points. Link layer and application layer security have been implemented to mitigate any potential security threats.

In order to meet the project objectives, the FPP mesh network is installed to provide radio canopy over the 700 km^2 FPP trial area thereby, making it easy to connect any future DG customer within any section of the trial area. The connection process is further simplified by adopting a "plug and play" installation method using pre-configured RF mesh equipment.

ENHANCEMENT AND OPTIMISATION

As part of the design and testing phase the following key enhancements have been identified that have been subsequently tested and implemented.

- One second integrity polling is replaced by exception based reporting which reduces the traffic load on the RF mesh network.
- The ANM has been reconfigured to reduce the rate of generation of keep alive messages.
- Reducing the length of identifiers such as substation and IED name can decrease the size of data payload generated on each transaction

CONCLUSION

The ANM system is becoming a relatively familiar concept in the industry for its effectiveness as a centralised management system to cope with local network constraints. The scalability of such systems to cover a wider geographic area and the capability to offer a vendor agnostic platform are key characteristics demonstrated by the project. The use of the IEC 61850 has enabled the project to commission a fully functional technical platform in less than a year. The conformance requirements specified by the project and the availability of integration tools contributed to the reduction of the commissioning time for the field devices. The FPP project is also stretching the capabilities of the standard by trialing its use for network control application outside the substation and over the wireless mesh network. The capability of FPP solution will be further tested during the trial phase during the integration of the ANM with variety of Generation customer networks, each with its unique technical characteristics.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Gordon Shephard and Rick Silva from Silver Spring Networks; Richard Schimmel and Bas Mulder from DNV GL; Finlay McNicol from Smarter Grid Solutions;

REFERENCES

[1] Department of Energy and Climate Change, HM Government, 2013, "UK Renewable Energy Roadmap 2013"

[2] Gilbert Manhangwe, "Flexible Plug and Play Low Carbon Networks (FPP) – Quadrature Booster Trial at 33 kV" CIRED, paper 789