SP ENERGY NETWORKS

Flexible Networks for a Low Carbon Future

Enhanced Substation Monitoring Deployment

September 2015

Contents

1. Introduction

This document sets out the enhanced substation monitoring plan and learning outcomes for the Flexible Networks LCNF Tier 2 project. It details the considerations, approach and methodology undertaken by SP Energy Networks to implement work package 1.2 of the project for enhanced secondary substation monitoring. The main purpose of this work package was to provide detailed network data which could inform the other work packages, determine the methodology of how Flexible Network technology innovations would be deployed and enable quantification of benefits.

To date, secondary substations in the UK distribution networks (defined here as comprising transformers 11kV or 6.6kV to 400V and associated cabling and switchgear) have very basic maximum demand indicators (MDI's) that do not provide any information on the timing, duration, or frequency of the peak demand. As these require manual reading, the data is gathered infrequently. For these reasons, , it has limited use for network planning and is no use for network operations. As network planning and reinforcement decisions require a good characterisation of the network and the connected demands and profiles, a lack of good quality data means that conservative assumptions must be made to safeguard the network and customers.

This work package was to develop a metering programme led by Flexible Networks requirements and also cognisant of enduring network planning and operational needs, taking due consideration of the relatively low cost margins required by secondary distribution networks. Based on analysis of the new monitoring data, , an assessment of the value of the network information could be made for facilitating increases in network capacity. Thus, enabling greater levels of low carbon technology to be connected than is presently permissible.

2. Background considerations

The numbers of secondary substations within most DNO license areas are typically in the significant 10,000's and the majority of these are of an age within the last 40+ years. Therefore the monitoring equipment selected for Flexible Networks had to be able to be retrofitted across a wide range of substation construction types and electrical apparatus age and design. Also, as we wanted to measure the network parameters at both primary substation, secondary substations and at points on the low voltage network, the monitoring devices needed to be able to measure values across a range of voltage and power levels.

It was identified at an early stage that while the existing IT and SCADA systems that existed within SP Energy Networks could have been developed to perform the network monitoring and data capture, but that would have required extensive development work which would significantly extend the project timescales, as it would require an extensive compatible communications network to be implemented. The Flexible Networks project timeframe also spanned the tail-end of a 5 year SCADA/IT system upgrade from ENMAC to PowerOn and to have tried to integrate the Flexible Networks monitoring into the existing SCADA systemwould have been be impossible due to development workload. For this reason it was decided to deploy a separate, stand alone data communications and acquisition system for Flexible Networks.

A simple solution for the monitoring data transmission was to use mobile network communications and a 3rd party data hosting service was utilised. This enabled various types of monitoring devices and protocols to be considered with simplified but secure data access arrangements set up.

Detailed site surveys were undertaken and these highlighted several other factors that needed to be taken into account when evaluating the suitability of particular monitoring devices, as described below.

It was apparent that the space available in the proximity of the network asset to install the monitoring devices was challenging. By ensuring any device size was kept as small as possible, enabled installation at nearly all of the sites initially identified for monitoring.

Also, the proximity of exposed live equipment and the measurement connections to the monitor were specified to be of a type that did not propose any hazard to the installation staff, persons using the monitor in future or the staff carrying out normal operational work at the substation or network location.

3. Monitoring requirements

At the outset of this work package for monitoring it was essential to understand what data would be needed to support and implement the other work packages of the project including how it would be used and what format it needed to be captured in. For this project, data requirements split into four distinct areas;

a) Dynamic Ratings – Asset loading, temperature and weather data
b) Flexible Network Control – Power flows and voltages across the network
c) Energy Efficiency – Energy consumption and power flows at substations
d) Voltage Optimisation – Voltage profiles across the 11kV and LV network

From the above requirements the required data values could be derived and site surveys undertaken to determine how the measurements could be practically achieved with reasonable network coverage.

The measurement values identified for collection at various points on the network were;

- Voltage
- Current
- Temperature (of selected transformers)
- Weather information (at selected sites) including;
    - Ambient temperature
    - Wind speed and direction
    - Solar radiation

Voltage – These measurements were to be taken be at several points on the network where the data could be used to see the voltage changes/profiles when rearranging the running configuration under Flexible Network Control. The data would also be used to understand the voltages at points on the LV distributors when implementing network voltage changes, the voltage profiles created with small scale embedded generation and to ensure customers voltage was maintained within statutory limits. From the measurements the percentage total harmonic distortion and frequency were also captured. The voltage measurements were recorded at 1 minute intervals to enable sufficient granularity of information to see fluctuations in the voltage caused by embedded generation, e.g. when a cloud suddenly shades or exposes the sunshine to numbers of photovoltaic (PV) installations.

Current – This was measured at primary and secondary transformer outputs, at some supply points on 11kV circuits and individual LV distributor phases in selected secondary substations (particularly where these supplied properties with PV generation fitted). The current data informed the work package on Dynamic Rating, by capturing the load profiles of the transformers and circuit conductors to understand the load-temperature relationship of the asset. On the Flexible Network Control work package the current data enabled determination of the loading profiles across sections of the network and how we could instigate alternative running arrangements to maximise the network asset utilisation. On the Energy Efficiency work package the current data was used to understand the energy usage at some larger customer substations and the demand to specific sections of network. On the Voltage Optimisation work package the current data was to identify load changes when implementing voltage changes to the network. The current data was recorded at 10 minute intervals, as this was considered sufficiently timely enough because of the thermal inertia and the time constant of heating/cooling effects in the network assets. From the current measurements the real, reactive and apparent power and power factor were derived and recorded in the data base for easy access.

Temperature – This was measured on primary transformers to more fully understand the internal heating/cooling behaviour of transformers targeted for Dynamic Rating. To date primary transformers only have a local (analogue) indication of the transformer winding temperature, with an alarm arrangement should the temperature exceed an upper limit. The monitoring allowed remote data capture of the transformer temperature profiles and correlation with corresponding network conditions.

Weather information – Weather stations were installed at substations in the vicinity of where asset Dynamic Ratings were to be applied to understand environmental cooling effects. The solar radiation information also provides data to correlate the local PV generation output to the system loading and voltage profiles.

4. Monitoring sites identification

The trial sites had been selected at the project conception and the 3 sites were chosen on the basis of simulating the impacts of wide scale take up of additional network load caused by electric vehicles (EV), heat pumps (HP) or solar PV. Both St Andrews and Whitchurch were heavily loaded networks and therefore provided a good opportunity to create additional demand headroom in an already constrained network. In Wrexham the local council initiative of equipping several thousand of their domestic properties with solar PV installations allowed us to determine the effects and evaluate solutions to facilitate this kind of LCT take up.

St Andrews – The town of St Andrews is fed by a typical SPD primary substation with two 15/21MVA transformers. The substation then supplies the area with 10 x 11kV radial circuits feeding almost 100 secondary substations. As the plan for this trial area was to deploy Flexible Network Control on the 11kV network and split points to adjacent 11kV networks, to deploy Dynamic Rating to the feeding 33kV OHL and 33/11kV transformers and to instigate Energy Efficiency measures to local larger customers, it was necessary to capture full loading and voltage profiles across the 11kV and LV networks. This entailed installing 3phase current and voltage monitors to each 11kV feeding circuit at the St Andrews primary and the three adjacent primary substations of Cupar to the west, Leuchars to the north and Anstruther to the south. On the secondary substations 3phase current and voltage monitors were fitted to the transformers and/or LV fuse board. Monitors were not installed on the smaller sized pole mounted transformers as these only feed low level loads which could be aggregated in the network analysis. A primary transformer temperature sensor and a local weather station were installed to capture data to support the Dynamic Rating analysis and deployment.

Whitchurch – The market town of Whitchurch is fed in a SPM typical semi-rural configuration of three primary transformers at Whitchurch Grid, Liverpool road and Yockings Gate, which share the load of the town and have the ability to be interconnected subject to the individual circuit ratings. As the plan for this trial area was to deploy Flexible Network Control on the 11kV network and split points to adjacent 11kV networks, to deploy Dynamic Rating to the 33/11kV transformers and to instigate Energy Efficiency measures to local larger customers, it was necessary to capture full loading and voltage profiles across the 11kV and LV networks. This entailed installing 3phase current and voltage monitors to each 11kV feeding circuit at the three primary substations. On the secondary substations 3phase current and voltage monitors were fitted to the transformers and/or LV fuse board. Monitors were not installed on the smaller sized pole mounted transformers as these only feed low level loads which could be aggregated in the network analysis. A primary transformer temperature sensor and a local weather station were installed to capture data to support the Dynamic Rating analysis and deployment.

Wrexham - The Borough of Wrexham is divided into many small districts and villages and as the local council had housing stock spread across this large area, the properties being fitted with PV were supplied from 28 different primary and 192 secondary substations. We identified that the primary substation with the greatest concentration of PV installations supplied from it was Ruabon primary and that 80% of the properties connected to Ruabon were supplied from secondary substations fed by just three of the seven outgoing 11kV circuits. Therefore the secondary substations connected to these three circuits were targeted for monitoring. Where the specific secondary substations being monitored had PV connected to them, all phases of the fuse board outgoing distributors were monitored for current to capture where load was importing onto the LV busbars and being exported to the other LV distributors. Also as the problem PV can create is voltage rise along the LV distributors, monitoring was installed at selected points on the LV network where it was anticipated rise in the voltage would occur. A local weather station was installed to capture data to analyse the relationship between solar radiation, PV output and load/voltage changes.

5. Monitor procurement

Tender specifications were produced which set out the measurement and data capture requirements. As this was fairly new territory for DNO's, other LCNF projects which had included secondary substation monitoring were consulted to pick up any learning available.

The specifications produced were kept fairly open to enable as wide a range of offerings as possible to be considered, however certain constraints on the live environment, data capture, communications or size for example were paramount.

A question that we had in mind when procuring monitors was depending upon the cost of the monitoring equipment and the time/effort it would take to install, would we be installing low costs units that wouldn't be worthwhile removing to another site to capture the data elsewhere, because of the installation/removal costs? Or if the cost of the monitors were significantly high enough and the installation/removal costs were low, then it would make sense to acquire devices which were fairly transportable to other sites.

In the end three different devices were selected for procurement, as between them they covered the various scenarios for device measurement types and installation cost. However the balance between the costs of the devices and their installation/removal was in any case at a point where it made sense to install all three devices for a period to capture the load and voltage profiles of a particular area of network and then once that was complete to move them to another constrained site.

For example, the typical cost of a secondary substation monitor was between £1400-£2400 compared to typical installation and removal costs of approximately £200 and £100 respectively.

Embedded Monitoring Systems – Subnet (HV and LV substation monitor)

The key features of the device for which it was selected were:-

- Cost
- Wide measurement capability, e.g. HV apparatus, LV apparatus, other analogues
- Up to 12 x 3phase circuits
- Digital I/O functionality
- Communication options
- Size

Selex-ES – Gridkey (LV substation monitor)

The key features of the device for which it was selected were:-

- Cost
- Specifically designed for LV fuse boards
- Up to 5 x 3phase circuits
- Ease of installation & simple connections
- Size
- Suitability for outdoor installation – IP rating

Landis & Gyr – E650 Smartmeter (LV supply monitor)

The key features of the device for which it was selected were:-

- Low cost
- Voltage & Load measurement (trial as substation monitor)
- Communications
- “Meter like” design for customer installations

Ashridge 852plus Transformer Temperature Monitor

The key features of the device for which it was selected were:-

- Transducer output of measured temperature values
- Low cost replacement for existing Winding Temperature Indicator unit
- Simple design, size and existing approvals

Skye Weather Station with Nortech ‘Envoy’ RTU

The key features of the device for which it was selected were:-

- Low cost and small numbers required
- Simple ‘used-before’ design that staff had experience installing
- No compatibility issues for data communication protocol to iHost

6. Monitoring installations

Test case sites were trialled for installation of the different devices, to resolve any practical issues, consider safety risks and to develop an installation guide with safety method statement. Following this a small number of teams were trained on the installation and setup of the devices.

An installation program was determined and generally the installation rate was four units per day in secondary substations and approximately 1-2 days per primary substation installation.

The units were mounted in close proximity to the apparatus being monitored as this kept connection lead length to a minimum.

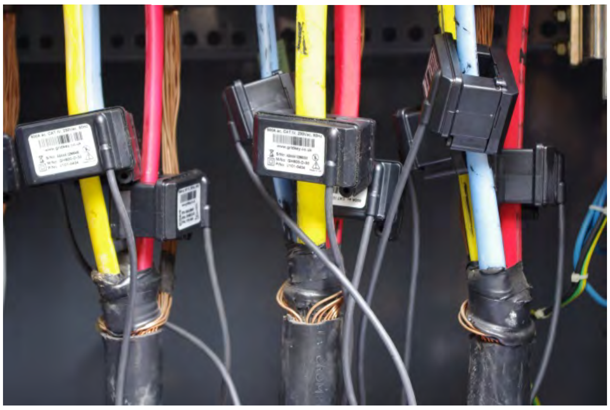
6.1. Voltage connections

On 33/11kV transformer outputs the voltage values were measured at the 11000/110V VT outputs. On secondary transformers the output voltages were measured on the 415/240V busbar connections using a specifically designed ‘Drummond’ busbar clamp. All voltage connections were fused near the connection point. The LV supply monitors were connected at the meter/cut-out terminals.

6.2. Current connections

On 33/11kV transformer outputs or HV feeders the current measurements were taken from the secondary wiring of metering or protection CTs using 5amp or 1amp clip-on interposing CTs.

On secondary transformer outputs the current measurements were taken using ‘wrap-around’ Rowgowski CTs or the Selex designed ‘Gridhound’ clip-on CT. These were fitted around separated cable cores or on sections of busbar. The design of some secondary transformer to LV board connections did not allow current transformers (CT’s) to be fitted and therefore the currents had to be measured at the fuses feeding the individual cable phases and the values aggregated to give the transformer loading.



The GPRS communications required the aerials for the units to be sited externally where the signal strength was low to improve data communication.

6.3. Transformer temperature

The 33/11kV primary transformers are currently fitted with Winding Temperature Indicators (WTI) which show the maximum temperature the transformer has reached since the indicator was last reset. These devices also operate alarms, trips and the cooling fans/pumps at pre-set temperatures. However the age of the WTI's is such that they could not provide any output for data to be captured of the operating temperature range of the transformers. Therefore replacement units were sought which provided all the existing functionality and a transducer signal output for the transformer temperature to be monitored.

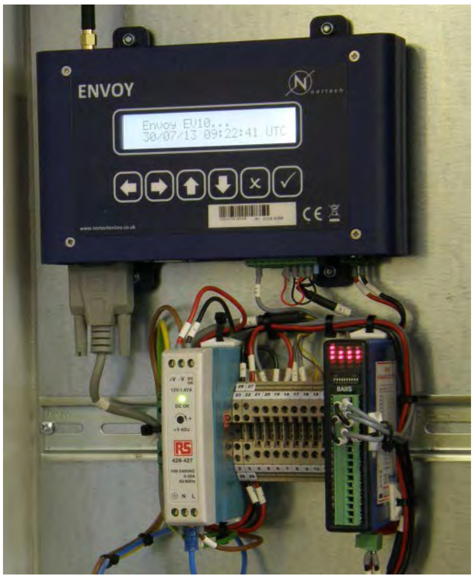
The device selected was an Ashridge 852plus for the following reasons:-

a) It had the outputs relays operate to the alarms, cooling fans/pumps and trip functions.
b) It had the transducer output at 0-10/4-20mA to provide a temperature signal input to the substation monitor.
c) It was of a suitable size to fit in place of the existing WTI unit.
d) It had a suitable IP rating for the environment where itwas to be located.
e) It had existing type 'approval' for use in SPEN (and NGC)

The 852plus is an electronic unit and using an electrical PT100 sensing probe which fitted into the existing temperature probe pocket replacing the existing WTI capilliary probe. The transducer output signal to the substation monitor was connected via a dedicated twisted pair cable.

6.4. Weather stations

Weather stations were installed at selected substations and 33kV overhead lines to enable correlation of weather data with other data parameters being recorded. As the ‘Skye’ weather station paired with an ‘Envoy’ RTU had been successfully used on a previous LCNF project, this arrangement was selected to undertake the collection of environmental data into iHost for Flexible networks.



7. Monitoring learning

Since the commissioning of the monitors, they have generally performed well in recording the data and transmitting the data to the iHost database. A few issues have been encountered, such as;

- The GPRS communications has been a bit intermittent in some weak signal areas. A signal strength meter was used to identify the best signal level position and at some sites the aerials were repositioned outside the substation enclosure.
- Some of the ‘fused lead’ voltage connections were supplied with 500mA quick-blow fuses (similar to those used in multi-meter type fused test leads), these were found to be too sensitive and would sometimes break. These were substituted for a larger size (generally 1.25A) when necessary.
- The intermittency of the data communications led to the development of a system from monitoring the data completeness being captured in the database, which is presented in the form of a report. This has helped identify trends in monitor data issues and provided a focus for problem solving.
- The detailed site surveys were critical in the identification and selection of monitors that would be easy to install and connect to the existing network apparatus.
- The selection of a number of monitors meant that we could deploy the most suitable monitor for a given installation scenario and also spread the risk that for any specific

monitor or component failure then the entire population of monitors would not be jeopardised.

- A visit was made by the technical team to the selected device manufacturers. This was invaluable for all concerned, for the user to fully understand the manufacture and assembly processes and for the suppliers to fully understand the user requirements and intended use methodologies. This also built up a co-operative working relationship between the suppliers and the end users and enabled the units to be configured and tested as much as possible prior to dispatch for installation.
- It was communicated with the manufacturer that the quality checks of the GPRS SIM card installation (where embedded inside the IP65 factory sealed unit) were critical, given that some of these units were being installed at height on the overhead line pole mounted transformers. The consequences of a poor SIM card connection would have meant the unit being taken down, returned to the factory and reinstalled at substantial cost.
- Undertaking test-case installations enabled a fully assessed installation guide and safety method statement to be produced prior to the training of the teams and commencement of the installation program.
- Having the iHost database installed and commissioned ready to receive data as each monitor was installed meant that immediate configuration and testing of data being captured could be carried out without any site revisits.
- When installing the first transformer temperature monitor, to avoid the excavation of a new cable, from the transformer compound to the substation control room, some spare cores of a multicore cable were utilised. However this caused some distortion to the low level signal across the distance it had to transmit, which caused error in the values. This was corrected by installing a dedicated twisted pair cable from the unit back to the substation monitor receiving the signal.

8. Future Monitoring

From the data recorded on this project it was learnt that the majority of the useful information came from the secondary transformer loading profiles. Whilst there is additional benefit from information of the individual circuit/phasing load profiles, the additional costs of measuring, recording, communicating and storing of this data may not always provide the same level of benefit.

Therefore we believe that a low-cost replacement for the existing MDI's which is permanently fitted with a captured-data communication function would probably give a greater cost/benefit. Should there be less predictable loads or generation which may give rise to the need for more detailed data information, then a more expensive monitor could be fitted to measure all the circuit phase loads as necessary.