SP ENERGY NETWORKS

Flexible Networks for a Low Carbon Future

Future Network Monitoring Strategy

September 2015

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Contents

Executive summary 2

Glossary 3

1 Introduction 4

2 Fundamental principles of monitoring 5

2.1 LCT monitoring strategy 5
2.2 Monitoring the HV Network 6
2.2.1 Primary substations 7
2.2.2 Primary transformers 7
2.2.3 33Kv overhead line circuits 8
2.2.4 Solar irradiance monitoring 8
2.2.5 HV circuits 9
2.3 Monitoring the LV Network 9
2.3.1 Secondary substations 9
2.3.2 Secondary substation monitoring specifications 11
2.3.3 LV feeders 11

3 Future monitoring rollout 12

3.1 Primary substations 12
3.1.1 Retrospective to existing primary substations 12
3.1.2 New primary substations 12
3.2 Secondary substations 12
3.2.1 Retrospective to existing secondary substations 12
3.2.2 New secondary substations 12
3.2.3 Redeployment 12
3.2.4 LV feeders 12

4 Tipping point for monitoring 13

4.1 HV Network 13
4.1.1 Primary substations 13
4.1.2 Primary transformers 13
4.1.3 33Kv overhead line circuits 13
4.1.4 HV circuits 13
4.2 LV Network 14
4.2.1 Secondary substations and LV feeders 14
4.2.2 Weather stations 15

5 Process for design staff 16

5.1 HV Network 16
5.1.1 Primary substation 16
5.1.2 Smart solutions 16
5.2 LV Network 16
5.2.1 Secondary substation 16

Executive Summary

Detailed primary and secondary network monitoring was undertaken for Flexible Networks to support analysis of the feasibility and performance of innovative techniques. Network information derived from the monitoring has provided the appropriate level of verification to enable integration into business as usual. Monitoring has also facilitated an improved understanding of network behaviour across voltage levels under a range of conditions. This has informed the development of recommendations for policy and practice including associated software tools to enhance our approach to network planning and operations in future. This ultimately improves our response to the future uptake of low carbon technology which will likely be clustered both geographically and temporally in terms of identifying loading hot-spots and deploying a suitable techno-economic solution.

A future low carbon technology (LCT) network monitoring strategy was developed as part of the RIIO-ED1 SPEN business plan. This includes early learning outcomes from Flexible Networks however, now it is possible to incorporate learning from all Flexible Networks activities. This future monitoring strategy builds on the existing LCT network monitoring strategy and widens application to both the HV and LV network, including proposed monitoring specifications. Elements considered included cost and anticipated network coverage.

The future monitoring strategy is as follows:

- Install "smart" MDIs instead of conventional MDIs in new secondary substations and replacement LV switchboards,
- Install "smart" MDIs in secondary substations at key locations across the LV network identified through application of the SPEN Network LCT Monitoring Strategy,
- Install secondary substation monitors with more detailed functionality e.g. monitoring of all LV distributors and phases at locations of high LCT clustering and network constraints as identified through application of the SPEN Network LCT Monitoring Strategy.

Smart meter data available in large volumes from around 2018 will complement the future monitoring strategy.

Based on our analysis, it is recommended that LV network monitoring is triggered by the following criteria;

- For existing secondary substations that are exceeding 90% of capacity based on the current MDI reading (smart MDI),
- Highly constrained network areas equivalent to approximately 0.75% of the SPEN LV network (detailed network monitoring).
- For other areas of the LV network not included in the above that are identified as undergoing rapid uptake of LCTs (smart MDI).
- LV feeder monitoring will be deployed to remote ends where network voltage reduction (optimisation) is applied.

Glossary

BAU	Business-As-Usual
DNO	Distribution Network Operator
HV	High Voltage
LCT	Low Carbon Technology
LCNF	Low Carbon Network Fund
LV	Low Voltage
MDI	Maximum Demand Indicator monitoring device
NOJA	Medium voltage auto-recloser switchgear
NMS	Network Management System
PV	Photovoltaics
RIIO-ED1	Revenue = Incentives + Innovation + Outputs – Electricity Distribution
RTTR	Real Time Thermal Ratings
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition (communications and control equipment)
SPD	SP Distribution (network license area)
SPEN	SP Energy Networks (network operating company)
SPM	SP Manweb (network license area)

1 Introduction

In the future, as low carbon technologies become more prevalent across distribution networks, more sophisticated network monitoring will be required to improve visibility of rapid embedded generation and load increases. To an extent, this will be provided by customer smart meters once a viable level of coverage is achieved towards the middle of ED1. However, the mechanism for this is still to be tested and there will be a cycle of learning and improvement that must take place to use smart meter information effectively.

This will be complemented by monitoring of key DNO plant to understand network (and customer) behaviour and response in both real-time and/or over longer term periods for network planning.

A number of smart network solutions being trialled and adopted by DNOs also require some monitoring and control functionality, for example;

- Voltage management
  - On-line transformer voltage relay tapping at primary and secondary level
  - HV and LV capacitors
  - Automatic voltage regulators (AVR)
- Network automation and flexible network control
- Dynamic or enhanced thermal asset ratings
- Energy storage
- Demand side response
- Embedded generation constraint

Monitoring may form part of an open loop or closed loop control feedback.

2 Future Monitoring Strategy

2.1 LCT Monitoring Strategy

As part of development of the RIIO-ED1 SPEN business plan, a future low carbon technology (LCT) network monitoring strategy was developed[1] to achieve the following aims;

- Enable early identification of LCT growth hot spots on the HV and LV networks
- Provide a robust framework with which to identify areas of the LV network that require monitoring to better understand the impact of LCT growth
- Provide guidance on available network capacity and appropriate response to areas impacted by LCT growth, from analysis of LV monitoring data

The strategy also addressed the required level of deployment of monitoring on the LV network to better understand LV feeder loading characteristics and trends due to LCT uptake and to optimise selection and deployment of network solutions. This was informed by early learning outcomes from analysis of LV network monitoring data collected as part of the Flexible Networks project.

Application of the LCT monitoring strategy will significantly improve quality and security of supply through early identification of network areas approaching thermal or voltage limits.

The future network monitoring strategy presented here builds on this strategy and widens application to both the HV and LV network.

[1] *SPEN, RIIO-ED1 LCT Network Monitoring Strategy, 2014. http://www.spenergynetworks.co.uk/pages/distribution_business_plan_supporting_annexes*

2.2 Monitoring the HV Network

A cascade network monitoring approach is being used at the three network trial sites with monitoring from the grid infeed down through the voltage levels of network to the LV system where customer's supplies are taken from. This is illustrated in Figure 1.

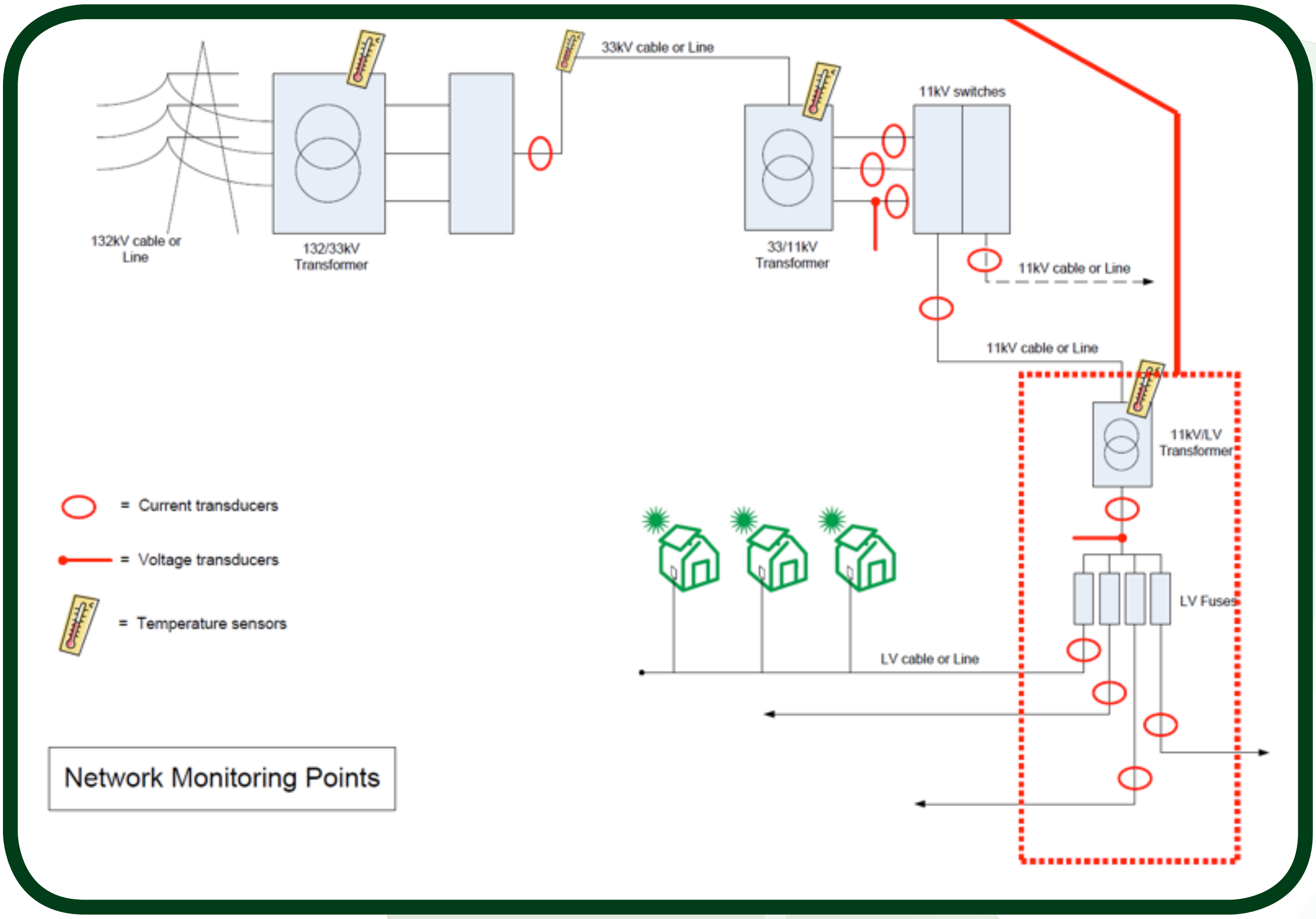

Figure 2-1 Flexible Networks monitoring points

The HV network is monitored on the 11kV busbars of the primary substation transformers and along the HV feeders at existing or future network control points (NOJA).

2.2.1 Primary Substations

Table 2-1 below itemises the future monitoring specifications for primary substations approaching demand or generation capacity due to underlying demand growth, large numbers of generation connections at HV and/or the connection of high amounts of LCT on the LV network. This level of data resolution is appropriate to understand the characteristics of the HV network with increasing LCT and to enable the implementation of smart solutions such as enhanced transformer thermal ratings, flexible network control, AVRs and wider network voltage management. HV phase imbalance was found to be comparatively negligible so individual phase monitoring is not specified.

The characteristics of voltage measurement sampling was analysed to evaluate the degree of loss of accuracy as the sampling and/or averaging period increased. It was found that a 10 minute voltage snapshot provided a similar resolution to a 5 minute voltage snapshot however a 10 minute average indicated a material loss of accuracy.

Table 2-1 Future monitoring specifications for primary substations

Variable	Resolution
RMS three-phase voltage	10 min snapshot
RMS three-phase current	10 min average
Power factor (per measured current)	10 min average

2.2.2 Primary Transformers

Where enhanced thermal ratings are applied, a top-oil temperature measurement device will be installed to record 10 minute average temperature, based on specifications developed as part of Flexible Networks. This also calculates the hot-spot winding temperature based on real-time transformer loading. Data acquisition will be through the network management system.

This measurement sampling is appropriate given the thermal inertia of primary transformers.

2.2.3 33kV Overhead Line Circuits

Where real time thermal ratings (RTTR) are to be implemented on 33kV overhead lines due to high amounts of wind generation connecting, weather monitors recording wind speed and direction, ambient temperature and solar radiation measurements will be installed at several key locations along the circuits. It is important to identify and monitor micro-climate regions along an overhead line as it is more likely that network thermal pinch points are in these regions. This will enable an improved characterisation of potential capacity release and management of risk. Monitoring specifications are given in Table 2-2. These provide inputs for a validated state estimation model to enable cost-effective calculation of the thermal loading conditions on all spans.

A graceful degradation algorithm has been developed for Flexible Networks. This can be deployed and adjusted for different circuits and different number of weather stations. As measurement availability reduces, the overhead line rating approaches the standard seasonal rating.

The weather monitoring can be redeployed on other overhead line circuits when the monitoring programme is complete due to reinforcement for example. However there will additional costs for installation at the new site.

Conductor temperature sensors are included in future monitoring specifications as this can enhance the RTTR system through deployment at limited number of wind shielded locations.

Table 2-2 Future monitoring specifications for 33kV OHL real time ratings

Variable	Resolution
Ambient temperature	5 min maximum, minimum, average
Solar irradiance	5 min maximum, minimum, average
Wind speed	5 min maximum, minimum, average
Wind direction	5 min maximum, minimum, average
Conductor temperature (optional)	5 min maximum, minimum, average

2.2.4 Solar Irradiance Monitoring

Solar irradiance measurements are very useful for the assessment of embedded PV generation and identification of available generation capacity headroom.

A low cost solar irradiance monitor will be installed at strategic primary substation locations in the SPM and SPD licence areas. Data communication facilities are not required as data can be collected during routine substation inspections which will reduce cost. Monitor specifications are given in Table 2-3.

Table 2-3 Solar irradiance monitor

Variable	Resolution
Solar irradiance	5 min average, maximum

2.2.5 HV Circuits

There are a number of existing NOJA control devices located along HV circuits in the SPEN network. NOJAs record data by exception rather than at fixed intervals, when a measured value departs from a deadband around the previously recorded value. As a protection-focussed device, NOJAs tend to respond most strongly to faults and fault-like events and thus deadbands are relatively large. Therefore, only limited loading data can be extracted from NOJA devices.

New generation automation equipment was installed at a number of sites in the St Andrews HV network following development of a functional specification and procurement. Real-time load and voltage measurements will be available from these devices. The next generation of equipment has been developed to allow integration with a future substation RTU being specified by SPEN which will act as a communications gateway to the SCADA system.

2.3 Monitoring the LV Network

2.3.1 Secondary Substations

Application of the RIIO-ED1 LCT Network Monitoring Strategy will identify areas of rapid LCT clustering corresponding to LV network constraints and thus candidate areas for network monitoring. The original SPEN RIIO-ED1 business plan includes for a total volume of about 1435 secondary substation monitors within the SPM and SPD licence areas at an approximate cost of £3000 per monitor. These monitors would typically be installed in ground-mounted secondary substations and larger capacity (100-200kVA) pole-mounted secondary substations. For this cost, it is possible to monitor all individual LV distributor phases and busbar phases. This equates to about 5% of the total SPEN population of ground mounted secondary transformers.

Detailed analysis as part of Flexible Networks assessed the benefits to be gained from monitoring of individual LV distributor phases in detail. This included identification of significant asset constraints, phase imbalance and clustering of embedded generation and is described below.

2.3.1.1 LV Phase Imbalance

LV phase imbalance was found to be significant, with 165 LV feeders having some material phase imbalance for the 100 highest loading points, out of the 233 LV feeders assessed. A total of 9% of LV feeders monitored were identified as suitable for rebalancing, with the potential to release more than 20% capacity headroom for these feeders and high enough peak load (>100A) to make it worthwhile rebalancing. However, the cost of the necessary cable re-jointing would make this an unviable option in the majority of cases. This could change if the cost of re-jointing can be reduced in the future. LV feeders with a mixture of residential, industrial and commercial loads and rural LV feeders were generally more likely to be unbalanced than residential feeders. The uptake of LCT such as heat pumps and electric vehicles will act to exacerbate any existing phase imbalance so these should be the areas of focus.

Existing secondary substation MDI data was found to not provide a reliable indication of LV feeder phase imbalance. It is recommended that areas of the network with rapid LCT clustering and close to capacity are monitored in detail e.g. individual LV distributor phases for secondary substations. However, the cost of detailed proactive monitoring more widely for LV phase imbalance is not justified compared to the business as usual approach of monitoring reactively following a blown fuse or customer complaint.

2.3.1.2 Characterisation of PV on the LV Network

A simple methodology has been developed for assessing PV generation hosting capacity of LV feeders using measured peak solar irradiance and a generic customer summer demand profile. This was verified using detailed power system modelling and comparison with measurements for the Ruabon LV network with a high clustering of PV. Characterisation of the impact of PV clustering was improved and informs when to deploy detailed monitoring at secondary substations and along LV feeders based on PV connection volumes. In some cases, it may be possible to apply a reduced voltage setting at the primary substation to facilitate much greater generation capacity release. Monitoring or remote LV feeder ends would then be required to track and verify network performance under a range of loading conditions.

It is recommended that only areas of the network with significant PV clustering are monitored in detail proactively. Monitoring at the secondary substation level should be suitable for wider deployment across the network.

2.3.1.3 Future Monitoring Strategy Refinement

Existing Maximum Demand Indicators (MDIs) record the phase current in Amps from current transducers on the transformer LV side only when the previous recorded value is exceeded. A low-cost replacement for the existing MDI's which monitors the current of the secondary transformer and the busbar voltage, which also has a captured-data communication function (a "smart" MDI), would provide significantly greater resolution of monitoring data at secondary substation level. It would also allow a higher volume of monitoring to be deployed across the network compared to the detailed secondary substation monitoring investigated as part of Flexible Networks and incorporated in the RIIO-ED1 LCT Network Monitoring Strategy.

In terms of network knowledge, a "smart" MDI could provide an indication of low loading patterns during summer days due to embedded generation uptake. Thus, the potential for reverse power flow on secondary transformers and LV feeder voltage rise sensitivity could be monitored. Changing network characteristics due to demand LCT clustering that could potentially lead to thermal overloading could also be detected through such data analysis. It would not be possible to analyse embedded generation influence and phase imbalance on the individual LV feeder level however detailed monitoring could be deployed to facilitate this for high LCT clustering.

Upon review, it was felt that the additional cost of measuring, recording, communicating and storing of data for detailed secondary substation monitoring did not provide the same level of benefit on a wider scale network rollout compared to a "smart" MDI. This leads to the following future monitoring strategy:

- Install "smart" MDIs instead of conventional MDIs in new secondary substations and replacement LV switchboards,
- Install "smart" MDIs in secondary substations at key locations across the LV network identified through application of the SPEN Network LCT Monitoring Strategy,
- Install secondary substation monitors with more detailed functionality e.g. monitoring of all LV distributors and phases at locations of high LCT clustering and network constraints as identified through application of the SPEN Network LCT Monitoring Strategy. This detailed monitoring data would be analysed to further improve characterisation of the LV network and provide verification of modelling tools.

Detailed LV distributor monitoring can be redeployed to other sites, following network reinforcement which helps to reduce costs. The main cost of the detailed monitoring is the monitoring equipment itself rather than the installation cost.

2.3.2 Secondary Substation Monitoring Specifications

It is recommended that the smart MDI have the following specifications as shown in Table 2 4.

Table 2-4 Recommended future monitoring specifications for secondary substations – Smart MDI

Variable	Resolution
RMS phase voltage	10 min snapshot
RMS phase current on HV incomer	10 min average
Power factor, per measured current	10 min average

Where detailed monitoring is installed, it will be based on the following design specifications given in Table 2-5.

Table 2-5 Future monitoring specifications for secondary substations – detailed monitoring

Variable	Resolution
RMS phase voltage	10 min snapshot
RMS phase current on LV tails	10 min average
Power factor (of each phase), per measured current	10 min average

2.3.3 LV Feeders

Data from smart meters will start to be available in larger volumes from around 2018 and this will complement the secondary substation monitoring programme. In particular, valuable data such as voltage rise and drop along LV feeders will become available to further verify LV network modelling tools and provide guidance on network capacity and behaviour, reducing the need for LV network monitoring.

However, it is likely that network voltage reduction (optimisation) will be deployed to a number of network areas to manage embedded PV generation uptake before smart meter data provides sufficient coverage and is integrated fully into business processes.

Some form of remote end monitoring will be required for LV feeders to monitor and verify the performance of the LV network at a reduced nominal network voltage. It is anticipated that this monitoring will be similar to that deployed for Flexible Networks.

3 Future Monitoring Rollout

3.1 Primary Substations

3.1.1 Retrospective to Existing Primary Substations

Monitoring can be easily retrofitted to existing primary substations as shown through Flexible Networks. A deployment methodology has been developed to guide this[2]. At least one year's worth of monitoring data should be available to inform the evaluation of network reinforcement solutions by network planners.

Primary substation monitoring data will be available through the NMS in real-time.

3.1.2 New Primary Substations

For all new primary substations, the monitoring specifications in Section 2.2.1 will be deployed to improve a general understanding of network behaviour and enable future assessment of smart solutions for constrained networks.

3.2 Secondary Substations

3.2.1 Retrospective to Existing Secondary Substations

For existing secondary substations identified as being LCT hotspots, as per the SPEN Network LCT Monitoring Strategy, a smart MDI will be fitted. A device specific installation methodology will be needed to support this but it will be broadly based on the Flexible Networks secondary substation monitoring installation methodology.

For limited numbers of secondary substations, detailed monitoring of individual LV distributor and distributor phase currents will be undertaken using the Flexible Networks secondary substation monitoring installation methodology.

Monitoring data will be acquired through a communications network into a data acquisition system where it will be accessible for viewing and analysis. The specifications of an enduring data acquisition system and the level of integration to the existing SCADA system are still to be finalised.

3.2.2 New Secondary Substations

Smart MDIs will be fitted to all new secondary substations and replacement LV switchboards.

3.2.3 Redeployment

The detailed LV distributor monitoring devices can be redeployed to other LV network locations at a later date once network reinforcements have taken place and there is no longer the need for the detailed level of data capture. If a smart solution is deployed, monitoring may need to remain in place to evaluate the incremental performance improvements of the network and provide data input as part of an open or closed smart solution control loop.

3.2.4 LV Feeders

Monitoring will be deployed for LV feeder remote ends in strategic locations where network voltage reduction (optimisation) is applied.

[2] *SPEN, Flexible Networks LCNF Project Work Package 1.2 Enhanced Substation Monitoring Deployment, September 2015.*

4 Tipping Point for Monitoring

4.1 HV Network

4.1.1 Primary Substations

An annual network review of primary substation loading is carried out to identify areas in which new connections might be expected or that are approaching capacity that may require reinforcement or additional infrastructure investment in the event of demand growth. SPEN current practice is to apply a base general, licensee area wide demand growth assumption that is refined in specific demand groups where there is local intelligence on future connections activity.

Primary substations identified as being close to capacity are examined in greater detail. Maximum demands for a number of previous years are analysed along with information on any new connections to determine trends in demand change which are then extrapolated forward to estimate the demand forecast for future years. As part of Flexible Networks, an enhanced load forecasting and risk characterisation tool has been developed to more accurately forecast future network group load growth trends.

In terms of determining when to deploy detailed monitoring of the specification in Table 2-1 to existing primary substations, this will be triggered once the primary substation/group is identified as being close to capacity during annual network review. The monitoring will then remain for the asset lifetime.

It may also be necessary to install detailed monitoring at other interconnecting primary substations where flexible network control schemes are being considered to enable redistribution of load during times of high demand.

Where there are high levels of embedded PV uptake within a primary network group, detailed network monitoring will also be deployed to enable consideration of potential smart solutions such as voltage management/ reduction or active network management techniques.

4.1.2 Primary Transformers

Top-oil temperature monitoring will be installed on primary transformers where primary groups are identified as approaching capacity during annual review and the transformers are identified as suitable for enhanced thermal ratings. Suitability will be evaluated through the methodology developed as part of Flexible Networks[3], this approach is being integrated into business-as-usual.

4.1.3 33kV Overhead Line Circuits

To facilitate deployment of a 33kV OHL real time thermal rating scheme, weather monitoring will be installed at a number of identified microclimate locations along the circuits.

4.1.4 HV Circuits

New generation automation equipment with improved network monitoring capabilities will be installed across the HV network to supplement or replace existing automation equipment where required and/or to facilitate flexible network control schemes. This will also be assessed in part for the ongoing RIIO-ED1 Protective Equipment and Supporting Systems Strategy.

[3] *SPEN, Flexible Networks Methodology and Learning Report Work package Work package 2.1: Dynamic thermal rating of assets – Primary Transformers, September 2015.*

4.2 LV Network

4.2.1 Secondary Substations and LV Feeders

There are a total of approximately 85,400 secondary substations in the SPM and SPD licence areas. Analysis of MDI measurements for a representative number of secondary substations found that up to 17.5% were above 85% of their rated capacity and 5% above 90% of capacity. It is noted that this could be for very brief periods during winter or during network meshing or backfeeding. However, MDI measurements do not allow this to be explored in any further detail. The deployment of "smart" MDIs which are expected to cost in the order of £400 will enable monitoring of about 7.5% of all secondary substations compared to 2% with more detailed monitoring.

LV feeder monitors will be required in strategic locations towards remote ends when network voltage reduction is deployed and are expected to cost approximately £250 each. It is anticipated that these will be deployed on approximately 500 LV feeders (corresponding to 150 – 200 secondary substations and 10 – 20 primary substations).

Therefore, it is recommended that secondary substation and LV feeder monitoring is deployed in the following manner;

- For existing secondary substations that are exceeding 90% of capacity based on the current MDI reading. This will enable more detailed investigation of the annual load duration curve and loading behaviour to inform reinforcement strategy.
- Approximately 0.75% of the SPEN LV network will be instrumented with detailed network monitoring to respond efficiently to highly constrained network areas and provide ongoing learning on LCT impact and customer type and behaviour.
- Additional "smart" MDI monitoring will be deployed to areas of the LV network that are identified as undergoing rapid uptake of LCTs (both demand and generation).
- LV feeder monitoring will be deployed to remote ends where voltage reduction is applied.

4.2.1 Secondary Substations and LV Feeders [continued]

Capital costs are presented in Table 4-1 for the future monitoring strategy. Compared to the original RIIO-ED1 LCT network monitoring strategy with a capital cost of £4.3M (1435 monitors at £3000 each), this provides a cost saving of 10% along with significantly greater volumes of monitoring on the LV network. Identification of LV networks approaching capacity and requiring reinforcement in future will be more proactive and effective in terms of responding to future LCT uptake.

Table 4-1 Future monitoring deployment and capital costs for secondary substations

Variable	Trigger	Smart MDI volumes	Detailed monitoring	LV Feeder Monitors	Capital cost
Detailed secondary substation monitoring	Highly constrained network areas		640 (~0.75% of LV network)		£1.92M
Existing secondary substations	>90% of capacity	3,850			£1.50M
Secondary substations across the LV network	Rapid uptake of LCTs	850 (further 1% of LV network)			£0.34M
Monitoring along LV feeders	Application of voltage management			500	£0.13M
Total		5,775	640	500	£3.9M

Learning outcomes from Electricity North West Smart Street suggest monitoring an LV feeder once the number of PV installations reaches 20. Flexible Networks found that triggering deployment of detailed monitoring when embedded PV generation approaches 800W per customer is a pragmatic metric. This will be further refined as greater resolution of LV network behaviour for various network types becomes available.

A standardised pole-mounted secondary substation monitoring design is not yet available but it is envisaged that it will become available during RIIO-ED1 and would be deployed to selected substations as part of the strategy above.

HV networks where flexible network control is being considered to provide some incremental capacity will also benefit from the strategic deployment of secondary substation smart MDI monitoring particularly towards the ends of feeders. These schemes are not being considered in large numbers for RIIO-ED1 in SPM and SPD so would not make up a large proportion of proposed secondary substation monitoring.

4.2.2 Weather Stations

Deployment of local weather monitoring to a few strategic regional primary substations will support understanding and confidence when assessing the feasibility of applying enhanced thermal rating of primary transformers. They will also enable an improved characterisation of seasonal solar irradiance profiles across SPEN network areas. This will inform the future response to forecast PV uptake increase.

5 Process for Design Staff

5.1 HV Network

5.1.1 Primary Substation

The new monitoring specification will form part of the procurement package for new primary substations, replacing the existing specification.

A new primary substation monitoring policy will be developed and once the primary substation/group is identified as being close to capacity during annual network review, the policy will stipulate the deployment of detailed monitoring.

5.1.2 Smart Solutions

Where enhanced transformer thermal ratings, overhead line real time thermal ratings, flexible network control etc are to be evaluated as potential network solutions to provide incremental capacity, any additional monitoring specifications will be defined for evaluation of each solution in the Design Policy.

5.2 LV Network

5.2.1 Secondary Substation

Automatic monthly reports comparing current capacity installed with RIIO-ED1 scenarios, and identifying secondary substations approaching defined metrics for embedded PV generation uptake and uptake of electric vehicles and heat pumps will be issued as per the RIIO-ED1 LCT Network Monitoring Strategy1. The defined metrics will then trigger the installation of smart MDI or more detailed monitoring depending on the substation characteristics as part of the LV network planning practice. Existing secondary substations that are exceeding 90% of capacity based on the current MDI reading will also trigger the installation of a smart MDI.

LV feeder monitoring in strategic locations will be triggered by the deployment of a network voltage reduction scheme.

More detailed monitoring will be required for problematic network areas with very rapidly increasing load/generation and existing issues and/or where smart solutions are planned for deployment (temporary meshing, switched capacitors, demand side response).

A number of LV monitoring data analysis methodologies have been developed as part of Flexible Networks and these are being integrated into SPEN network planning policy and practice. This will enable rapid calculation of key network metrics and characteristics.

The new monitoring specifications for secondary substations will also form part of the procurement package for new secondary substations, replacing the existing specification.