

Flexible Networks for a Low Carbon Future



**Recommendations
for Planning Policy
and Practice**

September 2015

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Executive Summary

Increasing amounts of low carbon technology including PV, electric vehicles, heat pumps and energy storage are likely to connect to the distribution network in the near future along with the growth of demand side response and generation ancillary services. Scottish Power Energy Networks (SPEN) is developing strategies for a more techno-economic response to load growth through the application of innovative techniques. This includes updating network planning and operations policy and codes of practice to enable these techniques to be suitably designed, deployed, operated and managed. Incorporation of innovative techniques into business as usual is being considered on a wider level to ensure integration into business functions from connections and network planning to procurement, operation and asset management.

This paper provides practical recommendations for enhancements and considerations for network planning policy and practice to help facilitate integration of the innovations being trialled within SPEN's "Flexible Networks" network innovation project into business-as-usual (BAU). These include the following;

- Use of enhanced seasonal ratings for primary transformers in network groups approaching firm capacity consistent with an appropriate level of risk.
- Use of real-time thermal ratings (RTTR) for 33kV overhead lines to enable increased wind generation connection with minimal additional risk.
- Flexible network control (FNC) to switch load automatically to other HV network groups when high loading approaches the firm capacity of the network group to enable additional demand growth or connections beyond the existing firm capacity.
- Strategies for distribution network voltage control through several innovative approaches;
 - Customised voltage management at primary substation transformers through seasonal tap settings to meet high load conditions in winter and increased embedded generation activity in summer, or through line drop compensation techniques.
 - The deployment of an automatic voltage regulator (AVR) to facilitate flexible network control schemes, where load transfer to long interconnectors is constrained due to voltage issues.
- Identification and deployment of cost-effective energy efficiency solutions in collaboration with customers, particularly industrial and commercial customers, to also achieve reductions in peak demand.
- Improved network monitoring to develop a holistic approach to network information gathering that is optimised for network planning and operations needs, including facilitation of feasibility and operation of innovative techniques.

Recommendations for network planning policy and practice

These new techniques are part of the set of possible reinforcement options available to the network planning engineer. However, assessment of suitability, capacity release and cost benefit followed by deployment may require a new approach and/or inputs. Thus, new planning methodologies are needed to identify and evaluate smart solutions.

Deployment of the technologies also has implications for existing policy on voltage, asset ratings and load index for example. Network policy should be revised to facilitate application of smart solutions.

Dynamic thermal ratings

Asset ratings policy should allow the use of enhanced thermal ratings for primary transformers in suitable network constrained cases. Enhanced thermal ratings should be calculated following a defined process, as developed for Flexible Networks. The new seasonal enhanced transformer ratings will then be utilised in annual network review, network connections, outage planning and calculation of load index for the specific network group where they are applied.

Asset ratings policy should also allow the use of real-time thermal ratings (RTTR) for 33kV circuits in suitable network constrained cases, managed through deployment of a well validated system in the control room. Seasonal variation of the circuit RTTR should be considered alongside loading to evaluate whether capacity is available when required.

Asset ratings policy should allow the use of dynamic thermal ratings in suitable network constrained cases

If demand side response and/or energy storage were available as a backup to circuit RTTR then the approach to calculating circuit ratings should be reconsidered however detailed consideration of this is beyond the scope of the Flexible Networks techniques trialled. It is recommended to conduct a fresh review on the assumptions made in ER P27 considering the lessons learnt from this project and other LCNF projects. We suggest that an ENA working group be set up to agree common requirements for the future wider implementation of dynamic line rating in BAU across DNO's.

Flexible network control

Load transfer through interconnections with other neighbouring HV groups is already carried out to an extent by network control engineers during post-fault restoration. However, it has not previously been applied in a planning, pre-fault context to release network capacity headroom and defer network reinforcement or in an operational context (dynamically) through the introduction of telecontrol functionality.

A detailed methodology and application guide was developed for flexible network control as part of Flexible Networks. Network reconfiguration scheme policies should be determined in advance, but periodically revised to reflect forecast network conditions which will affect the amount and duration of load transfer likely to be required and impact on reliability metrics. The review process should specifically address the long-term adequacy of each Flexible Network Control scheme.

Demand transfer should be considered when calculating load indices. Transfer Capability and Transfer Capacity are defined in ER P2/6 for calculating network capacity. However, the usage of "network capacity" and "maximum demand" should be consistent with load transfer based network control schemes applied and reflected in policy and network planning practice.

The usage of "network capacity" and "maximum demand" should be consistent with load transfer based network control schemes applied

Automatic voltage regulators

A planning methodology was developed as part of Flexible Networks to assess the capability of an AVR to mitigate voltage drop experienced as a result of load transfer based network control and/or automation. SPEN voltage policy specifically addresses the use of AVRs including design principles covering design and operation (including remote indications and control), mainly as a result of Flexible Networks business-as-usual integration activities.

Voltage policy should specifically address the use of AVRs including design principles covering design and operation

Learning from Flexible Networks led to recommendations for voltage policy to be amended in relation to the deployment of multiple regulators, rating and fault level capability. Policy and appropriate design guidelines for use of AVRs to facilitate renewable generation is still under discussion.

Energy efficiency

DNOs have a role to play and can benefit from facilitating the rollout of energy efficiency measures in cooperation with energy suppliers. However, the approach used for Flexible Networks will not be rolled out further due to limited capacity gain. Energy efficiency is likely to be driven in future through regulation and/or by a third party e.g. energy suppliers, on behalf of the DNO.

An intervention hierarchy was developed for Flexible Networks that provides direction for targeting specific energy efficiency works that offer best and most cost effective network benefit. This could be used to inform the development of a DNO or Ofgem customer energy efficiency incentive scheme.

Voltage optimisation

Voltage optimisation has not been used on a large-scale in the UK on the distribution network. For demand response, outcomes from Flexible Networks suggest that in the absence of local knowledge of experimental results, a reduction of 1% in active power demand in response to a 1% voltage reduction is a reasonable estimate. It is recommended that network loads are modelled on a constant current basis, except where knowledge of particular load behaviour dictates otherwise. Consistent with this, asset ratings in network models should be defined in Amps.

Recommendations for voltage policy comprise;

- A target voltage reduction across SPD, reducing voltage set point from 11.2kV to 11.1kV to facilitate increased generation connections,
- A further 1%-2% seasonal voltage reduction on specific SPEN primary networks if required, in case of higher distributed generation uptake, or,
- Alternatively, use of load drop compensation on primary transformer tap change control to facilitate increased PV connections.

Voltage policy should allow a further 1%-2% seasonal voltage reduction on specific primary networks to facilitate higher distributed generation uptake

A number of industry projects and task groups are assessing the technical and commercial implications of widening the statutory voltage limits. We are happy to share relevant learning from Flexible Networks with these projects.

Network monitoring

An enhanced load forecasting and risk characterisation tool was developed based on existing network monitoring to provide a more accurate forecast of future network group load growth trends in comparison to existing practice. This is now integrated with SPEN network planning practice.

Analysis of the detailed network monitoring data deployed for Flexible Networks in combination with network modelling led to the development of generic “rules-of-thumb” for the characterisation of PV generation at LV. The PV connections policy will be updated to reflect these which are as follows;

- A peak PV generation load factor of 90% for North Wales/Scotland,
- A generic minimum residential demand of 300W during periods of peak PV generation,

PV hosting capacity “rules-of-thumb” are tabulated below:

| Variable | LV Feeder Level (W/customer) | LV Network Level (W/customer) | % Capacity Gain |
|--|---------------------------------|----------------------------------|-----------------|
| Base Case | 580 | 310 | — |
| Improved PV Characterisation | 800 | 430 | 38% |
| Improved PV Characterisation + 2% Voltage Reduction | 1300 | 850 | -260% |

This enables a straightforward assessment of LV feeder PV hosting capacity which can be followed by more detailed monitoring and application of a voltage reduction at the primary substation once PV generation exceeds a trigger level.

A simple methodology to identify LV feeders with significant thermal phase imbalance and evaluate the options for mitigation was developed for use where detailed network monitoring is deployed.

A future network monitoring strategy was developed as part of Flexible Networks which incorporates learning achieved through analysis of detailed monitoring data including for innovative techniques. The key components are;

- Install “smart” MDIs instead of conventional MDIs in new secondary substations and replacement LV switchboards,
- Installation of “smart” MDIs in secondary substations at key locations across the LV network identified through application of the LCT Network Monitoring Strategy, and,
- Installation of secondary substation monitors with more detailed functionality at a small volume of selected locations of high LCT clustering and network constraints.

Glossary

| | |
|-----------------|---|
| BAU | Business-As-Usual |
| DNO | Distribution Network Operator |
| FCO | First Circuit Outage |
| HV | High Voltage |
| LCT | Low Carbon Technology |
| LCNF | Low Carbon Network Fund |
| LV | Low Voltage |
| MDI | Maximum Demand Indicator monitoring device |
| NMS | Network Management System |
| PV | Photovoltaics |
| RIIO-ED1 | Revenue = Incentives + Innovation + Outputs – Electricity Distribution 1 |
| SCADA | Supervisory Control and Data Acquisition (communications and control equipment) |
| SCO | Second Circuit Outage |
| SPD | Scottish Power Distribution (network license area) |
| SPEN | Scottish Power Energy Networks (network operating company) |
| SPM | Scottish Power Manweb (network license area) |

1 Introduction

This report provides practical recommendations for adaptation of DNO planning policy and practice to enable business-as-usual adoption of the technologies trialled in Flexible Networks. This is based on the trialling, experience and successful rollout of these technologies in SPEN, as evidenced by use in a number of network reinforcement solutions in the R100-ED1 regulatory period.

At a high level, the network planning process to assess the suitability of the Flexible Networks solutions for application to constrained networks follows a similar approach to traditional reinforcement techniques;

- Initial identification of constrained networks;
- Definition of a range of potential suitable reinforcement options;
- Calculation of potential capacity release;
- Consideration of cost benefit including capital and operational costs (maintenance, losses etc);

The new technologies are part of the set of possible reinforcement options available to the network planning engineer. However, assessment of suitability, capacity release and cost benefit followed by deployment requires a new approach and/or inputs as described below. Deployment of the technologies also has implications for existing policy on voltage, asset ratings and load index for example.

Other network planning aspects to consider for implementation include;

- Monitoring requirements,
- Asset management implications,
- Procurement updates,
- Implications for existing design standards and engineering recommendations e.g. P2/6, P27.

2 Integration into Business as Usual

2.1 Existing Planning Policy and Practice

At a high level, network planning practice used to inform planning and operational decisions includes;

- Annual network review
 - Load forecasting
 - Load index (for regulatory reporting)
 - Network planning
- Connection studies
 - Network planning

2.1.1 Annual network review

2.1.1.1 Load forecasting

Annual network review is undertaken to monitor load growth and identify areas approaching capacity limits that may require reinforcement or additional infrastructure investment, or for new connections. A base general load growth assumption is used and this assumption is modified for areas where there is additional local intelligence on future new connections activity or closures.

For networks and network groups approaching capacity, information on new connections e.g. large factories, large new housing estates, are a key factor in assessing future demand changes and appropriate response. There may also be more incremental load changes. These can be characterised through analysis of maximum demand for a number of previous years to determine trends in demand change which are then extrapolated forward to estimate the demand forecast for future years. The influence of weather conditions and outlier events such as temporary network backfeed are considered so that projections of demand growth are not unduly distorted.

Network loading is compared to asset ratings to ensure compliance with Engineering Recommendation P2/6 – Security of Supply, typically during First Circuit Outage (FCO) and Second Circuit Outage (SCO) contingency conditions on the 132kV and 33kV networks, including 33/11kV transformers and FCO on 11kV networks.

The following network scenarios are assessed;

- Group Demand, corresponds to winter max demand (FCO)
- Summer/winter load ratio, to give summer max demand (SCO)

2.1.1.2 Load Index

Load index is worked out for each network group as part of the annual network review process and gives an indication of when reinforcement to the group will be required. There are five load index levels (LI1 to LI5) defined by Ofgem based on loading percentage and peak load duration where LI5 is the most heavily loaded.

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

2 Integration into Business as Usual [continued]

2.1.2 Network Planning

Network planning includes network reinforcement identification and prioritisation activities. Identification of reinforcement requirements is through several means;

- Annual review of the network identifies any areas which potentially will require reinforcement in the next few years,
- Areas of the network which will require reinforcement can also be flagged up by designers carrying out network investigations during design of new connections,
- LV network constraints are often identified by customers when the voltage is approaching the statutory limits,
- Areas of network concern are also reported by the Network Control Centre and the local network operational staff. These are usually areas where the network is shown to be or anticipated to be stressed under outage conditions due to unplanned or planned outages, or a large number of customers cannot be restored until a fault is repaired.

When a potential reinforcement requirement is identified and initial investigations have been completed, each reinforcement request is ranked against a pre-approved set of criteria and added to the reinforcement programme for resolving at the appropriate time.

Appropriate network solutions are selected from a “toolbox” of solutions available to the network planner to resolve the issue. These are reviewed to identify the most effective based on a number of factors such as capital and operational costs, capacity headroom provided, network load growth trends, reliability, carbon etc.

Network reinforcement has until recently been based on the traditional techniques of asset replacement and reinforcement. Smart network techniques require specific new planning methodologies generally beyond simplistic network modelling based on maximum and minimum demand/generation values although not significantly more time-consuming. This will enable effective identification of a feasible solution and then accurate estimation of capacity headroom release and therefore cost-benefit for each network where their application is being considered.

New planning methodologies are required to identify and evaluate smart solutions

Network policy should also be aligned with the application of new network solutions and consistent with updated network planning and operations practice. For example, the traditional approach to calculating asset ratings or the definition of primary transformer voltage set-points may require revision.

Network policy should be revised to facilitate application of smart solutions

This report presents recommendations for DNO planning practice to facilitate implementation of Flexible Networks techniques, based on the development and testing of planning tools to support the Flexible Networks trials. Specific and more general policy recommendations are also made relevant to network planning, based on learning outcomes.

2 Integration into Business as Usual [continued]

2.2 Dynamic Thermal Ratings

2.2.1 Current Planning Policy and Practice

Present industry best-practice involves the use of fixed equipment ratings or seasonal ratings based on conservative seasonal conditions to allow remaining capacity headroom to be calculated. National standards assign different thermal ratings to network assets during each operating scenario, taking into account both the representative equipment loading and typical ambient conditions. The present P2/6 default of summer peak load is 67% of winter peak which is not representative of some networks e.g. city centre loads.

The use of generic asset ratings that do not consider the actual thermal conditions experienced can lead to unnecessary triggering of network reinforcements and/or corrective measures to reduce load due to indications that thermal headroom is exhausted.

2.2.2 Primary Transformers

In Flexible Networks, dynamic thermal ratings for primary transformers are provided as three enhanced seasonal ratings (winter, autumn/spring and summer) for use in network planning and operation. This considers the asset specific seasonal weather conditions, load profile and thermal characteristics.

The use of enhanced seasonal ratings to release thermal capacity is suitable for primary transformers where the network constraint is the transformer rating and traditional reinforcement would involve costly asset replacement and substation upgrade. The location of the transformer is also important; transformers located indoors are generally not suitable for application of enhanced seasonal thermal ratings due to increased temperatures within the substation enclosure.

An enhanced thermal ratings software tool was developed in Flexible Networks to estimate primary transformer enhanced rating and capacity release based on historical load profile and ambient temperature data¹. It also takes into consideration the rating of connected assets. The software tool is being made available to other DNOs. It is important to evaluate the variation in thermal rating with seasonal load profiles to ensure that the appropriate enhanced ratings are defined.

Recommendations for transformer ratings policy are to allow the use of enhanced thermal ratings in suitable network constrained cases, following a defined process agreed by the business to calculate ratings values (e.g. application of the software tool above). The new seasonal transformer ratings will then be updated in network models, the NMS and the asset database. This ensures that enhanced thermal ratings are then utilised in annual network review, network connections, outage planning and calculation of load index for the specific network group where they are applied.

Asset ratings policy should allow the use of enhanced thermal ratings in suitable network constrained cases, based on a defined ratings calculation process

The application of enhanced thermal ratings to a primary transformer would be accompanied by the deployment of a windings or top oil temperature monitor². This enables verification of transformer thermal characteristics which may differ from representative IEC parameters and a longer term monitoring capability over the period of enhanced ratings application. A site inspection should also be carried out to review the condition of the transformers and connected assets before applying enhanced ratings³.

This technique has already been adopted and is being applied in business as usual to a number of transformers, enabling SPEN to defer reinforcement projects at a number of locations resulting in savings for our customers.

¹TNEI & University of Strathclyde, *Enhanced Transformer Ratings Tool_v3.17*, July 2015.

²SP Energy Networks, *Methodology and Learning Report Dynamic thermal rating of assets – Primary Transformers*, May 2015.

³DNV-GI, *Prospects of applying RTTR to distribution transformers*, October 2014, Report No.: 14-2194, Rev.1.

2 Integration into Business as Usual [continued]

2.2.3 Overhead lines

A real time thermal rating (RTTR) management system was developed for 33kV overhead lines⁴. This is well suited to facilitating the increased connection of wind generation and can now be considered as a potential solution by the connections team if the circuit is likely to otherwise become overloaded. The RTTR management system would be deployed in conjunction with an Active Network Management (ANM) scheme to automatically constrain the generation output under infrequent conditions when the RTTR of the overhead line may be exceeded.

Key aspects to be considered in the early design of the scheme include;

- Feasibility of required capacity release using this technique based on regional weather stations, circuit loading, network configurations,
- Asset ratings upstream and downstream of the circuit that might constrain the capacity release,
- Identifying appropriate locations for weather stations (critical span location),

The RTTR is available to the control room for use following deployment of the management system.

Recommendations for circuit ratings policy are to allow the use of real-time thermal ratings in suitable network constrained cases, managed through deployment of a well validated system in the control room.

The circuit ratings should remain as static seasonal ratings in network models, the NMS and the asset database with appropriate notation to indicate that a RTTR management system is applied. Seasonal variation of the circuit RTTR should be considered alongside loading to evaluate whether capacity was available when required, during annual network review, network connections, outage planning and calculation of load index for the specific network group where they are applied.

If demand side response and/or energy storage were available as a backup to circuit RTTR then the approach to calculating circuit ratings should be reconsidered however detailed consideration of this is beyond the scope of the Flexible Networks techniques trialled. The current review of ER P2/6 should investigate this potential interaction and the implications for estimating firm capacity.

Our assessment of the number of weather stations required for dynamic line rating schemes differs from the conclusions reached by other DNO projects. Therefore different cost and asset risk profiles between DNO's could result. We suggest that an ENA working group be set up to agree common requirements for the implementation of dynamic line rating in BAU across DNO's.

2.3 Flexible Network Control

2.3.1 Current Planning Policy and Practice

Load transfer through interconnections with other neighbouring HV groups is already carried out to an extent by network control engineers during post-fault restoration. However, it has not previously been applied in a planning, pre-fault context to release network capacity headroom and defer network reinforcement.

Also, the introduction of Telecontrol for remote network control functionality enables a more dynamic open point through implementation of automatic switching sequences to better optimise loading to capacity.

⁴SP Energy Networks, Methodology and Learning Report Flexible Network Control, September 2015.

2 Integration into Business as Usual [continued]

2.3.1.1 Planning Practice

A methodology and application guide were developed to describe the actions necessary to assess the ability of load transfer based network control and/or automation to increase the capacity headroom in an 11kV distribution network, and to implement reconfiguration schemes which are considered beneficial⁵. The process assumes that capacity headroom is constrained by the rating of one or more primary substations, although there may also be thermal and voltage constraints in the 11kV network.

The process of assessing the effectiveness of a potential load transfer scheme can be considered as a number of stages, in which reconfiguration options to release headroom are modelled and analysed in progressively more detail. At each stage, infeasible or unattractive options may be rejected from consideration.

1. Analysis of primary substation load
2. Identification of load transfer options
3. Refinement of load models
4. Outline assessment, quantification and filtering
5. Detailed assessment, quantification and filtering, including
 - a. Detailed analysis of specific points in time
 - b. Voltage studies
 - c. Reliability assessment
6. Selection of options for development and implementation

Historically, network open points are positioned so that the customer numbers are evenly balanced in the event of a fault causing loss of one circuit to control risk. Reliability assessment is an important component to evaluate any change in network reliability due to reconfiguration schemes.

⁵University of Strathclyde, *Network Reconfiguration Planning Methodology and Application Guide*, July 2015.

2 Integration into Business as Usual [continued]

2.3.1.2 Policy

It is recommended that network reconfiguration scheme policies are determined in advance, but that these should be periodically revised – for example annually, ahead of the peak load season – to reflect forecast network conditions which will affect the amount and duration of load transfer likely to be required and impact on reliability metrics.

The review process should specifically address the long-term adequacy of each Flexible Network Control scheme, so that the need for future network reinforcement can be anticipated, and reinforcements developed and implemented before additional capacity headroom from Flexible Network Control is exhausted, or the costs of the scheme in switching or reliability become excessive.

Under particular conditions, the demand that can be met can be maximised by using flexible network control to switch some demand to a neighbouring group that has some capacity headroom. Such demand transfer may not be considered when calculating load indices⁶. Transfer Capability and Transfer Capacity are however defined in ER P2/6 for calculating network capacity. In any case, it is important to ensure that the usage of “network capacity” and “maximum demand” is consistent with any load transfer based network control schemes that are applied to the network. This should be reflected in policy and network planning practice. We have produced a detailed review of existing issues and lessons from “Flexible Networks for a Low Carbon Future” as applied to a successor to ER P2/6 including related issues with Ofgem load indices⁶.

The usage of “network capacity” and “maximum demand” should be consistent with load transfer based network control schemes applied

2.3.2 Integration of AVRs

2.3.2.1 Current Planning Policy and Practice

Automatic Voltage Regulators are not commonly used by network designers in the UK. AVRs have been installed on the SPD and SPM networks but not for flexible network control and on an ad-hoc basis with limited integration into wider business policy and practice to date.

2.3.2.2 Planning Practice

A planning methodology was developed to assess the capability of an AVR to mitigate voltage drop experienced as a result of load transfer based network control and/or automation⁷. This is based on application to an 11kV distribution network to increase the capacity headroom through network reconfiguration. Voltage constraints are increasingly likely as the length of HV feeder transfer grows.

Flexible Networks also developed a standard procurement specification for 11kV AVRs and a number of changes were recommended to the current asset data model;

- Additional nameplate data fields so the unit data for parameter set up is available to protection engineers,
- Data fields to record the frequency of tap change events to facilitate a duty based maintenance program in the future.

It was identified that there will need to be visibility of all AVR installations for load and generation at the early design stage for both Connections and Network Planning, for efficient business-as usual integration.

⁶University of Strathclyde, A successor to ER P2/6: existing issues and lessons from “Flexible Networks for a Low Carbon Future”, June 2015.

⁷TNEI Services Limited, AVR Planning Methodology, September 2015.

2 Integration into Business as Usual [continued]

2.3.2.3 Policy

SPEN voltage policy has evolved to specifically address the use of AVRs including design principles covering design and operation including remote indications and control. This is in a large part due to the activities in Flexible Networks to bring AVRs into business-as-usual.

Learning from Flexible Networks led to recommendations for the voltage policy to be amended to include the following 2 clarifications⁸:

- **Multiple Regulators:** Clarification that there is only to be one voltage regular on a main circuit. Additional devices can be situated on spur lines. Where devices are located on main lines which form part of a ring or interconnector the devices shall be designed so that they can be bypassed or configured to operate in the reverse direction to ensure operational flexibility.
- **Rating and Fault Level Capability:** Standard rating for a regulator on the 11kV and 33kV network will be 200A. Fault current level of the unit should be calculated as 25 times the nominal rating of 200A (5kA). This is less than the maximum fault current level on both the 11kV and 33kV networks. As the majority of these devices will be placed on rural networks they will be subject to much lower fault current ratings. Where system fault levels exceed the 5kA limit, larger units can be deployed if economical.

Policy and appropriate design guidelines for use of AVRs to facilitate renewable generation is still under discussion.

SPEN voltage policy now specifically addresses the use of AVRs, incorporating learning from Flexible Networks trials

2.4 Energy Efficiency

DNOs have a role to play and can benefit from facilitating the rollout of energy efficiency measures in cooperation with energy suppliers as this could provide a solution to easing network constraints and increase capacity headroom. However, the approach used for Flexible Networks will not be rolled out further due to limited capacity gain⁹.

However, this technique is likely to be driven in the future through regulation and/or by a third party e.g. energy suppliers, on behalf of a DNO. Recently introduced regulations require large undertakings to identify energy saving opportunities for all of their significant energy uses by December 2015. This coincides with the Government funded Electricity Demand Reduction (EDR) pilot scheme which could eventually form part of the Capacity Market. Consideration should be given to a process that would allow the DNO to pay a contribution in addition to the EDR payment for peak demand reduction on targeted areas of the network where this would defer reinforcement

Learning from this activity provided an intervention hierarchy that can provide direction for targeting specific energy efficiency works that offer best and most cost effective network benefit. These measures can in turn be targeted at stakeholders or specific building types where opportunities have been identified as most likely to exist. This could be used to inform the development of a DNO or Ofgem customer energy efficiency incentive scheme, or similar, developed to drive implementation of specific measures for maximum network benefit.

Energy efficiency is likely to be driven in future through regulation and/or by a third party e.g. energy suppliers, on behalf of the DNO

⁸SP Energy Networks, Methodology and Learning Report Integration of Voltage Regulators, August 2015.

⁹SP Energy Networks, Methodology & Learning report Energy Efficiency, September 2015.

2 Integration into Business as Usual [continued]

2.5 Voltage Optimisation

Voltage optimisation has not been used on a large-scale in the UK. Voltage optimisation was investigated in Flexible Networks as a technique to provide low cost incremental voltage capacity headroom for both demand and generation. This was through 1. Review of international studies of voltage reduction and impact on demand, 2. Several voltage reduction tests on Ruabon primary network, and 3. Theoretical exploration of the impact of reducing voltage on facilitating increased PV generation connection¹⁰.

2.5.1 Voltage modelling

A detailed review of the methods for modelling load and international experience of the response of load to controlled changes in network voltage was carried out. Outcomes suggest that in the absence of local knowledge of experimental results, a reduction of 1% in active power demand in response to a 1% voltage reduction is a reasonable estimate. It is thus recommended that network loads are modelled on a constant current basis, except where knowledge of particular load behaviour dictates otherwise. This can be achieved through use of the ZIP load model, configured to act as a constant current load. Consistent with this, asset ratings for transformers and circuits for example, in network models should be defined in Amps.

TNEI developed a ZIP (impedance-current-power model for voltage dependency) load model in IPSA for both real and reactive power which can take load profiles as input. Future features will include the ability to define reliability indices which is already available for standard, constant power loads.

2.5.2 Primary voltage set-point

Recommendations for voltage policy relating to primary substation voltage set-point were an outcome of the voltage optimisation study¹¹ and comprise;

- Implement a target voltage reduction across SPD, reducing voltage set point for 11.1kV to facilitate increased generation connections,
- Implement a further 1%-2% seasonal voltage reduction on specific primary networks in SPD and SPM if required, in case of higher distributed generation uptake¹², or,
- Alternatively, use of load drop compensation on primary transformer tap change control to facilitate increased PV connections,

During preparation of the SPEN RIIO-ED1 business plan, a more detailed characterisation of the impact of existing and future demand e.g. heat pumps and EV connections, which are likely to be geographically and temporally clustered was carried out¹³.

SPD target voltage should be reduced from 11.2kV to 11.1kV to facilitate increased generation connections, further voltage set point reductions or load drop compensation will be implemented where required/feasible

¹⁰SP Energy Networks, Voltage Optimisation Methodology and Learning Report, September 2015.

¹¹University of Strathclyde, Technical Note on Modelling of Load, January 2015.

¹²TNEI Services Limited, Improved Characterisation of PV Capacity at LV, September 2015.

¹³TNEI for SPEN, RIIO-ED1 HV and LV Network Investment Analysis Phase 2 – Final Report, April 2013.

2 Integration into Business as Usual [continued]

2.5.3 Statutory voltage limits

It is relevant to mention here that there are a number of industry projects and task groups assessing in detail the technical and commercial implications of widening the steady state voltage limits to bring GB into alignment with EU voltage limits such as the Western Power Distribution Equilibrium project. We will share any applicable learning from Flexible Networks in this area.

2.6 Improved Network Monitoring

2.6.1 Load forecasting

An enhanced load forecasting and risk characterisation tool was developed that provides a more accurate forecast of future network group load growth trends in comparison to existing practice¹⁴. The underlying methodology and application is described in detail in “Flexible Networks – Improved Use of Primary Substation Data”. This is integrated with the existing SPM load forecasting tool for use in annual network review during RIIO-ED1.

2.6.2 Improved secondary substation monitoring

A future network monitoring strategy has evolved from the “RIIO-ED1 LCT Network Monitoring Strategy” submitted as part of the SPEN RIIO-ED1 business plan to a strategy that captures the most recent learning outcomes from Flexible Networks¹⁵.

Key features include;

- 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 LCT Network Monitoring Strategy.
- Install secondary substation monitors with more detailed functionality e.g. monitoring of all LV distributors and phases at a small volume of selected locations of high LCT clustering and network constraints as identified through application of the LCT Network Monitoring Strategy.

The network monitoring strategy is being rolled out during RIIO-ED1.

“Smart” MDIs will be installed in secondary substations at key hot-spot locations across the LV network

¹⁴TNEI Services Limited, SP Energy Networks and University of Strathclyde, Improved Use of Primary Substation Data, January 2015.

¹⁵TNEI Services Limited, Future Network Monitoring Strategy, September 2015.

2 Integration into Business as Usual [continued]

2.6.3 PV Characterisation

Rules of thumb were developed for characterisation of PV generation at LV based on network modelling and verification with measured load, voltage and weather data as part of Flexible Networks¹⁶.

Key features include;

- A peak PV generation load factor of 90% for North Wales/Scotland,
- A generic minimum residential demand of 300W 300W during periods of peak PV generation,

PV hosting capacity “rules-of-thumb” are tabulated below:

| | LV Feeder Level (W/customer) | LV Network Level (W/ customer) | % Capacity Gain |
|---|---------------------------------|-----------------------------------|-----------------|
| Base Case | 580 | 310 | — |
| Improved PV Characterisation | 800 | 430 | 38% |
| Improved PV Characterisation + 2% Voltage Reduction | 1300 | 850 | ~260% |

Application of a seasonal reduction to the primary substation voltage set point can also be applied to release significant further generation capacity headroom.

The PV connection policy will be updated to reflect these rules-of-thumb and the application of a voltage set point reduction at the primary. This will also be included in the SPEN voltage policy. Once an LV feeder approaches the generic PV hosting capacity, it may be most cost-effective to apply voltage reduction at the primary substation rather than deploy detailed monitoring particularly if there are other parts of the LV network that will benefit from this. However, this needs to be considered on a case-by-case basis that includes evaluation of;

- Typical network winter loading and corresponding voltage drop (suitability for a permanent or seasonal voltage set point change or use of sophisticated line drop compensation algorithms that are available in some voltage relays),
- HV and LV network meshing and backfeeding arrangements to avoid any current circulation due to voltage mismatch,
- Bandwidth of the voltage relay,
- Potential impact on HV connected customers and HV connected generation.

Voltage reduction can also be applied to secondary substations although not investigated for Flexible Networks. Generally, ground mounted secondary substation transformers can be manually tapped and backfeeds are readily available however, this will require technician time to carry out the procedure and for travel. The adjustment of taps on a pole-mounted secondary transformer is potentially more problematic (lack of backfeeds and may require the transformer to be re-wired to select full range of tap positions).

¹⁶TNEI Services Limited, Improved Characterisation of PV Capacity at LV, September 2015.

2 Integration into Business as Usual [continued]

2.6.3 PV Characterisation [continued]

The following issues also need consideration;

- Voltage should remain within statutory limits in the LV network under the range of loading conditions likely to be experienced,
- All transformers in an LV group need to be at the same LV voltage to avoid a voltage gradient and prevent current circulation.
- There should be negligible impact on the HV network voltage including HV voltage control schemes.
- Any secondary substation voltage control scheme should be applied with consideration of primary substation voltage control schemes that exists or are likely to be applied in the future.

2.6.4 Load Modelling

University of Strathclyde recommended that SPEN should model network loads on a constant current basis, except where knowledge of particular load behaviour dictates otherwise, based on a detailed assessment of load modelling for Flexible Networks¹⁷. In IPSA, this can be achieved through use of the ZIP load model, configured to act as a constant current load. This new development will be evaluated further beyond Flexible Networks for business as usual integration and further validation.

A study of the level and patterns of load diversity among secondary substations in the three Flexible Networks test areas was carried out¹⁷. This has provided learning that can be applied to the modelling of load on 11kV networks, to a large extent validating existing assumptions that are used for ground mounted and demand power factor. We recognise that this may change over time however with the uptake of low carbon technology. This learning will be incorporated into future network modelling practice and any interactions with the use of a constant current load model evaluated.

In future, network loads should be modelled on a constant current basis, except where knowledge of particular load behaviour dictates otherwise

2.6.5 Characterisation of HV and LV imbalance

A simple methodology was developed to allow LV feeders with significant thermal phase imbalance to be rapidly identified based on detailed monitoring data and compared with cable thermal ratings¹⁸. Feeders can then be ranked and prioritised for investigation of phase rebalancing to improve headroom. Whilst this is only applicable to LV feeders with phase current monitoring fitted, learning outcomes from Flexible Networks suggest LV feeder types that may suffer greater imbalance so can inform network planning during annual review in future.

¹⁷University of Strathclyde, "Technical Note on Investigation of Diversity in Secondary Substation Load", February 2015.

¹⁸TNEI Services Limited and University of Strathclyde, HV and LV Phase Imbalance Assessment, September 2015.