2.4

Annex

SP Energy Networks 2015–2023 Business Plan

HV and LV network investment analysis

TNEI

March 2013

SP ENERGY NETWORKS

Title: RIIO-ED1 HV and LV Network Investment Analysis – Phase 2 Annex

Client: SP ENERGY NETWORKS

Report Nº: 8006-03-R4

Date: 19th March 2013

Part of the Petrofac group

DOCUMENT HISTORY AND STATUS

CONFIDENTIALITY (Confidential or not confidential):	Not confidential
Project No.:	8006
Project Name:	RIIO-ED1 Technical Analysis Support Phase 2
Author:	Russ Bryans, Catherine Cleary and Charlotte Higgins
Issued by:	TNEI Services Ltd

Revision	Date issued	Reviewed by	Approved by	Date Approved	Revision Type
D0	28/02/2013	RB			Preliminary Draft
R0	28/02/2013	RB	CEH	28/02/2013	First Issue
R1.1	28/02/2013	RB	CEH	28/02/2013	Reissue (Kilsyth changes)
R2	5/03/2013	RB	CEH	5/03/2013	Investment scaling, PV clustering results added
R3	11/03/2013	RB, CC	CEH	11/03/2013	SPD/SPM results updated
R4	19/03/2013	CEH	CEH	19/03/2013	SPD results updated

Quality Assurance
TNEI is registered with BS Quality Assurance Limited (Registration Number FS 27760) as compliant with BS EN ISO 9001. All work conducted by TNEI, its subsidiary companies and its subcontractors is carried out in accordance with in-house procedures and documentation.

TNEI Services Ltd

Bainbridge House
86 – 90 London Road
Manchester
M1 2PW
Tel: +44 (0) 161 233 4800
Fax: +44 (0) 161 233 4801

Milburn House
Dean Street
Newcastle Upon Tyne
NE1 1LE
Tel: +44 (0) 191 211 1400
Fax: +44 (0) 191 211 1432

Duart House
Finch Way
Strathclyde Business Park,
Bellshill
Glasgow
ML4 3PR
Tel : 0141 228 4755

Chester House
76-86 Chertsey Road
Woking
Surrey
GU21 5BJ
United Kingdom

1 Annex

TNEI Services Ltd (TNEI) has undertaken a bottom-up based assessment of required future network investment for the 11kV and LV Scottish Power Energy Networks (SPEN) distribution networks. This specifically considers the impact of future low carbon technology (LCT) uptake across GB distribution networks.

Three sample network areas were modelled that are representative of the wider SPM and SPD licence area networks and encapsulated a number of the key network features to be investigated. These include both rural and urban/suburban HV and LV networks with a mix of feeder types which would influence LCT clustering. The three networks were: SPM - Llynclys & Llansilin, Oswestry and Northwich; SPD – Kilsyth. Several representative areas of LV network for the sample networks were also explicitly modelled.

Two central scenarios were assessed for each of the sample network models based on the LCT uptakes in the Transform V2.0 EATL model (Scenario 1 and 2) as shown in Table 1. Network areas likely to experience material changes to network headroom and voltage constraints were highlighted for intact and N-1 contingency network configurations. Conventional and smart solutions were identified and modelled to mitigate future network model issues encountered as LCT was applied, based on a reinforcement solution cost-benefit analysis model and application of engineering judgement.

Table 1 LCT Uptake for each Scenario

	Heat Pumps	*Electric Vehicles*	*PV*
Scenario 1	High	Mid	Mid
Scenario 2	Mid	High	Mid

The SPEN HV network was classified into different "types" of network consistent with key characteristics associated with the interaction of network topology and low carbon technology uptake to enable a simple extrapolation of the forecast investment profile for the sample networks to the wider SPM and SPD licence areas. The average network demand headroom for SPM and SPD licence areas was also characterised based on demand headroom for individual HV networks to provide investment scaling factors for the representative HV networks assessed. Investment requirements are dominated by LCT demand growth.

A sensitivity analysis on Scenario 1 was carried out to assess the impact of PV clustering on network loading and voltage. This was based on the distribution shown in Figure 1 which anticipates that some areas of the LV network may experience a very high uptake of PV due to housing orientation, socio-economic factors or social housing initiatives for example.

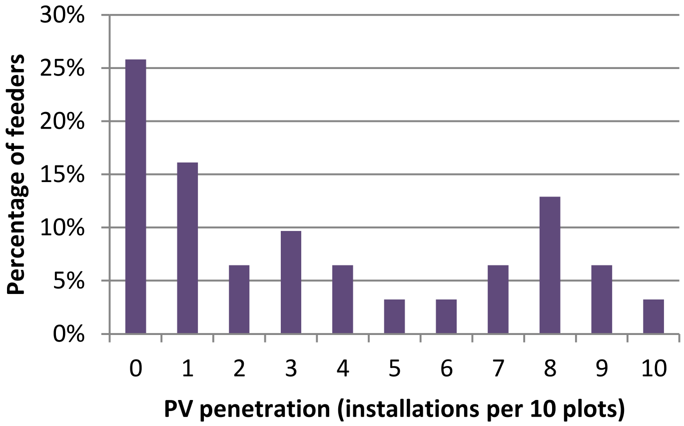


Figure 1 Percentage of LV feeders with a given PV Penetration

The influence of EV charging was also investigated to quantify the risks associated with unrestricted charging. For both domestic and commercial vehicles, a low controllability profile was developed in which EV fast charging (based on a two hour charge) is concentrated within a four hour period centred on the "teatime" network demand peak. A high controllability profile was also developed which is tariff led and assumes that both commercial and domestic EVs slow charge over a five hour period corresponding to low network demand during the night time. These are shown in Figure 2.

The un-controllable profiles will be applied to the uptakes in Scenario 1 (mid EV uptake) and controllable profiles to the uptakes in Scenario 2 (high EV uptake).

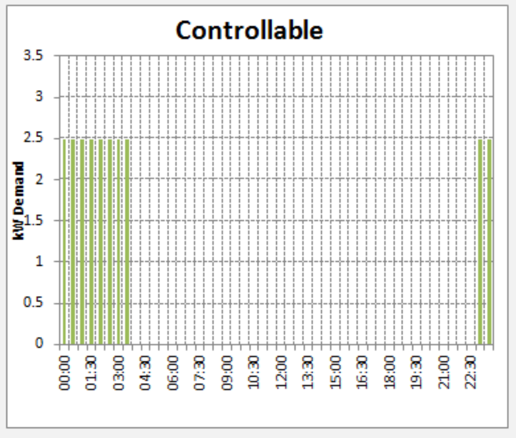
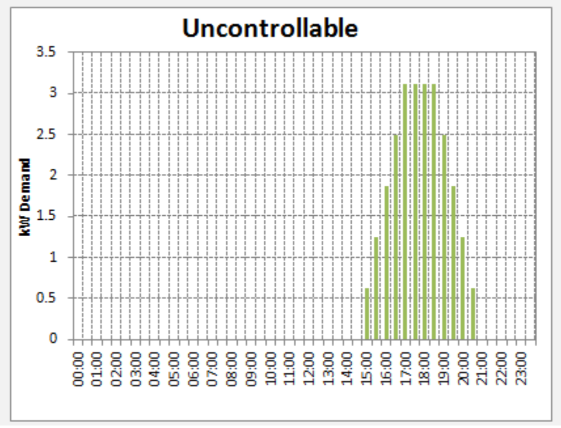
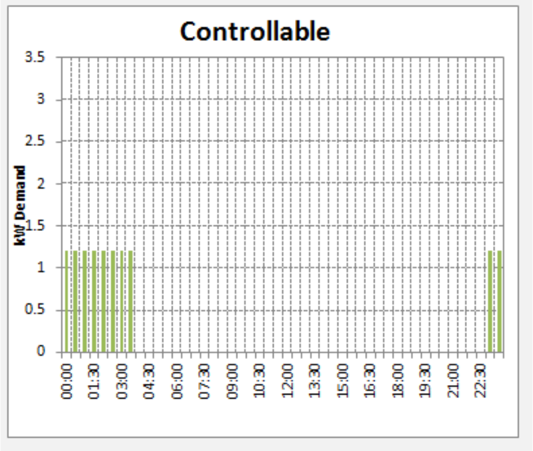
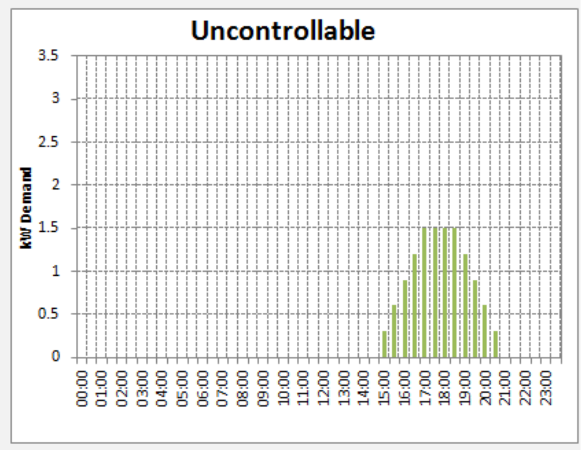
<table>
<tr><th></th><th>EV Controllable Charging</th><th>EV Uncontrollable charging</th></tr>
<tr><td>Domestic</td><td> </td><td> </td></tr>
<tr><td>Commercial</td><td> </td><td> </td></tr>
</table>

Figure 2 EV Charging Profiles

1.1 Network Issues and solutions

1.1.1 Northwich

The Northwich HV network is located in the SPM licence area within the Cheshire region. Northwich contains a compact mix of urban, semi-urban and rural network topologies with a mix of housing types and some quite large housing estates (>1500 plots). It also contains suburban meshed HV network surrounded by radial feeders more rural in their design.

Table 2 Northwich Network Characteristics

	Volumes	*Scenario 1 interventions*
Primary Transformers	7	2 new primary substations
Secondary Transformers	187	53 interventions [19 new substations]
11kV Circuit	127 km	+500m HV cable overlay
Modelled LV network	19.5 km	+850m split feeders [not including LV cable required for new secondary substations]

For Scenario 1, in 2019 demand growth causes under-voltage violations on several long OHL HV feeders. These are managed by in-line HV circuit voltage regulators. In-line voltage regulators have been deployed at HV on the SPD and SPM networks although they are not in common use. Currently available voltage regulators are not optimised for application on a distribution network in terms of construction, circuit tie-in, and reliability. However, it is envisaged that improved designs would develop with increased market uptake.

Thermal issues on secondary transformers and LV meshed feeders appear in 2020 and increase as LCT uptake rise. Approximately 25% of secondary transformers in the area are affected by 2030. Transformers smaller than 500kVA were uprated, otherwise new secondary substations were established. A number of LV split feeder or reconfiguration reinforcements were also required. Northwich requires a new primary substation by 2022 with a second primary substation required by 2028. It is likely that a third primary substation will be required soon after 2030. Very few HV split feeders or HV cable overlays were required. This is because the careful introduction of new primary in locations of demand growth or areas of network constraint serves to free capacity on the HV feeders.

Real-time Thermal Rating (RTTR) of overhead lines and cables was used at HV to manage several of the more heavily loaded HV feeders. This solution was used to delay reinforcement of these feeders until a new primary substation was deployed. If RTTR for OHLs is to be introduced, there may be implications due to defined clearances required by legislation for OHL conductors. RTTR on cables is challenging to implement due to uncertainties including soil type and conditions, conductor uniformity and thermal dissipation. It is expected that RTTR would be integrated into an Automatic Network Monitoring (ANM) system.

In 2028, the amount of embedded PV generation connected to the LV network starts to introduce over-voltage issues at LV. In suburban areas, adjustment of the secondary transformer taps to reduce LV voltage by 2.5% should be fairly straightforward as transformers can easily be manually tapped and back-feeds are readily available. Adverse power flows could occur between secondary substations at different voltage set points if they are interconnected such as in meshed networks. To overcome this, the voltage set point for the LV group was standardised.

Tap adjustment may introduce (or hasten) voltage legroom issues which would be reinforced in the same way as with normal demand growth i.e. splitting LV feeders or establishing new secondary transformers. However in Northwich, reinforcements have already been applied due to demand growth. These provide sufficient legroom before over-voltage issues appear and tap adjustment to reduce the LV voltage by -2.5% is implemented.

For Scenario 2, network issues experienced are very similar to Scenario 1. This is due to both scenarios applying similar levels of overall LCT demand uptake. The timing of some interventions is advanced or delayed by 1 year, but major reinforcements such as new primary substations still occur at the same time.

Scenario 2 comprises a higher uptake of EV which is assumed to be operating at a higher kW demand value than heat pumps at the time of PV peak generation. This has the effect of netting off some of the PV generation, thus reducing the impact on voltage rise and delaying over-voltage issues. The overvoltage issues which were mitigated by secondary transformer tap adjustment in Scenario 1 were delayed from 2028 until beyond 2030 in Scenario 2. This tap adjustment might be expected in early ED3.

1.1.2 Llynclys & Llansilin, Oswestry

The HV network area supplied by the primary substations of Llynclys and Llansilin was selected in the SPM licence area to capture the characteristics of a more rural network. This is located in the North Wales region of the SP Manweb licence area and is similar to the rural networks defined in Work stream 3, consisting of approximately 50% villages, 10% mixed and 40% rural farmsteads.

For Scenario 1, thermal and under-voltage network issues begin to appear in the rural network in 2022. Llynclys requires a new primary transformer and split HV feeder in 2022. A number of new or uprated secondary transformers are required with the majority of interventions for ground mounted transformers in the more built-up areas of the rural network.

The rural network begins to experience over-voltage issues in 2021 due to the uptake of embedded PV generation. This is somewhat earlier than the suburban Northwich network due to the longer, higher impedance radially operated overhead lines. In rural areas, the adjustment of secondary transformer taps is potentially more challenging as back feed capability is less common and some transformers would require re-wiring. The lack of a back-feed supply would involve interrupting customers’ supply to implement the tap change.

Table 3 Llynclys & Llansilin Network Characteristics

	Volumes	*Scenario 1 interventions*
Primary Transformers	1 [incl. resupply to 5 adjacent substations]	1 new primary transformer
Secondary Transformers	114 demand points [each demand point may represent multiple PM tx]	7 interventions [4 new substations]
11kV Circuit	65 km	+4km HV split feeder
Modelled LV network	1.3 km	None

Over-voltage was mitigated by applying a seasonal adjustment to the primary transformer target voltage in 2021. Early indications show that the enabling of a remote change of ±1% to the voltage set point of primary transformer automatic voltage control relays in SPEN is a viable solution which could be achieved without prohibitive expense. In 2027, in-line HV circuit voltage regulators are utilised to manage the reappearance of over-voltage issues. This avoids the wide-spread use of higher cost conventional reinforcement solutions at LV.

For Scenario 2, network issues are very similar to Scenario 1 although one new secondary transformer intervention is not required.

1.1.3 Kilsyth

The Kilsyth HV network is located in the SPD licence area and is typically radial in topology, serving in the region of 7500 metered customers. The makeup of the Kilsyth network is highly mixed, containing a town centre, suburban streets, terraced streets and dense urban housing. There are two predominantly commercial feeders, one rural feeder for villages and farms and the last feeder feeds new build housing and villages on a teed circuit.

For Scenario 1, under-voltage issues appear in Kilsyth from 2018 on long OHL HV feeders and are managed by in-line HV circuit voltage regulators. Thermal issues also appear on HV urban cables and are mitigated through soft meshing during N-1 network contingency conditions. Soft meshing is implemented in such a way that the network does not run solid under any conditions, but allows the spare capacity of nearby feeders to be utilised under N-1 conditions. This could be optimised with ‘smart’ switching points distributed along the feeders, where a unit that monitored the current flows can intelligently decide where the normally open point on the circuit should be located. This technology is currently tested by SPD for future implementation on the wider network.

A number of conventional reinforcements such as HV overhead line uprating, HV split feeders and HV and LV underground cable minor works are also required. RTTR on overhead lines was applied to resolve several thermal headroom issues on feeders. In general it was found that RTTR on cables did not offer a sufficient increase in thermal capacity and so conventional cable upgrades were required.

Thermal issues due to increased demand mean that a new primary substation is required in 2027. It is envisaged that this could provide additional capacity for up to 3-4 adjacent network groups and this is reflected in the investment modelling. This reinforcement may alternatively be realised as a primary transformer upgrade in other network groups where appropriate. A number of ground mounted secondary transformers are required to be upgraded from 2019 onwards.

Table 4 Kilsyth Network Characteristics

	Volumes	*Scenario 1 interventions*
Primary Transformers	2x 20MVA	1 new primary substation
Secondary Transformers	161	14 interventions [1 new substation]
11kV Circuit	99 km	+2.2km HV OHL Upgrade, +2.3km HV Split Feeder, +0.9km HV Cable Overlay and + 4km Split Ring HV Cable
Modelled LV network	8.5 km	20m upgraded + 50m new LV cable [not including LV cable required for new secondary substation]

Over-voltage issues are identified in 2024 due to the uptake of PV generation on the Kilsyth network. These are restricted to specific feeders on the LV network and were mitigated by adjusting the tap setting of individual secondary transformers to reduce the voltage level by 2.5%. This was only performed where there was sufficient voltage legroom in summer conditions to allow the new tap position to be maintained all year round, as regular manual tapping of secondary transformers is not considered to be an economically viable network policy.

In 2027, the increased uptake of PV causes widespread over-voltage problems during light load conditions. To address this, the primary transformer target voltage is manually adjusted to a ‘summer’ or light loading seasonal value of 11.0kV. It is envisaged that this would be performed centrally and may require investment in enabling communications infrastructure investment if not already installed in this substation. In the SPD network, SPEN are currently undertaking a survey of primary transformer relay types, communications links and undertaking maintenance where automatic voltage control at primary substation is not functioning. This survey should facilitate the development of a programme of work to, where necessary, modernise primary substations to enable a remote change of ±1%.

By this stage, industrial customers who might be expected to experience voltage legroom issues due to a decreased voltage set point are already supplied through an in-line voltage regulator on the main industrial feeder.

1.2 Sensitivity to PV Clustering

PV clustering was applied to the Northwich and the Kilsyth networks for Scenario 1. For Northwich, it was necessary to manually adjust existing secondary substation transformer taps much earlier. In the Kingsmead estate this was applied to all secondary substations in 2018 as compared to four secondary substations in 2028 under Scenario 1. This was due to the increased PV clustering at LV bringing forward over-voltage issues. Demand growth due to LCT necessitated four additional secondary substations in the Kingsmead estate. These were added in 2022 and 2027. The tap position on these was adjusted to maintain the nominal voltage at -2.5% at LV in 2028 for the PV clustering scenario. It was also no longer necessary to overlay some LV cable in 2025 to resolve over-voltage issues as these had been mitigated in 2018 with the transformer tap changes and for that particular LV feeder, the PV clustering algorithm had resulted in reduced local PV uptake. Other key network issues experienced due to demand growth remained the same.

For Kilsyth, voltage headroom issues are triggered four years earlier in 2020 for one secondary substation transformer. This is resolved by manually reducing the voltage set-point by 2.5%. Transformer tap positions are adjusted one year later than in Scenario 1 for the other secondary substation transformers; this is due to application of the PV clustering algorithm resulting in reduced local PV uptake. Over-voltage issues re-emerge in 2027 and this is mitigated by changing the primary substation voltage set point to a light loading seasonal value. Generally, other key network issues experienced due to demand growth remained the same.

This indicates that investment due to LCT generation for a central LCT uptake scenario is expected to be less material compared to investment required for LCT demand even with relatively high PV clustering.

There are some inter-dependencies with the timing of LCT generation and demand uptake which can be explored qualitatively for several hypothetical uptake variations. For example, if there is limited LCT demand uptake and PV uptake consistent with Scenario 1 then over-voltage issues can generally be mitigated with manual tap changes to primary and/or secondary substation transformer taps (where appropriate for network type) at low cost. However, there may also be the requirement for some LV cable works on already heavily loaded LV feeders that might suffer from under-voltages as a result of voltage set-point reduction.

If LCT demand uptake occurs in parallel with LCT generation uptake, similar to the scenarios assessed, then LV reinforcement via conventional solutions will be required for thermal issues. This would also act to increase voltage headroom and legroom, delaying over-voltages and making the network more robust to primary and secondary substation tap changes required to mitigate over-voltages due to PV uptake.

If LCT demand uptake occurs several years after high PV generation uptake then there will be reduced voltage legroom on the network due to transformer tap changes to resolve over-voltage issues. This may have the effect of bringing forward reinforcements to mitigate legroom issues.

In more rural areas or where a primary transformer setpoint adjustment of 1% is applied to mitigate over-voltage, this may introduce under-voltage issues in areas which remain heavily loaded under peak generation conditions. It is anticipated that localised voltage headroom or legroom issues at HV could be managed with in-line HV voltage regulators where appropriate for relatively low cost. Though this not likely to be applicable in areas of the HV network which are run normally interconnected.

To mitigate localised over-voltages on the LV network, LV cables could be overlaid or the LV feeder split to reduce voltage rise.

1.3 Sensitivity to EV Charging Controllability

Preliminary results for the EV charging controllability sensitivity analysis indicate that it is likely that a materially higher level of investment will be required if there is limited control of EV fast charging. The use of tariff led slow charging for EVs should generally result in reduced investment compared to the updated scenario assessments that use Workstream 3 EV charging profiles. However, this should be considered in the context of the feeder diversity across the network. If there is little variation between daytime peak demand and night time minimum demand due to Economy 7 heating for example then tariff led EV charging along with EV clustering may actually create a new demand peak at night.

If EV charging is tariff led then this also implies a reduced netting off of PV generation during daytime hours which may influence investment requirements associated with generation uptake.

1.4 Network Solutions

Currently, SPEN reinforce their distribution networks using conventional solutions in the vast majority of cases. Typically this would be based on more substations or increased transformer capacity and/or larger or more cables/overhead lines. The analysis carried out indicates that in the future, there will be a business case for utilising a variety of smart solutions instead of a purely conventional network reinforcement philosophy to resolve network issues and provide additional network capacity. This is consistent with outcomes from the Work stream 3 model by EATL.

To address thermal and voltage legroom issues, conventional and smart solutions were applied depending on the rate of demand growth. For high demand growth, conventional solutions were required, to provide enough headroom sufficient for a minimum of 5 years. Once deployed, these provide a large increase in local network capacity. Smart solutions are better suited to mitigating issues associated with lower rates of demand growth. This provides some flexibility in terms of the ability to delay of network investment and increase certainty of demand growth.

1.5 Network Investment

1.5.1 Cost Metrics

The total cost of reinforcement investment for LCT demand and generation was quantified for all three sample networks as shown in Table 5.

Table 5 Total Reinforcement Investment for Representative Networks

Investment (£m)	*Northwich*		*L&L*		*Kilsyth*	
	Generation	*Demand*	*Generation*	*Demand*	*Generation*	*Demand*
Scenario 1	0.5	9.6	0.1	2.6	0.04	3.5
Scenario 2	0.2	9.4	0.1	2.5	0.04	3.0

The cost of reinforcement per MW of LCT demand and generation was then derived on an annual basis. The average was based on the total investment required for each network (for generation or demand) to 2030 divided by the total MWs of generation or demand related LCT connected by 2030. The maximum was based on the total annual investment required (for generation or demand) divided by the total MWs of LCT generation or demand connected since the last investment. It provides an indication of the 'lumpiness' of the investment profile.

The average and maximum are provided in Table 6. This cost metric is somewhat decoupled from the existing network capacity in 2012 and provides a useful indicator of investment requirements by volume of LCT.

The maximum annual cost of reinforcement per additional MW of LCT indicates that there is significant variation of the annual cost metric. This is due to large reinforcements such as new primary substations requiring high levels of investment but generally providing enough network capacity to minimise additional reinforcements for a longer period of time.

It can be seen that at this stage, little investment is anticipated for the levels of PV uptakes modelled. Over-voltages due to PV can be managed by adjusting the voltage set-points for primary and secondary transformers and these are relatively low cost solutions. However, this will be dependent on the level of clustering of PV installations on the LV network and the timing of LCT generation and demand uptakes.

Table 6 Reinforcement Investment Cost Metrics for Representative Networks

Cost Metric (£m/MW)	*SPM*				*SPD*	
	Northwich		*L&L*		*Kilsyth*	
	Generation	*Demand*	*Generation*	*Demand*	*Generation*	*Demand*
Scenario 1 Ave	0.04	0.36	0.03	0.29	0.007	0.25
Scenario 1 Max	0.06	1.12	0.05	0.83	0.011	1.09
Scenario 2 Ave	0.02	0.37	0.03	0.29	0.007	0.21
Scenario 2 Max	0.03	1.16	0.05	0.74	0.022	0.96

Investment cost per MW of LCT demand is relatively consistent for all three sample networks. The meshed Northwich network requires the highest investment per MW of demand connected. This is partly due to Northwich having less existing demand headroom compared to the two other networks modelled and the behaviour of a meshed network under excessive loading i.e. meshed network capacity is exceeded in multiple areas simultaneously.

1.5.1.1 PV Clustering

Reinforcement investment metrics for assessment of sensitivity to PV clustering are provided in Table 7.

Table 7 Reinforcement Investment Cost Metrics for Representative Networks for PV Clustering

	SPM		*SPD*	
	Northwich		*Kilsyth*	
	Generation	*Demand*	*Generation*	*Demand*
Scenario 1 (£m)	0.3	9.6	0.04	3.4
Scenario 1 Ave (£/m)	0.02	0.36	0.007	0.24

This indicates little difference to Scenario 1 investment results for representative networks. Key findings for PV clustering sensitivity are discussed in more detail earlier in Section 1.2. High clustering will increase local investment requirements and may require upgrade of the LV network in case of heavily loaded feeders suffering from under-voltage (due to voltage set point reduction).

1.5.2 Networks

Forecast investment for RIIO-ED1 for Scottish Power Manweb (SPM) and Scottish Power Distribution (SPD) are shown in Table 8 for the LCT uptakes applied. This is based on scaling of required investment for the representative network areas to the licence areas. Consideration is given to network type (rural, suburban and urban) and representative HV network group demand headroom compared to average licence area HV network group headroom. Please note that the size of the Kilsyth representative network is comparatively less than the Northwich and Llynclys/Llansilin representative networks as a proportion of the respective licence areas. Thus, scaling of investment for the SPD licence area may be more sensitive to the specific characteristics of the Kilsyth network although these characteristics should be broadly representative of other SPD network groups.

Table 8 Forecast Reinforcement Investment for SPM and SPD licence areas.

Investment (£m)	***SPM***		***SPD***	
	ED1	***ED2***	***ED1***	***ED2***
Scenario 1	61.2	436.0	93.9	536.7
Scenario 2	68.7	398.2	90.4	454.3

LCT uptake increases rapidly from 2019 onwards and this has a significant influence on the network issues experienced in late ED1/early ED2 and the investment required. Significantly less investment is required in ED1 compared to ED2 for both SPM and SPD although specific network investment requirements in ED1 will depend on capacity within individual network groups.

For both SPM and SPD, investment requirements are primarily at HV for new primary substations, new or uprated secondary substations and cable and overhead line reinforcement. Investment at LV is for cable overlays and new LV meshed feeders. Investment for both licence areas is forecast to be primarily in conventional reinforcement solutions due to the rate of LCT uptake. Conventional solutions are also generally more costly so form a larger balance of costs.