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Transform Model Analysis and Support

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Transform Model Analysis and Support

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Transform Model Analysis and Support

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Transform Model Analysis and Support

by

Manuel Castro and Laurence Elner

Summary

As part of the revision to RIIO-ED1 business plan submission, Scottish Power Energy Networks (SPEN) have sought specialist advisory support from EA Technology to validate key elements of the Transform Model to project the future expenditure required to manage the connection of Low Carbon Technologies (LCTs) to the distribution network.

In order to address the questions raised by SPEN in the project proposal, EA Technology has developed detailed analyses to:

- Review the network specific parameters used to represent the distribution networks of the Scottish Power Distribution (SPD) and Scottish Power Manweb (SPMW) licence areas.
- Review the uptake levels of various LCTs (in particular PV) and benchmark against other distribution licence areas in Great Britain (GB).
- Quantify the SPMW electricity distribution infrastructure requirements to accommodate future levels of LCTs, identification of the drivers for network investment and their respective impact.

The key findings of the analyses performed by EA Technology can be summarised as follows:

- SPD LCT expenditure for the RIIO-ED1 period falls by 20% when unit costs for conventional solutions are corrected and optimism bias for conventional solutions is removed.
- SPMW LCT expenditure for the RIIO-ED1 period falls by 19% when unit costs for conventional solutions are corrected and optimism bias for conventional solutions is removed.
- SPMW LCT expenditure for the RIIO-ED1 period falls by a further 17% when an additional low-cost small-transformer replacement solution is added to the Transform solution set.
- Using the corrected unit cost rates and enabling the low-cost small-transformer replacement solution reduces benchmark cost rates (expressed as £/MW LCT) from £43.5k/MW (SPD) and £38.6k/MW (SPMW) to £34.6k/MW and £24.7k/MW (SPD and SPMW respectively) – both coming in below the GB average figure of £35.8k.
- Investment in network assets is split between thermal overloading (i.e. investment driven by load) and voltage headroom constraints (i.e. investment driven by generation). Specifically, within the 2015 – 2022 period, 41% (i.e. £10m) of the overall expenditure for network investment is driven by load whilst 59% (i.e. £14m) is driven by generation. Alternatively, within the 2016 – 2023 period, 58% (i.e. £19m) of the overall expenditure for network investment is driven by load whilst 42% (i.e. £14m) is driven by generation.
- SPMW distribution network is designed to be operated as a meshed network, thus benefiting from the capability of sharing loads amongst circuits, in particular LCTs. Therefore, the need for intervention in meshed networks is lesser than in radial networks. SPMW radial (i.e. rural) networks

drive 71% of the overall investment while meshed (i.e. urban) networks are only responsible for 29% of the overall investment over RIIO-ED1 period.

- The cost of a particular network intervention in meshed networks to release headroom is generally higher than the cost of intervention in radial networks. Since the number of meshed networks requiring intervention in the SPMW licence area is substantially lower than radial networks, then the overall investment expenditure in network assets in the meshed networks becomes lower than that of the radial networks.
- Operating SPMW distribution network as a meshed network enabling increased asset utilisation and with relatively high thresholds for network intervention assets permits the deferral of initial network investment. Going forward, as the uptake levels of LCTs grow, SPMW distribution network does require significant expenditure for network investment as the smaller, more incremental headroom release solutions become less effective.
- Over RIIO-ED1 period, the expenditure required for network assets in the SPMW network is 29% lower than that required in the GB representative network[1] both under the SPEN "best-view" scenario for SPMW licence area.
- It has been demonstrated that the overarching trends identified through analysing the investment profiles for SPMW distribution network over the RIIO-ED1 period are consistent, irrespective of exactly which years are examined, or the precise numbers of LCTs to be connected. In other words, the split between investment in radial and meshed networks and the shift in investment from LV networks towards HV networks are consistent and robust trends whether examining the 2015 – 2022 period, or the 2016 – 2023 period.

[1] It should be stressed that the GB "representative" distribution network is merely a scaled down version (i.e. by number of customers) of the entire GB network that was agreed by all DNOs and does not attempt to represent any specific geographic factors. Based upon this approach, a 'representative' network serving the same number of customers as the SPMW network can be used for comparison such that the levels and types of investment observed are directly comparable.

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1 Introduction

1.1 Context

As part of the revision to RIIO-ED1 business plan submission, Scottish Power Energy Networks (SPEN) have sought specialist advisory support from EA Technology Ltd to validate key elements of the Transform Model to project the future expenditure required to manage the connection of Low Carbon Technologies (LCTs) to the distribution network.

This work looks at the particulars of the SPEN licence areas to establish whether the networks are being adequately represented within the Transform Model and to review the uptake levels of various LCTs over the RIIO-ED1 period. Moreover, this work provides detailed analysis of the drivers and their impact on the SPMW electricity distribution infrastructure development to accommodate future levels of LCTs.

1.2 Objectives

The objective of the work presented in this report is provide detailed analysis on the:

- Review of the network specific parameters used to represent the distribution networks of the Scottish Power Distribution (SPD) and Scottish Power Manweb (SPMW) licence areas;
- Review of the uptake levels of various LCTs (in particular PV) and benchmark against other distribution licence areas in Great Britain (GB); and
- Quantification of the SPMW electricity distribution infrastructure requirements to accommodate future levels of LCTs, identification of the drivers for network investment and their respective impact.

1.3 Scope of work

In accordance with the project proposal, the analyses performed by EA Technology are based upon the network specific parameters provided and used by SPEN to represent its two distribution networks SPD and SPMW within the Transform Model.

EA Technology has benchmarked the expenditure required for network assets in the SPEN networks against a GB representative distribution network.

1.4 Structure of the report

This report details the approach, analyses and key findings of the work developed by EA Technology as a response to the project proposal commissioned by SPEN. The remainder of this report is structured as follows:

- Section 2 describes the details of the approach developed by EA Technology to address SPEN's questions.
- Section 3 reviews SPEN distribution network models used as a basis for Transform Model.
- Section 4 reviews LCT uptake levels used by SPEN distribution network models.
- Section 5 presents the drivers for network assets investment in SPMW and assesses their impact.
- Section 6 summarises the key findings of the work.

2 Approach

This section provides details of the approach followed by EA Technology to address the work plan specified in the project proposal. Figure 1 depicts an overview of the approach.

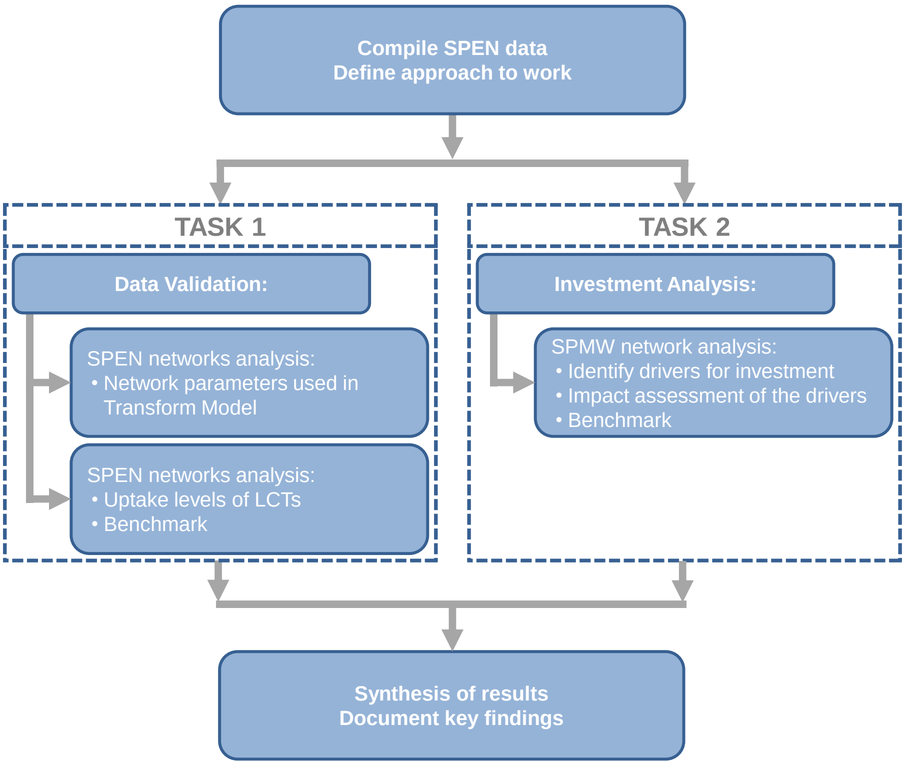

Figure 1: Overview of the overall approach

In order to address the questions raised by SPEN in "Task 1" of the project proposal, EA Technology reviewed and analysed: (i) network specific parameters used by SPEN to represent the distribution networks of the SPD and SPMW licence areas; and (ii) the uptake levels of various LCTs and benchmarked them against other distribution licence areas in GB.

In order to address the questions raised by SPEN in "Task 2" of the project proposal, EA Technology quantified and assessed the SPMW electricity distribution infrastructure requirements to accommodate future levels of LCTs, identified the drivers for network investment and their respective impact. The approach adopted is structured in the following main steps:

- Step 1: To quantify the overall level of future investment requirements in the SPMW distribution network and assess their respective drivers.
- Step 2: To map the overall network investment drivers (i.e. Step 1) into the individual representative networks of the SPMW licence area. This enables identification of the individual representative network types and characteristics (i.e. radial, meshed, urban, etc.) and quantifying their individual investment contribution towards the overall network investment.
- Step 3: To map the individual representative network investment drivers (i.e. Step 2) into the specific network solutions deployed and to identify their respective drivers (i.e. network type, headroom type, headroom level, solutions cost, uptake level of LCTs, etc.).
- Step 4: To benchmark the SPMW network investment propositions against a Great Britain (GB) representative distribution network in order to investigate the impact of the drivers for investment in networks designed to be operated as radial networks in contrast to meshed networks.

The analyses are based on the detailed application of the Transform Model developed by EA Technology and extensively used by Distribution Network Operators (DNOs) as a network investment and planning tool to support the development of their business plans for RIIO-ED1 and by Ofgem.

As EA Technology does not have access to all DNO-specific Transform Model implementations, a "representative" network has been constructed for comparison and benchmarking purposes. This is formed from taking the overall GB model populated with the parameters agreed with all DNOs through previous work[2,3] and scaling it to the proportion of customers connected to the SPMW distribution network. This allows a "representative" network serving the same number of customers as the SPMW network to be used for comparison such that the levels and types of investment observed are directly comparable. In this way, any peculiarities brought about by the way in which the SPMW network has been designed or is operated can be identified and the way in which the Transform Model deals with these specific issues can be analysed.

It should also be noted that SPEN have reviewed and updated the Transform Model to represent the two distribution networks SPD and SPMW as closely as possible. SPEN provided this data to EA Technology and it is this version of the model that has been used for this analysis.

3 Review of SPEN distribution network models

EA Technology has conducted a review of the Transform Model implementations used by SPEN to represent the two distribution networks SPD and SPMW has established the following key points:

- Unit costs needed to be modified for some solutions to account for the way in which the interconnected network is constructed and the fact that splitting feeders and replacing transformers involves a different level of work than would be found on radial networks.
- Optimism bias was being applied to conventional solutions, such as those outlined above, and this has now been removed (in line with common practice).
- The costs associated with replacing certain assets were excessive as the Transform Model assumed asset sizes for the replacement. This has led to the inclusion of a new solution to replace a 'small' transformer (with associated lower costs) in certain circumstances.

3.1 Headline changes in expenditure

Through implementing the adjustments highlighted in the above section, the RIIO-ED1 expenditure for SPD and SPMW has been reduced as follows:

- SPD LCT expenditure falls by 20% when unit costs are corrected and optimism bias for conventional solutions is removed.
- SPMW LCT expenditure falls by 19% when unit costs are corrected and optimism bias for conventional solutions is removed.
- SPMW LCT expenditure falls by a further 17% (i.e. -36% overall) when an additional low-cost small-transformer replacement solution is added to the Transform solution set.
- Using the corrected unit cost rates and enabling the low-cost small-transformer replacement solution reduces benchmark cost rates (expressed as £/MW LCT) from £43.5k/MW (SPD) and £38.6k/MW (SPMW) to £34.6k/MW and £24.7k/MW (SPD and SPMW respectively) – both coming in below the GB average figure of £35.8k.

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[2] EA Technology et al., Aug 2012. "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks"
[3] EA Technology, Jun 2013. "Analysis of Least Regrets Investments for RIIO-ED1".

3.2 Conclusions

By examining the SPEN Transform Models, several areas have been identified where improvements have been made to the accuracy of the representation of the SPD and SPMW networks, and consequently, the levels of expenditure required during RIIO-ED1.

4 Review of LCT uptake levels

4.1 Solar PV generation

EA Technology has conducted a review of the uptake levels of solar PV within the two SPEN licence areas. Table 1 and Table 2 present the uptake levels of PV considered in the DECC's low and high scenarios respectively.

In order to compare distinct licence areas, customer numbers per area have been used as a proxy to create an apportionment of DECC's projections for PV uptake in GB. This apportionment has then been scaled to be representative of 3.6kW PV units.

Table 1: PV uptake levels for DECC low scenario

Licence area	Customer numbers	2015 Transform PV values		2030 Transform PV values	
		PV uptake % (3.6kW PV installation per customer)	Ranking (descending)	PV uptake % (3.6kW PV installation per customer)	Ranking (descending)
WMID	2,446,951	3.6	5	8.7	6
EMID	2,614,165	3.6	6	8.9	5
ENWL	2,359,391	3.3	10	8.3	10
NPGN	1,575,686	3.3	11	8.3	11
NPGY	2,258,404	3.4	7	8.6	7
SWales	1,099,333	3.4	8	8.5	8
SWest	1,541,188	5.7	1	11.7	1
LPN	2,251,892	3.1	12	6.6	13
SPN	2,233,288	4.9	2	10.2	2
EPN	3,516,859	4.8	4	9.8	4
SPD	1,992,998	2.2	13	6.8	12
SPMW	1,485,153	3.3	9	8.4	9
SSEH	740,768	2.1	14	6.3	14
SSES	2,934,581	4.9	3	10.0	3
Total	29,050,657				
Mean	2,075,047	3.7		8.6	
Median	2,242,590	3.4		8.5	

Table 2: PV uptake levels for DECC high scenario

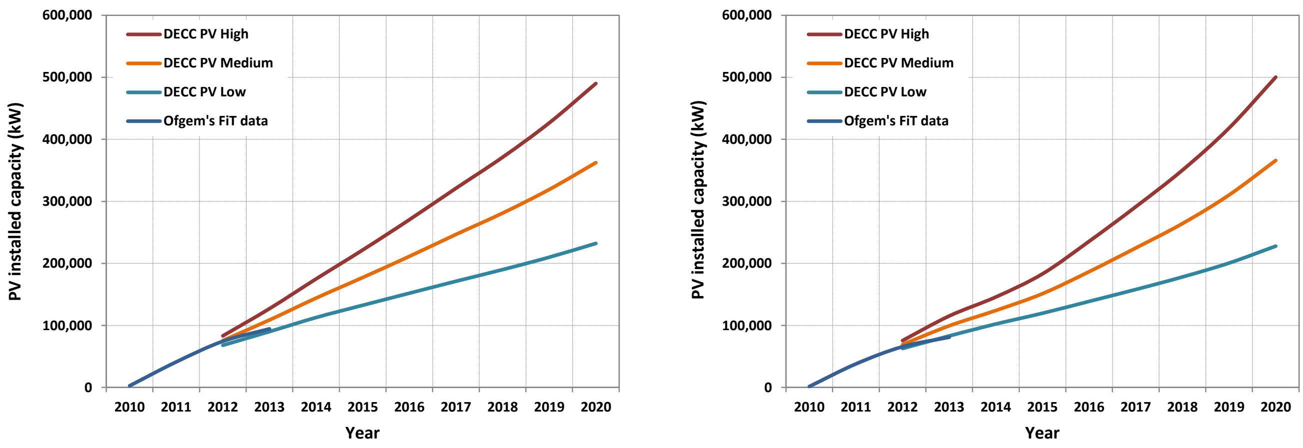
Licence area	Customer numbers	2015 Transform PV values		2030 Transform PV values	
		PV uptake % (3.6kW PV installation per customer)	Ranking (descending)	PV uptake % (3.6kW PV installation per customer)	Ranking (descending)
WMID	2,446,951	3.6	5	9.1	6
EMID	2,614,165	3.6	6	9.4	2
ENWL	2,359,391	3.3	10	8.9	9
NPGN	1,575,686	3.3	11	8.9	10
NPGY	2,258,404	3.4	7	9.2	3
SWales	1,099,333	3.4	8	9.1	5
SWest	1,541,188	5.8	1	10.5	1
LPN	2,251,892	2.8	12	6.2	14
SPN	2,233,288	5.0	3	9.2	4
EPN	3,516,859	4.8	4	8.9	11
SPD	1,992,998	2.0	13	8.9	12
SPMW	1,485,153	3.3	9	9.0	8
SSEH	740,768	1.9	14	7.6	13
SSES	2,934,581	5.0	2	9.0	7
Total	29,050,657				
Mean	2,075,047	3.7		8.8	
Median	2,242,590	3.4		9.0	

The review process has found that, when compared against DECC's scenarios (not against individual DNO best-view scenarios as this data is not available within the Transform Model):

- The number of PV installations for SPMW per connected customer was found to be the 9th and 8th highest out of the fourteen DNO licences for the low and high scenarios respectively.
- In each case, the uptake level is very slightly below both the mean and median of the fourteen DNO licences.
- The number of PV installations for SPD per connected customer was found to be the 13th and 12th highest out of the fourteen DNO licences for both the low and high scenarios.
- In each case, the uptake level is significantly below both the mean and median of the fourteen DNO licences.

It could therefore be stated that the uptake levels for the two SPEN licences did not seem to be excessively high.

Further work was undertaken to analyse how SPD and SPMW licence areas are tracking against DECC's PV projections thus far. For this purpose, Ofgem's FiT data has been used. Figure 2 illustrates the actual PV uptake over the last 3 years against the DECC projections.



(a) SPD network **(b) SPMW network**

Figure 2: Uptake levels of PV

By comparing these datasets, it could be observed in Figure 2 that for SPD and SPMW, the historic trend suggests that uptake levels are closely following the DECC “low” solar PV uptake levels and this can then be used to help inform the SPEN “best-view” of likely solar PV uptake for the future.

4.2 Conclusions

By examining the historic uptake levels of LCTs a better defined view of the likely levels of solar PV generation connecting to SPEN has been formed. In turn, this will allow a more accurate picture of the associated network expenditure to be constructed.

5 SPMW network investment analysis

This section quantifies and assesses the electricity distribution infrastructure requirements to accommodate future levels of LCTs in the SPMW network, identifies their drivers and measures their respective impact.

In this respect, the Transform Model is applied to SPEN’s “best view” scenario (i.e. scenario data provided by SPEN) representative of the SPMW licence area to provide an in-depth understanding of:

- “*How*” much future network investment is required to integrate LCTs in a technical and economically efficient manner;
- “*What*” solutions (i.e. conventional and/or smart) to deploy in the future network to efficiently integrate LCTs;
- “*Where*” in the network to install the technologies; and
- What are the drivers for network investment in the SPMW licence area and their measurable impact.

The analyses are performed for an eight year time horizon representative of the RIIO-ED1 period (i.e. 2015 – 2022[4]).

[4] The Transform Model works on the basis of calendar years rather than financial years, meaning that all RIIO-ED1 analysis is always carried out on the basis of January 2015 – December 2022

In addition, the analyses benchmark the SPMW distribution network investment strategies against a GB representative distribution network of similar characteristics and size. This allows an investigation into the impact of drivers for investment in distribution networks designed to be operated as meshed networks, such as SPMW, against those designed to be operated as radial networks, such as the majority of GB distribution networks.

5.1 SPMW network investment

This subsection quantifies the overall level of future investment requirements in the SPMW distribution network and assesses their respective drivers (i.e. Step 1).

Figure 3 details how much future investment is required in the SPMW distribution network for RIIO-ED1 period.

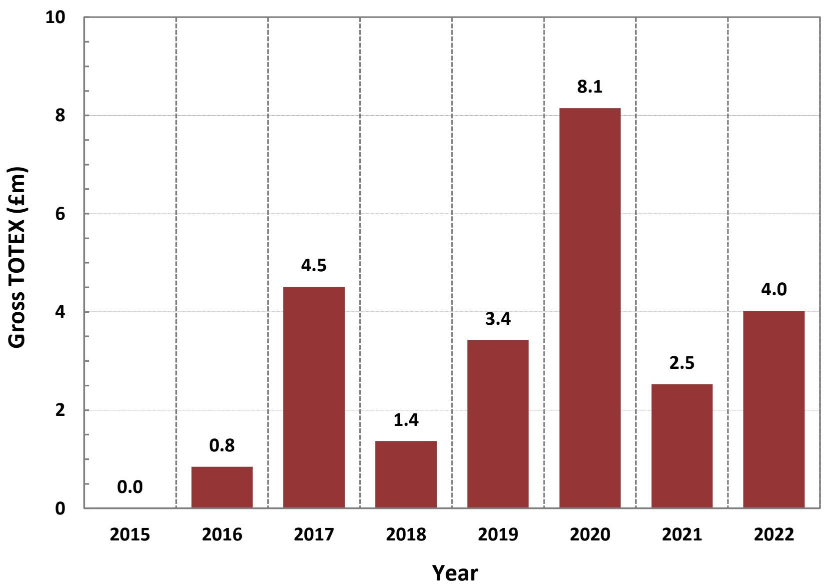


Figure 3: SPMW network investment for RIIO-ED1

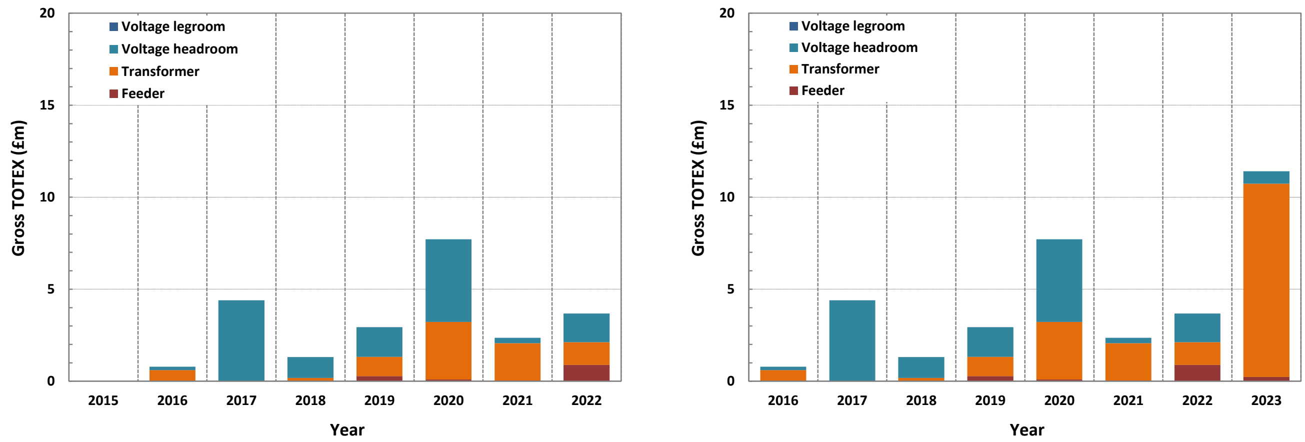
Figure 3 shows that the level of investment in network assets is relatively low in the initial years of the RIIO-ED1 period. It can be observed there are low or no network investments early in the period due to the relatively high thresholds of network intervention[5] specified by SPEN and due to the relatively low uptake levels of LCTs. Furthermore, the SPMW distribution network is designed to be operated as a meshed network, thus benefiting from the capability of sharing loads amongst circuits. The combined effect of these inherent characteristics of SPMW networks leads to less need for intervention in meshed networks compared to radial networks.

It is observed in Figure 3 that investment in network assets is required year-on-year throughout the RIIO-ED1 period. The magnitude of the total gross expenditure for the period is estimated to be £25m[6] (i.e. £19m discounted TOTEX). Broadly, this expenditure is driven by the presence of increasing levels of LCTs that require the deployment of a mixture of conventional and smart network solutions to mitigate network integration challenges.

[5] DNOs set the threshold at which they intervene in the network (e.g. generally expressed as a percentage of the rating of the asset). SPMW network intervention thresholds are found to be on average 18% higher than the GB representative network average. This means that SPMW utilise their assets much more significantly before applying a network intervention. Table 7 provides further details on the distribution network intervention thresholds for SPMW and GB.

[6] Number in Figure 3 may not sum due to rounding.

The analysis is extended to identify the drivers for the overall investment requirements in the SPMW distribution network. Thus, Figure 4 presents the drivers for prompting investment in terms of overloaded feeders, transformers and voltage headroom and legroom problems. Figure 4a introduces the gross TOTEX for RIIO-ED1 period based on calendar years (i.e. as in Transform Model) whilst Figure 4b extends the analysis a year further to capture the end of the financial year 2022 – 2023.



(a) Period: 2015 – 2022 **(b) Period: 2016 – 2023**

Figure 4: SPMW network investment drivers for RIIO-ED1

It is seen in Figure 4 that network investments are carried out as a consequence of thermal and voltage issues. Specifically, Figure 4a shows that thermal related investments (i.e. those driven by increased load) account for £10m and voltage headroom investments (i.e. those driven by increased generation) account for £14m of the overall network investments in the SPMW licence area. In other words, 41% of the overall expenditure for network investment is driven by overloaded feeders and transformers whereas 59% is driven by scarcity on voltage headroom caused by increased generation.

Figure 4b shows that considering the period of analysis to be 2016 – 2023, thermal related investments (i.e. load) are of the magnitude of £19m whilst voltage headroom related investments (i.e. generation) are of the order of £14m. Thus, 58% of the overall expenditure for network investment is driven by thermal issues due to increased load and 42% is driven by voltage headroom issues due to increased generation.

5.2 SPMW network specific investment

This subsection maps the overall network investment levels and respective drivers (i.e. Subsection 5.1) into the individual representative networks of the SPMW licence area. This enables identifying the individual representative network types and characteristics (i.e. radial, meshed, urban, etc.) and quantifying their individual investment contribution towards the overall network investment (i.e. Step 2).

The overall network investment levels are disaggregated by the individual representative networks of the SPMW licence area. The analysis identifies which networks are responsible for triggering investment and how much they contribute to the overall network investment requirements. Table 3 introduces the network specific investment levels as a percentage of the overall TOTEX during the period of analysis.

Table 3: SPMW network specific investment for RIIO-ED1 (% of the overall TOTEX)

Network	Network investment (% of overall TOTEX)
EHV2 Urban underground meshed	1.9
EHV4 Suburban mixed meshed	0.3
EHV5 Rural overhead radial	0
EHV6 Rural mixed radial	0
HV2 Urban underground meshed	1.7
HV4 Suburban underground meshed	0.0
HV6 Rural overhead radial	9.9
HV7 Rural mixed radial	7.9
LV4 Business park	0
LV7 New build housing estate	2.5
LV8 Terraced street	13.4
LV9 Rural village (overhead)	1.5
LV10 Rural village (underground)	4.7
LV11 Rural farmsteads small holdings	31.4
LV12 Meshed central business district	0
LV13 Meshed dense urban	5.7
LV14 Meshed town centre	0
LV15 Meshed business park	0
LV16 Meshed retail park	0
LV17 Meshed suburban street	5.8
LV18 Meshed new build housing estate	0.2
LV19 Meshed terraced street	13.1

Table 3 shows that the individual representative networks driving future investments in the SPMW licence area are the following (also highlighted in red in Table 3):

- HV6 Rural overhead radial;
- HV7 Rural mixed radial;
- LV8 Terraced street;
- LV11 Rural farmsteads small holdings; and
- LV19 Meshed terraced street.

It can be inferred from Table 3 that the bulk of expenditure in the SPMW network is driven by interventions on radial networks as opposed to meshed networks. Moreover, investment in network assets are primarily required in the low voltage (LV) networks and then transferred on to higher voltage (HV) networks that are directly connected. These findings are further explored below in greater detail.

The overall network investment levels are disaggregated by network type to benchmark the contribution to network investment of radial networks against meshed networks. Table 4 introduces the network investment levels as a percentage of the overall TOTEX during the period of analysis.

Table 4: SPMW network investment by network type (% of the overall TOTEX)

Network topology	Network investment (% of overall TOTEX)
Radial	71
Meshed	29

Table 4 demonstrates that the SPMW radial networks drive 71% of the overall investment while meshed networks are only responsible for 29% of the overall investment during the period of analysis. The intrinsic nature of the SPMW radial networks, particularly in rural areas, is such that these networks possess limited thermal headroom at the start of the RIIO-ED1 period, meaning that investment in network assets is required to accommodate the load growth associated with LCTs. SPMW distribution network is also designed to be operated as a meshed network, thus benefiting from the capability of sharing loads amongst circuits. SPMW meshed networks are also characterised by a relatively high level of asset headroom at the beginning of the period, leading to less need for intervention in meshed networks compared to radial networks. Table 5 specifies the level of thermal headroom available before intervention on the SPMW network at the start of the RIIO-ED1 period.

Table 5: SPMW network intervention threshold thermal headroom at the start of RIIO-ED1 period

Network	Intervention threshold thermal headroom (kW)
EHV2 Urban underground meshed	5,788
EHV4 Suburban mixed meshed	5,048
EHV5 Rural overhead radial	10,921
EHV6 Rural mixed radial	10,715
HV2 Urban underground meshed	4,571
HV4 Suburban underground meshed	2,416
HV6 Rural overhead radial	2,574
HV7 Rural mixed radial	2,489
LV4 Business park	124
LV7 New build housing estate	34
LV8 Terraced street	38
LV9 Rural village (overhead)	69
LV10 Rural village (underground)	34
LV11 Rural farmsteads small holdings	3
LV12 Meshed central business district	110
LV13 Meshed dense urban	115
LV14 Meshed town centre	123
LV15 Meshed business park	165
LV16 Meshed retail park	146
LV17 Meshed suburban street	98
LV18 Meshed new build housing estate	99
LV19 Meshed terraced street	69

It can be seen in Table 5 that the networks with lower headroom levels within a specific voltage level and network topology (i.e. radial or meshed) broadly correspond to the networks that drive the overall network investment expenditure presented in Table 3.

For LV networks, LV7, LV8, LV10 and LV11 radial networks register the lowest available starting headroom with LV8 and LV11 driving the most network investment within LV radial networks. For meshed networks, LV19 networks have the tightest available starting headroom and are responsible for driving investment within LV meshed networks.

For HV networks, HV6 and HV7, which are directly connected to LV7, LV8 and LV11, present the most constrained levels of available starting headroom and are observed to drive the most of the investment expenditure within HV networks during the RIIO-ED1 period (refer to Table 3 for network specific investment).

The network investment requirements in terms of overall expenditure are grouped by LV and HV networks. Figure 5 displays the cumulative levels of SPMW network investment expenditure for the RIIO-ED1 period.

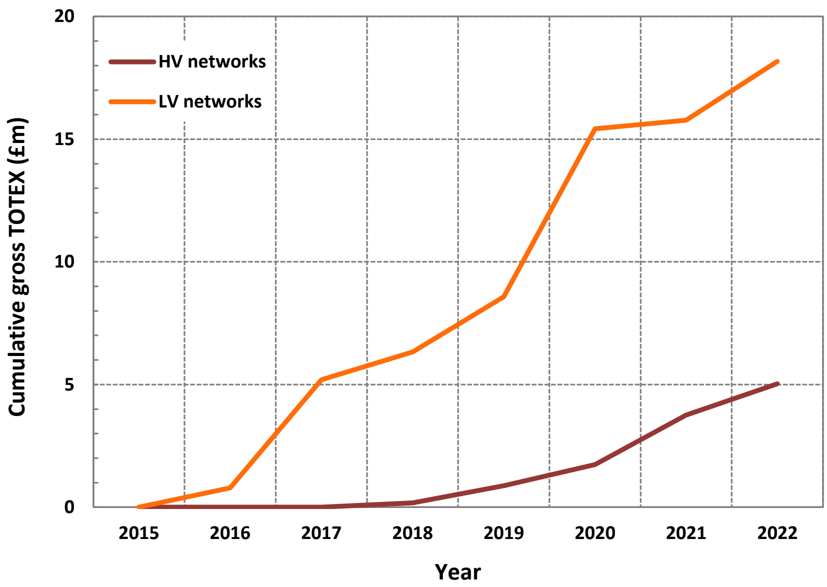


Figure 5: SPMW network investment by voltage level for RIIO-ED1

It can be seen in Figure 5 that investment in network assets is primarily required in the SPMW LV networks in order to accommodate the localised increasing levels of LCTs that are directly connected at the LV level. As a consequence, low or no investment in HV network assets is registered at the beginning of the RIIO-ED1 period. As the presence of LCTs rise in the network towards the middle of the period, investing in LV network assets only is not sufficient owing to the aggregation of LCTs in certain areas and therefore intervening in the SPMW HV networks becomes necessary.

5.3 SPMW network specific solutions investment

This subsection maps the network solutions deployed in the SPMW distribution licence area into the individual representative networks identified to drive significant network investment levels (i.e. Subsection 5.2). In particular, the analysis investigates:

- Which solutions (i.e. conventional and/or smart) to deploy in the future network to efficiently integrate LCTs;
- Where in the network to install the technologies; and
- How much of the overall investment they drive (i.e. Step 3).

In this sense, Table 6 shows the network solutions deployed and associated cost of intervention for the representative networks of SPMW licence area.

Table 6: SPMW network – network solutions deployed and associated costs

Network	Solution	Cost per intervention (£)	Number of networks	Network cost per intervention (£)
HV6 Rural overhead radial	4x Small 33/11 txfmr	499,765	337	2,107,343
	Generator for network support - HV	13,200		22,264
HV7 Rural mixed radial	4x Small 33/11 txfmr	499,765	276	1,724,190
LV8 Terraced street	3x LV Underground network split feeder	114,989	2,341	2,243,238
	4x LV Ground mounted 11/LV txfmr	17,591		514,763
	Generator for network support - LV	2,640		154,506
LV11 Rural farmsteads	2x LV Overhead minor works	51,106	22,290	5,695,755
	Switched capacitors - LV	11,110		1,238,208
LV19 Meshed terraced street	2x LV Underground network split feeder	76,659	6,804	2,607,939
	LV Ground mounted 11/LV txfmr	4,398		149,613
	RTTR for HV/LV txfmrs	2,860		97,297

It can be observed in Table 6 that the sum of "cost per intervention" deployed to release headroom in radial networks (e.g. LV11) is lower than that for meshed network (e.g. LV19). Nonetheless, as the number of LV11 radial networks is remarkably higher than LV19 meshed the sum of the "network cost per intervention" in the radial networks becomes approximately two times greater than that of the meshed networks.

For LV networks, network investment requirements are mostly driven by splitting feeders on the underground network (i.e. "LV Underground network split feeder") and by performing minor works on the overhead network (i.e. "LV Overhead minor works"). For HV networks, the deployment of "Small 33/11 transformers" constitute the driver for the overall network investment expenditure.

5.4 Benchmark network investment

This subsection benchmarks the SPMW distribution network investment strategies against GB representative distribution network of similar characteristics and size (i.e. Step 4). The analysis investigates the impact of drivers for investment in distribution networks designed to be operated as meshed networks, such as SPMW, against those designed to be operated as radial networks, such as the majority of GB distribution networks.

Figure 6 details how much future investment is required in the SPMW and representative distribution networks for RIIO-ED1 period.

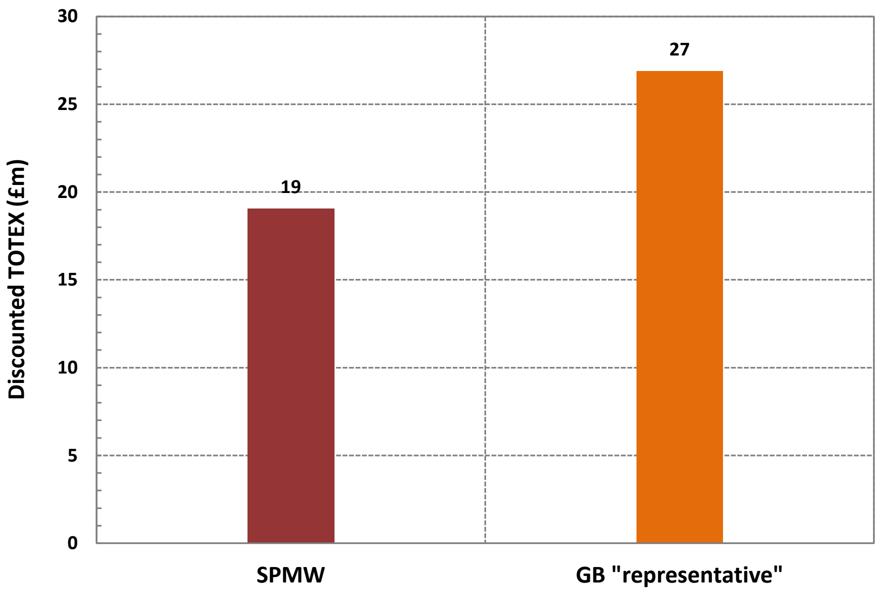


Figure 6: Distribution network investment for RIIO-ED1

Figure 6 shows that the overall level of investment in SPMW network is significantly lower than that required in the GB representative network. The magnitude of the overall network investment is estimated to be £19m for SPMW network and £27m for GB representative network. Broadly, the lower expenditure required in SPMW is driven by higher levels of network intervention threshold headroom adopted by SPEN to reflect the meshed nature of the networks. It should be noted that the metric "intervention threshold headroom" considers the presently available network headroom and the intervention threshold. Table 7 details the levels of intervention threshold headroom in SPMW and GB representative distribution networks.

Table 7: Distribution network intervention threshold headroom[7] at the start of RIIO-ED1 period

Network	SPMW intervention threshold thermal headroom (kW)	GB intervention threshold thermal headroom (kW)
EHV2 Urban underground meshed	5,788	-2,276
EHV4 Suburban mixed meshed	5,048	5,398
EHV5 Rural overhead radial	10,921	4,754
EHV6 Rural mixed radial	10,715	3,829
HV2 Urban underground meshed	4,571	1,592
HV4 Suburban underground meshed	2,416	608
HV6 Rural overhead radial	2,574	-166
HV7 Rural mixed radial	2,489	436
LV4 Business park	124	61
LV7 New build housing estate	34	101
LV8 Terraced street	38	45
LV9 Rural village (overhead)	69	95
LV10 Rural village (underground)	34	36
LV11 Rural farmsteads small holdings	3	34
LV12 Meshed central business district	110	146
LV13 Meshed dense urban	115	266
LV14 Meshed town centre	123	186
LV15 Meshed business park	165	245
LV16 Meshed retail park	146	223
LV17 Meshed suburban street	98	157
LV18 Meshed new build housing estate	99	164
LV19 Meshed terraced street	69	319

It can be seen in Table 7 that the intervention threshold headroom in the SPEN are generally higher than those considered in GB representative distribution network. Practically, SPEN's intervention threshold headroom at the start of the period are estimated to be on average 65% higher than the intervention threshold headroom for the GB representative distribution network. EA Technology has explored in previous work[8], the impact of the magnitude of network intervention thresholds in network investment, concluding for those instances that a 5% increase in all network intervention thresholds results in a 5-7% decrease in network investment requirements (depending on the investment strategy adopted).

The overall network investment levels are disaggregated by network type to benchmark the contribution to network investment of radial networks against meshed networks. Table 8 introduces network investment levels as a percentage of the overall TOTEX during the period of analysis.

Table 8: Distribution network investment by network type (% of the overall TOTEX)

Network topology	SPMW network investment (% of overall TOTEX)	GB network investment (% of overall TOTEX)
Radial	71	65
Meshed	29	35

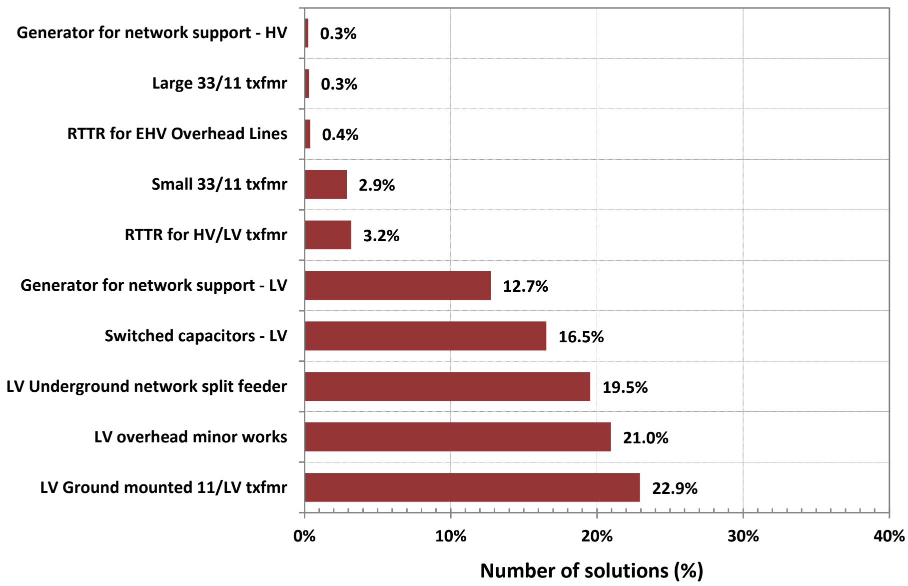
It is observed in Table 8 that the contribution to network investment from the SPMW radial and meshed networks is consistent with that attained for the GB representative distribution radial and meshed

[7] : Negative intervention threshold thermal headroom indicates the current utilisation of the asset is over and above the target threshold for intervention. Given that the Transform Model begins its analysis in 2013, certain feeders can be shown to be overloaded by 2015 in the GB model; characterised here by negative headroom.

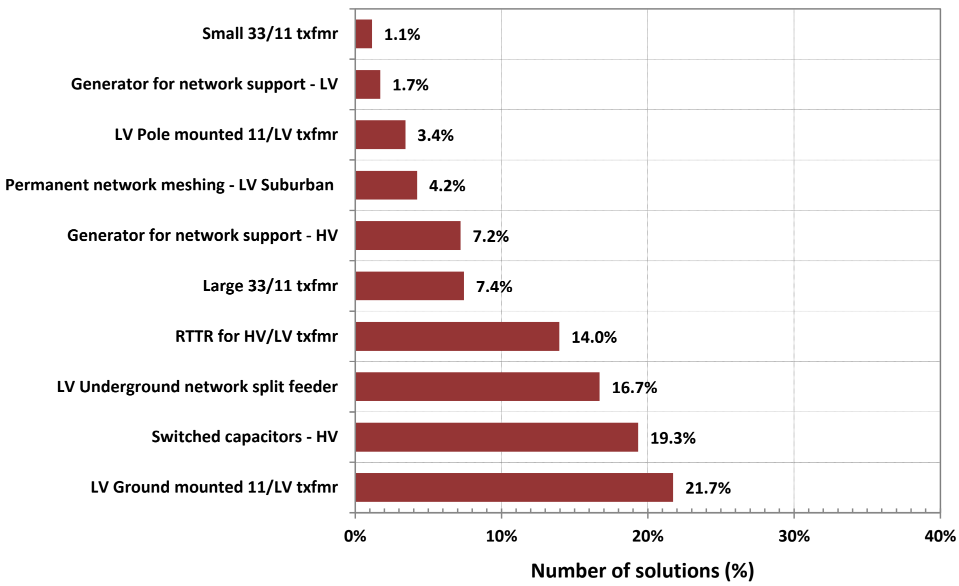
[8] EA Technology et al., Aug 2012. "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks". Refer to Section 8, Figure 8.23 for further details on the impact of network intervention thresholds in network investment.

networks. Consequently, it can be concluded the network intervention thresholds set by SPEN for the SPMW radial and meshed networks are proportionally consistent to those set for GB representative distribution.

The network solutions deployed in the SPMW network are benchmarked against the GB representative distribution network by identifying which, and on how many networks, solutions have been deployed. Hence, Figure 7 presents the ten most deployed network solutions in the SPMW and GB representative distribution networks for RIIO-ED1 period.



(a) SPMW network



(b) GB representative network

Figure 7: Distribution network solutions deployed for RIIO-ED1

Figure 7 shows that SPMW and GB representative distribution networks share in common seven of the ten most deployed network solutions with the “LV Ground mounted 11/LV transformer” being the most deployed solution in both networks. Regarding the deployment of distinct network solutions, it can be seen that for LV networks SPMW favours the deployment of minor works in the LV overhead network (i.e. “LV overhead minor works”) and the deployment of capacitors (i.e. “Switched capacitors - LV”). Similarly, for HV networks “RTTR for EHV overhead lines” is observed in SPMW networks only.

The cost of network solutions deployed in the SPMW network is now benchmarked against the GB representative distribution network and their impact on the overall expenditure of the SPMW networks is evaluated. Table 3 (i.e. Subsection 5.2) identified networks HV7, LV8, LV10 and LV11 to be the drivers for the overall network investment requirements in the SPMW licence area throughout the period of analysis. In this respect and without loss of generality, network “HV7 Rural mixed radial” is used for the purpose of benchmarking the cost of deployment of network solutions. Table 9 details the network solutions deployed and associated costs in the distribution network “HV7 Rural mixed radial” of SPMW and GB during the RIIO-ED1 periods.

Table 9: “HV7 Rural mixed radial” network – network solutions deployed and associated costs

Network model	Solution	Cost per intervention (£)	Overall cost of intervention (£)	Average cost of intervention (%)	Number of networks	Network cost per intervention (£)	Overall network cost of intervention (£)
SPMW	4x Small 33/11 txfmr	499,765	499,765	499,765	276	1,724,190	1,724,190
GB	2x Small 33/11 txfmr	249,883	300,745	100,248	173	215,524	259,393
	Temporary meshing - HV	31,200				26,910	
	RTTR for HV overhead lines	19,663				16,959	

It can be seen in Table 9 the overall network cost of intervention in the HV7 network is estimated to be £1.7m in the SPMW network compared with £0.3m in the equivalent GB network. The analysis suggests that when SPMW does require network investment this is very high. For instance, Table 9 demonstrates that the average cost of intervention in the SPMW licence area is approximately five times higher than in the GB HV7 networks.

A similar analysis has been performed for all the other networks that drive the investment requirements in the SPMW licence area and it has been concluded that operating SPMW distribution network as a meshed network and with significantly high network intervention thresholds defers initial network investment. Going forward, as the uptake levels of LCTs grow, SPMW distribution network does require significant expenditure for network investment because attempting to adopt an incremental approach where solutions that are lower cost and deliver lower headroom gains is not technically and economically efficient in this case. For instance, as the GB “representative” network model presents relatively lower network intervention thresholds than SPMW networks, it benefits from a more gradual investment across the period of analysis. For SPMW networks, the higher levels of intervention threshold results in fewer investment options being available other than to carry out more significant investments when these trigger thresholds are reached. In other words, it may be possible to deploy low cost, low headroom release solutions in the GB model (such as demand response, real time ratings, etc.) but the SPMW model only requires intervention when the load is significantly higher, meaning that such approaches do not represent good value and larger investments to carry out more significant reinforcement are required.

The analysis has also investigated the cost of solutions deployed in the networks that drive very low or no investment requirements in the SPMW network. Table 10 displays the network solutions deployed and associated costs in the “HV6 Rural overhead radial” network of SPMW and GB during RIIO-ED1 period.

Table 10: "HV6 Rural overhead radial" network – network solutions deployed and associated costs

Network model	Solution	Cost per intervention (£)	Overall cost per intervention (£)	Average cost of intervention (£)	Number of networks	Network cost per intervention (£)	Overall network cost of intervention (£)
SPMW	4x Small 33/11 txfmr	499,765	512,965	256,483	337	2,107,343	2,129,607
	Generator for network support - HV	13,200				22,264	
GB	3x Small 33/11 txfmr	374,824	607,739	151,935	338	1,054,192	7,008,241
	3x RTTR for HV overhead lines	39,325				66,361	
	3x Temporary meshing - HV	93,600				263,250	
	3x Switched capacitors - HV	99,990				5,624,438	

It is observed in Table 10 that the overall network cost of intervention in the HV6 network is estimated to be £2m in the SPMW network in contrast with £7m in the equivalent GB network. A similar approach has been adopted for all the other networks that drive very low or no investment requirements in the SPMW licence area and it has been concluded GB distribution networks do need significant levels of network expenditure so that over the RIIO-ED1 period the network expenditure in GB distribution networks is higher than in the SPMW network as demonstrated in Figure 6.

As concluded above, the primary reason for this is the higher intervention threshold headroom within the SPMW network, suggesting that the SPMW network can operate at a higher asset utilisation rate for longer and is therefore more resistant to reasonable levels of LCT uptake for longer periods than would be the case for other networks.

5.5 Conclusions

The analyses performed by EA Technology quantified and assessed the electricity distribution infrastructure requirements to accommodate future levels of LCTs in the SPMW network, identified their drivers and measured their respective impact. Specifically, EA Technology's Transform Model was applied to SPMW representative distribution network under SPEN's "best view" scenario to evaluate:

- "*How*" much future network investment is required to integrate LCTs in a technical and economically efficient manner;
- "*What*" solutions to deploy in the future network to efficiently integrate LCTs;
- "*Where*" in the network to install the technologies; and
- What are the drivers for network investment in the SPMW licence area and their measurable impact.

The key findings of the analysis can be summarised as follows:

- Investment in network assets is required throughout the RIIO-ED1 period. The magnitude of the total gross expenditure for the period is estimated to be £25m (i.e. £19m discounted TOTEX).
- Investment in network assets is mainly driven by thermal overloading of transformers and voltage headroom constraints compelled by the presence of increasing levels of LCTs over the RIIO-ED1 periods.
- SPMW radial networks drive 79% of the overall investment while meshed networks are only responsible for 21% of the overall investment throughout the RIIO-ED1 period.
- Investment in network assets for the SPMW are primarily required in the low voltage networks (i.e. LV7, LV8, LV10, LV11 and LV 19) and then transferred on to higher voltage networks from which these LV networks are fed (i.e. HV6 and HV7).

- The SPMW representative distribution networks driving the highest levels of expenditure for network investment are: “HV6 Rural overhead radial”, “HV7 Rural mixed radial”, “LV8 Terraced street”, “LV10 Rural village (underground)”, “LV11 Rural farmsteads small holdings” and “LV19 Meshed terraced street”.
- The cost of particular intervention in meshed networks to release headroom is generally higher than the cost of intervention in radial networks. Nonetheless, since the number of meshed networks requiring intervention is substantially lower than radial networks, the overall cost of intervention in the meshed networks becomes lower than that of the radial networks.
- The overall expenditure for investment in SPMW networks is driven by the deployment of “Small 33/11 transformers” at HV level and by “Overhead minor works” and “Underground network split feeder” at LV level.
- The benchmark analysis demonstrates the SPMW distribution network investment propositions are consistent with the investment propositions requirements adopted for the GB representative distribution network in terms of overall magnitude of investment and respective drivers (i.e. specific network types and network solutions deployed).

6 Summary of the key findings

The key findings of the analyses performed by EA Technology can be summarised as follows:

- SPD LCT expenditure for the RIIO-ED1 period falls by 20% when unit costs for conventional solutions are corrected and optimism bias for conventional solutions is removed.
- SPMW LCT expenditure for the RIIO-ED1 period falls by 19% when unit costs for conventional solutions are corrected and optimism bias for conventional solutions is removed.
- SPMW LCT expenditure for the RIIO-ED1 period falls by a further 17% when an additional low-cost small-transformer replacement solution is added to the Transform solution set.
- Using the corrected unit cost rates and enabling the low-cost small-transformer replacement solution reduces benchmark cost rates (expressed as £/MW LCT) from £43.5k/MW (SPD) and £38.6k/MW (SPMW) to £34.6k/MW and £24.7k/MW (SPD and SPMW respectively) – both coming in below the GB average figure of £35.8k.
- Investment in network assets is split between thermal overloading (i.e. investment driven by load) and voltage headroom constraints (i.e. investment driven by generation). Specifically, within the 2015 – 2022 period, 41% (i.e. £10m) of the overall expenditure for network investment is driven by load whilst 59% (i.e. £14m) is driven by generation. Alternatively, within the 2016 – 2023 period, 58% (i.e. £19m) of the overall expenditure for network investment is driven by load whilst 42% (i.e. £14m) is driven by generation.
- SPMW distribution network is designed to be operated as a meshed network, thus benefiting from the capability of sharing loads amongst circuits, in particular LCTs. Therefore, the need for intervention in meshed networks is lesser than in radial networks. SPMW radial (i.e. rural) networks drive 71% of the overall investment while meshed (i.e. urban) networks are only responsible for 29% of the overall investment over RIIO-ED1 period.
- The cost of a particular network intervention in meshed networks to release headroom is generally higher than the cost of intervention in radial networks. Since the number of meshed networks requiring intervention in the SPMW licence area is substantially lower than radial networks, then the overall investment expenditure in network assets in the meshed networks becomes lower than that of the radial networks.
- Operating SPMW distribution network as a meshed network enabling increased asset utilisation and with relatively high thresholds for network intervention assets permits the deferral of initial

network investment. Going forward, as the uptake levels of LCTs grow, SPMW distribution network does require significant expenditure for network investment as the smaller, more incremental headroom release solutions become less effective.

- Over RIIO-ED1 period, the expenditure required for network assets in the SPMW network is 29% lower than that required in the GB representative network[9] both under the SPEN "best-view" scenario for SPMW licence area.
- It has been demonstrated that the overarching trends identified through analysing the investment profiles for SPMW distribution network over the RIIO-ED1 period are consistent, irrespective of exactly which years are examined, or the precise numbers of LCTs to be connected. In other words, the split between investment in radial and meshed networks and the shift in investment from LV networks towards HV networks are consistent and robust trends whether examining the 2015 – 2022 period, or the 2016 – 2023 period.

[9] It should be stressed that the GB "representative" distribution network is merely a scaled down version (i.e. by number of customers) of the entire GB network that was agreed by all DNOs and does not attempt to represent any specific geographic factors. Based upon this approach, a 'representative' network serving the same number of customers as the SPMW network can be used for comparison such that the levels and types of investment observed are directly comparable.

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