SP Energy Networks 2015–2023 Business Plan

Updated March 2014

Annex

SP Manweb Company Specific Factors

SP Energy Networks

March 2014

SP ENERGY NETWORKS

SP Manweb Company Specific Factors

March 2014

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1. Scope

The purpose of this annex is to summarise the evidence for our claim for recognition in Ofgem's cost assessment of the higher net costs associated with our interconnected network ("SPM special case").

2. Table of linkages

This strategy supports our ED1 Business Plan. For ease of navigation, the following table links this strategy to other relevant parts of our plan.

Document	Chapter / Section
SP Energy Networks Business Plan 2015-2023	Chapter B2 – Our Challenges d. Our Unique Manweb Network
SP Energy Networks Business Plan 2015-2023	Chapter C6 – Expenditure c. SP Manweb Company Specific Factors d. Load Related Investment e. Non Load Related Investment m. Cost Efficiency and Benchmarking
SP Energy Networks Business Plan 2015-2023 - Annexes	Annex C5 – Black Start Capability – SPEN
SP Energy Networks Business Plan 2015-2023 - Annexes	Annex C6 – Cost Assessment, Efficiency and Benchmarking – SPEN
SP Energy Networks Business Plan 2015-2023 - Annexes	Annex C6 – Expenditure Supplementary Annex – SPEN

3. Executive summary

The SPM interconnected network configuration provides substantive benefits in terms of customer interruptions (CI). We have the lowest CI score for our SPM interconnected network areas of all DNOs, with fewer than half the number of interruptions than the next best performing network. An interconnected network can also more readily accommodate changes to load patterns arising from the transition to a low carbon energy sector. LCNF funded projects have identified interconnection as one of the main potential ways to ensure that networks play their role in the decarbonisation of the energy sector, and most DNOs have set out plans to improve interconnection over ED1.

However, there are also higher costs with operating and maintaining an interconnected network. The principal costs relate to the greater number of substations required to provide an interconnected network relative to a radial design, and associated equipment in terms of transformers, switchgear and communications.

We estimate the incremental costs of SPM's interconnected network equal to £128 million over RIIO-ED1. Our cost estimates have been informed by a study commissioned by Parsons Brinckerhoff Power (PB Power) as well as Mott McDonald (MM), two engineering consultancies. Both PB Power and MM considers that our estimate for the special case adjustment is conservative.

We also engaged NERA Economic Consulting to consider how our performance on the affected benchmarking models published by Ofgem changed pre- and post- our special case adjustment. NERA's analysis shows that we are an outlier in the relevant benchmarking models prior to the adjustment for our special case, and that we are within the pack (and closer to SPD) with the proposed adjustment. NERA's analysis supports our view that the cost estimates provide a reasonable estimate of the differential costs of operating an interconnected as opposed to a radial system.

We have developed a strategy to minimise the costs imposed by our legacy network design on customers going-forward. Wholesale reconfiguration of our interconnected network is not practical nor is it desirable. Our strategy over ED1 is focussed on considering the merits of an interconnected or radial design, based on balancing the costs and benefits to customers, at the time of network renewal and new customer connections. Our strategy avoids asset redundancy and retains the option value in responding to the development of a low carbon energy sector.

4. Section A – Overview and Rationale of the SPM Special Case

4.1. A1 Introduction and Structure of this Annex

The purpose of this annex is to summarise the evidence for our claim for recognition in Ofgem's cost assessment of the higher net costs associated with our interconnected network ("SPM special case").

In its assessment of companies' fast-track business plans, Ofgem employed a range of benchmarking techniques to determine its view of efficient costs[1]. As part of its assessment, Ofgem seeks to control for company specific factors to ensure that its benchmarking reflects efficiency as opposed to DNO specific characteristics. For SPM, Ofgem recognised the possibility that the extra complexity of SPM interconnected network requires a "special factor" that controls for omitted factors from the modelling, but considered that we had not yet submitted sufficient evidence to justify it. Specifically, Ofgem commented[2]:

1 Ofgem (6 December 2013) RIIO-ED1 business plan expenditure assessment – methodology and results. Link: https://www.ofgem.gov.uk/ofgem-publications/85039/costassessmentmethdologyandresultsmasterv2.pdf

2 Ofgem (6 December 2013) op. cit. para 4.14-4.16

"SPEN states that the SPM network has greater complexity, involves more components and is more expensive to construct and maintain than the standard industry network design…. It suggests that its network is 30 per cent more costly to run than a standard design but does not put forward sufficient quantitative evidence to show how this figure has been calculated or how they will mitigate it… we have decided not to apply a company specific factor at this stage for SPM as they have presented insufficient information. We will review this as part of the slow-track assessment based on the information SPEN submits in its revised plan."

In the period since our fast-track submission we have undertaken further substantive work to estimate the costs associated with operating our more complex network, and to justify such costs in order to meet Ofgem's expectations. We have undertaken our own internal review of the net incremental costs associated with operating the network. We also commissioned Parsons Brinckerhoff Power (PB Power), independent technical consultants, to review our strategy for managing and developing the network, and the associated incremental costs and benefits. PB Power considered that there were substantive benefits associated with an interconnected network, supported our strategy for managing future network development, and considered our cost estimate of £128 million for the special case was conservative[3].

In addition, we also asked Mott MacDonald (MM) to consider the costs and benefits associated from a theoretical network modelling perspective, and the MM report supports the conclusions of both our own and PB Power's analysis in relation to the benefits, and higher costs associated with an interconnected network.

We also engaged NERA Economic Consulting (NERA) to model our pre and post special case adjustment efficiency score for the affected models to demonstrate that the adjustment were reasonable in terms of model ranking changes, e.g. the adjustment puts us "back in the pack".

We summarise the findings of our own special case cost estimates in section B of this annex and the consultants' reports are added as appendices

This annex is structured as follows:

- *Section A2 provides a brief history of the development of the SPM network interconnected configuration, together with the costs and benefits associated with the system;*
- *Section A3 sets out our strategy for network development, i.e. balancing the benefits / optionality associated with an interconnected network with minimising costs to customers;*
- *Section A4 summarises our estimate of the incremental cost of the interconnected configuration equal to £128 million over RIIO-ED1.*
- *Section A5 sets out the results from incorporating the special case values within Ofgem's suite of models used as part of the fast-track assessment; and,*
- *Section A6 draws conclusions.*

4.2. A2 History of SPM's Interconnected Network, Benefits and Areas of Higher Cost

In this section, we briefly summarise the differences in the design of the SPM interconnected network, the benefits associated with the design, and the areas of higher cost. We provided a full detailed technical description of the difference in the configuration of SPM's network relative to standard network design in our fast-track submission[4].

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3 These reports are included in Appendix A and B. The reports are: PB (February 2014) Assessment of Special Case for SP Manweb Operating an Interconnected Network; and MM Assessment of Special Case for SP Manweb Operating an Interconnected Network,

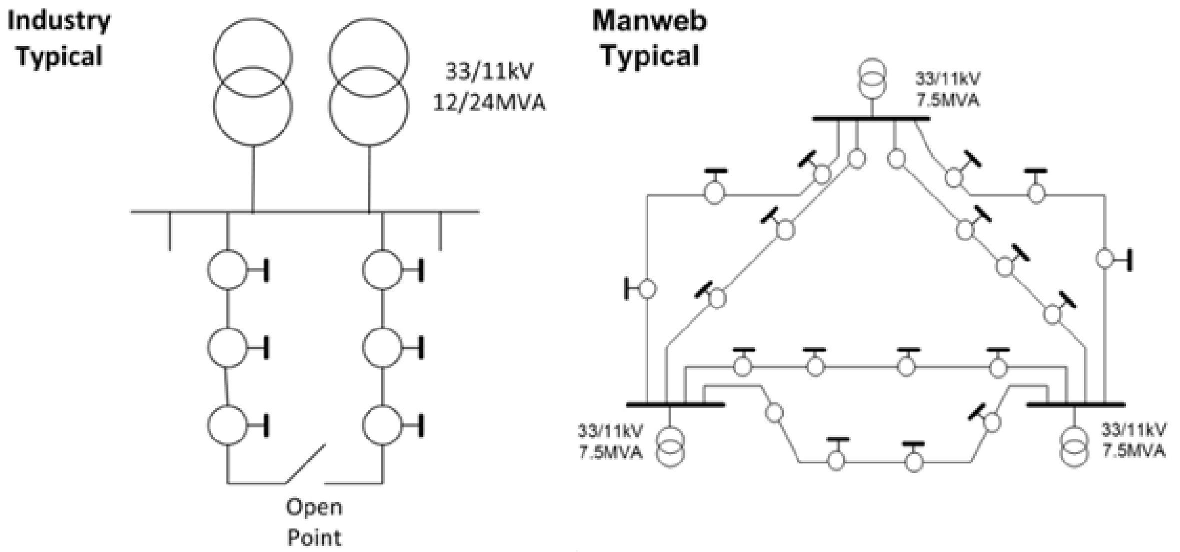
4 SP Manweb Urban Networks see appendix C

SPM network was developed as an interconnected as opposed to a radial network.

Most (but not all) of the electricity area board networks that existed prior to privatisation were developed as radial networks. Typically, in a radial configuration, a substation will be supplied from the 33kV system which will in turn supply several 11kV/LV substations strung out along each feeder. The radial design minimises the amount of switchgear required but such a system has inherent reliability limitations: a single failure in a transformer or feeder results in loss of supply. To reduce the loss of supply, the 33/11kV substation could have two transformers (one to back up the other) and the 11kV feeders arranged to have switchable back-feeds so that any loss of supply will only be as long as it takes to localise the fault and change over to an alternative supply. Under this arrangement, the two transformers need to be sized so that one of them is capable of meeting the entire load on the substation, with the result that under normal conditions neither transformer achieves a utilisation greater than 50%. A radial system will also incorporate two transformers at the 132kV to 33kV level, and at the 11kV/LV level where there is sufficient load and potential loss of supply to justify such back-up.

By contrast, under a meshed or 'interconnected' configuration, all feeders at all voltage levels are supplied from two or more ends, and these ends always terminate at separate substations. The network comprises a mesh of uniform circuits, more dense at the higher voltages, with each mesh receiving distributed in-feeds from the voltage level above. An interconnected network has higher utilisation factors than radial networks of up to around 80% depending on the number of interconnected transformers. (See also PB Power[5] and Mott MacDonald[6] for an explanation of the design differences.)

Figure A1: The Interconnected SPM Networks Employs More Substations and Associated Equipment



In total around 55% of the SPM network is designed and operated as an interconnected network, entirely interconnected at 33kV, 11kV and low voltage (LV) often described as X-type. Of the remaining network, 23% is designed as a radial network, interconnected at 33kV and 11kV but less so at LV often described as Y-Type, and 22% is designed as a radial network with single transformers feeding a non-interconnected 11kV and LV.

The interconnected network is focussed on the more dense urban areas where the costs of developing an interconnected system are lower, and the benefits (in terms of reduced loss of load) greater.

The interconnected network provides greater system security, and is adept to meet LCT growth

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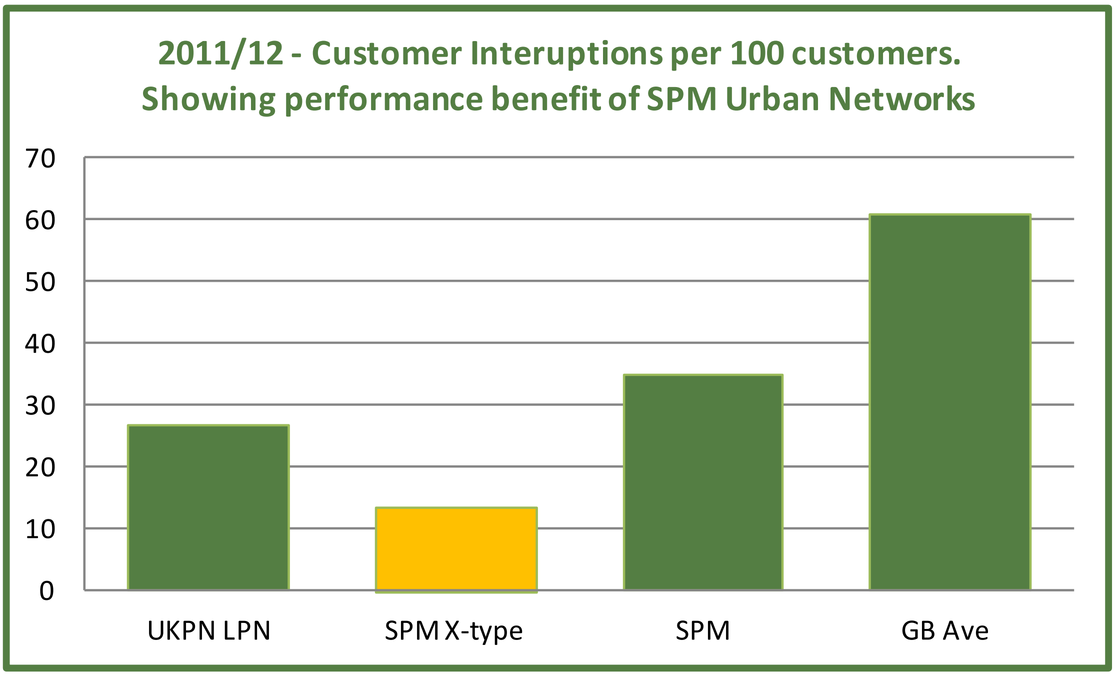
5 PB Power Assessment of Special Case for SP Manweb Operating an Interconnected Network section 3.2

6 MM Assessment of Special Case for SP Manweb Operating an Interconnected Network, section 1.12

Any single fault or failure on an interconnected network will rarely result in any loss of supply, even for a short period of time. The enhanced performance in terms of loss of supply is reflected in the customer interruptions (CI) and customers' minutes lost (CML) statistics published by Ofgem.

SPM has a much lower rate of CIs than all other DNOs except for the London DNO (UKPN LPN). However, the London DNO is itself an outlier as it benefits from a predominantly underground network with far fewer outages. Our network also includes a high proportion of radial network mainly in rural areas. More disaggregated analysis shows that CIs on our urban network (i.e. excluding rural network areas which are predominantly radial and with overhead lines) is better even than London DNO. Our ranking for CMLs is also markedly better than the average DNOs.

Figure A2: SPM's Urban Network Has Best CI Performance



Figures A2 shows Customer Interruptions per 100 customers, 2011/12, Source: NAFIRS

The other main (and prospectively greater) advantage to the interconnected system is its flexibility in adapting to meeting changing patterns of load growth. In an interconnected network, overloaded elements of the system can be resolved relatively easily by installing a new substation between the overloaded substations without the need to replace existing circuits. Conversely, if demand falls in an area, substations can be decommissioned and the equipment used elsewhere in the system where there is increasing demand. By contrast, in radial networks, the introduction of new or larger substations can lead to circuits having to be replaced or reinforced due to the non-uniformity of the network.

The flexibility of the system, and its potential role in facilitating low carbon technology (LCT), has been recognised by projects within the LCNF. As summarised in the PB Power report, our engineering advisers, interconnected systems confer many advantages in responding to the adoption of low carbon energy. For example, interconnected systems can more easily accommodate substantive new loads such as heat pumps. They also offer greater operational flexibility compared to radial systems and thus can more easily accommodate distributed generation (DG), and bi-directional flows, e.g. arising from DG as well as electric vehicles[7]. Indeed, two of the potential solutions to accommodating LCT arising from the development of the Transform model[8] –

7 PB Power (February 2014) op. cit., section 3.5.

8 The Transform model has been developed by the industry as part of the Smart Grid Forum jointly run by DECC/Ofgem.

which involves modelling the adaptation of networks to a low carbon energy scenario – involve the permanent interconnection of LV urban and suburban networks[9].

Not surprisingly, PB Power's review of other companies' plans demonstrates that most DNOs proposed interconnection at the LV level in their fast-track business plans, and interconnection is the focus of a number of LCNF projects promoting low carbon technology deployment[10].

In summary, as well as customer benefits in terms of reduced outage levels, there is a significant potential value (an option value) to the current SPM interconnected network design in meeting the challenges associated with LCT. The option value informs our strategy for managing and developing the system going-forward (as we explain below).

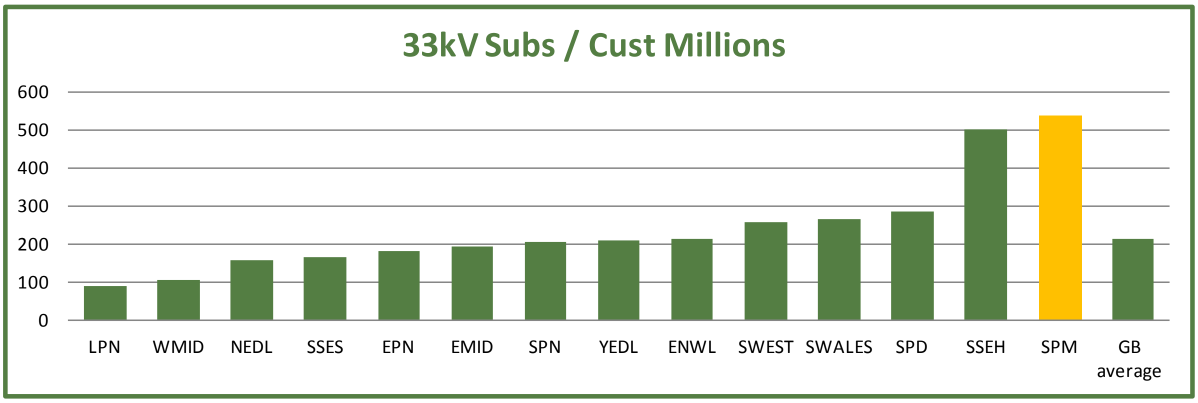
An interconnected network requires more specialised equipment and is more expensive to operate

The principal additional costs associated with operating an interconnected network relate to the requirement for [11]:

- *More primary substations and transformers*
- *More 33kV switchgear (i.e. circuit breakers); and*
- *Greater protection and control at 33and 11kV substations*

The greater number of substations required for the operation of our interconnected network is illustrated in the following charts which shows that we have more than twice the number of transformers than average when scaled by customers served, and a greater number of substations than any DNO with the exception of SSEH. SSEH has a higher number of substations because it is a predominantly rural network. LPN (UKPN LPN) – which could also be described as an interconnected system – has a relatively small number of substations because it is interconnected at relatively high voltage (i.e. predominantly 132/11kV)[12].

Figure A3: SPM Has More Than Twice the Number of 33kV Substations as Average DNO



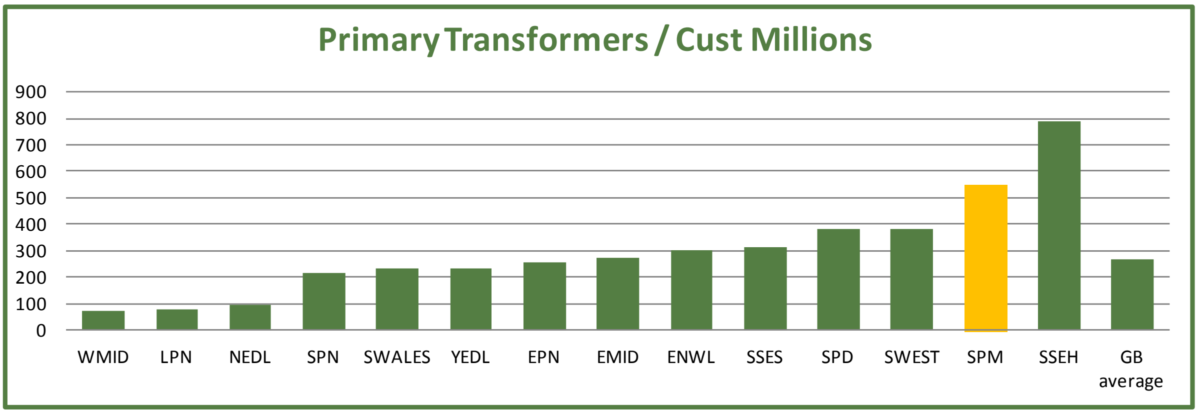
9 PB Power (February 2014) op. cit., section 3.5.

10 PB Power (February 2014) section 3.4.5

11 We set out in detail the additional costs associated with our interconnected network in section B of this report. We have also subjected our cost estimates to an external review by PB, engineering consultants. PB Power (February 2014) sections 4.2.3 and 4.3.4

12 This point is supported by PB Power. See PB Power (February 2014) sections 4.2.1

Figure A4: SPM Has More Than Twice the Number of Primary Transformers as Average DNO



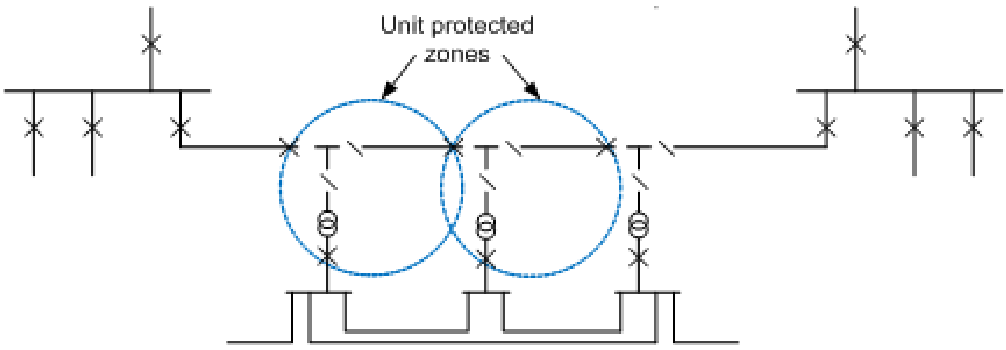
There is also a requirement for greater switchgear at each primary substation. On traditional radial designed networks the circuit is controlled by the switch or circuit breaker at the source or infeed end of the circuit. If a fault occurs; the switch opens the circuit and disconnects the fault from the network with the high probability of loss of load. Customers will be without power until the fault is located and manual or remote switching restores the non-faulted section of the circuit to service.

On interconnected networks where the circuits are fed from two (or more) source or infeeding substations there are switches or circuit breakers at each substation. When a fault is detected on one of these individual circuits then the switches or circuit breakers at each of the substations operate to open that individual circuit and disconnect only the faulted section from the network. The remaining substations therefore remain supplied from either source or infeeding substations at the ends of the interconnected circuit. The occurrence of a single fault rarely results in lost load or customer interruptions.

The interconnected design requires additional volumes of switchgear than is the case on radial networks.

Finally, the third cost area comprises greater need for protection and control. As described above traditional radial designed networks use circuit breakers at the source or infeeding substations to control the radial circuit. For the circuit breaker to work, the source or infeeding substation requires protection equipment to detect a fault on the circuit, and command the controlling switch to open to remove the fault safely from the circuit.

Figure A5: Unit Protection Applies Along Interconnected Circuits



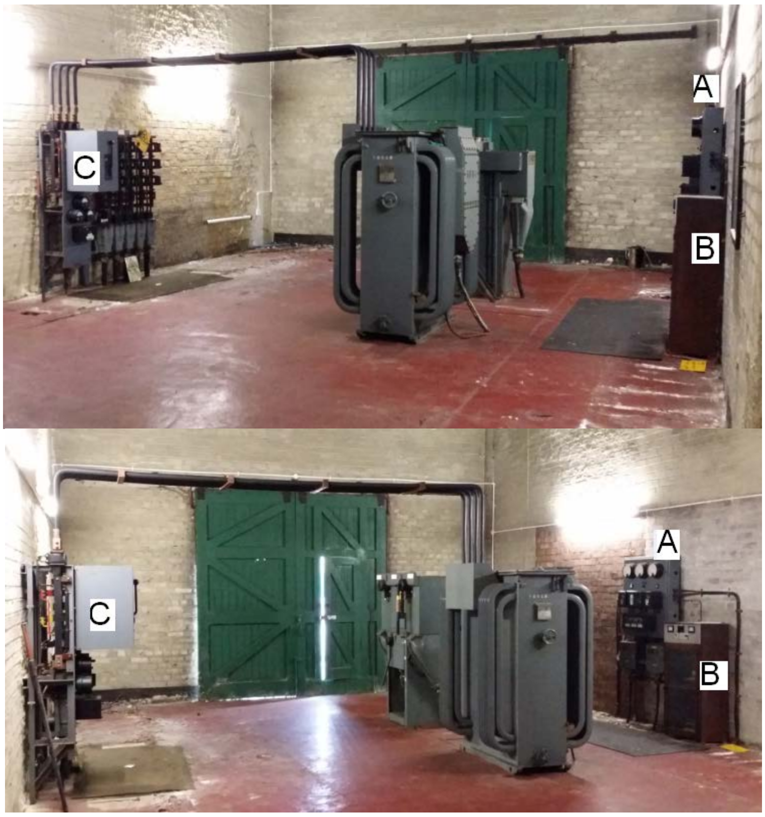
On interconnected networks where the circuits are fed from two or more source or infeeding substations, the circuits are configured with switches or circuit breakers at each end of the individual circuits between the substations along the interconnected circuit. To allow a fault to be detected in one of these individual circuits (or 'units') between the substations requires protection for each individual circuit or unit ('unit protection'). This protection takes the form of devices known as relays connected to each end of the circuit and connected together by small pilot wires so that they can work together to detect a fault and remove only the faulted circuit safely from the system, and not to interrupt the remainder of the substations along the interconnected circuit.

The interconnected system therefore requires additional volumes of protection, control and pilot wires than is the case on radial networks. As an illustration Figure A6 shows a typical 11/0.430kV Y-type or radial substation with minimal components and Figure A7 shows a typical 11/0.430kV X-type unit protected and interconnected substation with the additional components highlighted.

Figure A6: A typical Y-Type 11/0.430kV non unit protected substation the SPM network

Indicates minimal components required, a transformer, a ring main unit and an LV fuse board

Figure A7: A typical X-Type 11/0.430kV ‘unit protected ‘substation on the SPM interconnected network



Additional components on the Unit Protection panel (A) a Battery unit (B) and a switch on the LV fuse board (C)

4.3. A3 Our Strategy for Managing our Network to Minimise Costs to Customers

Overall, our strategy for managing the network recognises the customer benefits from lower outage levels, and the potential option value for meeting LCF, while realising opportunities to adopt lower cost radial networks where there are no technical constraints, and there is a clear cost advantage.

Substantive reconfiguration of our network is not technically feasible, cost-effective, and we would lose a valuable option for accommodating LCT. As set out above, there are considerable benefits to SPM’s interconnected network in terms of high levels of system security. There are also potential benefits in terms of system flexibility, and the ability to facilitate LCT. As set out in the PB Power report, network operators with traditional radial networks are considering how the application of interconnection accommodates future LCT through LCNF projects. The Transform model – developed by the Smart Network Forum – also proposes interconnection as a means to accommodate LCT.

There are also substantive one-off costs (e.g. in terms of existing asset redundancy), as well as technical obstacles (e.g. purchase of land in urban areas to locate larger substations) that prohibit the substantive reconfiguration of our network.

Our strategy is to consider reconfiguring local parts of the network when providing additional capacity including new connections, as well as network renewal. For each case, we consider whether the adoption of a radial network design is technically feasible in the context of the interconnected network. If technically feasible, we consider the relative cost-effectiveness of radial versus interconnected solutions taking into account on the one hand the lower costs associated with radial networks, and on the other, the better system performance and security associated with interconnected configuration, and scope to facilitate low carbon technology (LCT). Our strategy has been in place throughout the current and previous price controls, and there are examples of where we have retained both interconnected configuration and adopted radial designs based on the analysis of the costs and benefits.

Our strategy for developing the network in terms of radial versus interconnected configuration will evolve during the course of ED1 – informed by LCNF projects examining the role of interconnected networks, and with the (partial) resolution of uncertainty as to the role and uptake of LCT.

4.4. A4 We Conservatively Estimate Additional Net Costs At £128m over RIIO-ED1

We provide a detailed derivation of our special case cost estimate in section B. In terms of developing our cost estimates, we adopted the following approach.

- *We have identified the additional net assets employed/activities undertaken for our interconnected network compared to a radial network. In general, we have compared SPM with SPD, as the comparison holds constant other company specific factors (e.g., the level of efficiency, consistent asset management policy). However, we have also considered the assets employed and activities undertaken by SPM relative to other DNOs.*

- *We have sourced the costs of the net additional assets employed (greater number of substations, switchgear etc.) and activities undertaken from our Unit Cost Manual, which is the basis for costing our investment plan.*

- *We have netted-off areas where SPM enjoys a cost advantage from operating an interconnected network relative to a radial design. For example, in estimating the costs of greater levels of replacement activity for substations and related equipment, we have taken into account the lower unit cost of some equipment.*

- *Our special case includes costs for those assets/activities where we can provide a robust and objective cost estimate. There are a number of areas of higher cost that we cannot easily quantify which we describe in the supporting documents and which we have not costed. We have also excluded any costs associated with additional assets/activities which we considered were below a certain threshold*[13]*.*

- *We asked PB Power and MM to review our strategy for managing the network and our cost estimates, and their views have informed our cost estimates. For example, as we set out in the detailed cost annex, we amended our approach to load investment and primary transformer replacement following challenges by PB Power.*

- *Overall, we consider that our approach provides a conservative estimate of the cost of operating SPM's network, a view supported by PB Power's assessment of our costs.*

4.5. A5 Our Replication of Ofgem's benchmarking Shows a Modest Improvement in SPM's Position

We have examined the impact SPM's special case makes on Ofgem's benchmarking. We have used Ofgem's benchmarking files adjusted for our new Business Plan (BP) forecasts as submitted to Ofgem along with this submission. Our examination shows that the SPM special case leads to a modest improvement in SPM's benchmarking position for the relevant models, and brings SPM into line with the other DNOs' efficiency scores.

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13 Examples of costs we excluded on de minimis grounds include: primary transformer tap changer maintenance; increased battery capacity at primary substations related to operating 33kV switchgear over lighter duty 11kV switchgear

To conduct this examination, we have allocated the SPM special factor adjustment across Ofgem's activity level models as described in Table 1[14].

We make two assumptions to test the impact of SPM's special factor on efficiency results:

- *Ofgem's expert assessments of unit costs do not change as a result of the addition of SPM's special factor – since these are hard coded into Ofgem's files;*
- *The special factor adjustments only affect Ofgem's unit cost adjustments, not volume adjustments.*

Table 1: Special Factor Adjustment by Ofgem Benchmarking Activity

Ofgem Benchmarking Category	CV Table	Special Case Adjustment (£m)
Asset replacement	CV3	37.0
Asset refurbishment	CV5	4.4
Civil works	CV6	16.3
BT21CN	CV10	23.2
Resilience	CV11	0.9
I&M	CV13	6.5
Troublecall	CV15a	2.8
ONIs	CV15b	3.5
Reinforcement	CV101	22.1
Op IT & Telecoms	CV105	11.1
Total		**127.8**

Figure A8 shows the results of including SPM's special factor claim in Ofgem's benchmarking for the principal activity level models set out in Table 1.

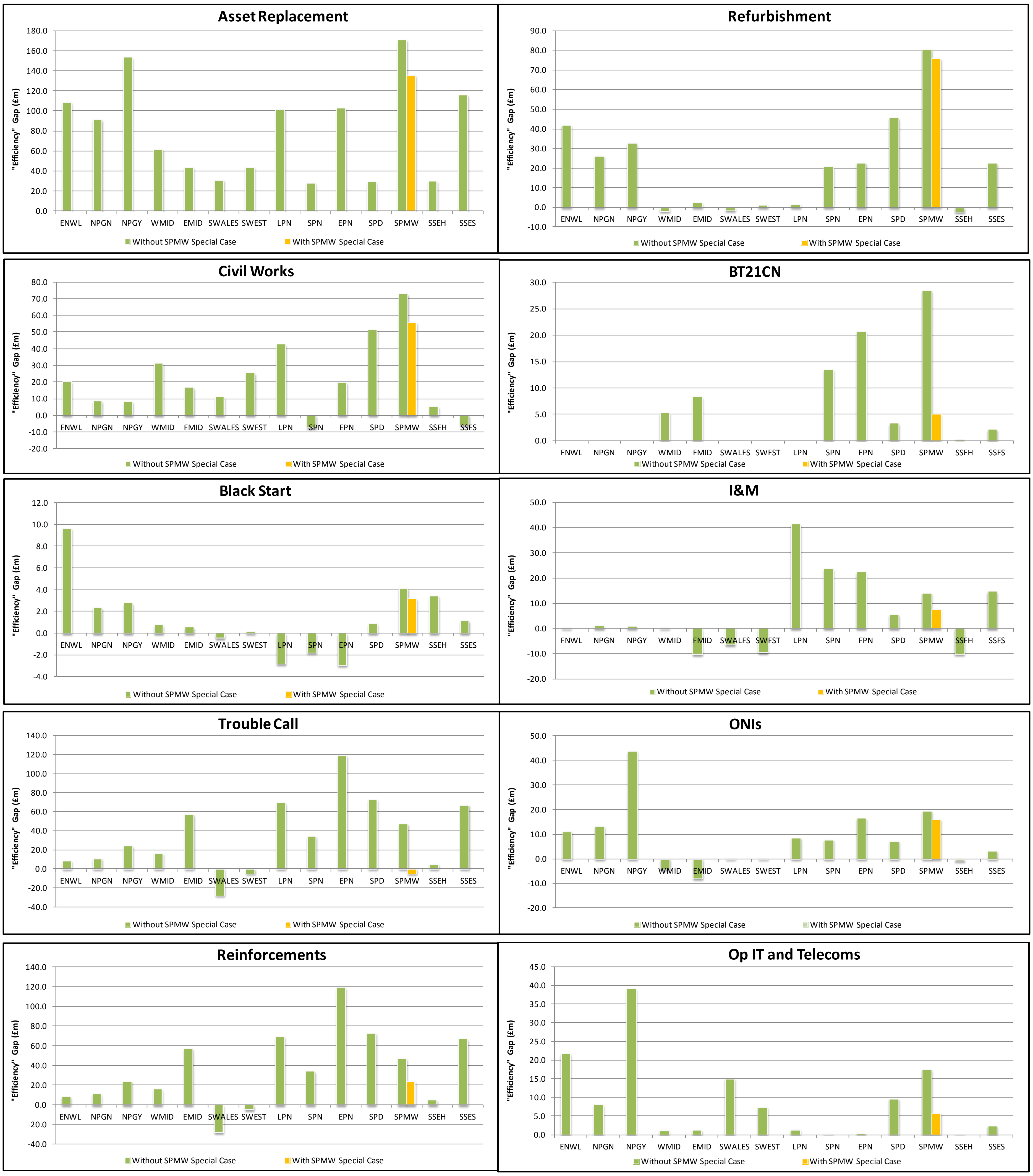
The Figure shows SPM's and other DNO's "efficiency gap" – the difference between SPM business plan costs and Ofgem's modelled total expenditure[15].

14 Ofgem assesses DNO expenditure using three benchmarking approaches: an activity level assessment where DNO expenditure is separated into activities each of which has a separate assessment; and two totex regression approaches using a high level size index explanatory factor and a bottom up index of activity level explanatory factors respectively.

15 We examine the efficiency gap using net submitted business plan expenditure and net modelled expenditure – the same expenditure measures that Ofgem uses to calculate its efficiency scores.

In general, for the ten affected activity models, our analysis shows that: (i) SPM was an outlier prior to the special factor adjustment, and (ii) is within the pack, and consistent with SPD's ranking post-adjustment. In other words, the benchmarking analysis suggests that the cost estimates are a fair reflection of the cost of operating and maintaining an interconnected network.

Figure A8: In general, SPM Is an Outlier Pre Special Case; Moves into Pack with Adjustment



4.6. A6 Conclusions

In Section A of this annex we have set out the evidence for a special case adjustment for our interconnected SPM network. In summary, we note that:

- *The SPM interconnected network configuration provides substantive benefits in terms of customer interruptions, and can more readily accommodate changes to load patterns arising from the shift to a low carbon energy sector. However, these benefits are also associated with higher costs.*

- *Wholesale reconfiguration of our interconnected network is not practical nor is it desirable. Our strategy is focussed on considering the merits of an interconnected or radial design, based on balancing the costs and benefits to customers, at the time of network renewal and new customer connections. Our strategy avoids asset redundancy and retains the option value in responding to the development of a low carbon energy sector.*

- *We estimate the incremental costs of SPM's interconnected network equal to £128 million over RIIO-ED1. Our cost estimates have been informed by a study commissioned by PB Power; PB Power considers that our estimate for the special case adjustment is conservative. NERA's analysis also shows that we are an outlier in the relevant benchmarking models prior to the adjustment for our special case, and we are within the pack (and closer to SPD) with the proposed adjustment.*

- *Finally, we note that Ofgem recognised the higher costs associated with our interconnected network at DPCR5[16]; for consistency we would expect an adjustment at RIIO-ED1 based on our revised cost estimates.*

- *In Section B of this Annex we set out the component costs of the SPM special case in more detail*

16 Ofgem DPRC5 determination states: '1.68. The lower of the industry-wide median unit cost and the DNO's own unit cost was then applied to all DNOs except where specific issues were identified by a DNO and accepted by Ofgem. These included the additional costs associated with operating within central London (EDFE LPN) and unique switchgear associated with the specific network topology for SP Manweb'.

5. Section - B Derivation of Costs for SPM Special Case

5.1. Introduction and structure of this annex.

In this section, we set out in detail the derivation of our special case cost estimate relating to SPM's interconnected network. This section should be read along with the following documents.

- PB Power cost estimates: We commissioned Parsons Brinckerhoff (PB Power), engineering consultants, to review our strategy for managing and developing the SPM network, and the associated incremental costs and benefits, and we amended our cost estimates based on initial feedback provided by PB Power. PB Power considered that there were substantive benefits associated with an X-Type configured network, supported our strategy for managing future network development, and considered our cost estimate of £128 million for the special case was conservative[17]. In this annex, we set out how we have taken into account PB Power's views in estimating incremental costs.

- MM network modelling: We also commissioned MM to undertake theoretical modelling of the development of an interconnected network, and compare this to a radial design. This report also supports our view on the costs and benefits associated with an interconnected network. The report adopts a higher-level technical approach, and is for a technical reader.

This annex is structured as follows:

- *Section B1 provides a summary of our cost estimates, and our overall approach for estimating such costs.*
- *Section B2 sets out our special case estimate for load related investment.*
- *Section B3 sets out our estimates for non load investment costs*
- *Section B4 sets out our estimates for operating costs*

5.2. B1 Overview of Costs and Our Approach

As we describe in section A, around 55% of the overall SPM network is designed and run as an 'X-Type' or interconnected network, entirely interconnected at 33kV, 11kV and LV. Of the remaining network, 23% is designed as a 'Y-type' network, interconnected at 33kV and 11kV but less so at LV and 22% is designed as a radial network with single transformers feeding a non-interconnected 11kV and LV.

The greater number of substations for interconnected 33kV and 11kV networks, and associated equipment comprise the greater part of our higher costs (i.e. the non-load related expenditure in the Table 2 below). The remaining principal costs areas relate to operating and maintenance costs on the 33kV network (£8.7 million), and meeting increased load across all voltages (£22.1 million).

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17 These reports are included in Appendix A & B. The reports are: PB Power (February 2014) Assessment of Special Case for SP Manweb Operating an Interconnected Network; and Mott MacDonald (February 2014) Assessment of Special Case for SP Manweb, Operating an Interconnected Network

Table 2: Special Case Adjustment by Spending Category

Spending Category		SPMW Proposed Special Case Adjustment (£m)
Capex	Load Related Expenditure - All Voltages	22.1
	33kV - Non Load Expenditure	56.0
	Other 33kV capex	18.4
	HV - Non Load Expenditure	18.6
Opex and Maintenance	33kV (I&M)	8.7
	HV (I&M)	2.1
	LV	1.8
Total		**127.7**

In order to estimate our special case adjustment, we have considered the actual costs of the SPM interconnected network with those of a notional SPM radial network. In general, we have calculated the extra costs of operating the SPM interconnected network based on comparison with SPD's network costs, taking into account both differences in activity levels as well as unit costs[18]. We consider SPD provides a reasonable basis for estimating SPM costs as if it were a radial network for the following reasons:

- *SPM and SPD have a similar demographic; many customers are based in urban networks with SPD's Glasgow and Edinburgh being similar to SPM's Merseyside and Warrington.*
- *Both SPM and SPD have extensive west coast and rural networks areas constructed at 11kV in traditional rural network design.*
- *SPM and SPD share the same asset management, and operational policies, and in general have similar unit costs.*
- *Furthermore Ofgem in its fast track determination considered SPD to be efficient on asset replacement and refurbishment cost[19].*

5.3. B2 Load related investments - all voltages (£22.1m)

In order to be able to quantify load related costs, we commissioned PB Power and MM to estimate the cost differential between the expansion of an interconnected 33kV and 11kV system and an equivalent radial system. The two consultants applied different approaches to the analysis with MM applying a top down theoretical modelling approach and PB Power applying a bottom up approach based on a comprehensive evaluation of the development stages of interconnected and radial networks. Further details of the two approaches can be found in their respective reports.

18 SP unit cost manual

19 Ofgem – Assessment of the RIIO-ED1 business plans section 1.2 page 71

The PB Power report estimated the cost of providing an incremental increase in load was 39.3% greater for an interconnected system relative to a radial system at 132/33kV level and 47.2% greater at the 33/11kV voltage level. The MM report concluded a similar cost differential of 44% at 132/33kV level and a higher cost differential of 74% at the 33/11kV voltage level. Although the modelling approaches adopted by the two consultants were very different, the two sets of results are broadly of a similar magnitude of order (with the MM's estimates being somewhat higher).

For the purpose of evaluating how the Load Related part of our RIIO-ED1 plan compares with a radial network, we have used the lower cost differentials from the PB Power report in order to provide a conservative estimate.

Table 3 below shows the cost differentials applied to the 132/33kV and 33/11kV part of our load related plan.

The table also includes 6.6kV to 11kV uprating costs. The PB Power estimates for non-load related expenditure are not relevant to these costs, as these projects involve the replacement of transformers and voltage reference transformers. For these costs, we have taken the asset replacement special case adjustment as outlined in the non load sections of this paper. The secondary transformers changes associated with 6.6kV to 11kV in an interconnected network are higher due to the additional CTs associated with the unit protection. We have estimated the unit cost differential based on SP unit cost manual – which suggests an additional cost of £1.9k[20] per transformer as set in the table 2 below.

In addition to load related reinforcement schemes, our plan includes the replacement of four 33kV RMUs for fault level reasons. 33kV RMUs are unique to interconnected networks and therefore the whole cost of the RMU replacement is considered as an additional cost relative to the cost of operating a radial system. At a cost of £400k for each RMU with indoor 33kV circuit breakers, we estimate the associated additional load related cost for the 4 units is £1.6 million.

Overall, we estimate a special case adjustment for load related investment of **22.1m,** as set out in the table:

Table 3: Special Case Adjustment for Load Related Investment (CV101)

Reinforcement Schemes	Expenditure (£m)	Cost Differential	Special Case Adjustment (£m)
Cal:	**A**	**B**	**C=A*B**
132/33kV	44.2	39.9%*	12.5
33/11kV	23.3	47.2%*	7.5
6.6kV to 11kV upgrade	8.0	253 transformers & £1.9k (diff cost ea)	0.5
Sub total	31.3		8.0
RMU	1.6	4 RMU's * £0.4(ea)	1.6
Total	**75.5**		**22.1**

** Conservative estimates taken from PB report.*

20 Difference between and X & Y-type transformer cost as SP Unit Cost Manual pages 48 and 25

5.4. B3. Cost Associated with 33kV & 11KV Network Non Load Investment:

B3.1 - 33kV Asset Modernisation Capex

In this section, we examine the assets which require modernisation in turn and identify the ED1 replacement costs specifically related to SPM's interconnected network as compared to a typical radial network.

Asset modernisation makes up £56.03m of the £74.4m 33kV non load investment listed in Table 2 above. The breakdown of this expenditure is shown in the table below.

Asset modernisation is required for a variety of reasons such as: to improve reliability of aged or poor condition assets; requirements to migrate from copper to fibre communication channels; resulting from BT's 21st century network changes; and, to ensure our primary substations remain resilient for extended duration power outages known as 'Black Start'[21] events. We summarise the costs in the following table, and provide a more detailed description below.

Table 4: 33kV Asset Modernisation Capex (CV3, CV5, CV10, CV11)

Spending Category	SPM Proposed Special Case Adjustment (£m)
Primary Transformers	5.7
Outdoor GM Circuit Breakers	7.8
Indoor GM Circuit Breakers	11.8
Pilot Wire Protection	3.2
BT21CN	23.2
General Protection	4.2
Total	**56.0**

Primary Transformers

In order to estimate the primary transformer special case adjustment for SPM's interconnected network, we considered the replacement volume and unit cost for SPM over ED1 and compared this with the MVA equivalents for a notional radial system based on the supporting evidence from PB Power's analysis[22]. This comparison is shown in the table below and consists of the following steps:

- *Based on our asset age and condition profile SPM plans to replace 89 primary transformers in ED1 to manage our HI 5 assets which cost £0.18m each based on unit costs in SP's unit cost manual[23].*

21 For more detail on Black Start see Annex C5 – Black Start Capability – SPEN

22 These reports are included in Appendix A and B. The reports are: PB (February 2014) Assessment of Special Case for SP Manweb Operating an Interconnected Network; and MM Assessment of Special Case for SP Manweb Operating an Interconnected Network

23 SP Unit Cost Manual, page 52.

*Therefore in total this will cost **£16.1m**;*

- *A typical radial network employs fewer transformers. Taking SPD's number of transformers, and scaling the number for the difference in MVA between typical radial networks and SPM, we calculate that SPM would need to replace 37[24] primary transformers if it were designed as a radial network. However, the transformers for a radial network are larger, and more expensive, at a unit cost of £0.27m each (based on SPN's unit cost manual for SPD)[25]. The lower number of transformer but higher unit cost equates to a total cost of **£9.8m** that we estimate SPM would incur if it were a radial network;*

- *The difference between these two figures is SPM's estimated special case adjustment, which is £6.3m for primary transformer asset modernisation In the specific example of primary transformers, we have also made an efficiency adjustment based on anticipated benefit from the Iberdrola Global purchasing arrangements, which results in us concluding a conservative estimate of **£5.7m** for the special case adjustment.*

We apply a similar framework to this for all of our special case adjustments, which we show in the following subsections.

Table 5: Asset Modernisation – Primary Transformers (CV3)

	No. of Assets	Unit Cost (£m)	Total Cost (£m)
Calc:	**A**	**B**	**C = A*B**
SPMW Integrated Network	89 (7.5MVA)	0.2	16.1
Typical Radial Network	37 (13/24MVA)	0.3	9.8
Difference (=Special Case Adjustment)	52.0	-0.1	6.3
Efficiency Adjusted			**5.7**

Note: numbers in table may appear to not calculate due to number rounding.

Outdoor Ground Mounted Circuit Breaker at Primary substations

Following the same approach as above, the table below shows the calculation of the SPM special case adjustment for outdoor ground mounted circuit breakers. The key figures used in the table are as follows:

- *SPM plans to replace 99 outdoor oil circuit breakers in ED1, due to age and condition and to reduce our risk exposure to HI5 assets and improve the reliability of our network , at a cost of 0.08m each[26].*

- *33kV circuit breakers would not be required in primary substations in a radial network. Hence, the costs associated with a radial network are zero in the table, and our special case adjustment is equal to the gross SPM cost **£7.88m**.*

24 See PB power report section 4.3, page 18

25 SP Unit Cost Manual, page 60.

26 SP Unit Cost Manual, page 51.

Table 6: Asset Modernisation – Outdoor Circuit Breakers (CV3)

Spending Category	No. of Assets	Unit Cost (£m)	Total Cost (£m)
Calc:	A	B	C = A*B
SPMW Integrated Network	99	0.1	7.8
Typical Radial Network	0.0	0.0	0.0
Difference (=Special Case Adjustment)	99	0.0	**7.8**

Note: numbers in table may appear to not calculate due to number rounding.

Indoor Ground Mounted Circuit Breaker at Primary substations

Following the same approach as above, the table below shows the calculation of the SPM special case adjustment for indoor ground mounted circuit breakers. The key figures used in the table are as follows:

- *SPM plan to replace 6 indoor circuit breakers and 33 indoor Ring Main Units in ED1 to improve age/condition profile of our assets, i.e. to address the prevalence of assets classified as HI5. Ring main units are no longer commercially available for use on the SPM network, therefore each unit will be replaced by a 3 panel board comprising of 3 indoor circuit breakers. This totals 105 indoor circuit breaker units in ED1. These units cost 0.11m each which includes civils and protections modifications as well as an efficiency factor[27].*
- *Again, 33kV circuit breakers would not usually be required in primary substations in a radial network and therefore the equivalent costs for a radial network are zero in the table, and our special case adjustment is equal to **£11.8m**.*

Table 7: Asset Modernisation – Indoor Circuit Breakers (CV3)

	No. of Assets	Unit Cost (£m)	Total Cost (£m)
Calc:	A	B	C = A*B
SPMW Integrated Network	105	0.1	11.8
Typical Radial Network	0	0	0.0
Difference (=Special Case Adjustment)	105	0	**11.8**

Note: numbers in table may appear to not calculate due to number rounding; 33kV indoor circuit breaker replacement at grid sites is not relevant to the SPMW special factors.

27 SP Unit Cost Manual, page 29.

Pilot wires: underground and overhead (hardex) cables for assets at Primary substations

We follow the same approach as above to derive our special case adjustment for the following two categories: underground and overhead pilot cables. The table below shows the calculation of the special case adjustment, which consists of the following key items:

- *SPM require robust communications channels for its unit protection to operate effectively and reliably to avoid unnecessary CI/CML should a fault occur.*
- *SPM has planned approximately 150 targeted overlays of poorly performing underground pilot cables over ED1 (approximately 70km of cable), at an average cost of £0.09m/km[28];*
- *Additionally, SPM plans to replace 25 end of life 'Hardex' pilot cables on the overhead network over ED1. For overhead cable a combination of overhead and underground fibre based technology must be deployed since Hardex – the self-supporting pilot cable which is 'under slung' from 33kV overhead lines – no longer has a recognised manufacturer.[29] The cost of each replacement is therefore averaged at £0.02m/km for the overhead sections*
- *For a typical radial network, a direct comparison is not available. Other DNOs do utilise pilot cables in 33kV networks protection, particularly with intertrip signalling. However, due to disparity in volumes, no direct comparison from which to calculate an adjustment is available. In the absence of a clear comparison, we note that during ED1 the SPD network requires an investment of some £5.66m on the same asset base.*
- *Taking SPD's costs as industry typical for SPM, we calculate a special case adjustment of* ***£3.23*** *as in the table.*

Table 8: Asset Modernisation – Pilot Wires (CV3)

	Underground Pilot Cables (£m)	Overhead Pilot Cables (£m)	Total
SPMW Integrated Network	7.4	1.5	8.9
Typical Radial Network (SPD)	5.6	0.1	5.7
Difference (=Special Case Adjustment)			**3.2**

Note: we only provide the total cost of these activities in the table as unit costs vary substantially for these assets, and are based on individually tailored solutions on a circuit by circuit basis.

28 This is slightly higher than the SP unit cost manual page 35, as that cost is based on 1km sections we are undertaking a mixture of long and short overlays so have targeted a 15% headroom

29 Attempts to encourage entrants into hardex manufacturing through our procurement route have proved unsuccessful. Hence the need to replace with a combination of fibre based technology and ug pilot cable on the most cost effective basis per circuit.

BT21CN – 33kV network communications

All DNOs are required to modernise rented pilot dependent services such as protection signalling or unit protection circuits, as the migration of British Telecom (BT) to its new communications platform in 2018 will prevent the correct functioning of this equipment. Malfunction of this equipment could cause substantial CI/CML increases due to increased fault clearance times. Therefore, modernisation of this equipment needs to be conducted in the first three years of ED1 (i.e. before BT's 2018 roll-out).

Interconnected networks require more communication equipment to link unit protection, and operational I.T. to a greater number of substations. As a consequence, SPM has to replace more of these circuits than most DNOs to ensure the we maintain optimal levels of site monitoring and control, along with correct operation and reliability of the interconnected network 'unit protection' schemes. These communication channels are more complex than required for protection and communication on radial networks

The table below calculates the SPM special case in the same way as above, using the following key items:

- *SPM will need to modernize 192 protection circuits over the first three years of ED1 to ensure that: faults on our network can be identified and removed by our unit protection schemes in a timely manner; increases in CI/CML are avoided; we retain our current levels of site monitoring and control; and that we future proof our ability to accommodate new requirements posed by smart grids. SPM has a greater dependency and a higher specification on these circuits than is required for traditional radial networks. These are at an average unit cost of £0.15m each;*

- *We compare SPM's costs with those of SPD to calculate an adjustment. SPD will have to replace 34 of these circuits ahead of BT's communication migration. We provide the total cost of these activities in the table as unit costs vary substantially for these and are based on individually tailored solutions on a circuit by circuit basis.*

- *Taking SPD's costs as industry typical for SPM, we calculate a special case adjustment of* ***£23.2m*** *as in the table.*

Table 9: Asset Modernisation – BT21CN (CV10)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	192	0.15	28.2
Typical radial network	34	0.15	5.0
Difference (= Special case adjustment)	**158**		**23.2**

** Comparable unit cost level is not applicable as each solution is individually engineered and costed.*

33kV protection moderisation at Primary substations

SPM has a large number of life expired protection installations that must be replaced during ED1. The scale of this replacement work reflects our strategy to adopt a holistic approach for primary substation switchgear and protection modernisation – aligning replacement of protection, batteries and chargers for both local and remote end equipment when completing major substation modernisation work involving replacement of the main plant[30].

30 However, we note that our holistic approach is not always possible and standalone protection moderisation programs modernisations are required for some ageing protection assets. This is typically the result of short life expectancy, short vendor support periods and obsolescence driven by the rapid development of protection technology.

Given our unit protection strategy, protection modernization in SPM is more costly per unit than for traditional radial networks. As a result, we calculate a special case adjustment here using the same method as above, shown in the table below. The table includes the following key items:

- *SPM plan to invest in 433 units of protection modernisation in ED1. Of these, SPM plans to replace 262 installations of unit protection schemes associated directly with primary substation 33kV switchgear replacement to ensure the network remains protected. The replacement of the 433 units equates to a cost of £5.56m at an average cost per installation of £0.013m.*

- *As described above, these 33kV circuit breakers would not usually be required in primary substations in a radial network. Hence we would not be required to make this investment in protection modernisation*

- *Also SPM plan to replace a further 171 installations associated with grid substations and primary transformers at an average cost of £0.007m, and a total cost of £1.17m*

- *Therefore in the table below we have listed the total SPM protection modernisation investment in ED1 and deducted the element attributed to 33kV unit protection. We calculate a special case adjustment of **£4.2m** as in the table.*

Table 10: Asset Modernisation – Protection (CV5)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	433	0.01	5.4
Typical radial network	171	0.01	1.2
Difference (= Special case adjustment)	**262**		**4.2**

33kV Protection modernisation at grid sites is not relevant to the SPM special factors.

B3.2 - 33kV: Other Capex

In this section, we examine the other non-load capex that SPM plans to spend over ED1 which is specifically related to SPM's interconnected network as compared to a typical radial network. Other capex makes up £18.4m of the £74.4m 33kV non load investment listed in Table 2. SPM requires to make increased expenditure over traditional radial networks based on increased volumes of substations, switchgear and ancillary equipment. In estimating our special case, we compare SPM's required level of activity with SPD, as well as any differences in unit costs.

The breakdown of this expenditure is shown in the table below, and the rest of this section examines each category in turn.

Table 11: Other Capex by Spending Category (CV6, CV9, CV105)

Spending Category	SPMW Proposed Special Case Adjustment (£m)
Black Start Resilience at Primary Substations	0.9
RTU Replacement	6.4
Ethernet Comms and Infrastructure	4.7
Substation Civils	6.4
Total	**18.4**

Black Start Resilience at Primaries

Following the same approach as above, the table below shows the calculation of the SPM special case adjustment. The key figures used in the table are as follows:

- *SPM plans to make 415 primary substations resilient to 72 hour extended duration power outages in ED1 (referred to as black starts). The overall investment is £2.51m at an average unit cost of £0.006m each.*
- *Given the lack of data for other DNOs, we use SPD as our comparator for a radial system. SPD is installing 255 units, with the same average unit cost as SPM. The comparison shows that an interconnected network requires a far higher level of investment.*
- *Taking SPD's costs as indicative of the costs for a notional SPM radial network, we calculate a special case adjustment of **£0.9m** as in the table*

Table 12: Other Capex – Black Start Resilience at Primary Substations (CV11)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	415	0.01	2.5
Typical radial network	255	0.01	1.6
Difference (= Special case adjustment)	**160**		**0.9**

Note: black start resilience at 132kV substation is not relevant to the SPMW Special Factors.

RTU Replacement at Primary substations

Following the same approach as above, the table below shows the calculation of the SPM special case adjustment for RTU replacement. The key figures used in the table are as follows:

- *SPM plans to replace 833 RTUs at primary substations in ED1. These cost £0.02m each.*

- *Given the absence of data for other DNOs, we use SPD as a comparator with a typical radial network. SPD is installing 386 units, with similar unit cost as SPM.*
- *Taking SPD's volumes as industry typical for SPM, we calculate a special case adjustment of* ***£6.4m*** *as in the table*

Table 13: Other Capex – RTU Replacement (CV105)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	833	0.02	14.8
Typical radial network	380	0.02	8.4
Difference (= Special case adjustment)	**453**		**6.4**

Ethernet Comms and Infrastructure at Primary substations

Following the same approach as above, the table below shows the calculation of the SPM special case adjustment. The key figures used in the table are as follows:

- *SPM plans to install 710 digital comms units at primary substations in ED1. These cost £0.014m each*
- *As above, we use SPD as our radial network comparator. The comparison shows that a far higher number of digital comms units are required for an interconnected network, with SPD proposing to install 400 units. Both SPM and SPD have similar unit costs.*
- *Taking SPD's costs as indicative of the costs for a notional SPM radial network, we calculate a special case adjustment of* ***£4.7m*** *as in the table*

Table 14: Other Capex – Ethernet Comms and Infrastructure (CV105)

Spending Category	No. of Assets	Unit Cost (£m)	Total Cost (£m)
Calc:	**A**	**B**	**C = A*B**
SPMW Integrated Network	710	0.01	10
Typical Radial Network	400	0.01	5.3
Difference (=Special Case Adjustment)	310		**4.7**

Note: Operational IT and Ethernet development to grid substations is not relevant to SPMW special factors.

Primary Substation Civils

Following the same approach as above, the table below shows the calculation of the SPM special case adjustment for substation civils. The key figures used in the table are as follows:

- *SPM plans to modernise 598 primary substations in ED1. These cost £0.04m each;*
- *SPM has a larger number of brick built primary sites for its interconnected network. SPD is modernising 454 primary substations, although SPD can achieve a lower average unit cost as it has fewer of the more costly brick-built sites.*

In the table below we have used the SPD volumes and the SPM unit cost, we calculate a special case adjustment of ***£6.4m****.*

Table 15: Other Capex – Substation Civils (CV6)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	598	0.04	24.5
Typical radial network	454	0.04	18.1
Difference (= Special case adjustment)	**144**		**6.4**

We recognise a reduced unit cost is used in Scotland of £0.034m, using this unit cost in the comparison would yield an additional cost adjustment of £2.4m.

B3.3 - 11kV Asset Modernisation Capex

In this section, we examine the 11kV non-load capex that SPM plans to spend over ED1 which is specifically related to SPM's interconnected network as compared to a typical radial network. 11kV capex makes up £18.6m of the £127.8m in Table 2 above. The breakdown of this expenditure is shown in the table below, and the rest of this section examines each category in turn.

Table 16: 11kV Asset Modernisation Capex (CV3, CV6)

Spending Category	SPMW Proposed Special Case Adjustment (£m)
X Type' RMU	7.4
X Type' Transformer	0.2
Batteries at secondary substations	1.0
Substation civils	10.1
Total	**18.7**

Note: numbers in table may appear to not calculate due to number rounding

‘X type’ RMU’s at secondary substations

Following the same approach as above, the table below shows the calculation of the SPM special case adjustment for X-type RMUs. The key figures used in the table are as follows:

- *SPM plan to replace 1706 indoor X-type RMUs in ED1 to improve asset condition and to reduce the prevalence of assets categorised as HI5. X-type ring main units are required at secondary substations along an 11kV interconnected circuit between two or more primary substations in a similar way but at one voltage layer down to that shown in figure 1 above. The total ED1 investment is £26.7m at a unit cost of £.016m*[31]

- *On a traditional radial network, including SPM’s rural network, the ring main units would be Y-type and be replaced at a lower unit cost of £.011m*[32]

- *We have calculated the cost of replacement of the SPM volumes ring main units at the traditional radial network cost using our SPD unit cost of £0.011m. Overall, we calculate a special case adjustment of* ***£7.4m*** *as in the table*

Table 17: 11kV Capex: ‘X Type’ RMU (CV3)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	1706	0.016	26.5
Typical radial network	1706	0.011	19.1
Difference (= Special case adjustment)	**0**		**7.4**

‘X type’ Transformers at secondary substations

Following the same approach as above, the table below shows the calculation of the SPM special case adjustment for X-type transformers. The key figures used in the table are as follows:

- *SPM plan to replace 281 indoor X-type secondary transformers in ED1 due to age and condition and to reduce prevalence of assets categorised as HI5s. X-type transformers have additional components connected to the HV voltage side of the transformer in the form of additional current transformers (CTs) to allow the unit protection schemes to operate as described above. These CTs require additional termination accommodation for the cable connecting the transformer to the X-type RMU. The total ED1 investment is £2.5m at a unit cost of £.012m*[33].

- *On a traditional radial network, including SPM’s rural network the same volumes of secondary transformers would be Y-type and be replaced at a lower unit cost of £.01m*[34].

- *We have calculated the cost of replacement of the SPM volumes X-type secondary transformers at the traditional radial network cost using our SPM Y-type unit cost of £0.011m. We calculate a special case adjustment of* ***£0.2m*** *as in the table*

31 SP Unit Cost Manual, page 46

32 SP Unit Cost Manual, page 47

33 SP Unit cost Manual, page 48

34 SP Unit Cost Manual, page 25.

Table 18: 11kV Capex: 'X Type' Transformers (CV3)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	218	0.012	2.5
Typical radial network	218	0.011	2.3
Difference (= Special case adjustment)	**0**		**0.2**

Batteries at Secondary Substations

SPM's interconnected network requires additional tripping batteries at secondary substations than is the case for radial networks.

We have assessed the associated extra cost over the ED1 period based upon the difference between planned SPM and SPD investment in batteries for ground mounted HV secondary substations, using SPD as an average for the industry operating radial networks, for necessary batteries for activities such as network automation or remote control.

As before, the table below shows the calculation of the SPM special case adjustment. The key figures used in the table are as follows:

- *To arrive at the special case adjustment estimate, we compare planned investment in these assets at ground mounted HV substations for SPM's interconnected network with the equivalent for SPD's radial network.*
- *SPM's planned investment in these assets is £1.26m; SPD's planned investment in these assets is £0.25m.*
- *Taking SPD's volumes as industry typical for a notional SPM radial network, we calculate a special case adjustment of **£1.1m** as in the table*

Table 19: 11kV Capex: Capex Batteries at Secondary Substations (CV3)

Spending Category	Total Expenditure (£m)
SPMW Integrated Network	1.3
Typical Radial Network	0.3
Difference (=Special Case Adjustment)	**1.0**

Secondary Substation Civils

SPM's interconnected network requires the use of unit protection for it to work effectively to safely remove faults from our network, and to minimise CI & CML.

SPM's interconnected unit protection requires secure well heated/ventilated buildings to remain serviceable. As a result, SPM has a larger number of brick built substations than other DNOs with radial networks, which use more open compound and glass reinforced plastic (GRP) style substations.

As before, the table below shows the calculation of the SPM special case adjustment. The key steps in the calculations are as follows:

- *We compare SPM's number of brick built substations requiring investment in ED1 with that of SPD as a typical radial network comparator;*
- *SPM has 5197 such substations in its ED1 plan compared to only 2377 for SPD;*
- *We use SPM average unit cost of maintaining brick buildings which is £.004m.*
- *In the table below we have used the SPD volumes and the SPM unit cost. We calculate a special case adjustment of* ***£10.1m***

Table 20: 11kV Capex: Substation Civils (CV3)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	5197	0.004	19.1
Typical radial network	2377	0.004	9.0
Difference (= Special case adjustment)	**2820**		**10.1**

5.5. B4. Cost Associated with 33kV, 11kV and LV Network Non Load Operating Costs

B4.1 - 33kV: Opex

In addition to the 33kV capex costs for the initial build or replacement of the interconnected 33kV unit protected network associated with primary substations, there are also additional operating costs. 33kV (I&M) Opex makes up £8.7 of the £127.8m in Table 2 above. These costs are set out below and consist of routine and post fault maintenance on 33kV circuit breakers at primary substations, unit protection communication channel (pilot wire) rental and repair activities, unit protection battery maintenance, and 33kV cable repairs

Table 21:33kV Opex (CV13, CV15a, CV15b)

Spending Category	SPMW Proposed Special Case Adjustment (£m)
33kV CB Maintenance at Primaries	2.2
33kV Unit Protection Pilot Wire failures	3.4
33kV rented 3rd Party Charges	2.2
33kV Cable fault repairs	1.0
33kV Unit Protection Battery Maintenance	0.02
Total	**8.7**

33kV CB maintenance at primaries

We have determined the volumes and costs of maintaining substation 33kV circuit breakers and associated equipment (such as reference voltage transformers, disconnector's and earth switches as appropriate) associated with SPM discrete 33kV unit protection systems, inc. post fault based on the SPM substation maintenance policy[35] and unit costs, inclusive of post fault. We show the calculation of the SPM special case adjustment in the table below

- *33kV circuit breakers would not usually be required in primary substations in a radial network.*
- *We calculate a special case adjustment of **£2.2m***

Table 21: 33kV Opex: CB Maintenance at Primaries (CV13)

Spending Category	SPMW Proposed Special Case Adjustment (£m)
33kV CB (all types) Maintenance incl. post fault	2.0
33kV thermo vision inspections	0.3
Total	**2.2**

33kV unit pilot wire failures

SPM require 33kV pilot wires for effective operation of its unit protection between primary substations. The pilot wires are also used for remote monitoring and control of 33kV equipment at the substation. SPM owns and operates its underground pilot cable network in urban areas in line with effective asset stewardship, and importantly to identify and repair faults to prevent incorrect operation of the unit protection, which would result in increased CI & CML.

35 SP Plant Maintenance Policy SUB-01-009

SPM has a greater dependency and higher volume of underground cables than typical radial networks. We show the calculation of the SPM special case adjustment in the table below

The key steps in the calculations are as follows:

- *Based on current fault and repair rate SPM will invest in the repair of 582 repairs over ED1, which equates to an average 6 repairs per month.*

- *For a typical radial network, a direct comparison is not available. Other DNOs do utilise pilot cables in 33kV networks protection, particularly with intertrip signalling. However, due to disparity in volumes, no direct comparison from which to calculate an adjustment is available. In the absence of a clear comparison, we note that during ED1 on the SPD network we will require to repair 164 pilots equating an average 1.75 per month.*

- *In the table below we have used the SPD volumes and the SPM unit cost, we calculate a special case adjustment of **£3.4m***

Table 22: 33kV Opex: Pilot Wire Failures (CV15b)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	582	0.01	4.8
Typical radial network	164	0.01	1.4
Difference (= Special case adjustment)	**418**		**3.4**

33kV rented 3rd party pilot wire charges

As stated above SPM interconnected network relies on pilots wires for effective operation of its unit protection between primary substations and remote monitoring and control of 33kV switchgear at substations. In non urban areas where we use overhead line circuits rather than underground cables, we do not own our own pilot wires, other than 25 under slung pilots known as Hardex as referred to in sections above. In this case we rent 3rd party communication channels from British Telecom and other service providers.

The table below shows the calculation. The key steps in the calculations are as follows:

- *In ED1 SPM will invest a combined £6.75m in the rental of 132kV and 33kV rented pilots. We estimate 55% of this cost (£3.7m) is attributed to 33kV networks and 45% (£3.05m) to 132kV networks[36].*

- *For a typical radial network, a direct comparison is not available. Other DNOs do utilise pilot cables in 33kV networks protection, particularly with intertrip signalling. However, due to disparity in volumes, no direct comparison from which to calculate an adjustment is available. In the absence of a clear comparison, we note that during ED1 SPD will invest £1.6m on rented pilots for its 33kV network protection signalling in rural areas.*

- *In the table below we have used the SPD volumes and costs. we calculate a special case adjustment of **£2.1m***

---

36 The allocation is not an even split on substation numbers between the voltage levels as 132KV protection systems required more complex protection systems requiring a greater number of communication channels than for the same number of 33kV substation and circuits

Table 23: 33kV Opex: Rented Pilot Wire Costs (CV13)

Spending Category	Total Expenditure (£m)
SPMW Integrated Network	3.7
Typical Radial Network	1.6
Difference (=Special Case Adjustment)	**2.1**

33kV Cable Fault repairs

SPM interconnected network operates with high utilisation factors as described in part A of this annex and supported by both PB Power[37] and Mott Macdonald[38]. The high utilization factors offer many benefits in terms of reduced investment costs in some areas, however operating at higher utilisation factors does increase the fault level of the systems and the fault current that flows at the time of a circuit fault. For cable faults this results in high levels of carbonisation and deterioration of insulation papers in the 33kV cable in the vicinity of the cable fault. If these sections of cables (with heavily carbonised insulating paper) are not removed and replaced at the time of repair, then it will result in future failure of the cable, at the location immediately adjacent to the original fault.

To mitigate the risk of failure, the average excavation and length of replacement cable for a 33kV cable faults is between 24 and 35 metres compared to around 20 metres in SPD.

We show the calculation of the SPM special case adjustment in the table below. The key steps in the calculations are as follows:

- *SPM expect to repair 832 33kV cable faults in ED1, typically 8-9 faults a month at an average unit cost of £9.4k reflecting the additional damage to the cable either side of the actual fault requiring a larger cable excavation and repair.*
- *Using SPD as a comparator for a typical radial network, SPD achieve a similar 33kV cable fault repair for an average unit cost of £8.3k taking into account the lower operating fault level and less damage caused, requiring a shorter excavation and repair.*
- *We have taken SPM expected fault volumes and SPD repair costs as the SPM comparator resulting in a special case adjustment of* ***£1.0m***

37 PB Power Assessment of Special Case for SP Manweb Operating an Interconnected Network section 3.2

38 MM Assessment of Special Case for SP Manweb Operating an Interconnected Network, section 1.12

Table 24: 33kV Opex: Cable Fault Repairs (CV15a)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	832	0.0095	7.9
Typical radial network	832	0.008	6.9
Difference (= Special case adjustment)	**0**		**1.0**

33kV unit protection battery replacement

As described in previous sections, SPM operates an interconnected network, with unit protection to deliver a safe and reliable electricity network. The unit protection relays rely on pilot cables to ensure the protection relays at either end of the circuit communicate correctly to detect faults. One type of unit protection relay used throughout the more urban and semi urban areas in called 'Translay' where the pilot cables are run overhead or over non SPM owned pilots. For safety, isolation transformers are used between the pilot wires and the substation relay panels and protection relays. This then requires the use of an additional battery to that of the normal substation battery per 33kV circuit. These are relatively low cost items but are discrete to the SPM interconnected network.

We show the calculation of the SPM special case adjustment in the table below. The key steps in the calculations are as follows:

- *SPM will replace 362 of these batteries over ED1 at a total cost of £0.02m*
- *These unit protection schemes are not present on typical radial networks so the batteries would not normally be required in primary substations in a radial network.*
- *We calculate a special case adjustment of **£0.02m** as in the table*
-

Table 25: 33kV Opex: Protection Battery Maintenance (CV13)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	362	0.0001	0.02
Typical radial network	0	0.000	0.0
Difference (= Special case adjustment)	**0**		**0.02**

B4.2 - 11kV: Opex

In addition to the 11kV capex costs for the initial build or replacement of the 'X-type' network associated with secondary substations there are also additional operating (I&M) costs. These costs consist of routine and post fault maintenance on 11kV circuit breakers mainly within 11kV X-type RMUs, but also found in multi panel switchboards at HV customer sites and at mid-interconnector switching sites, where two or more interconnected circuits join.

The higher level of maintenance is related to the fact that SPM's interconnected network requires HV circuit breakers at each secondary substation along the interconnector, in order for its unit protection principle to operate safely and effectively. For a fault on a circuit along the interconnector between two or more primary substations, then the two circuit breakers (typically one at each of the X-type RMU's) at each adjacent secondary substation will operate to remove just the faulted section and will ensure that no customers are disconnected[39]. This places additional duty on the circuit breakers and they have to be maintained for safety.

We show the calculation of the SPM special case adjustment in a similar way as for capex. However, as network fault rates are specific to each DNO we have reflected this by comparing X-type and Y-type I&M volumes and costs for SPM's volumes only.

The table below shows the calculation. The key steps in the calculations are as follows:

- *SPM has a secondary substation opex cost associated with maintenance and post fault maintenance of £4.7m;*
- *This is dominated by additional cost of maintenance and post fault maintenance costs associated with 6464 circuit breakers incorporated in X type RMUs and to a lesser extent circuit breakers at HV customer sites and mid-feeder switching sites.*
- *In a typical radial network (Y-type) these breakers are not in position, but the RMUs would be present in a Y-type configuration with reduced operational duty and often with a fused switch replacing the oil filled circuit breaker, the maintenance cost of which is therefore reduced. This has a combined opex cost associated with routine maintenance of £2.6m*
- *We calculate a special case adjustment of **£2.1m** as in the table below.*

Table 26: 11kV Opex (CV13)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	15414	0.0003	4.7
Typical radial network	13494	0.0002	2.6
Difference (= Special case adjustment)	**1920**		**2.1**

B4.2 – Low Voltage (LV): Opex

Like the higher voltages the LV networks in SPM are operated interconnected, extensively in urban areas, with a circuit being connected to 2, or 3 secondary substations. This has benefits in relation to the accommodation of LCT as discussed in section A2 of this annex[40].

We have not requested any capex adjustment for the SPM interconnected low voltage network. There is however additional operating costs in relation to the SPM interconnected networks

We have explained how SPM's interconnected network achieves the best CI performance[41]. However, the complexity of SPM interconnected system means LV cable fault location is more involved, even with the use of modern fault location equipment complex interconnected cable networks necessitate "live" cut and test techniques to allow the network to be sectioned, and to enable an accurate fault location.

39 By contrast, on a typical radial network one circuit breaker will operate at the primary substation and disconnect the entire circuit and disconnect all the connected customers until, the fault is localised and the circuit restored

40 PB Power (February 2014) section 3.4.5

41 Nafirs annual reports Table 3 (IIP)

With use of current fault locating technology, this additional live cut and test is not usually required on traditional radial network faults.

We show the calculation of the SPM special case adjustment in the table below. The key steps in the calculations are as follows:

- *In ED1 SPM estimates it will need to locate and repair 15,152 LV cable faults based on current volumes, equating to an expenditure of £48.3 million at an average unit cost of £3.19k*
- *We assume SPD unit cost is typical for a radial network operator for similar LV cable fault repairs. SPD costs are also closely aligned to SPM in terms of materials and excavation costs based on common procurement strategy. SPD average unit cost is £3.07k. We have therefore taken SPM expected fault volumes and SPD repair unit costs as the SPM comparator.*
- *We calculate a special case adjustment of* ***£1.8m*** *as in the table below.*

Table 27: LV Opex: Underground Cable Repair (CV15a)

Spending Category	No. of Assets A	Unit Cost (£m) B	Total Cost (£m) C=A * B
SPMW Integrated Network	15152	0.0032	48.3
Typical radial network	15152	0.0031	46.5
Difference (= Special case adjustment)	**0**		**1.8**

6. Appendix A – Parsons Brinckerhoff (PB) Power Assessment of Special Case for SP Manweb Operating an Interconnected Network (February 2014)

PARSONS BRINCKERHOFF

MARCH 2014

ASSESSMENT OF SPECIAL CASE FOR SP MANWEB OPERATING AN INTERCONNECTED NETWORK

SP Energy Networks

[2014 00363 – 001]

FINAL

Assessment of Special Case for SP Manweb Operating an Interconnected Network

2014 00363

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4.0	4th March	All	Incorporation of QA comments

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EXECUTIVE SUMMARY

This report documents an independent review of the "Special Case" associated with the Scottish Power Manweb (SPM) interconnected electrical network.

Parsons Brinckerhoff have significant industry experience which has enabled them to provide an impartial critique of the benefits and drawbacks of the SPM interconnected network, along with an appraisal of the additional costs and their justification. Other supporting evidence has been presented where appropriate.

Continued operation of the SPM 132 kV, 33 kV and 11 kV networks as an interconnected system is backed by the solid evidence of the benefits brought about by such system configurations, including system performance and the ability of the network to accommodate Low Carbon Technologies (LCTs).

System performance statistics taken from the Ofgem - Electricity Distribution Annual Report for 2010-11[1] clearly demonstrate that customers connected to the SPM network receive one of the best standards of supply. In particular, on average only 54 customers are affected by each fault compared to 178 customers affected by each fault in the worst performing Distribution Network Operator's area.

Extensive engagement by SP Energy Networks, Ofgem and other DNOs has shown that stakeholders consider system supply standards to be of upmost importance. Therefore, it can be concluded that the interconnected SPM network caters better for one of their customers' key priorities.

Permanent meshing of LV urban networks and permanent meshing of sub-urban networks are identified as two of the top enablers arising from the Ofgem 'Transform' economic model which has been used in the development of RIIO investment plans for smart network interventions. Additional evidence of the benefits of interconnected networks when accommodating LCTs comes from the detailed nodal system analysis commissioned by SP Energy Networks and undertaken by TNEI. Study results have demonstrated that when accommodating future LCT demand, intervention to reinforce the system would be required later in an interconnected system than in a radial system.

Network operators with traditional radial networks are assessing how the application of interconnection accommodates future LCT demand through Low Carbon Networks Fund projects. These projects have hypothesised that interconnection will provide network benefits for accommodating future LCT demand. Successful outcomes from these projects' trials could lead to increased use of the interconnected network configuration already used in the SPM and UK Power Networks LPN systems.

In their RIIO business plan SP Energy Networks recognise the additional costs of operating an interconnected network and as a consequence of this higher operational cost, they state their intent to use a radial system topology where appropriate, as supported by their design policy. SPM planning procedures incorporate an optioneering stage through which a range of alternative design solutions including radial and interconnected configurations are formed. Most recently, alternatives using "Smart Technologies" are also developed. Procedures for approving network changes incorporate a thorough appraisal of technical and economic factors. Presently, interconnected configurations are generally considered to be most preferable for developments within existing interconnected systems, whilst radial configurations are preferred for developments on greenfield sites and those on the periphery of urban areas supplied by interconnected networks. An advantage of the SPM methodology is its flexibility to accommodate new technologies and respond to system changes, to deliver the most suitable design for the future system. It is understood that the cost benefit analysis of alternatives is being improved to strengthen the evaluation stage as more learning becomes available and more evidence is developed through projects such as those supported by the Low Carbon Networks Fund.

[1] https://www.ofgem.gov.uk/ofgem-publications/46553/electricitydistributionannualreportfor201011.pdf

It is our opinion that the policy for planning the development of the SPM network is a satisfactory approach as it ensures that alternative network configurations are properly evaluated to establish the most suitable designs for network developments. We do not see evidence to support the need for a detailed strategy for transitioning from the existing system to an overall radial topology because of the significant practical and technical inhibitors, along with the expected major changes to power systems due to the uptake of LCTs and DGs. It is considered inappropriate to prepare a programme for change because it may be more effective to operate interconnected or partly interconnected in the future and substantial evidence suggests that more networks are likely to be configured in this way.

Additional costs associated with the operation, maintenance, asset replacement and extension of an interconnected network have been reviewed and found to be well justified. Also, the additional cost of reinforcing an interconnected system above the cost of adding capacity to a radial system has been evaluated based on real case studies. Summating the individual extra costs of operating an interconnected system indicates an overall additional cost of approximately £127.8 million for the ED1 period (£16 million per year).

1 INTRODUCTION

The SP Energy Networks (SPEN) RIIO-ED1 submission for the Scottish Power Manweb (SPM) licence area discusses the nature of the SPM interconnected networks and sets out the budgetary costs for operating the network for the period 2015-2023.

Ofgem's report on the Assessment of the RIIO-ED1 Business Plans, with regard to SPM's proposed expenditure, states:

"SPEN has suggested there are additional costs associated with operating its SPMW interconnected network but it has failed to provide adequate evidence to quantify this claim."

In response to this SPM have gathered evidence and prepared several documents which identify, explain and quantify additional costs associated with SPM operating and developing an interconnected system.

Parsons Brinckerhoff has been engaged by SP Energy Networks to undertake an independent review of the implications of operating, maintaining and expanding SPM's interconnected network when compared with a conventional radial network, including the incremental difference in operating costs and the costs of providing additional capacity.

Based on our significant industry experience and knowledge, we present in this report our impartial critique of the SPM costs along with their associated justification, and provide other supporting evidence.

2 BACKGROUND

2.1 SPM System

SPM provides electricity to over 1.487 million customers across a diverse geographical foot print that encompasses both large urbanised areas of Merseyside together with rural areas of Cheshire, North & Mid Wales and Shropshire.

The majority of the SPM 33 kV, 11kV and LV networks are operated solidly interconnected, particularly in urban areas. This dates back to the design and construction of the network around the time that Britain's electricity supply was nationalised.

Networks interconnected across all distribution voltages are normally designated as 'X-type' configurations, whilst systems with radial LV networks are referred to as 'Y-type'.

The approximate split of the SPM network, based on geographical footprint, is as follows:-

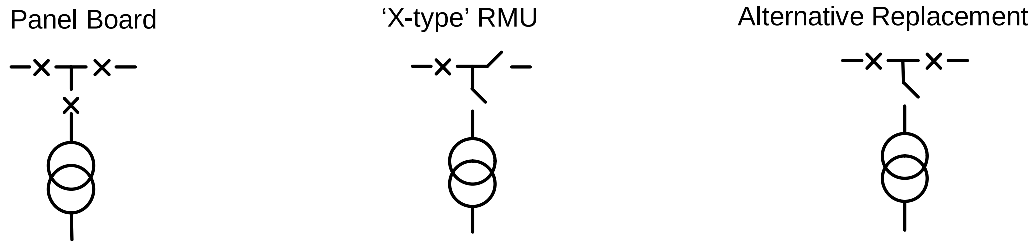
- 55% 'X-type' network, solidly interconnected at 33 kV, 11kV and LV.
- 23% 'Y-type' network, solidly interconnected at 33 kV and 11kV but less so at LV
- 22% is designed as a radial network with single transformers feeding a non-interconnected 11kV and LV system

The SPM urban network was designed to be interconnected so as to maximise transformer utilisation and provide flexibility to reconfigure to adapt to new load centres. Interconnection is a key driver for transformer utilisation as it facilitates load sharing across the capacity of several substations, enabling the benefits of combined headroom for additional contingency capacity. Further to this, another key point in the original design was uniformity of transformer sizes and cables (non-tapering). Uniformity simplifies the connection of additional transformers in new locations without the need for reinforcement (uprating) of existing cables. Unit protection provides support for enhanced fault isolation, with an ideal philosophy of keeping all customers on a feeder on supply following tripping of protection, by implementing overlapping protection zones. A fault can be isolated in the 'X-type' network between substations and customers are able to be supplied from adjacent substations via interconnection at lower voltages.

Statistics show that arguably SPM's network configuration provides the best performance of any UK Distribution Network Operator (DNO), with fewer customers disconnected during a fault than any other network. Such performance requires a switchgear and protection network architecture more complex than a radial system in order to isolate a fault with fewer customer outages.

In order to develop the interconnected topology, ring main units (RMU's) were originally installed at the primary substations and secondary substations along the interconnectors between infeeding substations. These RMU's comprise 2 ring switches and a circuit breaker or fused switch in a single unit of switchgear.

Figure 1: Typical switchgear installation at interconnected substations.



In the urban network design the RMU is configured as an ‘X-type’ as shown in Figure 1, with one ring switch connected to the local transformer, the other ring switch and the circuit breaker being connected to the incoming and outgoing circuits along the interconnector. Suitable 33 kV RMU’s are no longer manufactured and therefore the design and application has evolved to comprise a 3 panel switchboard or a 2 switch and disconnector alternative, again as shown in Figure 1.

This differs from traditional design across other DNOs in that it provides SPM with flexibility to retain a higher proportion of customers ‘on supply’ following a fault by eliminating the manual switching time necessary to restore customers on radial systems.

SPM recognise the costs associated with maintaining an interconnected network and as a result the design philosophy for rural networks has changed over the years towards a more radial system. The rural system is designed partially as a ‘Y-type’ network, interconnected at 33 kV and 11kV but less so at LV, and partially as a more radial system which is not interconnected below 33 kV.

By being interconnected, the design of the SPM network is largely unique in the UK since the majority of the other DNOs operate mainly radial systems. However, depending on load density and geography, 33 kV networks of other companies can run fully interconnected, possibly using distance protection. This interconnection may be as simple loops back to the same substation via 4 or more substations on the loop circuit, or with several interconnection ties between different substations which may be either permanently interconnected or on auto transfer systems.

The main distinguishing feature of the Manweb distribution system is therefore the degree of interconnection at 33kV and 11kV for both ‘X-type’ and ‘Y-type’ networks and the degree of LV interconnection on ‘X-type’ networks.

2.2 Scope of this Review

The scope of work defined by SPM is included as Appendix A of this report.

A significant part of the scope was an independent review of SP Energy Networks' assessment of the differences between operating an interconnected network and operating a radial network. A number of documents and other sources of information addressing the benefits and costs of an interconnected network have been provided by SP Energy Networks, including those listed in Table 1, these are included in Appendix B of this report for the reader's convenience.

During the development of the RIIO resubmission, some information has been refined to provide more accurate assessments of the extra costs associated with the operation of an interconnected system. The SP Energy Networks' "Summary of Revised Additional Costs" document provided on 26th February 2014 provides updates to the additional cost values and justification given in the original source documents.

Table 1: Documents provided by SP Energy Networks.

	Title **(Filename if different to title)**	**Source**	**Comment**
B1	SP Manweb Urban Networks (Manweb special case master v3.docx)	Email from M Bebbington 15th January 2014 15:35	A document comparing the design of the interconnected network with the more conventional radial networks of other DNOs. (comments in sections 3.2 and 5.1)
B2	Manweb 33 kV unit protected networks.docx	Email from M Bebbington 27th January 2014 16:58	A document quantifying the additional costs of modernising and operating unit protected 33 kV networks. (comments in section 4.4)
B3	SPM 11kV Urban Network cost comparison (Manweb secondary x type network cost case.docx)	Email from M Bebbington 27th January 2014 16:58	A document quantifying the additional operational and asset replacement costs for an 11kV interconnected system. (comments in sections 4.3 and 5.1)
B4	Summary of REVISED additional costs for the SPM "Special Case" (PB Power Summary of REVISED Additional Costs for the SPM Special Case 25022014.docx)	Email from A Jones 26th February 2014 12:23	Updated additional cost values and associated justification.

3 OPERATION OF AN INTERCONNECTED NETWORK

3.1 Introduction

The operation of an interconnected network is discussed in this section including benefits such as enhanced system performance and the ability to accommodate Low Carbon Technologies (LCTs). Also it is discussed how network operators with traditional radial networks are assessing how the application of interconnection and unit protection will benefit the accommodation of future LCT demand through Low Carbon Network Fund projects. These projects have hypothesised that interconnection and unit protection will provide network benefits for accommodating future LCT demand. Successful outcomes from these project's trials could lead to increased use of the interconnected network configuration already used in the SPM and UK Power Networks LPN systems.

There are also some disadvantages associated with the operation of an interconnected network; additional equipment not required in radial networks and system complexity introduces challenges and indirect costs which are evaluated in section 4 of this report.

Operation and planning of a more complex system can require additional time. Also, a greater understanding and arguably higher level of engineering skill is required. The requirement for such attributes can have negative consequences in recruitment and higher salary expectations.

The SPM design is based on LV circuits being protected by up to three fused LV circuits in parallel. Better performance of an interconnected system can be explained by only one of the three fuses operating to clear the fault, based on the assumption that the fault 'blows' to an open circuit. Definition of typical circuitry and the mechanism of fault clearance are essential to support the conclusion that most consumers would not suffer an interruption following the LV fault.

As a way of introduction to the general factors affecting operation of an interconnected network, first we review the 'SP Manweb Urban Networks' document.

3.2 Review of "SP Manweb Urban Networks" Document

The 'SP Manweb Urban Networks' document (Appendix B1) compares the nature of interconnected network architecture with that of a traditional radial network commonly operated by other UK DNOs. The document discusses the design and explores the benefits of the architecture and also comments on its state of preparation for adaptation to future low carbon networks.

SP Energy Networks provides a clear argument throughout the document for an interconnected network. The following key points summarise the benefits over radial networks identified by SPM:

- Offers 'frontier performance'
- Accepts power flows in either direction
- Uniformity provides the ability to move underutilised transformers
- Higher utilisation implies that the initial capital cost per kVA of fulfilled demand is minimised (the original justification at 1950's prices and forecasts)
- Low carbon ready network

SP Energy Networks discuss in their document, the major differences between radial and interconnected network architectures and promotes the transformer utilisation factor as a key argument for interconnected networks.

Further supporting evidence for some of the specific benefits discussed in the 'SP Manweb Urban Networks' document is provided within the following three subsections:-

Subsection 3.3: regarding system performance

Subsection 3.4: regarding evidence of other DNOs who are considering interconnection

Subsection 3.5: regarding benefits for the connection of low carbon technologies.

SP Energy Networks mention in their 'SP Manweb Urban Networks' document, the use of automation in today's radial systems to provide controlled interconnectivity and improve supply performance, recognising that other DNOs have some equipment additional/different to that of the SPM network.

In addition to the benefits, the SP Energy Networks' document offers the following limitations associated with the expense:

- Additional switchgear and unit protection
- Robust communications links

The use of smaller transformers and associated high utilisation factors can impact on practical factors, such as substation footprint, maintenance requirements and civil works, but also capex and opex costs. The SP Energy Networks' document highlights the additional equipment required in an interconnected system, particularly the switchgear and unit protection with associated batteries and communications. Cost implications associated with the extra requirements are addressed separately in section 4 of this report.

SP Energy Networks are unable and do not quantify the benefits and determine whether these offset the additional expenditure to maintain the interconnected network. Present regulatory targets do not facilitate an economic evaluation of the value of the better performance provided by the interconnected network. Also, the results of a cost benefit analysis would be of little consequence since, as fully discussed in the source document, the network cannot easily be reconstructed wholesale as a radial system.

The 'SP Manweb Urban Networks' document also refers to the conversion of the existing network to a radial system, however, this aspect is covered in section 5.3 of this report

> The document supports the statement that the SPM interconnected network achieves high asset utilisation, uniformity, flexibility and minimises substation footprint whilst achieving optimum customer performance. It also readily accommodates low carbon developments in both generation and loading.

3.3 System Performance Benefits (CI's and CML's)

The SP Energy Networks document reviewed in section 3.2 states that the Customer Performance of the SPM network as a whole is second only to that of central London (UKPN LPN). Data taken from the Ofgem - Electricity Distribution Annual Report for 2010-11[2], summarised in
Table 2, unquestionably indicates the high level of performance provided by the interconnected SPM network. This is particularly highlighted by SPM having the lowest average number of customers interrupted per fault. With an average of only 54 customers affected per fault, SPM's performance is less than a third of the worst performing DNO, in which an average of 178 customers are affected by each fault.

When considering the data and especially when comparing with UKPN, it is highlighted that one must be mindful of the concentrated nature of the central London area and associated distribution network leading to a very high load density. The rural areas in Wales, Cheshire and Shropshire within the SPM area are not supplied via an interconnected network and obviously have a lower performance than the interconnected urban area. Therefore, the overall performance values for SPM are an average and the lower performance values for the rural areas effectively dilute the higher performance in the urban areas.

SP Energy Networks highlight in their 'SP Manweb Urban Networks' document that the adverse west coast weather experienced in Wales has a significant impact on interruption frequency and average minutes lost values. Consequently it is not appropriate to undertake a direct comparison of the overall results for the SPM system as a whole with the results for UK Power Networks LPN. It is postulated that the geography of the SPM network area has a significant and opposing effect on system performance parameters compared with the positive benefits of interconnection; this disguises the full benefit of the SPM interconnection.

In their document SP Energy Networks present performance parameters for only its urban areas for a comparable period and demonstrates how they are better than the equivalent values for UK Power Networks LPN (2010/11).

> Quantitative evidence supports the statement:-
>
> The increased performance advantages of the SPM interconnected network are undisputable.

Table 2 : Summary of 2010-11 performance data published by Ofgem.

Parameter (2010-11 Performance)	SPM	Range of All DNOs	
		Min	Max
CI **Customer Interruptions per 100 customers**	39.3	24.4	102.2
CML **Customer Minutes Lost per customer.**	47.5	32.4	89.5
Interruption Frequency	1 every 2 years	1 every year	1 every 3 years
Average minutes of lost supply per customer per year (including storms)	63 minutes	37 minutes	116 minutes
Customers interrupted per fault	54	54	178

2 https://www.ofgem.gov.uk/ofgem-publications/46553/electricitydistributionannualreportfor201011.pdf

3.4 Evidence of other DNOs considering interconnection

In this section the ways in which DNOs are targeting innovation funding towards the use of interconnection in HV and LV networks is considered. Evidence of DNOs considering a shift towards interconnected distribution networks is provided.

We have reviewed RIIO-ED1 business plans from each DNO and have identified areas where a DNO's proposed innovation is targeted towards interconnection of HV and LV distribution networks through the next price control period. Under this review we have also identified key on-going projects which present evidence that there is a clear interest, on a national scale, in developing interconnected distribution networks.

In the majority of cases the DNOs held stakeholder engagement workshops prior to the submission of their business plans to investigate customer satisfaction and areas where they could improve. Although the results suggest that the majority of customers were generally satisfied with the level of service they are receiving, their view was that the performance of the network could be improved to reduce power cuts and this has been used to support DNO's proposals for investment to improve system performance.

3.4.1 Northern Powergrid (NPG)

In their business plan Northern Powergrid mention network meshing as a solution to improve 'network management and flexibility', and 'network reliability and availability[3]. NPG seeks to reduce the number and duration of power cuts experienced by customers and recognises the benefits of releasing capacity and reduced network electrical losses through meshing. NPG identify the UKPN smart LV networks project as one of the key external learning resources.

3.4.2 Western Power Distribution (WPD)

WPD's business plan allocates £3.1m of investment to address 'worst served' customer connections over the RIIO-ED1 period[4]. WPD propose to install additional protection equipment to prevent faults from affecting these customers. The business plan also states that network automation and interconnection will also be carried out to ensure there are alternative routes of supply when a fault occurs. The investment comes as a result of stakeholders indicating their support for investment to improve network performance.

LCNF - Project FALCON - Flexible Approaches to Low Carbon Networks

WPD's Project FALCON focuses on releasing capacity in suburban and rural areas through several techniques (four engineering and two commercial). One of the engineering techniques is to implement and operate an interconnected HV network. WPD provide the following overview[5]:-

"One of the several intervention approaches to reduce the cost of reinforcing the 11kV grid. Project FALCON intends to provide an understanding of the dynamic nature of utilisation of the 11kV network, to deliver cheaper and faster connections. One of the engineering techniques being used in this project is the creation of meshed (interconnected) 11kV networks in suburban and rural areas to maximise capacity."

[3] http://www.yourpowergridplan.com/som_download.cfm?t=media:documentmedia&i=1739&p=file

[4] http://www.westernpower.co.uk/docs/About-us/Stakeholder-information/Our-future-business-plan/WPD-RII-ED1-Business-Plan/WPD-RIIO-ED1-Business-Plan.aspx

[5] http://www.westernpowerinnovation.co.uk/Documents/Project-FALCON-Presentation-EUW-13.aspx

3.4.3 Electricity North West Limited (ENWL)

ENWL targets the use of retrofit smart devices for fuses and link boxes to form part of their innovation strategy in their RIIO-ED1 business plan[6]. These devices are intended to be used to create interconnected networks and provide flexibility to reconfigure networks in real time. ENWL has assigned £1.2m of funding to develop and deploy these devices on low voltage feeders to trial the performance. The investment is designed to improve optimal power flows through networks and customers are expected to benefit from improved power quality and a reduction in harmonic distortion at point of connection.

LCNF Project - C_2C - Capacity to Customers

ENWL propose to make efficient use of spare capacity in existing HV circuits in order to facilitate the connection of new loads and generation[7]. The project explores the redesign of the network to facilitate closure of normally open points; feeders will be interconnected, allowing spare conductor capacity to be released to customers (for generation projects, new loads), without compromising levels of security of supply.

LCNF Project - Project eta - LV Network Management and Interconnection

The ENWL eta project aims to build on the methods learned in the C_2C project by incorporating interconnected design into LV networks.

ENWL provide the following overview[8]:-

"Eta will develop a methodology for interconnecting LV networks, including design considerations, the selection and deployment of voltage regulation equipment and the protection arrangements required for safe interconnected operation, particularly for fault scenarios and cold load pick up."

3.4.4 UK Power Networks (UKPN)

It has already been discussed that UKPN operate their Central London (LPN) network interconnected, similar to SPM's. It has been identified from their business plan that UKPN already consider meshed networks as part of 'business as usual' for smart grids. UKPN is targeting more automation of LV networks, notably 'soft' normally-open points.

LCNF Project - Flexible Urban Network – Low Voltage

UKPN's Flexible Urban Network project addresses the challenge to defer reinforcement of the network by conventional means, particularly at LV. This project aims to explore the use of power electronics in network design as a key facilitator to ensure most efficient power distribution across low voltage networks. The project trials the integration of 'soft' normally-open points to provide flexible power transfer between substations for capacity sharing. UKPN state the following[9]:-

"The overarching aim of this project is to explore the use of power electronics to enable the deferment of reinforcement and facilitate the connection of low carbon technologies and distributed generation in urban areas, by meshing existing networks which are not meshed, and by breaking down boundaries within existing meshed networks."

[6] http://cdn2.enwl.co.uk/ENW_WJBP-PDF-Annexes-New.pdf

[7] http://www.enwl.co.uk/docs/c2c-key-documents/c2c-submission-to-low-carbon-networks-fund.pdf?sfvrsn=6

[8] https://www.ofgem.gov.uk/ofgem-publications/84695/lcnfsubmissionfromelectricitynorthwest-eta.pdf

[9] http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Flexible-Urban-Networks-Low-Voltage/Project-Documents/FUN+-+LV+Bid+Submission+2013.pdf

3.4.5 Conclusions

Evidence supports the statement that:-

4 out of 5 of the other DNOs operating in the UK have incorporated some aspect of interconnection in their business plans for the RIIO-ED1 period. The majority of the proposed investment is being targeted towards interconnection in low voltage distribution networks. The benefits of interconnection are being explored by a number of projects supported by the LCN fund.

3.5 Benefits to Low Carbon Technologies

This section will discuss the advantages of an interconnected network with regard to the uptake of Low Carbon Technologies. Discussions include; key drivers for LCTs, future LCT loads, integration of distributed generation into interconnected networks and the use of unit protection schemes.

Examples of LCTs include:

- Heat pumps
- Electric vehicles
- Photovoltaic systems

3.5.1 Key Drivers - Ofgem Smart Grid Forum

The Smart Grid Forum (Ofgem) helps to provide DNOs with a common focus in addressing future networks challenges through several work streams. A key outcome of Work Stream 3 is the development of the ‘Transform’ model which is a network model that is designed to estimate the impact that various Low Carbon Technologies would have on distribution networks in Great Britain. The Transform model is intended compare the deployment of smart and conventional solutions over the ED1 period and beyond to 2050. The model has indicated that at a national level, the investment required in distribution networks could be reduced by the integration of smarter solutions.

Two of the top solutions resulting from the transform model are permanent meshing of LV urban and sub-urban networks. Through analysis it is speculated that the ‘tipping’ point (where a top down solution is required, rather than a case-by-case investment appraisal) for meshing LV urban and sub-urban networks is likely to be in the ED1 and ED2 price control periods respectively.

In task 3.2 of the Work Stream 3 the Transform model was modified for detailed examination of each of the 14 licence areas, where inputs are tailored for specific network topology. DNOs were encouraged to make use of this model to determine the benefits to Low Carbon Technologies in the RIIO submission.

SP Energy Networks completed an assessment of their networks using the Transform model to establish the most cost effective investments for creating network capacity for demand growth including the uptake of LCTs. Also, they commissioned independent analysis to validate the outputs.

3.5.2 New LCT Loads

The increase in LCT loads poses significant challenges to the performance and design of both HV and LV systems as well as producing potential benefits.

LCT loads have similar effects on current and voltage as other load increases; predominantly steady state current, steady state voltage regulation and harmonics.

It is generally recognised that accommodation of LCTs is facilitated by interconnected LV network design and this is supported by the results of the studies commissioned by SP Energy Networks. (TNEI 2.4 Annex to SPEN 2015 – 2023 Business Plan).

3.5.3 Distributed Generation

LCT generation affects net loading and influences steady state current, steady state voltage regulation and harmonics.

It is recognised that there are issues associated with moving from a passive system to an active system able to accommodate distributed generation (DG). Additional protection is required to safely operate a radial system with bi-directional power flows[10].Typically radial systems use protection relays located at the source substation. Consequently the protection requirements become more complex on a radial circuit with DG connected, in order for protection relays to recognise the additional fault infeed along the feeder.

In order to successfully manage a system with significant DG penetration a change to the protection of feeders in a radial network would need to be considered. For the same reasons that we discussed previously, the use of unit protection in interconnected systems can place a large burden on capex and opex costs. It is therefore necessary to recognise and understand the financial implications due to the additional protection requirements to accommodate a regulatory driven initiative for increased levels of DG across all DNO networks.

Interconnected networks overcome some of the issues of the integration of distributed generation into radial systems and offer the following advantages:-

- Unit protection on the SPM system is more advanced than protection on radial systems and therefore more likely to accept DG connections (bi-directional power flows)
- Lateral paths for power place less demand on the system above, deferring costs for network reinforcement
- Wider distribution of reactive power to support local voltages
- Localised energy source reduces electrical losses

Conversely there are some problems:-

- Short circuit levels are generally higher in interconnected systems, less short circuit capacity to accommodate DG than a radial system
- Voltage control becomes more complex
- System operation becomes more complex, e.g. control of downstream power flows following upstream circuit outages

The ENWL C_2C project suggests that there are advantages of connecting DG to an interconnected circuit and hypothesises that interconnection of feeders releases additional circuit capacity to provide more headroom in existing circuits to accommodate DG, as discussed in section 3.4.3

SP Energy Networks commissioned engineering consultancy TNEI to assess HV and LV investment requirements influenced by the uptake of LCTs, including PV generation, and the application of smart solutions. This work involved analysing typical networks including one featuring an interconnected

[10] http://www.esbi.ie/news/pdf/White-Paper-Review-EGIP-Requirements-for-the-Irish-Distribution-System.pdf

configuration feeding urban and suburban areas and another with a radial configuration feeding rural areas. The study report is included in the SP Energy Networks Business Plan as Annex 2.4[11]. It states in section 1.1.2:

"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 TNEI study results clearly indicate the benefits provided by the interconnected network in terms of the voltage rise being within limits for longer and also maintaining customer's supplies whilst altering secondary transformer tap positions to mitigate LV voltage rise issues.

In table 6 of the TNEI report, the ranges of annual investment costs in £million/MW are provided for the different typical networks for addressing both LCT demand and generation. These values show that when system modifications are required, the necessary investment associated with LCT demand growth is greater in an interconnected system than in a radial system. Also, it is shown that investment to mitigate issues with PV generation penetration is marginally greater in interconnected systems compared with radial systems.

3.5.4 Unit Protection Schemes

SPM's unit protection on "X-type" substations contributes significantly to the optimum customer performance. Other DNO's are investing in increased automation and unit protection to pursue improvements.

The use of enhanced communication schemes is an enabler for integrating LCTs into 'smarter grids'. Interconnected networks already provide a robust communications platform due to the pilot interconnections required for unit protection schemes. It could therefore be considered that interconnected networks are more developed and prepared for a change to adopt LCTs.

From a wider DNO perspective, it was identified that £40m is committed in UKPN's business plan over the next price control period to increase network automation, part of which will incorporate unit protection in five LV network groups in Central London. The proportion of the fund allocated for unit protection schemes is unclear; however the capital expenditure is such that it represents a significant investment in greater control at LV.

Use of unit protection schemes on HV and LV systems are less apparent in the detailed business plans from other DNOs, however, business plans and project application sheets do not provide detail of methods used to protect circuits in the interconnected system projects discussed in subsection 3.4.

3.5.5 Conclusions

> Evidence supports the statement that:-
>
> Encouragement of both DG and low carbon initiatives is facilitated by an interconnected network. In view of the uncertain take up of these developments in both load and generation, it is not considered opportune to move away from the established design of SPM interconnected network.

[11] http://www.spenergynetworks.co.uk/userfiles/file/201303_A2_4_TNEI_HV_LV_network_investment_analysis.pdf

4 REVIEW OF COSTS OF AN INTERCONNECTED NETWORK

4.1 Introduction

There are some benefits from the interconnected nature of the networks, particularly with respect to network performance, but conversely there are 2 main disadvantages (i) that it is difficult and costly to unwind the configuration to that of a more conventional network and (ii) the networks are more expensive to build, extend and operate.

Although these factors have been established historically and accepted, Ofgem have sought an accurate assessment and evidence to support the additional costs. SP Energy Networks have documented such assessments and provided justification in a series of documents which are reviewed in this section. Additional assessments of the costs of the reinforcement of equivalent interconnected and radial systems are also provided.

4.2 Review of SPM "11kV Urban Network Cost Comparison" Document

A review of the document "11kV Urban Network Cost Comparison" has been completed. We have provided a brief summary of the key points of the dialogue.

The document studies a comparison of costs for an interconnected 11 kV system "X- type" configuration and an equivalent "Y- type" configuration.

It is discussed that the customer benefits of a high degree of interconnection in urban areas are generally offset by the significant cost in the upkeep of a more complex network than a radial system. The key comparisons covered in the document are:-

- capex
- opex
- performance (CIs & CMLs)

4.2.1 Capex

The additional capex per annum associated with an interconnected 11 kV network is evaluated based on specific plans for ED1. Actual numbers of units to be replaced are considered along with the difference in the costs for the equipment needed in an interconnected network and that needed in a radial network. The evaluations have been found to be well justified.

Approximate overall 11 kV system additional costs are also calculated in the document "11kV Urban Network Cost Comparison" based on costs for replacing the whole interconnected 11 kV system compared to replacement of a radial 11 kV system. The calculation depends on three important assumptions; a forty year asset life, the split of the cable network between interconnected and radial systems and one distribution substation per kilometre of cable.

The assumption that the HV urban network comprises 70% "X" type and 30% "Y" type architecture seems fair based on local knowledge, but could be determined more accurately perhaps in relation to the terms used in the LTDS - 'dense urban' and 'sub urban' networks in order to fully understand the assumption and provide a more accurate assessment.

The assumption of one secondary substation per km of HV cable has a very significant impact on the calculated cost differential. It is possible that in practice there would be more than one distribution substation per kilometre of cable in an interconnected system and consequently it is suggested that the delta cost value calculated by SP Energy Networks could actually be less than in reality. In addition, it may not be appropriate to apply the same assumptions for "X" type networks and "Y" type networks given the density of substations in urban networks and because larger distribution substations would likely be used in a radial system. This relates to our previous comment which seeks further clarification of 'urban' in terms of 'dense urban' and 'sub urban' networks used in the SPM LTDS.

Conversely, it is possible that asset life is greater than 40 years, so the cost differential per annum could be less than that calculated by SP Energy Networks.

It is noted that the civil costs associated with a brick built substation are much greater than the container design used within radial systems (£20k compared to £8k). It is noted that a brick built substation is necessary because GRP buildings are not suitable for the use of the switchgear. In addition to the extra cost of "X" type housings, we suggest that additional disadvantages are possible difficulties with planning consent and the switchgear requirements of the "X" type substation. There are distinct advantages to be gained from the use of alternatives to brick built substations, but although these may be being considered at the moment, they are not a proven solution. We therefore concur with this assessment that it is most appropriate to use brick buildings for interconnected systems, as indicated in this extract from the SP Energy Networks' document:

"It is also a requirement to have the correct environment to house an 'X-type' substation to ensure the equipment performs to its optimum when required. Currently in SPM all 'X-type' substations are of brick or similar block construction, with no approved GRP or containerised alternative"

The document considers the costs of replacing equipment at HV customer installations. The general theme of the document is that assets are replaced at the end of lifecycle. This is supported by our understanding that these costs are wholly borne by SP Energy Networks and HV customers do not share the cost burden for replacement of aging assets at the point of connection.

The "11kV Urban Network Cost Comparison" document concludes that the interconnected system total 11 kV asset replacement costs would be approximately £239 million more than the radial system over the 40 year lifespan. This equates to approximately £6 million more per year and £48 million more over the ED1 period which is greater than the additional cost evaluated based on specific ED1 plans. The difference is easily explained by the simplistic assumption that the additional cost is divided equally between the 40 years and due to the total system replacement cost dependencies discussed above. However, it is considered that the lifespan calculation provides a useful illustration of the differences between the interconnected and radial 11kV networks.

4.2.2 Opex

Additional opex costs associated with an 11kV interconnected network are estimated based on the aspects considered unique to the interconnected arrangement, namely; repair of pilot faults and post fault maintenance on additional switchgear. Additional inspection requirements of "X" type substations are discounted because it is considered that this is compensated for by the need for additional switching in a radial system.

4.2.3 Performance

We agree with SP Energy Networks' methodology for estimation of the penalties incurred due to reduction in security of supply. The document quotes figures for total costs for IIS increase in penalties which provide additional support for the SPM "Special Case".

4.2.4 Conclusions

> Evidence supports the statement that:-
>
> We are in agreement with SP Energy Networks' estimates for additional costs incurred through the operation of an HV interconnected network.

4.3 Review of SPM "SPM 33 kV Unit Protected Networks" Document

The "SPM 33 kV Unit Protected Networks" document evaluates the additional costs of an interconnected 33 kV system above a traditional radial system. Additional operating and maintenance costs are considered, along with extra asset modernisation costs and reinforcement costs.

Included is a table of additional operational and maintenance costs associated with the extra 33kV switchgear and unit protection. Although the list of additional cost elements is comprehensive and detailed, the estimated additional costs could be considered less than actual and therefore an underestimate of extra costs. As explained in the SP Energy Networks document, no allowance has been made for the fact that there are more 33/11kV transformer sites in the SPM system than in a traditional radial system. The transformers have a lower rating than in a traditional radial system and operate individually. No allowance has been made for the greater maintenance costs for a greater number of sites. In addition no allowance has been made for additional losses associated with high utilisation in an interconnected system. Conversely, there could be an argument that if transformers operate with a higher utilisation, then the combined capacity must be less for the same demand, and less capacity must correspond to less fixed transformer losses.

Within the evaluation of the asset modernisation costs, the document considers replacement of 33 kV switchgear (non Grid), 33 kV RMUs and pilots in urban and rural regions. Indeed, it is considered that all of these equipments are unique to interconnected systems and it is appropriate to consider associated costs as in addition to those of a radial system.

With regard to the replacement of primary transformers, the replacement of 89 units within the SPM network is compared to the replacement of the equivalent capacity in a radial system. A cost differential of £1,269k is concluded based on total MVA capacity, i.e. 89 x 7.5MVA compared with 56 x 12MVA. However, it is considered that this evaluation is actually conservative.

It is suggested that use of the forced cooled ratings would be more appropriate since this is how transformers are utilised in practice. The resultant evaluation would then be 89 x 10MVA compared with 37 x 24MVA and the cost differential would be:-

- 89 x £181k - 37 x £265 k = £6,304k rather than the £1,269k featured.

  (£6.3 million corresponds to £5.65million when efficiencies are applied)

Concerning the section on load related and non load related reinforcement, the following statement is considered crucial to the future design concept:-

"The Greenfield and Brownfield solutions will be considered for radial network solutions if this is the least cost solution and can be achieved without a detrimental impact on the overall stability of the existing network infrastructure."

There could be a considerable danger that this statement could be interpreted as the future design concept default being "business as usual" and not in line with our understanding that alternative design options are formed during the planning process and fully evaluated before deciding the technically and economic preferred solution.

The justification and reasoning behind the evaluation of the additional 33 kV capex attributed to the operation of the interconnection of the SPM network has been reviewed and found to be fair. Numbers of units are based on specific plans for ED1 and extra expenditure calculated using SP Energy Networks' unit costs.

Evidence supports the statement that:-

Additional 33kV system asset replacement costs and operating costs for the ED1 period have been evaluated by SP Energy Networks and found to be well considered by this review.

4.4 Supporting Evidence for Additional Reinforcement Costs

In addition to the extra costs associated with the replacement of the existing interconnected network based upon asset health, there are also extra costs associated with the expansion of the system. In order to be able to quantify these additional costs, the cost differential between the expansion of an interconnected 33 kV and 11 kV system and an equivalent radial system is evaluated in subsequent subsections.

Both systems are considered to have a similar initial capacity and be subject to the same demand increases to ensure a fair comparison.

4.4.1 33 kV Reinforcement Comparisons

Reinforcement costs of two actual interconnected 33 kV systems, namely the Warrington Group and Lostock Group have been compared with costs of hypothetical equivalent radial systems. Both reinforcement schemes are realistic solutions including the installation of additional 132/33kV transformer capacity to facilitate comparison with the reinforcement of the equivalent radial system. It is noted that installation of transformer capacity may not be the preferred solution in either the interconnected or radial system. Both schemes to reinforce the interconnected system offer the advantages of releasing existing capacity which was not realised due to circuit power flows limits arising from the way circuits share. As a consequence of this, the schemes may not realise all of the installed capacity, or may include costs associated with reconfiguration which would not be required in a radial system. Issues such as suboptimal sharing of circuits and fault levels are common within an interconnected network and can result in technical influences on the development of a system and increase costs.

4.4.1.1 33 kV Warrington Group Reinforcement

The existing interconnected Warrington Group comprises the following Grid Supply Points:-

Grid Supply Points 132/33 kV	-	Sankey Bridges Grid	2 x 60MVA
		Warrington Grid	2 x 60MVA
		Dallam Grid	1 x 60MVA

The present demand of 170MVA is within the present firm capacity of 179MVA. The operating regime is such that the five transformer group is operated as a four transformer group with one transformer at Sankey Bridges Grid operating open on hot standby. Such operation is required to mitigate fault level issues.

Load growth in the Warrington Group has led to the need for reinforcement and a potential solution is to install a new 132/33 kV 60MVA grid transformer at Thelwall substation supplied by a new 132kV circuit comprising 1.5km overhead line and 1.2km of cable. The reinforcement works, as shown in Figure 2, would cost approximately £5,600,000 and would increase the firm capacity to approximately 266MVA in total. To comply with fault level criteria, studies were undertaken to establish the reconfigured system.
The group was split into two, Warrington North and Warrington South specifically:-

Warrington North Grid Supply Points	-	Sankey Bridges Grid	1 x 60MVA
		Warrington Grid	1 x 60MVA
		Dallam Grid	1 x 60MVA
Warrington South Grid Supply Points	-	Sankey Bridges Grid	1 x 60MVA
		Warrington Grid	1 x 60MVA
		Thelwall Grid	1 x 60MVA

The additional available capacity as a result of the reinforcement is 87MVA; 59MVA extra capacity in the South Group due to the installation of the new transformer at Thelwall substation and 28MVA in the North Group due to operating the second transformer at Sankey Bridges permanently in service rather than on hot standby.

Reinforcement of the equivalent radial system comprises the installation of an additional 60MVA 132/33 kV transformer along with the associated switchgear, as shown in the second column of Figure 2. Based on the existing 132 kV circuit topology, it is assumed that the 132 kV circuit required for the reinforcement of the equivalent radial system is the same as that required in the interconnected system. However, it is recognised that the geographic location of existing equipment has a significant impact on the costs of reinforcements in radial and interconnected systems.

The detailed cost make-up of the reinforcement of the interconnected scheme based upon SP Energy Networks costs is presented in Table 4 along with the development of the costs for the reinforcement of the equivalent radial system.

The cost for adding 59MVA to the capacity of the interconnected system is £5.6 million, compared to a cost of £4.9 million to increase the capacity of the radial system by 72MVA. The £/MVA cost for the interconnected and radial system are £95k/MVA and £68k/MVA respectively (interconnected cost is approximately 40% more expensive).

It is highlighted that the possible reinforcement of the interconnected Warrington scheme is based upon tee-ing the 132 kV circuit rather than installing additional 132 kV switchgear in order to be economic. This may not be possible in all cases and therefore may be atypical, consequently the cost differential between the interconnected system and radial system expansion costs could be considered as conservative.

4.4.1.2 33 kV Lostock Group Reinforcement

The existing interconnected Lostock Group comprises the following Grid Supply Points:-

Grid Supply Points 132/33 kV	-	Elworth Grid	2 x 45MVA
		Knutsford Grid	2 x 45MVA
		Winsford Grid	1 x 45MVA
		Lostock Grid	1 x 45MVA
		Hartford Grid	1 x 45MVA

Local generation provides 56MW of infeed into the 33kV system at Elworth Grid. At present, when the generator is operating at full export capacity the 33kV feeders from Elworth Grid are overloaded.

To mitigate overloading issues on these circuits and accommodate future load growth it is proposed to install an additional 60MVA grid transformer at Winsford Grid and split the system into two groups, as shown in Figure 3. It is further proposed that the 33kV system is modified and reconfigured, including up-rating of the feeder between Elworth Grid and Winsford Grid, to accommodate the larger power flows.

The installation of the new grid transformer allows the original group to be split into two:-

Group one	-	Elworth Grid	2 x 45MVA
		Knutsford Grid	2 x 45MVA
Group two	-	Winsford Grid	1 x 45MVA, 1 x 60MVA
		Hartford Grid	1 x 45MVA
		Lostock Grid	1 x 45MVA

Again, reinforcement of the equivalent radial system comprises the installation of an additional 132/33 kV transformer along with the associated switchgear as shown in the second column of Figure 3. No 132kV circuit is included in the interconnected system reinforcement cost because there is already sufficient 132 kV interconnected circuits at Winsford. However, for the radial system it is assumed that a 3km 132 kV cable circuit is required for the reinforcement of the radial system based on the assumed location of the hypothetical 132/33 kV substations in the equivalent radial system and the routes of existing 132kV circuits.

Table 5 presents the detailed cost make-up of the reinforcement of the interconnected scheme based upon SP Energy Networks costs alongside the development of the costs for the reinforcement of the equivalent radial system.

The cost for adding 72MVA to the capacity of the interconnected system is £7.2 million, compared to a cost of £5.2 million to increase the capacity of the radial system by 72MVA. The £/MVA cost for the interconnected and radial system are £100k/MVA and £72k/MVA respectively (interconnected cost is approximately 40% more expensive).

4.4.1.3 33 kV Group Reinforcement Comparison Conclusions

This simple comparison using typical development costs clearly shows that the overall development of an interconnected network is significantly more expensive than the equivalent development in a radial system. Table 3 shows close correlation between the costs per MVA of installed capacity for the two 33 kV solutions and their equivalent radial reinforcement. The average cost differential is £27.5k/MVA which corresponds to approximately 40% of the average cost of the radial development.

Table 3 : Summary of £/MVA values for 33 kV reinforcement.

	Interconnected Reinforcement Cost £/MVA	Equivalent Radial Reinforcement Cost £/MVA	Cost Differential £/MVA	Cost Differential % of Radial Cost
Warrington Solution	£95k/MVA	£68k/MVA	£27k/MVA	39.7%
Lostock Solution	£100k/MVA	£72k/MVA	£28k/MVA	38.9%
Average	£97.5k/MVA	£70k/MVA	£27.5k/MVA	39.3%

The results also highlight the dependency on the 132kV circuit costs. In practice the length of the necessary 132kV circuits will be highly dependent upon the location of existing circuits. It is possible that the 132kV circuit back to a grid supply point in a radial system would be longer than the tee circuit required in an interconnected system.

Table 4 : Warrington group 33 kV Reinforcement cost makeup.

Expenditure Item	**Interconnected Topology** *(taken from SPM scheme paperwork)*	**Radial Topology** *(taken from SPM scheme paperwork & typical costs)*
Substation Civil Works	273,030 *Plinths = £26,640* *Trenches = £26,640* *Transformer bunds =£106,550* *Drainage = £39,950* *Access Road = £39,950* *Ground works = £33,300*	295,848 *Trenches = £31,968* *Plinths, noise enclosure, fire wall and tx bunds =£126,000* *Drainage = £47,940* *Access Road = £47,940* *Ground works = £22,500* *Security cabins = £19,500*
Substation Plant	1,884,670 *60MVA Grid tx = £932,400* *Aux tx = £66,600* *LNER =£53,200* *132kV Disconnector = £39,950* *132kV Surge arrestor = £26,640* *Busbars = £26,640* *Earthing = £26,640* *LVAC = £26,640* *Multicores = £39,960* *Site Preliminaries = £66,600* *Protection = £99,900* *Commissioning = £39,960* *33 kV Circuit Breaker = £79,920* *33 kV Protection Panel = £53,260* *Multicores = £13,320* *33 kV tx tails & jointing=£133,200* *Site Preliminaries = £133,200*	1,427,820 *60MVA Grid tx = £920,100* *Aux tx = £60,000* *LNER =£18,000* *132kV circuit breaker and disconnector = £178,200* *132kV Surge arrestor = £18,600* *Earthing = £15,000* *LVAC = £37,800* *Protection = £118,200* *33 kV Circuit Breaker = £61,920*
132kV Protection	326,340 *Protection, intertripping and telecomms*	348,000
132kV ohl mods	166,500	0
Pre Engineering Studies	66,600	66,600
132kV Cable	2,757,240 *tee circuit*	2,757,240 *(assumed same)*
Reconfiguration and Protection Changes	113,220	0
TOTAL	5,587,600 Approximately £5.6 million	4,895,508 Approximately £4.9 million

Figure 2: Reinforcement of the Warrington interconnected group and equivalent radial system.

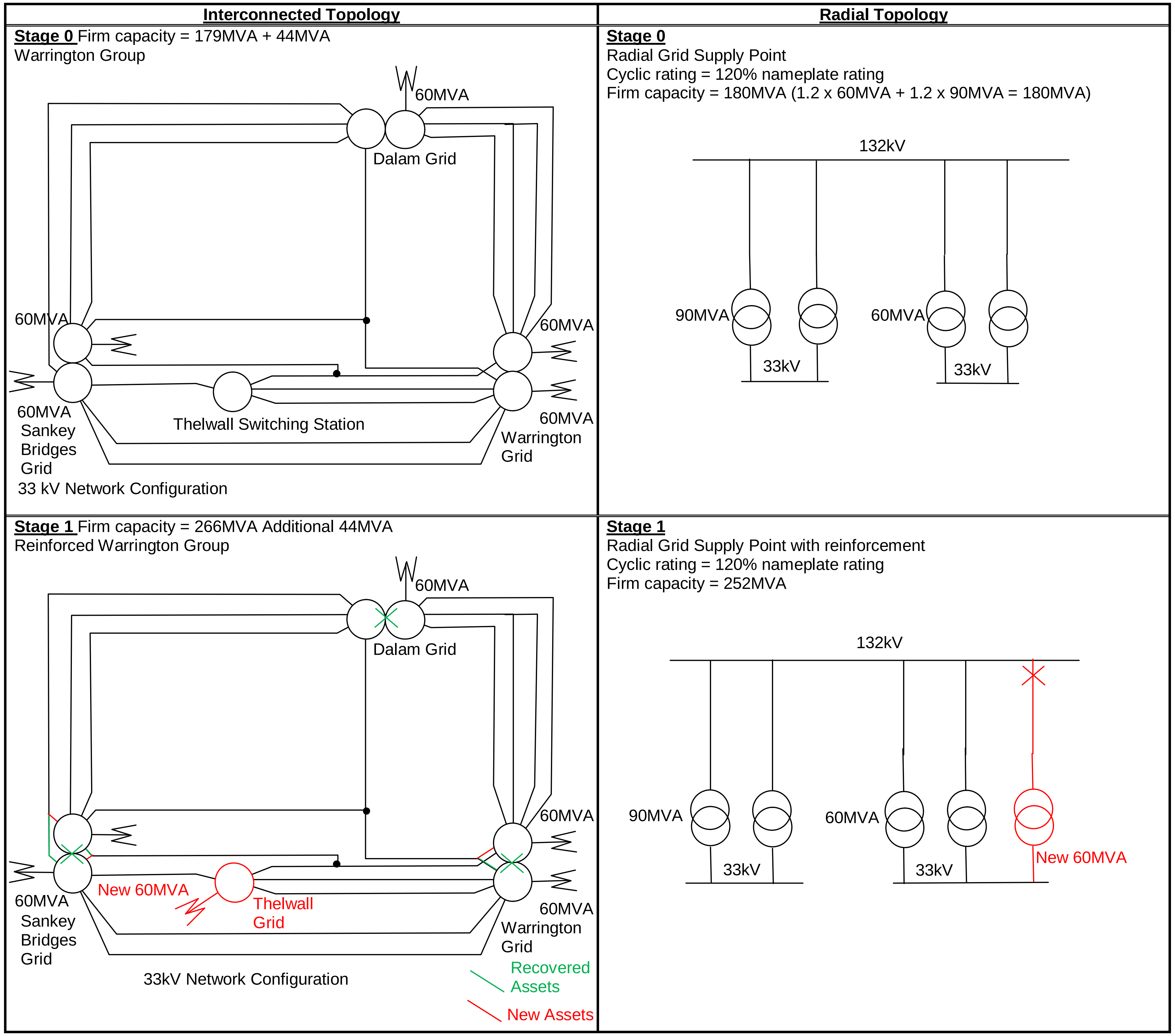
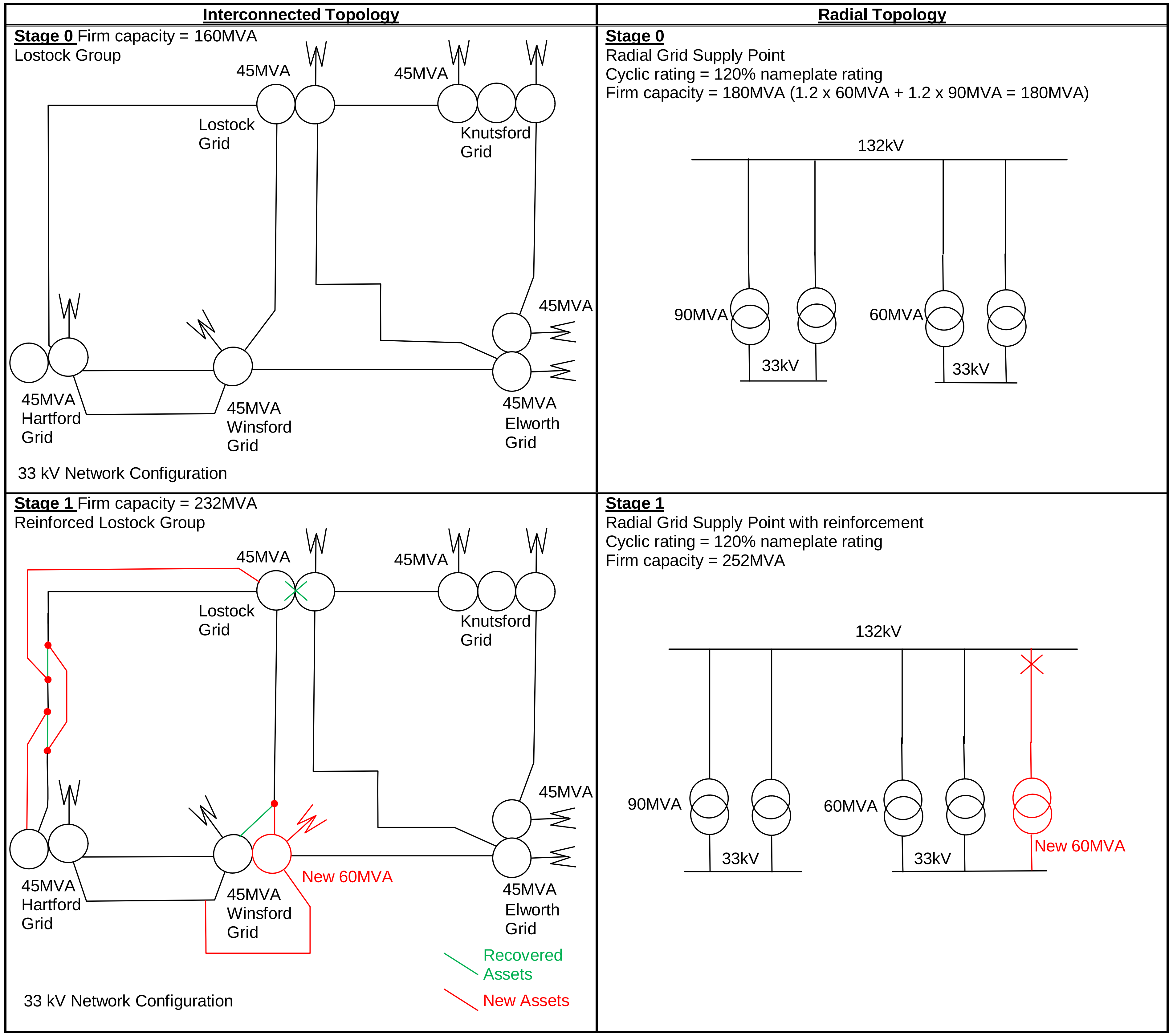


Table 5 : Lostock group 33 kV Reinforcement cost makeup.

Expenditure Item	**Interconnected Topology** *(taken from SPM scheme paperwork)*	**Radial Topology** *(taken from SPM scheme paperwork & typical costs)*
Substation Civil Works	734,358 *Plinths = £162,354* *Gantries = £17,338* *Trenches =* *Transformer bunds = £144,480* *Drainage = £5779* *Internal Road = £20,227* *Ground works =* *Landscape and environment works = £102,135* *Fence Works = £103,417* *Building modifications = £44,344* *Demolition = £1445* *Fire wall = 57,792* *Compound works = £47,151* *floodlighting = £28,896*	295,848 *Trenches = £31,968* *Plinths, noise enclosure, fire wall and tx bunds =£126,000* *Drainage = £47,940* *Access Road = £47,940* *Ground works = £22,500* *Security cabins = £19,500*
Substation Plant	3,836,101 *60MVA Grid tx = £1,011,360* *Aux tx = £86,688* *NER and CT =£53,200* *Disconnectors = £202,272* *Surge arrestor = £34,676* *Busbars = £65,016* *Earthing = £9,970* *LVAC = £10,114* *Multicores = £79,464* *Dead tank CB (120) = £93,912* *Bay interlocking = £14,448* *Site Preliminaries = £28,896* *Cable sealing ends = £93,912* *Commissioning =* *Post insulators = £8,668* *33 kV Switchgear installation = £1,466,471* *Fdr Int Protn & FR = £202,272* *Protn = £57,792* *DAR = £86,688* *Line post-mounted CT = £41,177* *Cable slip over CT = £6,502* *Line CVT =£82,354* *PW circuit mods = £23,116* *Bay MK = £5,779*	1,427,820 *60MVA Grid tx = £920,100* *Aux tx = £60,000* *LNER =£18,000* *132kV circuit breaker and disconnector = £178,200* *132kV Surge arrestor = £18,600* *Earthing = £15,000* *LVAC = £37,800* *Protection = £118,200* *33 kV Circuit Breaker = £61,920*
Protection/ Coms/SCADA	306,297 *Protection, intertripping and telecomms*	348,000
132kV ohl mods	642,936	0
Pre Engineering Studies	85,966	85,966
33kV Cable Interconnection	1,421,000	0
132 kV Cable		3,000,000 *Assumed 3km at £1.0 million per km*
Reconfiguration and Protection Changes	105,470	0
TOTAL	7,132,128 Approximately £7.2 million	5,157,634 Approximately £5.2 million

Figure 3: Reinforcement of the Lostock interconnected group and equivalent radial system.



4.4.2 11 kV Reinforcement Comparison

In this section we consider a stage by stage reinforcement of an interconnected 11 kV system and an equivalent radial system, as depicted in Figure 5.

Both systems are considered to have the same initial capacity and be subject to the same demand increases.

In the interconnected system, additional capacity is provided by adding individual 7.5 MVA 33/11 kV transformers along with the associated switchgear and protection until there are five in the group. Additional reinforcement beyond this is shown to involve two new 7.5 MVA 33/11 kV transformers and splitting the network to avoid excessive fault levels.

In the radial system the total additional capacity is provided by the installation of two primary substations, each with two dual rated parallel 33/11 kV 12/24 MVA transformers.

The expected costs based on today's costs are tabulated in Table 6. The costs for the reinforcement of the interconnected system are approximated at £2.8million based upon the budget for a real connection scheme recently prepared by SP Energy Networks. A detailed breakdown is provided for this connection scheme in Table 7 along with the development of the costs for the equivalent radial system reinforcement. We have assumed that a new 33 kV double circuit of 3.7km would be required for the equivalent radial system based on the average length of urban 33kV circuits in the SP Distribution network and the need for a circuit for each of the two new transformers. It is assumed that there is capacity in the 33 kV system to provide the additional supply capacity at 11 kV. 20 km of 11 kV cable has been allowed for in the evaluation of the equivalent radial cost, based upon an average 2.5 km diversion of 8 x 11 kV circuits. At £5.4million, the cost of the installation of additional capacity in the equivalent radial system is greater than the £2.8million cost of adding extra capacity in the interconnected network. However, more capacity is created in the equivalent radial system.

Initially it is conceived that a new transformer in the radial system is installed without force cooling and that the fans and pumps are installed when the higher rating is required. Only four 11 kV feeder circuit breakers are considered to be installed at the first instance, and four more added at the time of the installation of the transformer cooling. An allowance of £100k is estimated for the later upgrade activities and 11kV switchboard extension.

The substation civil works costs for the interconnected scheme include construction of bays for the new transformer and also an additional transformer for future expansion. The costs (£256,773) have therefore been deducted from subsequent development stages where a second primary transformer has been installed at the new primary substation, i.e. stages 2 and 4.

The costs against capacity for the two network topologies are plotted in the graph shown in Figure 4.

The total cost for adding 40MVA to the capacity of the interconnected system is £13.5million, compared to a cost of £11million to increase the capacity of the radial system by 48MVA. The £/MVA costs for the interconnected and radial system are £337k/MVA and £229k/MVA respectively (interconnected cost is approximately 47.2% more expensive).

This simple comparison using typical development costs clearly shows that the overall development of an interconnected network can be significantly more expensive than the equivalent development in a radial system.

Table 6: Overall costs for four stages of development.

Development Stage	Interconnected Topology Cost	Interconnected Topology Cumulative Total	Radial Topology Cost	Radial Topology Cumulative Total
Development Stage 1	£2.8 million	£2.8 million	£5.4 million	£5.4 million
Development Stage 2	£2.55 million	£5.6 million	£0.1 million	£5.5 million
Development Stage 3	£2.8 million	£8.4 million	£5.4 million	£10.9 million
Development Stage 4	£5.35 million	£13.5 million	£0.1 million	£11.0 million
TOTAL	£13.5 million		£11 million	

Figure 4: Graph showing the investment costs against increase in capacity.

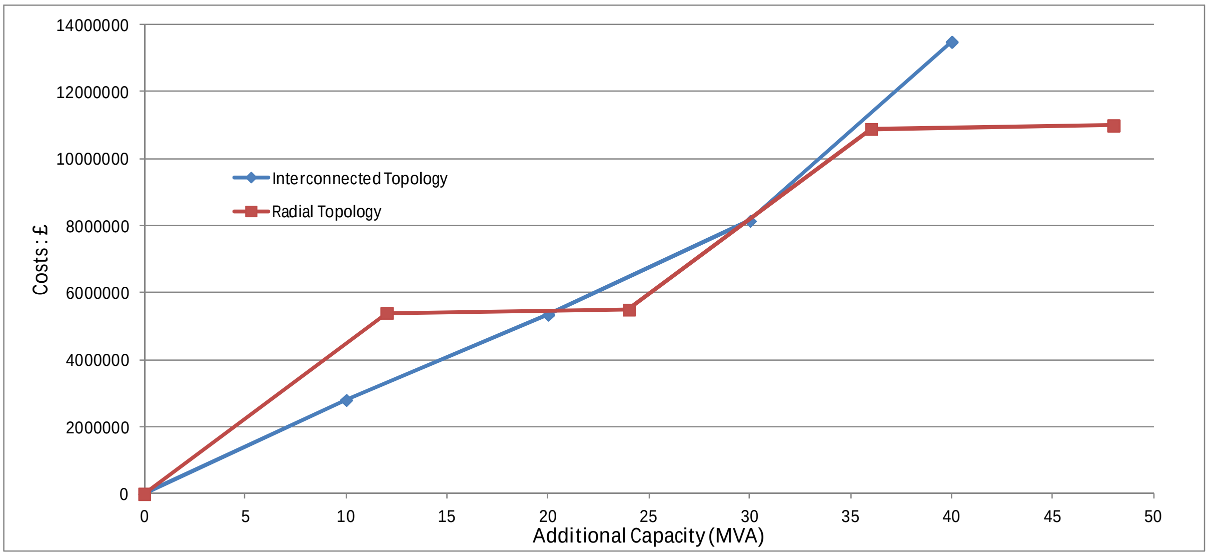
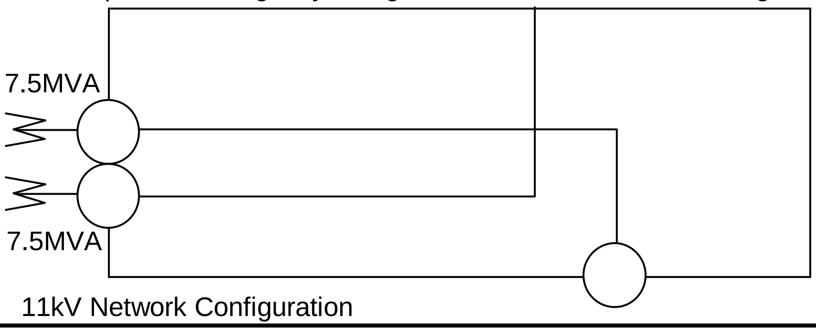
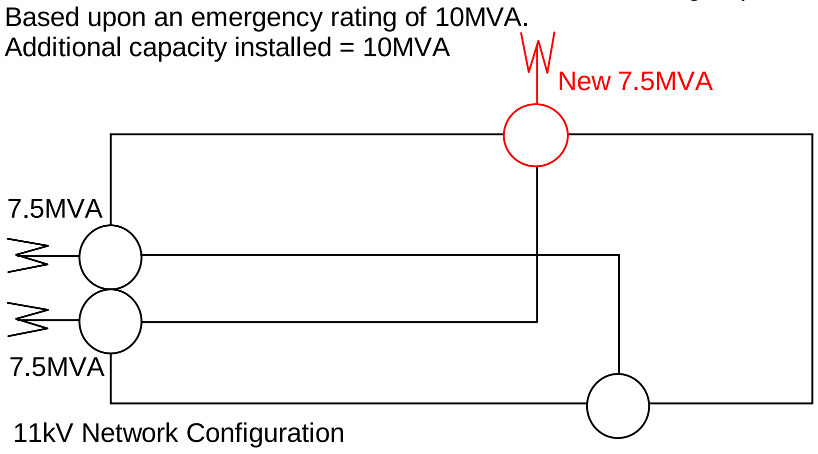
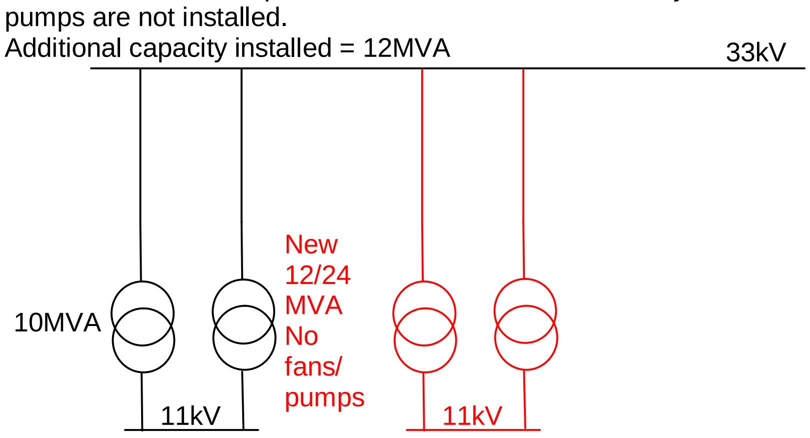
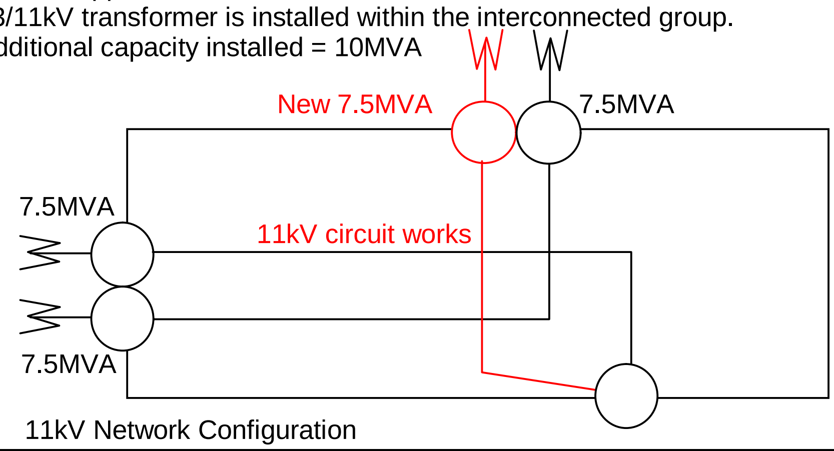
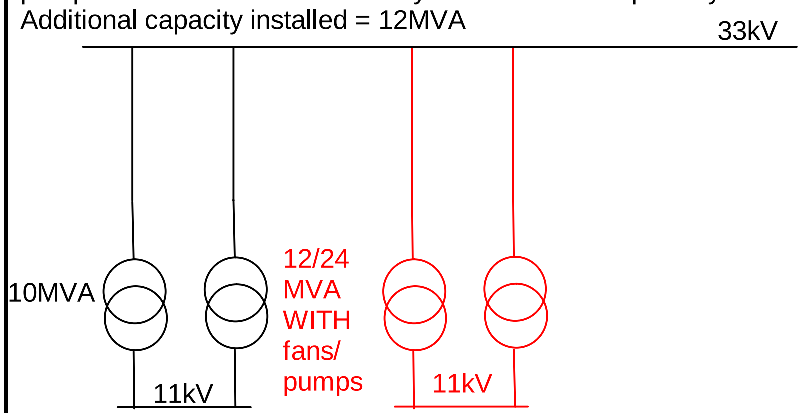
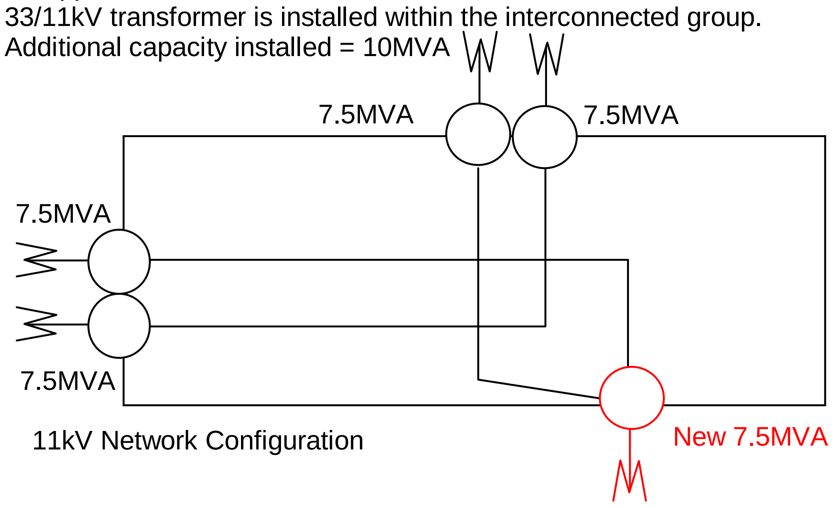
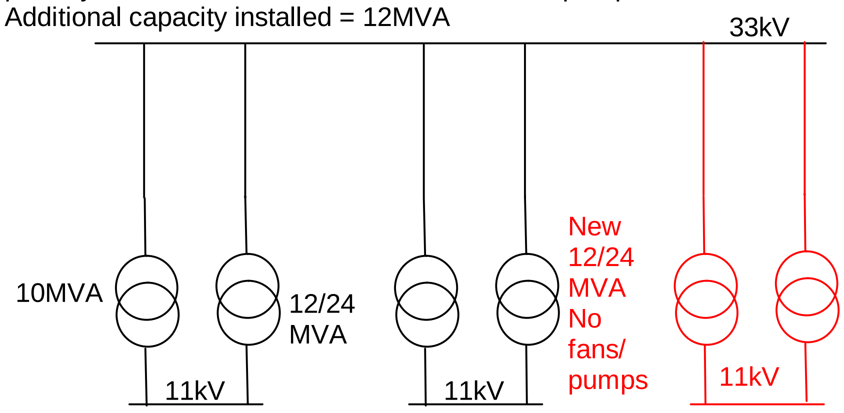
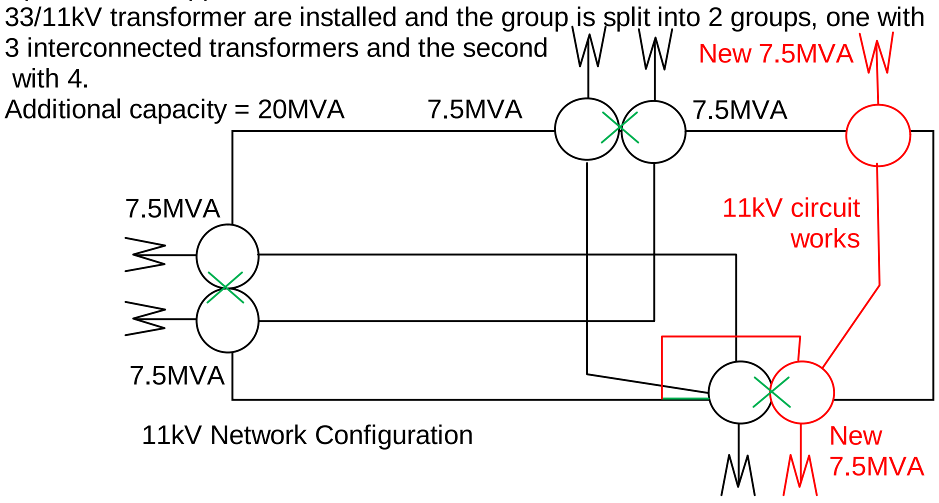
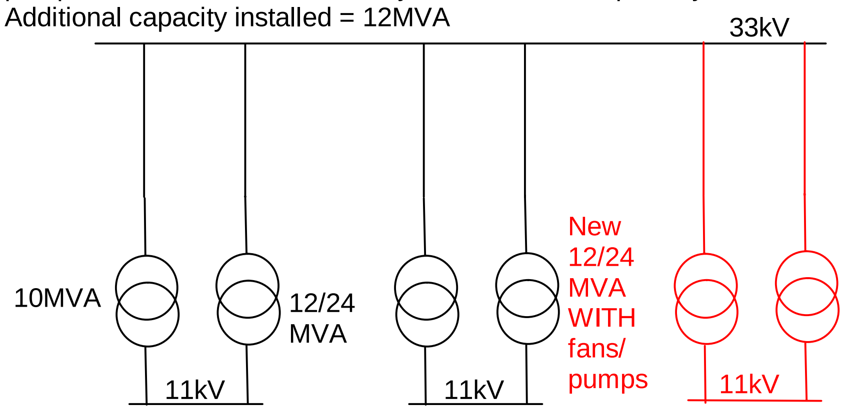


Table 7: 11 kV system development stage cost makeup.

Expenditure Item	**Interconnected Topology** *(taken from SPM scheme paperwork)*	**Radial Topology** *(taken from SPM scheme paperwork & typical costs)*
Land and Fees including wayleaves	5,925	5,925 *(assumed to be the same as interconnected configuration substation)*
Substation Civil Works	256,773	401,190 *Civils for Brick Building = £194k* *Civils transformer bunds and blast wall = £130k* *Road access = £13k* *Fencing = £32k* *Ground/Drainage works = £32k*
Substation Plant	971,009 *33 kV and 11kV switchgear and transformer*	953,100 *2 feeder bays 33 kV switchgear 2x25k=£65k* *2 transformer bays 11kV switchgear=2x£17k= £44k* *1 bus-section bay 11kV switchgear = £26k* *4 feeder bays 11kV switchgear=4x£13.6k= £70k* *2 x 12/24MVA transformers = 2x£265k = £684k* *Protection and alarms panel = £32k* *Battery = £13k* *LV auto changeover = £19k*
Underground 33 kV Cables	884,915 *2.75km 150mm^2 cable*	2,220,000 *3.7km double circuit 33 kV cable @ £300k/km* .
Underground 11kV Cables	650,251 *8.5km 185mm^2 cable*	1,800,000 *20km 11 kV cable @ £90k/km*
Underground Cables LV	47,999 *225m 185mm^2 LV waveform*	47,999 *(assumed same cable works to provide LV supply)*
TOTAL	2,816,872 Approximately £2.8 million	5,428,214 Approximately £5.4 million

Interconnected Topology	**Radial Topology**
Stage 0 Firm capacity = 10MVA Demand = 10MVA An existing system at the edge of a green field site is operating at firm capacity Based upon an emergency rating of a 7.5MVA transformer being 10MVA, 	**Stage 0** Firm capacity = 10MVA Demand = 10MVA An existing system at the edge of a green field site is operating at firm capacity 
Development Stage 1 New firm capacity = 20MVA Demand = 20MVA An application is received for new demand of 10MVA and a 3rd 7.5MVA 33/11kV transformer is installed within the interconnected group. Based upon an emergency rating of 10MVA. Additional capacity installed = 10MVA 	**Development Stage 1** New firm capacity = 22MVA Demand = 20MVA An application is received for new demand of 10MVA and a new primary substation must be established 2 x 12/24MVA 33/11kV transformers are installed due to the expectation of further demand. Initially the fans and pumps are not installed. Additional capacity installed = 12MVA 
Development Stage 2 New firm capacity = 30MVA Demand = 30MVA Another application is received for new demand of 10MVA and a 4th 7.5MVA 33/11kV transformer is installed within the interconnected group. Additional capacity installed = 10MVA 	**Development Stage 2** New firm capacity = 34MVA Demand = 30MVA An application is received for new demand of 10MVA and so the fans and pumps are installed at the recently established new primary substation Additional capacity installed = 12MVA 
Development Stage 3 New firm capacity = 40MVA Demand = 40MVA An application is received for new demand of 10MVA and a 5th 7.5MVA 33/11kV transformer is installed within the interconnected group. Additional capacity installed = 10MVA 	**Development Stage 3** New firm capacity = 46MVA Demand = 40MVA An application is received for new demand of 10MVA and so another new primary substation is installed without fans and pumps. Additional capacity installed = 12MVA 
Development Stage 4 New firm capacity=20+30= 50MVA Demand = 50MVA Upon another application for new demand of 10MVA, a 6th and 7th 7.5MVA 33/11kV transformer are installed and the group is split into 2 groups, one with 3 interconnected transformers and the second with 4. Additional capacity = 20MVA 	**Development Stage 4** New firm capacity = 58MVA Demand = 50MVA An application is received for new demand of 10MVA and so the fans and pumps are installed at the recently established new primary substation Additional capacity installed = 12MVA  **Figure 5: Stage by stage reinforcement of an interconnected system and a radial system.**

4.5 Summary of "Special Case" Additional Costs

4.5.1 Evaluation of the Total Additional Costs

The justified additional costs evaluated in the SP Energy Networks' documents reviewed in the preceding subsections of this report are brought together in Table 9.

For some expense types, the extra costs due to interconnection have been calculated fairly based on the use of specific numbers of units identified in the SPM plan and the use of SPM unit costs. Others have been calculated based on the difference between the planned cost for the SPM network and the planned cost for SP Energy Networks' other distribution area, SPD, in Scotland. It is considered fair to adopt this approach because the SPD costs are believed to be an appropriate approximation for the SPM area if it were to operate with a radial configuration based on the following reasons:

- They have a similar demographic; many customers are based in urban networks with Glasgow and Edinburgh being similar to Merseyside and Warrington.
- Both have extensive coasts on the West, and nearby areas are dominated by rural networks.

Also, comparison of the SPM expenditure with that of SPD offers the advantage that both use the same unit costs for a large number of tasks and they share the same asset management policies and operational policies.

4.5.2 Review of ED1 Additional Load Related Expenditure

The SP Energy Networks' business plan for the RIIO ED1 period indicates investment in load related schemes of £44.2 million for 132/33kV transformers and £31.3 million for the installation of 33/11kV transformer schemes. The latter includes £8 million for the upgrade of 6.6 kV systems to 11 kV, involving the replacement of 281 x 33/6.6kV transformers. The replacement 33/11kV units for the SPM interconnected network are each £1.9k more expensive than the equivalent unit for a radial system.

Table 8 presents how much of this load related investment can be considered as costs incurred due to the operation of an interconnected network. These additional costs have been calculated based on the extra cost of the units being upgraded and by applying the average percentages evaluated from the previous comparison of the equivalent reinforcement of interconnected and radial systems. A cost differential of 39.3% has been used for 132/33kV schemes based on an average of the analyses presented in subsections 4.4.1.1 and 4.4.1.2. Similarly, a cost differential of 47.2% has been utilised for 33/11kV schemes based on the analysis presented in subsection 4.4.2.

Table 8: Additional SPM load related costs, ED1 transformer schemes.

Reinforcement Schemes	Investment £	Cost Differential %	Additional cost for operating interconnected network £
Primary 132/33kV	£44.2 million	39.3%	£12.5 million
Secondary 33/11kV			
Load related transformer replacement	£23.3 million	47.2%	£7.5 million
6.6 kV to 11kV upgrade	£8 million	253 x £1.9k	£0.48 million
Total 33/11kV	£31.3 million		£8.0 million

In addition to the transformer schemes, the SPM plan for load related reinforcement includes the replacement of 33kV RMUs for fault level reasons. 33kV RMUs are unique to interconnected networks and therefore the whole cost of the RMU replacement is considered as an extra above the normal cost of operating a radial system. At a cost of £400k for each RMU, the associated additional load related cost for the 4 units is £1.6 million.

The overall additional cost associated with load related investment is estimated to be:

Primary 132/33kV	£12.5 million
Secondary 33/11kV	£8.0 million
RMU Replacement (load related)	£1.6 million
TOTAL Additional Load Related Cost	£22.1 million

4.5.3 Conclusions

Evidence supports the statement that:-

Based on the assumptions being true, the additional costs associated with the operation, maintenance and extension of an interconnected network above a radial network is approximately £127.8 million over the ED1 period

Table 9: Summary of additional costs for the SPM "Special Case".

	Asset	Additional Cost over ED1 period £million	Comment
Capex 33 kV	Primary transformers	£5.65	Differential due to the need to replace 89 x 7.5MVA transformers in ED1 each costing £181k compared to an equivalent replacement in a typical radial system of 37 x 12/24MVA transformers each costing £265k, after an efficiency factor has been applied.
	Primary substation outdoor 33 kV switchgear	£7.79	Based upon the need to replace 99 outdoor oil circuit breakers in ED1 costing £77k each. 33kV switchgear would not normally be present in primary substations in a traditional radial system.
	Primary substations indoor 33 kV switchgear	£11.76	Based upon the need to replace 105 indoor units in ED1 costing £112k per site including civils and protection modifications including an efficiency factor. Again, 33kV switchgear would not normally be present in primary substations in a traditional radial system.
	33 kV protection modernisation	£4.38	Based upon the plan to modernise 255 x 33kV protection installations in ED1. The protection requirements for an interconnected network are more onerous than in a radial system and an extra £17.2k per site is required.
	BT21CN	£23.22	Based upon the plan to modernise 192 x 33kV protection units at £147k each in ED1 to operate with the new BT21CN communications services. There are significantly more units in the SPM system due to the requirements to protect the interconnected network. The difference is evaluated based on the expected SPD cost of £4.96 million for the replacement of 54 units.
	33kV unit protection pilots	£3.228	Cost differential between SPM and SPD expectations for overlaying pilot circuits.
	Black start resilience at Primaries	£0.91	Installation of higher volumes of 72hr resilience at Primaries based on the difference in the numbers required in the SPM and SPD networks.
	RTU replacement	£6.37	Replacement of more RTUs in the SPM system based on the difference between the numbers required in the SPM and SPD networks.
	Ethernet comms Infrastructure	£4.75	Replacement of more of the digital comms that service substation comms based on the difference in the volumes required for SPM and SPD.
	Substation civils	£6.34	Based on there being more brick built substation primary sites in SPM area, using the SPD system as an average for the industry and multiplying the number of additional units by the SPM unit cost.
	Sub-total	**£74.4**	
Capex 11 kV	'X type' RMU	£7.33	Based on the cost difference of £4.8k between 'X-type' and 'Y-type' RMU's as per the SPEN unit cost manual and replacement of 1706 units in SPM during ED1, along with application of an efficiency factor.
	'X type' transformer	£0.17	Based on the cost difference of £1.9k between 'X-type' and 'Y-type' secondary transformers as per the SPEN unit cost manual and replacement of 218 units in SPM during ED1 along with application of an efficiency factor.
	Batteries at secondary substations	£1.00	'X type' secondary substations require tripping batteries whilst 'Y- type' do not. The associated extra cost over the ED1 period has been assessed based upon the difference between planned SPM and SPD investment in batteries for Ground Mounted HV Substations, using SPD as an average for the industry operating radial networks.
	Substation civils	£10.13	Due to 'X-type' requirements for secure well heated/ventilated buildings there are a larger number of brick built substations in the SPM network when compared with other DNOs which utilise more GRPs and open compound substations. The additional cost of the extra brick buildings is calculated based upon the difference in their number in the SPM and SPD systems and the SPM unit costs.
	Sub-total	**£18.63**	
Opex 33 kV	Primary substation maintenance including post fault maintenance on 33kV circuit breakers	£1.82	There are more 33kV primary substations in the SPM network and the associated extra cost for their maintenance is evaluated based on the SPEN maintenance frequency for EHV switchgear for unit protected zones and maintenance unit costs. Also includes cost of additional post fault maintenance because 2 EHV circuit breakers are involved in interconnected systems, but only 1 in radial systems; 120 extra units each year at unit rates.
	Primary substation battery maintenance	£0.022	Protection associated with 33 kV switchgear; 60 units per year at £362 each
	33kV unit protection pilot repairs	£3.36	Repairs associated with pilot circuits; 5 repairs per month with an efficiency factor applied.
	33kV cable fault repairs	£0.97	Additional costs are associated with the length of cable being repaired in an interconnected system being 20-75% longer than in the equivalent radial system. A longer length of cable must be replaced because the higher fault level leads to more damage around the fault.
	Substn civil maintenance	£0.406	Additional costs are associated with the greater number of substations within the SPM network.
	33kV rented pilots	£2.17	More rented pilots are required in the SPM network to service the 33kV unit protection. The extra cost is evaluated based on the difference between the numbers in the SPM and SPD systems.
	Sub-total	**£8.74**	
Opex 11 kV	Post fault maintenance on 11kV circuit breakers	£2.10	Cost of additional post fault maintenance because 2 EHV circuit breakers are involved in interconnected systems, but only 1 in radial systems; 200 extra units each year at unit rates.
	Sub-total	**£2.10**	
LV	LV cable fault repair	**£1.83**	Cost associated with the one extra joint hole per open circuit fault repair required in an interconnected system when compared to the equivalent fault repair in a radial system.
Load	All load related schemes	**£22.1**	Additional load related expenditure evaluated in section 4.5.2.
TOTAL		**£127.8 million**	

4.6 Comparison of Business Plan Expenditure Values

A comparison has been made between the SPM costs (interconnected network) with those of the ENWL and NEDL radial networks with largely similar geographies and customer bases. Attributes for each of the three DNOs have been extracted from the respective annual reports and long term development statements, in order to provide some perspective on the costs relating, primarily, to capex and opex.

Table 10 presents a breakdown of the projected annual costs from the RIIO business plans for ENW, SPM and NPG (NEDL) networks, as summarised in Ofgem's RIIO-ED1 assessment document.

Table 10: Breakdown of ENW, SPM and NPG (North East) average annual costs

	ENW	NPG (NEDL)	SPM
Customers (m)	2.4	1.6	1.5
Area (sq km)	12500	14300	13000
Circuits (km)	57000	40000	54432
Primary substations	364	250	808
Total energy supplied (GWh)	24000	15330	16000
Capex (£m)*	98.9	60.7	133.4
Opex (£m)*	40.7	39.9	45.5
Load related expenditure (£m)*	18.5	12.5	33
Closely associated indirects (£m)*	42	30.5	41.3
Business support (£m)*	31.9	17.6	17.4
Smart meters (£m)*	0.6	1.6	0.5
Non-operational capex (£m)*	5.1	7.7	6.5
Totex RIIO (£m)*	**238.08**	**170.90**	**277.82**

*(average annual costs)

Values in the table illustrate that there are more primary substations per customer within the SPM network and that the capex and opex figures are significantly higher for the SPM network.

Comparison of the sum of the capex and opex costs for the three licence areas show cost differentials of approximately £40 million and £80 million per annum between SPM, ENWL and NEDL respectively.

The annual capex and opex figures are directly compared as follows:

Interconnected network:

- SPM (£178.9 million)

Radial network:

- ENWL (£139.6 million)
- NEDL (£100.6 million)

Based on Table 9 a cost differential of approximately £127.8 million is justified over the ED1 period for the SP Manweb 'Special Case'. This equates to an average of £16 million per annum on top of the costs required to maintain and operate a radial network.

The comparison with figures for ENWL and NEDL, even normalised based on the number of customers, suggests that the additional justified costs of the SPM network could be conservative, however this comparison is considered to be approximate rather than accurate benchmarking.

4.6.1 Conclusions

Evidence supports the statement that:-

The justified additional costs are lower than the cost differentials apparent from the simple comparison of the capex and opex values in the RIIO business plans.

5 FUTURE SPM NETWORK DEVELOPMENT

5.1 Continuing use of an Interconnected Network

In their 'SP Manweb Urban Networks' document (Appendix B1), SP Energy Networks discount the possibility of making an immediate wholesale change from an interconnected network to a more traditional network based on the results of several external and internal system reviews. The factors that make such a change unjustifiable include:-

a. impact on network performance

b. the capital expenditure required

c. conversion would result in stranded assets due to the existing use of standardised cables and the need for some replacement

d. there is no need to create additional capacity, especially since capacity is being released during ongoing uprating of 6.6 kV systems to 11 kV

e. anticipated improvements to the monitoring within urban networks is expected to further improve the performance of the interconnected network

We concur with SP Energy Networks points that immediate wholesale conversion to a radial topology is not preferable for the following reasons:-

- Stakeholder feedback does indeed suggest that customers' priority is to 'maintain current service levels'.
- The current regulatory regime supports annual improvements in network performance through the IIS and would penalise the reduction in system performance that would arise from conversion to a radial topology.
- The associated significant capital expenditure cannot be justified for other reasons.
- Interconnected networks may facilitate the connection of future LCTs so it is inappropriate to move away from an interconnected networks at this time, as it may be necessary to revert back in the short-term future when more LCTs are connected.

Although, the 'SP Manweb Urban Networks' document conveys a general acceptance of the infeasibility to adopt a totally new design philosophy, what is very apparent is that SP Energy Networks accepts that there are less expensive ways to build new networks which are more cost efficient to operate. They indicate how this is influencing their plans for the future through the comment in their business plan:

"We recognise that it is more cost effective to build new networks as a more traditional design, and therefore when we, or an independent connections provider, are designing new networks, we will build a non-interconnected design where possible, provided this will not impact on existing customer performance; for more information refer to Annex 2.10"

Also, in the SP Energy Networks "11kV Urban Network Cost Comparison" document it is stated:

"The Greenfield and Brownfield solutions will be considered for radial network solutions if this is the least cost solution and can be achieved without a detrimental impact on the overall stability of the existing network infrastructure".

SP Energy Networks' statement to use radial configurations is supported by their design policy. SPM planning procedures are understood to incorporate an optioneering stage for the formation of a range of alternative design solutions including consideration of the application of the latest Smart technologies along with radial and interconnected network configurations. SPM procedures for approving network changes incorporate a thorough appraisal of technical and economic factors. In general, interconnected configurations are considered to be most preferable for developments within existing interconnected systems, whilst radial configurations are preferred for developments on greenfield sites and those on the periphery of urban areas supplied by interconnected networks. An advantage of the SPM ‘case by case’ approach is its flexibility to accommodate new technologies and respond to system changes, to deliver the most suitable design for the future system depending on local conditions. It is understood that the methodology for the cost benefit analysis of alternatives is being improved to strengthen the evaluation stage as more learning becomes available and more evidence is developed through projects such as those supported by the Low Carbon Networks Fund.

SP Energy Networks have already undertaken and commissioned studies to examine the differences between the operation of an interconnected and traditional radial system taking into consideration the latest technical developments such as automation, remote monitoring and control. These have informed their design policy and procedures so ensuring that decisions regarding the future development of their system are made with full awareness and the latest information are encapsulated in their plans.

Although no complete assessment of previous studies has been conducted, it is our observation that the general principles defined in the studies do not provide a methodology for converting the existing interconnected SPM system to a radial topology as they also conclude that it is inappropriate to do so. In general, it is considered that the development of a design strategy for the overall existing system covering a long development period would be difficult since the nature, extent and location of system requirements cannot be forecast accurately.

Despite stating their broad intention to use radial topologies where appropriate, in their ‘SP Manweb Urban Networks’ document SP Energy Networks state that they see “no feasible alternative when replacing existing assets in interconnected areas other than to replace like for like”. Their design policy, which provides guidance for generic reinforcement of the network, prevents “like for like” replacement without proper justification and review. The aforementioned optioneering stage includes scope to review the implementation of a radial topology and ensures a thorough evaluation leading to the choice of the optimal design.

Evidence supports the statement that:-

Justified reasons support SP Energy Networks’ decision to continue to operate an interconnected network and not to undertake a wholesale change. Based on their recognition of the greater costs associated with an interconnected topology, they have indicated an intent to use radial network configurations where appropriate. Correct application of the SPM design policy should ensure approved plans for future developments are based upon thorough evaluation of alternatives. Also, the policy should prevent “like for like” replacement without proper justification and review.

5.2 Consumer Priorities

5.2.1 Stakeholder Engagement & Customer Satisfaction Surveys

It is found that stakeholder engagement feedback prioritises a reliable network and this suggests that the SPM network should continue operating in an interconnected arrangement.

The electricity industry is regulated to protect consumer interests and consequently prior to the RIIO submissions, SP Energy Networks conducted significant research into consumer priorities to inform their strategy for future investment. Transcripts from in-depth interviews and focus groups, along with notes from SP Energy Networks workshop events[12] were analysed in order to identify stakeholder main concerns.

Fundamentally the results of the customer engagement surveys provided clarity that customers considered security of supply to be most important factor going forward. SP Energy Networks found that for domestic customers their view was typically in relation to their present reliability of electricity supply and they sought a reduction in the number and length of power cuts they experienced.

Other stakeholders had more of a focus on the future and ensuring that the electricity network is able to cope with future demand and generation securing electricity supply for years to come.

It was concluded that:

"security of supply for the present and the future should be central to any business plan that SP Energy Networks develops".

In order to achieve this:

"it was felt that SP Energy Networks needs to develop a greater understanding of its own network and thus focus on monitoring in the first instance, building in additional capacity where it is needed most".

The stakeholder feedback was put forward in the RIIO submission to present a case for network investment, to ensure that SP Energy Networks are able to deliver the security of supply received by customers in previous years.

Similar feedback was identified from stakeholder engagement with other DNOs. The summary of WPD's feedback shown in Figure 6 indicates that maintaining the current levels of service was in the top 3 priorities at all 6 engagement events involving more than 200 customers. UKPN also held a stakeholder engagement workshop to generate feedback on RIIO-ED1 outputs,

Figure 7 presents a key extract from their report[13].

Ofgem's Consumer First initiative is a research programme designed to develop an understanding of consumers' opinions across the energy market. In 2012, a series of workshops were held across Great Britain to identify priorities for DNOs over the next 10-15 years. The overall aims of this research[14] were:

- *"to work with consumers to help them understand how the use of electricity might change in the medium term and the effect this might have on how it is distributed";*
- *"identify consumers' preferences around providing future capacity in the network in the context of potential changes to use of electricity"; and*

[12] http://www.spenergynetworks.co.uk/userfiles/file/201212_A1_2_Explain_Stakeholder_Feedback-Report_Phase%201.pdf.
[13] http://www.ukpowernetworks.co.uk/internet/en/have-your-say/documents/UKPNresponse_to_outputs_consultation.pdf

[14] https://www.ofgem.gov.uk/ofgem-publications/47153/riioed1conresconsumerpriorities.pdf

- *"understand consumer priorities for DNOs under the six key output areas identified in the RIIO-ED1 model for the next price control period, i.e. reliability and capacity, environmental impact, social obligations, safety, customer satisfaction, and communications."*

A broad range of panellists representing energy consumers identified that reliability should be the most important output measure of DNOs' performance. Within this category panellists concluded that the top two most important targets were:

- *"Fewer or no interruptions: Panellists thought that the most important thing that DNOs should do is "keep the lights on". They did not expect 100% reliability in all areas, as there was an understanding that extreme weather conditions cannot always be protected against."*
- *"Quick reconnection policy - Panellists felt that where there are interruptions, targets should be set around maximum reconnection times."*

Figure 6: WPD Stakeholder engagement feedback[15].

Summary of stakeholder feedback

	Rank	Stakeholder priorities identified	May 2011			Feb 2012		
			Exeter	Bristol	Cardiff	Nottingham	Birmingham	Gloucester
		Number of stakeholders	**37**	**32**	**31**	**34**	**50**	**34**
HIGH PRIORITY	1	Maintain current service levels	Highest (Top 3)	Highest (Top 3)	Highest (Top 3)	Highest (Top 3)	Highest (Top 3)	Highest (Top 3)
HIGH PRIORITY	2	Low carbon innovation[1]	Highest (Top 3)	High	High	Highest (Top 3)	High	High
HIGH PRIORITY	3	Flood (and climate change) mitigation	High	Highest (Top 3)	Highest (Top 3)	Med/low	Highest (Top 3)	Highest (Top 3)
HIGH PRIORITY	4	Future proofing asset replacement	High	High	High	High	High	High
HIGH PRIORITY	5	Network resilience to severe weather and emergencies	High	High/ med	Highest (Top 3)	Medium	Highest (Top 3)	High
HIGH PRIORITY	6	Reducing power cuts	Medium	Medium	Medium	Highest (Top 3)	High	Highest (Top 3)
MEDIUM PRIORITY	7	Oil/gas leaks from equipment	Highest (Top 3)	Highest (Top 3)	Medium	Medium	Med/low	Med/low
MEDIUM PRIORITY	8	Customer communication	Med/low	Med/low	Medium	Medium	High/med	High
MEDIUM PRIORITY	9	Remote ('worst served') customers	Medium	High/ med	Medium	Med/low	Medium	Medium
MEDIUM PRIORITY	10	Improving the new connections service	Med/low	Low	Low	High	High/med	High
MEDIUM PRIORITY	11	Undergrounding in National Parks and AONBs	Medium	Medium	High	Low	Medium	Med/low
LOW PRIORITY	12	Reducing business carbon footprint*	Med/low	Med/low	High/ med	-	-	-
LOW PRIORITY	13	Metal theft prevention*	-	-	-	Med/low	High/med	Low
LOW PRIORITY	14	Reducing dips (short interruptions)*	Med/low	High/ med	Low	-	-	-
LOW PRIORITY	15	Protecting habitats and species	Med/low	High/ med	Medium	Low	Med/low	Low

*Any workshops where feedback is denoted by a dash, indicates that the topic was not discussed at that event.

[1]Priorities subsequently grouped under the category of 'innovation to facilitate a low carbon future':

[15] http://www.westernpower.co.uk/docs/About-us/Stakeholder-information/Our-future-business-plan/Seperate-documents/Stakeholder-Engagement.aspx

Figure 7: UKPD Stakeholder engagement feedback.

Stakeholder Feedback on UKPN RIIO-ED1 Outputs

		Network availability
Output measure	Proposal: Existing (E), UKPN (U), Stakeholder (S)	Stakeholders comments
		Network availability was an important issue for stakeholders, with many of them expressing support for all of the existing outputs. It was also suggested that performance against these should be made more visible to stakeholders.

In their 'SP Manweb Urban Networks' document, SP Energy Networks estimates that an additional 7% of customers would experience an interruption to supply each year should the SPM 11kV interconnected network be converted to a radial topology. Since it is also understood that CIs and CMLs are reduced due to interconnection at LV, SP Energy Networks could quantify the additional CIs that would be incurred by such a wholesale change of the LV network.

Evidence supports the statement that:-

Extensive engagement by SP Energy Networks, Ofgem and other DNOs has shown that stakeholders consider system supply standards to be a priority. Therefore, it is postulated that if the SPM network were to be converted into a more radial arrangement, the expected reduction in network performance would conflict with the customers' most important priorities.

5.2.2 Regulatory Influence

For RIIO-ED1 SP Energy Networks has agreed to accept Ofgem's methodology for setting the reliability targets, rather than proposing alternatives themselves. The Ofgem CI and CML methodology for setting targets for both planned outages and unplanned outages use historic data and therefore SPM's previous high performance sets the standard for its future targets. Consequently, SPM has the second and third lowest targets for unplanned CIs and CML, respectively, indicated in Ofgem's illustrative targets shown in Figure 8.

Figure 8 : Ofgem's illustrative IIS targets (extract from Strategy decision for the RIIO-ED1 electricity distribution price control. Reliability and Safety[16])

Appendix 2 – Interruptions Incentive Scheme

Tables for the Interruptions Incentive Scheme

Table 1 - Indicative targets for unplanned Customer Interruptions (CIs)

DNO	Current Average	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23
ENWL	48.1	47.9	47.6	47.4	47.2	46.9	46.7	46.5	46.2	46.0	45.8	45.5
NPgN	63.2	62.3	61.3	60.4	60.1	59.8	59.5	59.2	58.9	58.6	58.3	58.1
NPgY	70.3	69.2	68.2	67.2	66.2	65.2	64.2	63.2	62.3	61.3	60.4	59.5
WMID	93.6	92.2	90.9	89.5	88.2	86.8	85.5	84.2	83.0	81.7	80.5	79.3
EMID	59.2	58.3	57.4	56.6	55.7	54.9	54.1	53.8	53.5	53.2	53.0	52.7
SWALES	55.6	55.3	55.0	54.7	54.4	54.2	53.9	53.6	53.4	53.1	52.8	52.6
SWEST	57.3	57.0	56.7	56.5	56.2	55.9	55.6	55.3	55.1	54.8	54.5	54.2
LPN	29.3	29.1	29.0	28.8	28.7	28.5	28.4	28.3	28.1	28.0	27.8	27.7
SPN	73.2	72.1	71.0	69.9	68.9	67.8	66.8	65.8	65.5	65.2	64.8	64.5
EPN	75.0	73.9	72.8	71.7	70.6	69.6	69.2	68.9	68.5	68.2	67.9	67.5
SPD	51.8	51.5	51.3	51.0	50.8	50.5	50.3	50.0	49.8	49.5	49.3	49.0
SPMW	37.6	37.4	37.2	37.0	36.9	36.7	36.5	36.3	36.1	35.9	35.8	35.6
SSEH	69.0	68.6	68.3	67.9	67.6	67.3	66.9	66.6	66.3	65.9	65.6	65.3
SSES	64.8	63.9	62.9	62.0	61.0	60.7	60.4	60.1	59.8	59.5	59.2	58.9

* Current average (LV, HV, NGC, DG, OCS 08/09 - 11/12) (EHV, 132kV 02/03 - 11/12)

Table 2 – Indicative targets for unplanned Customer Minutes Lost (CMLs)

DNO	Current Average Performance*	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23
ENWL	43.4	44.3	43.6	42.8	41.9	41.1	40.3	39.5	38.7	37.9	37.2	36.5
NPgN	62.8	57.6	56.5	55.3	54.3	53.2	52.2	51.2	50.2	49.2	48.3	47.4
NPgY	63.2	62.7	61.5	60.2	59.0	57.8	56.7	55.6	54.5	53.4	52.4	51.3
WMID	67.3	65.7	64.2	62.8	61.5	60.1	58.8	57.6	56.3	55.1	53.9	52.8
EMID	45.5	45.3	44.3	43.3	42.3	41.4	40.4	39.5	38.7	37.8	37.0	36.2
SWALES	28.7	41.6	41.6	41.6	41.6	41.6	40.7	39.8	38.8	37.9	37.1	36.2
SWEST	35.0	49.5	49.5	49.5	49.5	49.5	48.6	47.6	46.6	45.6	44.6	43.6
LPN	41.4	42.2	41.8	41.2	40.5	39.9	39.3	38.7	38.2	37.6	37.0	36.5
SPN	70.3	54.6	53.3	52.1	51.0	49.8	48.7	47.6	46.6	45.5	44.6	43.6
EPN	64.7	55.6	54.3	53.1	51.9	50.8	49.7	48.6	47.5	46.5	45.5	44.5
SPD	47.8	46.7	45.8	44.8	43.9	43.0	42.2	41.3	40.5	39.7	38.9	38.1
SPMW	41.0	40.0	39.1	38.2	37.3	36.4	35.6	34.8	34.0	33.2	32.5	31.8
SSEH	62.8	59.9	58.6	57.3	56.0	54.8	53.6	52.4	51.3	50.2	49.1	48.1
SSES	59.4	53.3	52.2	51.1	50.1	49.1	48.1	47.2	46.2	45.3	44.5	43.6

* Current average (LV, HV, NGC, DG, OCS 08/09 - 11/12) (EHV, 132kV 02/03 - 11/12)

It is clear from the RIIO document that the preferred methods for CI and CML targets imposed by our regulatory IIS system in fact disincentivise SPM from using radial network topologies.

If a change in design philosophy towards a radial network was imposed due to price control measures, SPM would likely be penalised for their reduced performance as targets are set from historic data.

[16] https://www.ofgem.gov.uk/ofgem-publications/47073/riioed1decreliabilitysafety.pdf

Evidence supports the statement that:-

The regulatory influence, particularly the interruption incentive scheme, disincentivises SPM from using radial network topologies and would likely penalise SP Energy Networks if performance was reduced by the use of radial systems.

5.3 Technical and Practical Influences

There are technical and practical reasons which prevent the SPM system from being converted to a radial topology readily, however, there are also technical problems with continuing to operate an interconnected network.

Conversion to a radial system is likely to involve removal of some substations within a group and replacement of others with larger dual rated transformers. Land is a likely practical implication, since there is unlikely to be sufficient space for the larger footprint of the replacement substation at an existing smaller substation location.

The ratings and capacity of the circuits and transformers within the existing network are too small and not appropriate for subsequent re-use in a radial topology. Consequently, conversion would result in redundant assets. There would also probably be a need for new circuits with higher ratings and potentially more circuits would be needed radiating from the new larger substations.

Additional redundant assets could be the 33 kV switchgear since it would not be required in a radial system design.

Apart from the major factors such as space and equipment, there are many other detailed technical issues that impact on the decision to convert from an interconnected network to a radial system. Typical considerations include:-

- The fault level constraints for 33 kV and 11 kV interconnected systems are well defined and align with those for many radial systems and therefore should not present a problem.
- The steady state switchgear current ratings of the existing interconnected arrangement may be sufficient, but would need to be checked.
- The protection philosophy would be very different for a radial system.
- The rating/design of 11kV/LV transformers/switchboards could change.
- Circuit standardisation.
- Application of standard rates for components of capex and opex.

Another technical issue with regard to changing to a radial configuration is the effect on power flows in downstream systems due to switching in upstream systems, such as the transmission system. Operation of a radial system makes understanding subsequent power flows easier and avoids all potential overloads of parallel circuits in downstream systems.

However, support for the change from an interconnected SPM network to a radial system comes from other technical factors, such as the unavailability of 33 kV ‘X-type’ RMUs, changing requirements for unit protection pilots and the potential for installing better monitoring of urban networks.

The original design of the SPM interconnected system has had to be modified to accommodate the fact that “X” type 33 kV RMUs (two switches and one c/b) are no longer manufactured and now “3 panel boards" (three c/bs) have to be employed to control 33/11 kV transformers and associated 33 kV feeders.

> Evidence supports the statement that:-
>
> There are technical and practical issues which would obstruct the conversion of the SPM interconnected network to a radial system. However, there are other technical issues which are impeding the development and ability to sustain the interconnected network.

5.4 Costs of Replacement with Traditional Radial System

The cost of the wholesale replacement of the interconnected SPM system with a radial system is very difficult to estimate. To make a meaningful estimate, the cost of any replacement (for comparison purposes) would need to:-

- Identify a specific complete interconnected system
- Define the associated redesigned system
- Apply standard rates for components of capex and opex
- Include in opex, the cost of losses (including iron loss) in the comparison
- Address system performance in terms of CI/CML

However, the costs are likely to be significant and unacceptable without further justification such as demand growth or asset health. This dependency and the associated uncertainty regarding timing, make it difficult to plan any change.

Also, we suggest that present cost benefit analysis and regulatory pressures do not encourage the additional expenditure necessary for the conversion away from an interconnected arrangement.

> Evidence supports the statement that:-
>
> The costs of converting to a radial system are expected to be large, but are difficult to quantify due to uncertainties.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Overall Conclusions

Evidence is available to support the SPM "Special Case" and associated additional costs for continuing to operate an interconnected network. The various documents SPM have prepared address a wide variety of aspects and include a lot of data to support their case. System performance statistics clearly indicate that the SPM interconnected network provides a high level of system security which is aligned with priorities identified through customer engagement by SP Energy Networks and other DNOs. Also, interconnected networks are expected to accommodate LCTs more readily.

The SPM standard design indisputably involves additional equipment and therefore inherently incurs additional capex and opex. The additional costs expected during the ED1 period as estimated by SP Energy Networks have been reviewed and found to be well justified in the majority of cases. However, a simple comparison of capex and opex for similar network operators as indicted in their business plans has shown that SPM's cost differential is greater than the additional costs justified by SP Energy Networks.

SP Energy Networks recognise the additional costs of operating an interconnected network in their RIIO business plan and in the documents provided for this review. Based on this opinion, they state their intent to use radial system topologies where appropriate. This is supported in their design policy which includes provision for an assessment on a 'case by case' basis for implementation of radial or interconnected designs. Also, SP Energy Networks are understood to be changing their equipment specifications accordingly. Evaluation of options within the SPM procedures ensures that the most appropriate solution will be implemented. At the moment radial systems are favoured for new connections in rural areas and in areas on the periphery of existing interconnected networks.

There is little scope for SPM to depart from perpetuating the current interconnected design philosophy in urban areas that already operate an interconnected network. This is particularly so as the performance in terms of CIs and CMLs is very good and price reviews seek to improve further on this performance. It is believed that the SPM design policy and procedures ensure that alternative designs are properly evaluated to provide the most appropriate system solution. Flexibility within the design policy will ensure that the evaluation of alternative designs can always take the latest information into consideration as more learning becomes available.

We have not found a case for SPM to have an overall design strategy or systematic programme for the transition of the existing system to an overall radial topology. It is considered inappropriate to develop a plan for such a change because the significant expense is not justified, because of technical issues, and because of the expected major changes to power systems due to the uptake of LCTs and DGs.

Additional costs associated with the operation, maintenance, asset replacement and extension of an interconnected network have been reviewed and found to be well justified. Also, the additional cost of reinforcing an interconnected system above the cost of adding capacity to a radial system has been evaluated based on real case studies. Summating the individual extra costs of operating an interconnected system indicates an overall additional cost of approximately £127.8 million for the ED1 period (£16 million per year).

6.2 Detailed Conclusions

The following conclusions have been drawn from each of the sections in this document.

OPERATION OF INTERCONNECTED NETWORKS

- SP Energy Networks provided evidence that supports the view that the SPM interconnected network achieves high asset utilisation, uniformity, flexibility and minimises substation footprint whilst achieving optimum customer performance. It also readily accommodates low carbon developments in generation and load technologies.
- The increased system performance advantages of the SPM interconnected network are indisputable.
- 4 out of 5 of the other DNOs operating in the UK have incorporated some aspect of interconnection in their business plans for the RIIO-ED1 period. The majority of the proposed investment is being targeted towards interconnection in low voltage distribution networks. The benefits of interconnection are being explored by a number of projects supported by the LCN fund.
- Encouragement of both DG and low carbon initiatives is facilitated by an interconnected network. In view of the uncertain take up of these developments in both load and generation, it is not considered opportune to move away from the established design of SPM interconnected network.

REVIEW OF COSTS OF AN INTERCONNECTED NETWORK

- The interconnected nature of the SPM network dictates that additional expenditure is required for the maintenance and operations primarily due to higher number of primary substations, associated switchgear and protection costs.
- Additional 33 kV asset replacement costs and operating costs for the ED1 period of have been evaluated by SP Energy Networks and found to be well considered by this review.
- We are in agreement with SP Energy Network's estimates for additional costs incurred through the operation of the interconnected SPM network.

FUTURE SPM NETWORK DEVELOPMENT

- Justified reasons support SP Energy Networks' decision to continue to operate an interconnected network and not to undertake a wholesale change. Based on their recognition of the greater costs associated with an interconnected topology, they have indicated an intent to use radial network configurations where appropriate. Correct application of the SPM design policy should ensure approved plans for future developments are based upon thorough evaluation of alternatives, Also, the policy should prevent "like for like" replacement without proper justification and review.
- Extensive engagement by SP Energy Networks, Ofgem and other DNOs has shown that stakeholders consider system supply standards to be a priority. Therefore, it is postulated that if the SPM were to use more radial arrangements, the expected reduction in network performance would conflict with the customers' most important priorities.
- There are technical and practical issues that would obstruct the conversion of the SPM interconnected network to a radial system. However, there are other technical issues which are impeding the development and ability to sustain the interconnected network.

APPENDIX A - SPM SCOPE OF WORK

SCOPE OF WORK DEFINED BY SP ENERGY NETWORKS ON 14/1/2014

Assessment of Special Case for SP Manweb Operating an Interconnected Network

Background

As part of Ofgem's review of SP Manweb's RIIO-ED1 Business Plan submission, Ofgem are seeking evidence that justifies the additional costs associated with SP Manweb operating and developing an interconnected system.

Requirement

We require an independent review of the benefits and limitations of SP Manweb's interconnected network when compared with a conventional radial network including the incremental difference of operating cost and cost of providing additional capacity.

Deliverables

A review of SP Manweb's interconnected system including the following:

1. Development of a typical test interconnected and conventional radial system including all voltage levels.
2. Analysis of a range of underlying demand scenarios and anticipated LCT uptakes based on WS3 Model outputs.
3. Analysis of reinforcement requirements for the development of the two systems.
4. Comparison of results including cost benefit analysis.
5. Detailed analysis of benefits of incremental capacity increase and accommodation of LCT.
6. Review of supply security (CI/CML).
7. Comparison of findings with business plan submission.
8. Detailed assessment of potential increase in CI/CML if the SPM network was radial.
9. Overall review of SPM rural/urban 33 kV network and comparison/evaluation with radial network including Capital/O+M costs.
10. Document SPM Strategy/vision for the future system including potential reduction in Capital/O+M costs and details of trials of unit to non-unit conversions.
11. Review of reinforcement requirements for LCT/generic demand growth and commentary outlining whether the SPM special case is considered to be independent of driver.
12. Preparation of a clear and concise report that can be included as an Annex to our own report to Ofgem. Draft report to be issued for review no later than Friday 7th February and final report to be issued no later than Friday 14th February.

APPENDIX B - SPM SOURCE DOCUMENTS

	Filename	Source	Comment
B1	Manweb special case master v3.docx	Email from M Bebbington 15th January 2014 15:35	A document comparing the design of the interconnected network with the more conventional radial networks of other DNOs
B2	Manweb 33 kV unit protected networks.docx	Email from M Bebbington 27th January 2014 16:58	A document quantifying the additional costs of modernising and operating unit protected 33 kV networks.
B3	Manweb secondary x type network cost case (2).docx	Email from M Bebbington 27th January 2014 16:58	A document quantifying the additional operational and asset replacement costs for an 11kV interconnected system.
B4	Summary of REVISED additional costs for the SPM "Special Case" (PB Power Summary of REVISED Additional Costs for the SPM Special Case 25022014.docx)	Email from A Jones 26th February 2014 12:23	Updated additional cost values and associated justification.

Scope

This paper is intended to provide background information to be read in conjunction with the SP Energy Networks RIIO-ED1 submission for the SPM licence area.

It will outline the fundamental design differences between traditional electricity distribution network design in that of the UK, and the Manweb urban network design, discuss capital and operational costs and compare and contrast performance. The paper will also comment on previous operational efficiency reviews, the implications of change and SPEN current philosophy on continued operation of the Manweb urban network design.

Comment will also be made on the SP Manweb ED1expenditure proposals in relation to the continued stewardship of the urban network.

Introduction

SP Manweb provides electricity to over 1.487 million customers across a diverse geographical foot print that encompasses both large urbanised areas of Merseyside together rural areas of Cheshire, North & Mid Wales and Shropshire

Over 66% of our customers live in the major urbanised conurbations of Merseyside and the Wirral, together with other large towns and cities across Cheshire, where the electricity network is primarily constructed from underground cables. Our remaining customers across our semi urban and rural networks and are connected to network which more generally comprises of a mix of overhead lines and underground cables

It is recognised that not all electricity networks are the same. At industry privatisation in 1989 our shareholders inherited an electricity distribution network that is unique in the UK and overall delivers the highest customer performance outside central London; it can be argued that the design of the urbanised network delivers the best customer performance in Great Britain.

The SP Manweb urban network was designed and built throughout the 1950-1970s with a design philosophy of high transformer utilisation to target lowest economic costs based on commodity price forecasts at that time. Smaller transformers than industry standard are run constantly interconnected at all voltages and standard cable sizes are used throughout.

To supply our customers over our geographical footprint around 55% of the SPM network is designed and run as an “X-Type” network, solidly interconnected at 33 kV, 11kV and LV. Of the remaining, 23% of the network is designed as a “Y-type” network, solidly interconnected at 33 kV and 11kV but less so at LV and 22% is designed as a radial network with single transformers feeding a non-interconnected 11kV and LV.

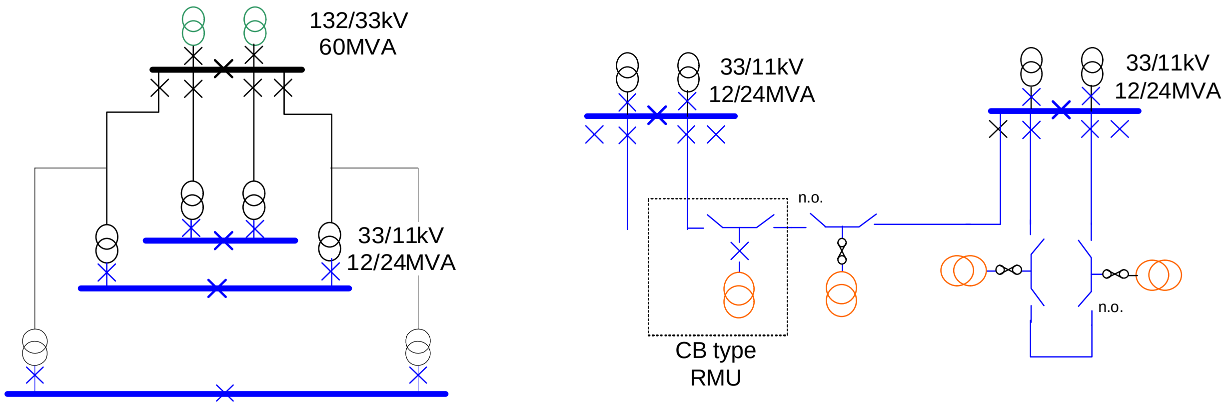
This paper is written to describe the electricity network that supplies the SP Manweb customers in the urban areas, X Type Networks, to outline its design features, operating requirements and performance as a supplement to the SP Manweb RIIO ED1 submission.

Traditional Industry Network Design

Before considering the SP Manweb Urban Network philosophy it is worth while briefly summarising the traditional network design in use across the wider GB network (including SPD).

The accepted industry wide design is based on duplicate radial transformer feeders, operated in parallel as show below.

At 132 and 33 kV, the transformers can be connected singularly or banked with multiple transformers (at up to 3 substations) connected to the higher voltage or source circuit breaker.



33 kV networks tend to radiate outwards from 132kV bulk supply points, similarly 11kv networks tend to radiate outwards from primary substations. Historically companies will have tapered the network cables, as the cable travels further form the supplying transformer, but more recently uniform (standardised) cables have been employed.

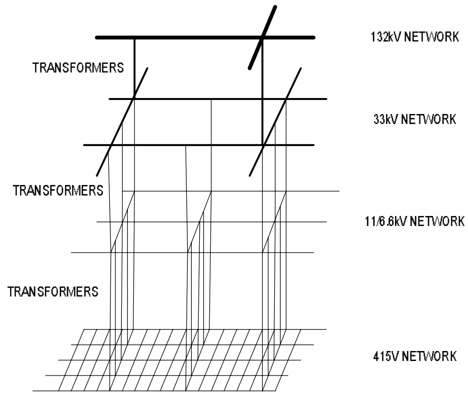
11kV networks fed from primary substations can be constructed as radial 'or looped' circuits back to the same substation, or can be built as an interconnector to an adjacent primary substation to provide post fault support and resilience. In all cases the circuit must be run with a split or 'normal open point 'at an electrically convenient point on the circuit.

The LV network whilst having the capability to offer interconnection will in all cases will be run radially with fuses or links removed at substations, LV surface mounted pillars or beneath ground link boxes.

The recognised benefits of this network philosophy are in its simple design, simple protection arrangements, requiring less distributed switchgear and protection with consequential reduced capital and operating costs.

Some of the pertinent limiting factors of this design are that of Fault Level management, transformer utilisation factor is limited to 50%, triggering reinforcement and hence capital expenditure at earlier point of overall load growth, and customer interruptions (CI's) are increased over that of an interconnected network design. It is recognised however that advances in network controllable

points and automation algorithms has improved the quality of supply performance on these networks in recent years.
Cables emanating from large substations are often none uniform along their length, and are often tapered as the distance from the substation increases. By nature these networks are not readily extended without considerable effort and expenditure to develop a new substation, and laying more cable to increase the circuits capacity, therefore they are not considered as Smart ready as interconnected networks



SYSTEM OF NETWORKS FOR DISTRIBUTION OF ELECTRICITY

SP Manweb Urban Networks

The origins of the Manweb Urban Network design can be traced back to the period shortly after the electricity industry was nationalised in 1947, and it was developed and expanded over the next 30 years and continues to be modified and extended today. The design methodologies varies significantly from the traditional industry network design described above of duplicate radial networks, emanating from transforming stations, and is based on a design philosophy of high transformer utilisation, where smaller transformers than industry standard are run interconnected at lower voltages and standard cable sizes are used throughout. Each voltage layer providing support to the voltage layer immediately above (LV, HV, EHV and 132kV) offering a fully integrated and interconnected network

The design was developed by Peter d'E Stowell the former Manweb Chief Engineer, and whilst there are elements of similar design in restricted parts of Edinburgh, and throughout the Central London area, the SP Manweb urban network is considered unique in the UK.

The underlying principle of the Manweb urban network is to maximise the utilisation factor of high voltage transformers supplying any given load group through the combination of 3 key features, uniformity, interconnection and unit protection.

Uniformity

The uniformity of the Manweb network design takes two separate forms, uniformity of equipment ratings and uniformity of application.

Although design and specifications of component parts of the Manweb network have evolved throughout the last 50 years, the ratings of these component parts have remained extensively the same.

Typical ratings are as follows:-

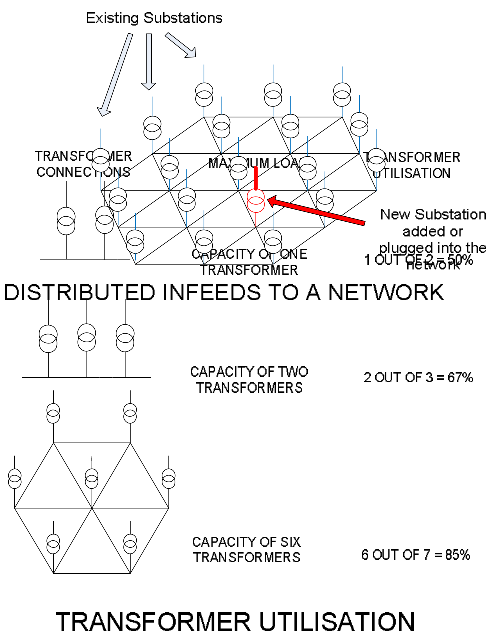
- 60MVA grid transformers (132/33 kv), with 20MVA 33 kV circuits
- 7.5MVA primary transformers (33 kV /hv) with 3.5MVA hv circuits

- 500kVA hv/lv secondary transformers (hv/0.415kV) with 170kVA lv circuits ,

At each voltage level therefore there is a standard rating for circuits, between each voltage level there is a standard transformer rating, and at each voltage layer there is a standard design covering switchgear, protection and relay settings.

This uniformity of equipment and ratings provides opportunity for expansion in line with network growth and facilitates reinforcement by the addition of a new transformer with minimal cable laying and no change to protection or settings. This was a key driver through the expansion period of the electricity network in its early years and is equally pertinent today as it delivers a scalable solution to meet the demands for the anticipated load growth on the distribution networks as we migrate to, and accommodate Low Carbon technologies.

Interconnection



The benefits of uniformity can be applied to any network configuration however when a uniform network is configured to operate in an interconnected manner then the benefits can be multiplied. Interconnection in this context means the circuits of each voltage layer run from one infeeding substation to another substation and are predominately operated with all intermediate switches in the circuit ‘closed’ position.

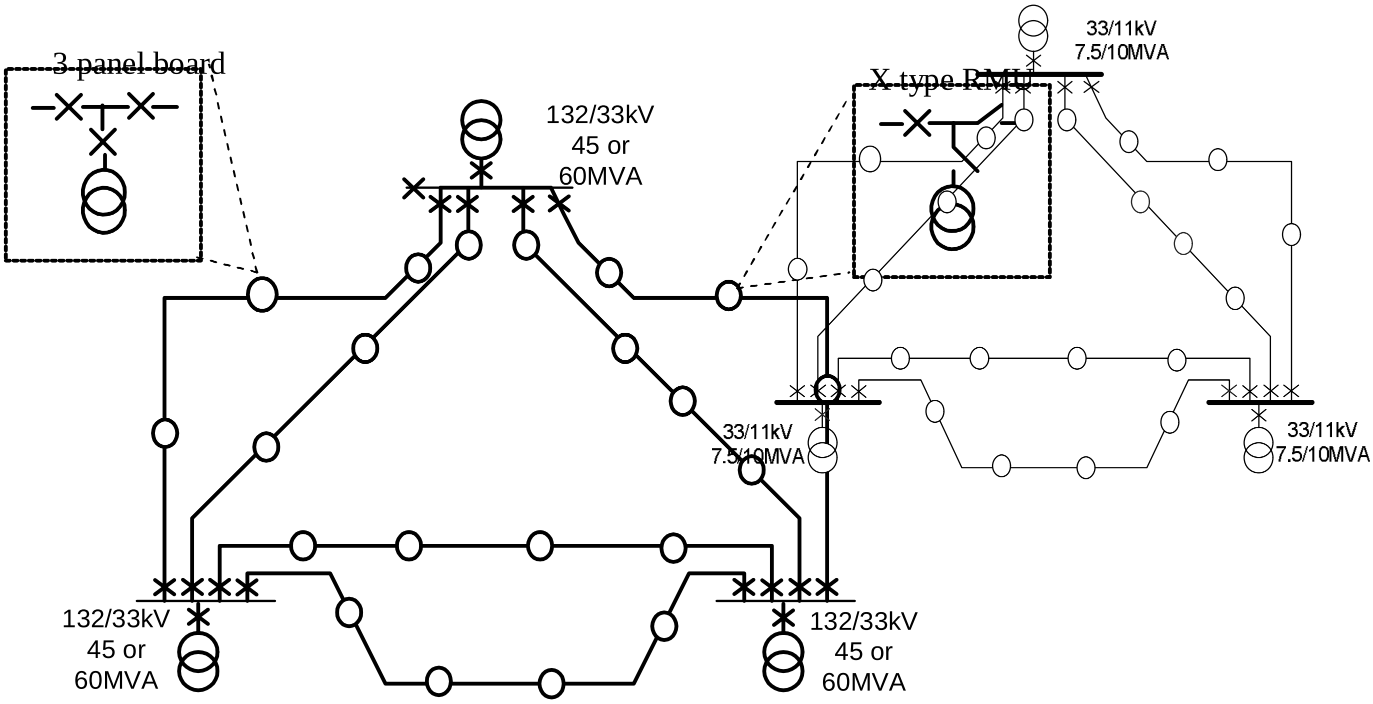
In the early development of the cable network at each voltage level, it was important to install uniform sized cables rather than employ tapered networks, in order to establish the grid or lattice interconnected network for the future, facilitating the connection of additional transformers due to load growth.

Equally during the depressions of the 1980’s and more recently, as load centres move, then underutilised transformers can simply be unplugged and re-established closer to the new load with minimal network alteration.

By operating interconnected networks between in feeding substations it is possible to increase the utilisation factor of high value (and cost) transformers. By operating smaller than industry standard transformers in this manner it is possible to reduce the physical foot print and therefore cost of associated plant and civil accommodation.

In an ideal network, utilisation factors of up to 85% are possible. However in order to operate the equipment on the Manweb Network safely within its design fault level parameters then it is normal to operate via interconnected cables up to 4* 60MVA Grid Transformers, or 5 * 7.5MVA primary transformers. This still achieves utilisation factors of 75% and 80% respectively but maintains fault level within the design criteria of 750MVA and 250MVA. It is equally permissible to interconnect

secondary substations via the LV network, with the limiting factor that no lv circuit can be controlled by more than 3 fuses from separate substations. Beneath ground LV link boxes are used extensively on the LV network to split up the LV interconnected network to achieve this requirement.



With higher utilisation factors incremental load growth can be absorbed more efficiently before reinforcement is triggered. When the group load reaches its maximum then a further transformer can be simply added or 'plugged in' to the network or the transformer group can be reconfigured by the movement of network split points.

Ring Main Units (RMU's) were originally installed at the primary substations and secondary substations along the interconnectors between infeeding substations. These RMU's comprise of 2 ring switches and a circuit breaker or fused switch in a single unit of switchgear.

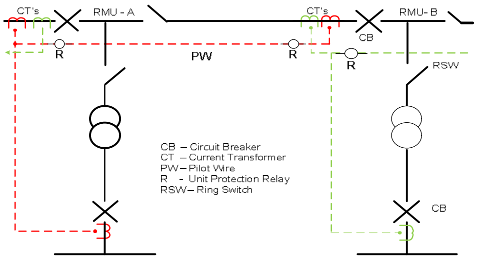
In the Urban network design the RMU is configured as an 'X-type' and is illustrated above, with one ring switch connected to local transformer, the other ring switch and the circuit breaker being connected to the incoming and outgoing cables along the interconnector. At 33 kV suitable RMU's are no longer manufactured therefore the design and application has evolved to comprise of a 3 panel switchboard again illustrated above.

There is a Circuit Breaker on the lower voltage side of the transformer

Unit Protection

Unit protection in its simplest form utilises the *Mertz Price* principle, which effectively checks that load current entering a protected zone is equal to the load current leaving the protected zone. As long as this is the case then the protection remains in balance and does not operate. Should a fault develop in the protected zone then the current entering the protected zone will be the sum of the load current plus the fault current, the current leaving the protected zone will be the load current only, therefore the protection becomes out of balance and will operate a protection relay, which in turn will operate the controlling circuit breakers for the protected zone, and the circuit will be safely disconnected from service.

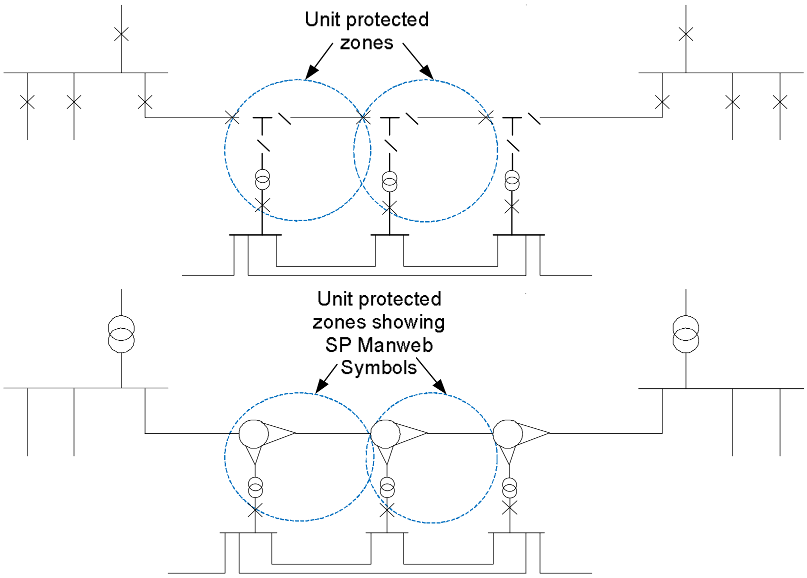
Unit protection as applied to the SP Manweb network interconnected distribution network, whilst generally based on the basic principle above is more sophisticated and has been developed to protect substation, transformers and its feeding cables. A simplified representation of unit or 'zone' of protection as applied to the SP Manweb Urban network is illustrated in the figures below.



The summated output of the pair of CT's at RMU A and the output of the CT's at remote RMU B are connected via communication cables commonly referred to as 'Pilot Wires' run alongside the main distribution cable between substations this illustrated by the red section of the drawing above

Under normal circumstances the load current entering the unit protected zone at RMU B will balance with the load current of the local transformer at RMU-A together with the outgoing load current along the remainder of the interconnector, and the protection relays connected to the pilot wires will remain stable.

If a fault occurs within the unit protected zone on the distribution cable between the two RMU's or on locally connected transformer at RMU A, then the normal load current entering and leaving the protected zone will be incremented by the fault current entering the protected Zones at RMU A and RMU B, and will not balance. Therefore the protection relays connected to the pilot wires will operate, and cause the controlling circuit breakers to operate and remove the faulted zone. The protection relays connected into Pilot Wires are powered by DC battery systems



By overlapping unit protected zones along the interconnector, a fault or outage in any given unit protected zone can be occur without disconnecting customers, as these supplies will be maintained by the adjacent network via the interconnecting cables from neighbouring substations. In the more traditional 'Y' type networks used elsewhere in SP Manweb on semi urban and rural networks and the wider GB electricity network as a whole, a similar fault will result in loss of supplies to the entire customer base connected to the interconnector, or radially operated circuit, with as a consequence a poorer customer performance.

Unit Protection on interconnected networks as applied to SP Manweb networks operating at 33 kV is generally comprised of 'Translay' Protection and at 11kV, 'Solkor' Protection. Whilst their operation can be traced back to the fundamental principles outlined above each of these protection schemes are much more sophisticated and reference to manufactures literature, or support documentation should be made if a detailed understanding of the individual protection scheme is required.

Performance

It has already been stated that the Customer Performance of the SP Manweb network as a whole is second only to that of Central London. (UKPN LPN), with customers in SP Manweb likely to see a power interruption once in every 2 years, lasting typically 63 minutes, and customers in Central London once in every 3 years lasting a similar duration. It is also true that with an average of 53 customers interrupted per fault on SP Manweb network; this is the lowest number of customers impacted by a fault (and therefore the best performance) on any electricity network in Great Britain (Data taken from Ofgem - Electricity Distribution Annual Report for 2010-11)

	2010/11 - CUSTOMER INTERRUPTIONS PER 100 CUSTOMERS:		2010/11 - CUSTOMER MINUTES LOST	
DNO	Target	Performance	Target	Performance
LPN	33.4	24.4	41	42.4
SPMW	45.6	39.3	61.1	47.5
ENWL	52.9	47.8	55.6	47.3
SPD	60.1	50.7	65.5	49.4
SWales	79.5	58.4	44.6	32.4
SWest	73.6	61.5	51	42.6
EMID	75.7	61.7	69	54.9
SSES	73.8	63.6	69.1	64.1
NPGN	68.3	65.2	71.3	71.1
NPGY	75.3	69.9	76	68.2
SSEH	77	74	75.1	78.4
SPN	85	76.9	87.6	73.2

Table ranked on CI performance

The statistics above relate to total network performance for individual Distribution Network Operators.
Looking at the SP Manweb values in more detail it is clear that they are a combination of both our urban and rural networks performance, which due to the prominence of the west coast weather systems is exposed to extremes in weather conditions and consequently a greater fault rate than that experienced by the relatively benign urban networks.

As described above the design of the SP Manweb urban network is such that for any 33 kV or hv network fault the CI's should be zero, as the faulted circuit is protected by unit protection and customer supplies are maintained by the wider interconnected network. In reality there are interruptions to customer's supplies on these networks due to a combination factors, such as:-

- Second circuit faults occurring simultaneously with the first circuit fault leaving sections of network stranded or islanded.
- Failures of unit protection systems to operate correctly due to faulty relays or faulty/damaged pilot cables.
- Failures of circuit breakers to operate correctly
- 'Designed in' customer losses such as radially fed HV customers or IDNO's, or elements of radial networks embedded within the urban network
- Failures on the fringe of the urban areas where the overall circuit can be configured using a mixture of Urban X-type and Semi Rural Y-Type network
- More recently developments in organised 3rd party interference/intervention – Metal theft

For faults on lv interconnected networks then for the majority of fault conditions only a small percentage of the customers connected to the lv cable circuit will be interrupted as fuses at one end of the circuit only will trip to remove the fault, with supplies to the remaining customers connected to the lv circuit maintained from the remote ends of the 2 way or 3 way interconnected circuit.

The Central London electricity system of LPN consists entirely of underground urban networks, and is operated in an interconnected mode, therefore it is appropriate to compare the SPM urban network directly with the performance of LPN as a whole, in order to demonstrate the performance advantage of the SP Manweb urban network design.

By extracting the customer performance for the SP Manweb urban networks for the same reporting year as shown above (2010/11), the CI per 100 customers is 13.22 and the CML per 100 customers is performance is 22.0 minutes, this equates to customers connected to the SP Manweb urban networks likely to see a power interruption once in every 8 years, some 2.5 times better performance than that of LPN network, with the interruptions affecting less customers per fault and lasting on average for shorter periods.

This SP Manweb urban network has demonstrated consistently over time its frontier network performance in terms of CI and CML.

Network Design and Efficiency Reviews

The SP Manweb Urban network is unique in design and delivers frontier network and customer performance as discussed in the previous sections, a heritage as an organisation that SP Energy Networks is rightly proud of. However it is recognised both within SP Energy Networks and the wider industry that this network has greater complexity, involves more components and is more expensive to construct and maintain than the recognised industry network design, (Y Type).

This is something that SP Energy Networks is continually aware of and has reviewed and evaluated on a number of occasions both internally and externally buy the engagement of independent consultants, in order that we can consider if it remains viable to continue to propagate the SP Manweb urban networks ‘X-type’, and to consider alternative network designs and solutions.

These reviews were conducted as follows

External : -

- Mertz and Mclellan 1998
- ABB 2000

Internal :

- Martin Deehan 1998
- Jane Wilkie 2006.

The engineering aspects of these reviews remain unchanged over time and common threads of these reviews can be summarised as follows:

- Urban LV interconnected networks should if designed and operated correctly provide better performance than traditional radial networks but are expensive as they are generally longer networks

- Urban 11kV interconnected network design delivers frontier customer performance, but at a cost premium over traditional radial networks with or without automation. However it's not cost effective/or desirable to convert wholesale to 'Y-type' networks
- It is considered that urban 33 kV interconnected network provides little or no customer performance benefit and is significantly more expensive than traditional dual radial transformers operated in parallel configurations, due to additional switchgear requirements. (*Author Comment - whilst the benefits of a development of a dual radial transformer solution may be true for green field developments, the various reports have failed to recommend substantial proposals of how we would complete a migration from the existing interconnected network. Both in terms of the additional network reinforcement, or the more onerous task of acquiring suitable 'larger' sites for the development of additional urban substations. Analysis of SP Manweb 33 kV customer performance indicates major contributors to CI/CML are from faults affecting rural radial primary transformers or radial urban transformers. Occasional malfunctioning equipment on the SP Manweb urban network does incur customer interruptions; however this is the exception rather than the rule.)*
- The SP Manweb urban 33 kV and 11kV cable networks utilise standardised and are uniform cable sizes migration to industry designs would in many locations leave stranded assets as the cable sizes and rating would be inadequate.
- The SP Manweb urban networks utilisation factor is very much higher than for traditional networks, which implies that SP Manweb are working their network harder. Therefore there is less spare capacity than on traditional networks. (*Author Comment through the introduction of the UK network Load Measure we will reduce our trigger point for reinforcement by 20%. We will alos continue high voltage network uprating programme from 6.6kV to 11Kv to release latent capacity in our hv cable networks throughout ED1*)
- The SP Manweb urban network represents the most cost effective network, both in cost per kVA of capacity and maximum demand. However the incremental cost of SP Manweb's urban network arrangement is approximately 30% more expensive in terms of total cost per unit of network capacity
- No reports deal adequately with the consequential reinforcement of Bulk Supply points as a consequence of breaking up 33 kV network, and reducing the currently high utilisation factor of Grid transformers at Bulk Supply Points.

In summary the advantage of the SP Urban Network is confirmed as offering frontier CI performance over that of traditional radial networks. The network design is also inherently "smart" as the network is designed to accept power flowing in either direction, and alternative paths are available when there is a fault. The network is more ready to facilitate customer uptake of low carbon technologies and the associated costs are lower as reinforcement is facilitated in the main by 'plug in' substations and minimal cable lying.

The disadvantage of the SP Urban Network design is that it is more expensive to build, as it requires more switchgear and unit protection which in turn requires a means of reliable communication network between substation sites and a more robust building construction.

The design reviews have confirmed that the size and complexity of the existing network does not allow wholesale change to the network design in urban areas, without a major impact on the performance of the network to existing customers and significant capital spend.

Whilst savings could be made by developing less complicated 'Y-Type' networks these savings would be offset by additional capital expenditure and future operating costs required to supplement the existing transformer capacity within the network as a whole, as current high utilisation factors on which the network was fundamentally designed over the last 60 years or so would be brought down to the industry norm of 50%

Internal estimates based on the last five years of data supplied to Ofgem through the quality of supply reporting scheme indicate that for the 11kV network alone should it be converted to 'Y-Type' network, the result would see an additional 104,000 or 7% of our customers experience a power cut each year.

This is unacceptable to our customers who through stakeholder engagement events across the Manweb licence area including one held in Merseyside have told us they want to experience less power cuts, and also against the Ofgem proposals to reduce the Customer Interruption (CI) allowance throughout the RIIO ED1 period.

We therefore have no feasible alternative when replacing existing assets in interconnected areas other than to replace like for like, and to maintain the existing network arrangements.
However we recognise that it is more cost effective to build new networks as a more traditional design, and therefore when SPEN, or an Independent Connection provider (ICP) are designing new networks or connections on our network , we will build a non-interconnected design where possible, provided this will not impact or compromise on existing customer performance.

Key Challenges in ED1to maintain the SP Manweb Urban Networks

SP Manweb have outlined in its RIIO- ED1 submission a number of areas of expenditure specifically related to the continued successful operation and integrity of the urban network, over and above expenditure for the areas of its more traditionally designed networks.
Specific details are contained in the relevant CV tables, however key activities and threads are itemised below :-

- Ongoing maintenance of substation environment to provide a safe, watertight environment for X Type substations, this will not only ensure safe operation of primary equipment but will safeguard the integrity of the associated unit protection equipment.
- Ongoing maintenance and repair of the 11kV and 33 kV network communications system (Pilot Wires), without which the integrity of the associated unit protection systems will fall into disrepute, with significant deterioration in performance of the protection systems and consequential decrease in customer performance.
- Maintenance and inspection of LV link Boxes (including confirming network configuration of the internal switching points) utilised in the operation and control of LV interconnected network.
- Ongoing maintenance of 33 kV RMU's used extensively on X-type interconnected 33 kV networks

- Replacement of 25 ‘end of life’HI5, 33 kV RMU’s with 3 panel switchboards (33 kV RMU’s are now out of production).
- Ongoing maintenance of secondary substation (11 or 6kV/LV substation) battery systems associated with X-type networks – Simple Y-type secondary substations are generally battery free.
- Continue its 6.6kv network updating programme to 11kV to release more capacity from the current interconnected cable networks.
- Continue to install remote control facilities (SACDA) on Urban Networks as part of Asset modernisations schemes to allow better monitoring of interconnected network performance

Introduction.

This is a supplementary discussion paper to the SPM Special Case
The SPM Network consistently delivers frontier performance of reliability, second only to UKPN London network in the Ofgem overall CI performance tables.

The foundation of the SPM network design lies in the early 1950's when drivers were different to those of today. However the advantages of the network design are still enjoyed by our customers through the reliability and flexibility it delivers.

To achieve the level of performance that SPM and LPN provide relies on heavily on interconnection and the use of unit protection, which increases the construction and life cycle costs.

Ofgem have recognised this in previous price review outcomes, see extract below from the DPRC5 outcome.

'*1.68. The lower of the industry-wide median unit cost and the DNO's own unit cost was then applied to all DNOs except where specific issues were identified by a DNO and accepted by Ofgem. These included the additional costs associated with operating within central London (EDFE LPN) and unique switchgear associated with the specific network topology for SP Manweb'*.

Review.

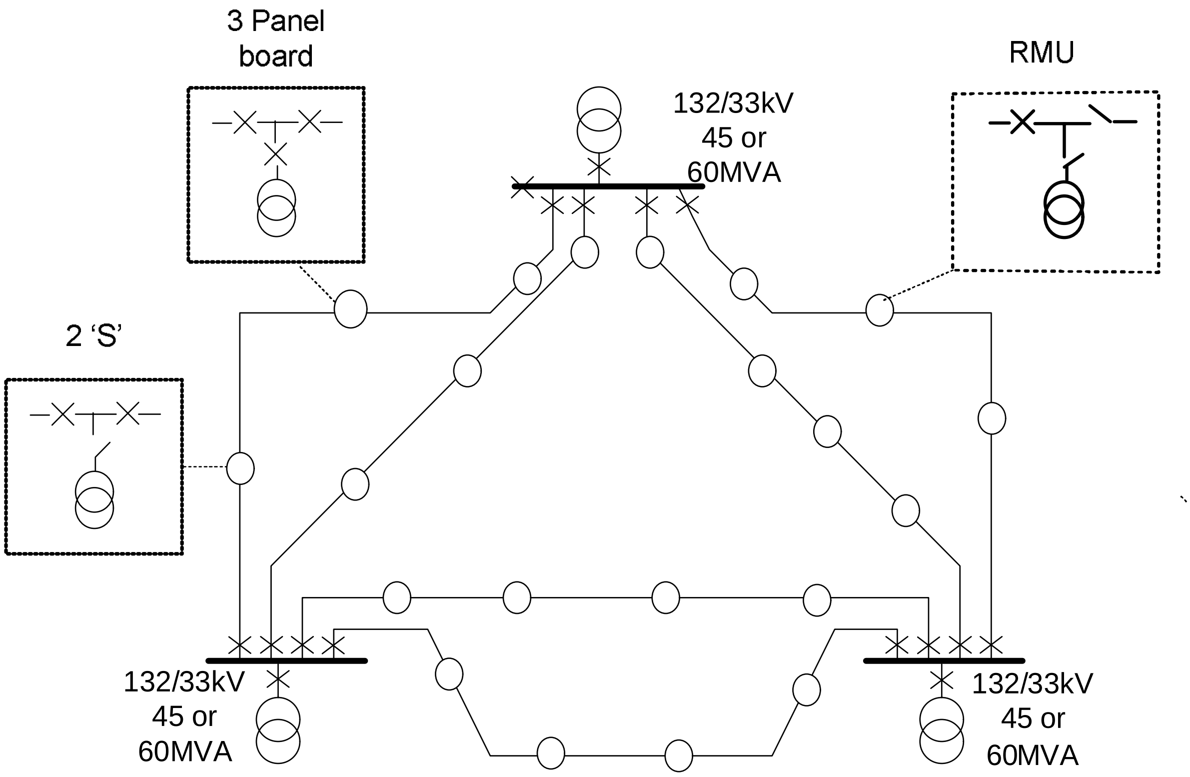
To supply customers over the SPM geographical footprint around 55% of the overall SPM network is designed and run as an 'X-Type' network, solidly interconnected at 33 kV, 11kV and LV. Of the remaining, 23% of the network is designed as a 'Y-type' network, solidly interconnected at 33 kV and 11kV but less so at LV and 22% is designed as a radial network with single transformers feeding a non-interconnected 11kV and LV.

Of the SPM 33 kV network over 90% is operated interconnected with Unit Protection, the remainder is designed and constructed in the more typical industry radial network.

The additional costs of the SPM 33 kV Network over and above the traditional industry design are in essence associated the components required to operate a Unit Protection system.

This requires 33 kV switchgear at primary substations, such as Ring Main Units (RMU's) or Panel boards in the Urban areas, or Two Switch substations (2'S')or Panel Boards in the Rural areas, together with additional protection requirements in the form of pilot cables(PW's), current transformers (CT's), relay panels, and larger batteries.

The diagram below illustrates the typical SPM 33 kV interconnected network, with single transformer Grid Substations, interconnected by 33 kV circuits to increase utilisation factor of the Grid Transformers together with providing the 33 kV supply to primary transformers



The interconnecting circuits between the substations there will comprise not only the primary conductors (Underground cables or Overhead lines) but also a communications path for the Unit Protection schemes. The Communications path is generally a SPM owned Underground pilot cable in urban areas and a rented circuit in rural areas. The rented pilots currently are copper path and will be subject to conversion due to BT21CN compliance in the early years of ED1.

Operating and Maintenance costs

The table below collates the operational costs of the 33 kV network excluding Grid substations and faults on the Overhead lines/Underground cables as these costs will in effect be common to all networks operators irrespective of the design philosophy. The analysis has used an even distribution volumes based on the Plant Maintenance Policy SUB-01-009 (issue 6)

Within the table again costs elements exclusive to the SPM network design at primary substations are highlighted in green, and are summated to provide a cost indication to operate and maintain the additional assets, costs not highlighted are cost elements which would be borne by all network operators. Whilst it is recognised that the SPM network using smaller than standard primary transformers sizes increases the number of primary sites per head of population/ orMVA of load the cost of maintaining these over larger duplex arrangements supporting a similar population base and geographic footprint has not been analysed and has therefore been excluded.

In addition periodic plant defects or suspension of operational practices (SOP's) notices are identified in SPM or nationally via the ENA, for each item of plant affected mitigation costs will be incrementally more expensive in SPM due to its additional volumes of switchgear. There are currently no SOP's impacting SPM plant that required work programmes therefore no costs included.

The current operating costs of rented private wires (pilots) for unit protection are not anticipated to change following work to mitigate BT21CN. Therefore costs left as current.

The net cost of operating and maintaining the SPM 33 kV unit protected 33 kV network is circa

£1.85 million/annum or £14.8million over ED1 period

Non Grid 33kV Additional opex

Plant & Apparatus	Opex unit cost	Volume	Cost	Comment
33kV RMU	864	362	26064	assume even distribution on 12 year cycle.
contacts	2000	2	3017	5% of inspected units @ replacement/year at 2k per set
33kV OCB (id)	440	47	1723	(409 - 362 part of RMU's = 1 in 12 year maint
contacts	2000	0	392	5% of inspected units @ replacement/year at 2k per set
33kV OCB (od)	440	128	9387	1 in 6 year maint
contacts	2000	2	3933	5% of inspected units @ replacement/year at 2k per set
33KV VCG/GCB (id)	148	824	10163	1 in 12 year maint - maint fleet = xx= yy per year
33KV VCG/GCB (od)	148	416	10261	1 in 6 year maint - maint fleet = xx= yy per year
Disco/ESW	148	91	2236	assume 1 in 6 maint same as breakers
Fault throwers	56	119	1111	
Battery chargers checks	40	812	32480	annual check
Battery Cells checks	60	812	48720	annual check
V T's	150	660	13400	526 fixed - 134 withdrawable
CB trip test	15	1777	26655	annual check
CB minor maint	278	18	4865	assume 5% of Oil and 0% of VCB/GCB
thermovision	25	91	2267	volumes same as disco/earth switches but opposite cycle.
Translay batteries	60	362	2715	1 in 8 year replacement
Primary transformers Slow speed	896	203	60629	1 in 3 year maint fleet = 203 = 68 per year
Primary transformers High speed	896	606	90496	1 in 6 year maint fleet = 606 = 101 per year
Primary Tx Pre winter check	65	809	52585	annual check
Bi- annual DGA	50	809	20225	
Roof repairs	5500	60	330000	assume 1/6 for 33kV switch rooms 5/6 for 11kV switch rooms)
PFM oil breakers	440	120	52800	average 10 per month
contacts	2000	6	12000	5% of inspected units @ replacement/year at 2k per set
rented pilots			680000	Annual bill 896k for 132/33kV - 33kV element circa £600k
33kV Protection Maint	300	463	138974	maint days * maint volumes at 3 days/rmu 1 day per circuit end 1 day per Tx + 20% prep @£300/day
Plant painting	2500	243	50563	30% of plant is o/d painted on 1 in 12 year basis
		Sub Total	**1687660**	
Pilot faults			360000	run rate of 5 repairs per month - not circuits
110v battery change	2300	34	78200	
48v battery change	828	206	170568	
		Sub Total	**608768**	
Costs				
Additional running costs due to SPM unit protection 33kV	**£ 1,851,414**	**per annum**		
	Represents costs applicable to unit protection design not incurred by 'Traditional Industry Design'			
	*Excludes Grid Substation/33kV cable & lines costsas assumed common to all DNO's			

Asset Modernisation

In ED1 asset modernisation costs are based on the current Health index and Criticality.
Taking the headline assets identified for replacement in ED1 specifically related to the Manweb Special Case in turn

Primary Transformers

SPM plan to replace 89 primary transformers in ED1

Comparing SPM unit costs with SPD, the costs of a primary transformer replacement on a unit by unit basis typically £84k less expensive in SPM, however as SPM use smaller sized transformers than industry standard, aMVA forMVA comparison is more sensible.

The 89 identified replacement units in SPM equate to 668MVA. Using SPD 12/24mva transformers this capacity would require 56 units

ED1 Cost = 89 * £181 = £16,109k (Compared to SPD 56 * £265 = £14,840k)

ED1 Cost Delta = 16,109 – 14,840 = £1,269k

33 kV Circuit breaker replacement (non Grid)

SPM plan to replace 105 oil circuit breakers in ED1. (6 indoor and 99 outdoor)

Due to the interconnected/unit protected designs of the SPM 33 kV network these circuit breakers can be considered as additional units to any other UK network operator as 33 kV switchgear is centred on Grid sites.

ED1 Cost = 99* £138.5 = £13,711k & 6 *£110= £660k = £14,371k

33 kV Ring Main Units - RMU's

SPM plan to replace 33 ring main units in ED1

The 33 kV Oil based Ring Main Unit was unique to SPM. These devices are obsolete and require to be replaced by alternative designs/configuration of plant. In essence this is a 3 panel board. The unit cost of a replacement Ground mounted 33 kV circuit breaker is £110K however additional civil work and protection modification cost increases the cost to a unit cost of £400k per site.

ED1 cost = 33 * £400 = £13.2million

33 kV underground pilots in urban and 'underslung' Hardex pilot replacement in semi rural locations)

SPM plan in ED1 to spend £9.8 million on asset modernisation of its existing pilot cable infrastructure that supports the 33 kV unit protected network

These investments will be split into two areas:-

£7.1 million on targeted overlays of poorly performing underground pilot cables with approximate length of 70km, together with a further £2.8million on the replacement of 25 end of life 'Hardex' pilot cables on the overhead network.

Hardex is the name given to the self supporting pilot cable which is 'under slung' from 33 kV overhead lines. There is no recognised manufacturer of this type of cable and attempts to encourage entrants into the manufacturing arena through our procurement route has proved fruitless, necessitating a replacement fibre based technology to be deployed.

Other Network Operators utilise pilot cables in 33 kV networks protection particularly with intertrip signalling, whilst a direct comparison is not available due to the disparity in volumes it is noted that during in ED1 our SPD network requires an investment of some £3.3 million less on the same asset base.

ED1 Cost Delta = £3.3million

BT21CN – 33 kV network

SPM require to modernise 192 unit protection circuits in the first 3 years of ED1

In 2018 BT will instigate forced service migration to their new communications platform. Without mitigation work, deficiencies with the new BT21CN delivered communications services will prevent correct operation of the main protection equipment causing potentially significant CI/CML impact (due to extended fault clearance times and discrimination issues), and we will be reliant on backup protection for fault clearance.

The unit protection philosophy of the SPM network means BT21CN mitigation is more onerous in terms of volumes than traditions industry network design costs, as a comparator the SPD network will require an investment of circa £5 million to make its protection complaint with the BT21CN

SPM = 192*£150k = 28.8 £million (Compared to SPD expenditure of £4.96million on 54 units at similar unit cost)

ED1 Cost Delta = 28.8 – 4.96 £million = £23.84 million *

*comparable unit cost level is not applicable as each solution is individually engineered and costed.

33 kV protection modernisation

SPM plan 255 units of protection modernisation in ED1

This is due to the greater volume of life expired assets which require replacement during ED1 and also reflects our strategy to adopt a holistic approach to substation modernisation which aligns replacement of protection, batteries and chargers for both local & remote end equipment when completing major substation modernisation work involving replacement of the main plant.

Our preferred approach wherever possible is to align (HI5/4) protection modernisation and plant modernisation works, however standalone protection modernisation programmes are required for some HI5 protection assets, due to the relatively short life expectancy and vendor support periods, obsolescence driven by the rapid development of protection technology and short life expectancy of some types of electronic components.

The unit protection philosophy of the SPM network means the Protection modernisation is more onerous in terms of volumes than traditional industry network design costs, as a comparator the SPD network will require an investment of circa £4.94 million over the same period but will deliver 554 units , equating to a unit cost of £9k unit

The cost delta of Protection Modernisation on Unit Protected networks over industry standard design is in the order of £27.5k - £9k = 18.5k per unit

ED1 cost SPM = 255 @ £27.5k = £7.01million (compared to 255@£9k £2.295 million)

ED1 Cost Delta = £7.01 – £2.295million = £4.715 million

Summary of Asset Modernisation Costs uplift for SPM unit protection networks

Primary Transformers	£1.3m
33 kV Circuit breaker replacement (non Grid)	£14.4m
33 kV Ring Main Units - RMU's	£13.2m
33 kV U/G pilots & Hardex	£3.3m
BT31CN	£23.8m
Protection modernisation	£ 4.7 m
Total	£60.7 million

Load related and non load related reinforcement

The Asset replacement costs of like assets are contained in the Unit cost manual Asset-02-004 where like for like assets are installed the costs are the same in SPM and SPD, where costs are specific to SPM information on the detail is also contained in the Unit Cost manual.

Delta costs for 33 kV network schemes involved in both load and non load reinforcement categories have been quantified in terms of reviewing individual design papers, however using the rationale of this paper it is fair to indicate that both load related and no load related costs will incur delta costs over traditional network should the work interface with the existing 33 kV interconnected network. The delta costs can be obtained by reviewing the cost differentials in the Unit cost manual Asset-02-004

Greenfield and Brownfield solutions will be considered for radial network solutions if this is the least cost solution and can be achieved without a detrimental impact on the overall stability of the existing network infrastructure.

Summary

The proposed asset modernisation costs in ED1 associated with the SPM 33 kV unit protected network will incur an uplift of £60.7million over traditional radial network designs.

The operating costs in ED1 associated with the SPM 33 kV unit protected network will incur an uplift of £14.8million over traditional radial network designs.

SPM 33 kV network consistently delivers upper quartile performance in terms of customer interruptions. Analysis of the events that dominate the Customer Interruptions at this voltage level in SPM are related to circuit breakers failing to trip at Grid Sites in Urban areas or loss of radially run 33/11kV transformer feeder arrangements in rural areas. The 33 kV unit protected network has had no bearing on the impact of these events, conversely other west coast networks operating more traditional network designs consistently incur greater Customer interruptions on 33 kV networks (Source NAFIRS National System and performance reports)

Introduction.

This is a supplementary discussion paper to the SPM Special Case

The SPM Network is consistently delivers frontier performance of reliability, second only to UKPN London network in the Ofgem overall CI performance tables. Indeed when the Urban networks of SPM's Mersey and Wirral Networks constructed predominately of 'X-type' networks are reviewed in isolation the performance is industry leading.

The foundation of the SPM urban network design lies in the early 1950's when drivers were different to those of today. However the advantages of the network design are still enjoyed by our customers through the reliability and flexibility it delivers.

To achieve the level of performance that SPM and LPN provide relies on heavily on interconnection and the use of unit protection, which increases the construction and life cycle costs.
Ofgem have recognised this in previous price review outcomes, see extract below from the DPRC5 outcome.

'*1.68. The lower of the industry-wide median unit cost and the DNO's own unit cost was then applied to all DNOs except where specific issues were identified by a DNO and accepted by Ofgem. These included the additional costs associated with operating within central London (EDFE LPN) and unique switchgear associated with the specific network topology for SP Manweb*'.

Review.

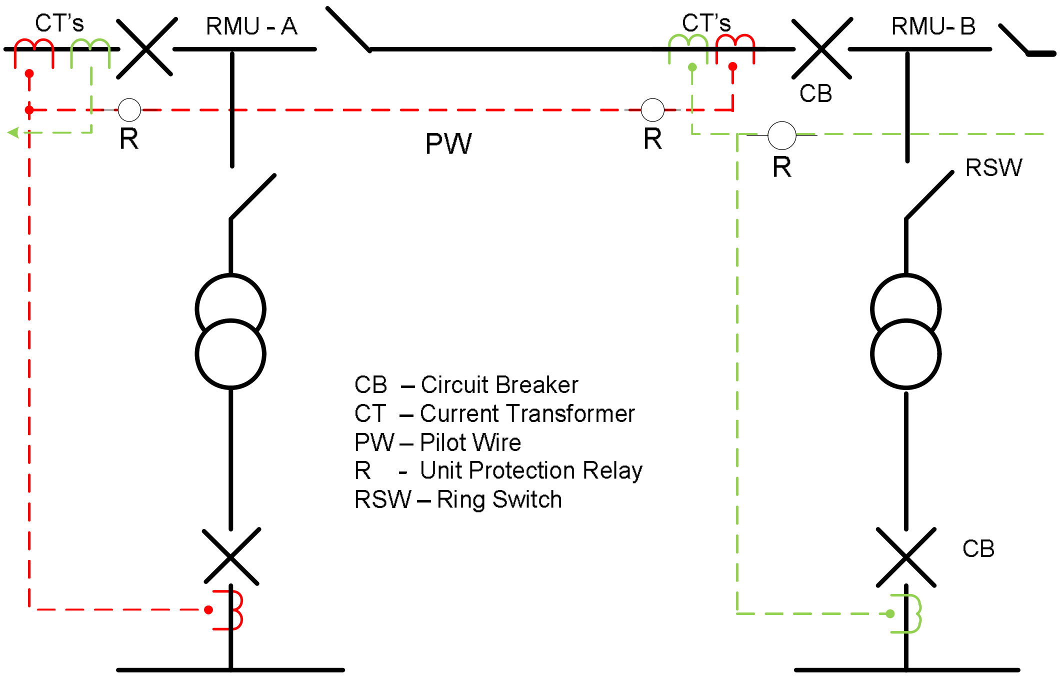
To supply our customers over our geographical footprint around 55% of the SPM network is designed and run as an 'X-Type' network, solidly interconnected at 33 kV, 11kV and LV. Of the remaining, 23% of the network is designed as a 'Y-type' network, solidly interconnected at 33 kV and 11kV but less so at LV and 22% is designed as a radial network with single transformers feeding a non-interconnected 11kV and LV.

To illustrate the relative costs associated with the SPM Manweb 'X- type' Network this paper examines the relative lifecycle costs of the SPM 'X- type' network at secondary substation and associated cable network level. Primary substation costs and LV network reorganisation costs have been excluded.

Capex

The additional costs of an 'X-type' Network are in essence associated the additional components of operating a Unit Protection system.

The key components for Unit Protection 'X-type' networks over traditional 'Y-type' substations are associated with additional switchgear requirements in the form of an LV (415 volt) circuit breaker, bespoke hv cable box for 11/.415kV transformer, and additional auxiliary switches fitted to the 11kV Ring main unit, together with additional protection requirements in the form of pilot cables(PW's), current transformers (CT's), relay panels, and batteries.



It also a requirement to have the correct environment to house an 'X-type' substation to ensure the equipment performs to its optimum when required. Currently in SPM all 'X-type' substations are of brick or similar block construction, with no approved GRP or containerised alternative.

The SPM hv(11&6kv variants) underground network consists of circa 7230 km of cable

Approximately 70% of this network is designed and constructed as 'X-type' the remaining 30% is designed and constructed as 'Y-type'.

Assuming the average length of each hv circuit is 1kM then based on the Unit cost manual Asset-02-004 issue , then the asset replacement would be:-

- 1km of 'X-type' network is £182/km
- 1km of 'Y- type' network is £141.5/km

To replace the 'X-type' network on a like for like basis then this would cost.

5060km at £182k per km = £920million. (excluding Primary substation costs).

Included in the cost of RMU substation replacement is the co-incident replacement of the associated 500KVA transformer. This is due to:-

a) Space Limitations/logistics considerations within the substation environment

and

b) Requirement to replace the compound filled transformer HV cable box (housing the protection CT's and CT's and wiring

To replace this network as 'Y-type'.

5060km at £141.5k per km = £716million. (Excluding LV reinforcement /reconfiguration costs) Therefore the capital replacement costs are circa £204million or 29% greater for 'X-type' network than 'Y-type' network. (cost breakdown in Appendix 1)

HV Customer Installations

Historically HV customer installations have been supplied with a mixture of Multiplanel boards and RMU's, depending upon the customer load requirement, with customer connections being successfully connected via RMU's into the SPM X-type network whilst maintaining system stability on the unit protected network.

It is no longer possible to purchase suitably equipped RMU's for these X-type installations, leaving no option but to replace switchgear of this configuration with more expensive 3 or 5 panel boards. All new connection again being constructed from a Panel Board design.

Details on these designs can be obtained from Manweb system Design – HV network Document ESDD-2-204

HV customer connections to traditional Y type networks can be connected to RMU's or multipanel boards depending on customer design parameters in line with wider industry practice.

SPM have 761 customers connected to its HV network (11/6kv), 134 are fed directly from Primary substations the remaining 627 are fed from the secondary network

Applying the same ratio as above it is assumed 70% are connected to the X-type network and 30% to the Y-type.

440 units connected to the X type network when being replaced would be upgraded from X-type RMU substations to multi panel boards (For the purpose of this exercise we will assume these connections are 90% single feeder connection and 10%dual feeder connection.

To replace the 440 HV customer connections in SPM with X type equipment

- Replacement cost of an single feeder X type HV connection = £101k/site
- Replacement cost of an dual feeder X type HV connection = £149k/site

To replace the 440 HV customer connections in SPM with Y type equipment

- Replacement cost of an single feeder Y type HV connection = £24k/site
- Replacement cost of an dual feeder X type HV connection = £48k/site

To replace the HV customers with 'X-type' network using modern panel board equipment would cost.

440 * 0.9 at £101k per site = £40 million, plus

440 *0.1 at 149k per site = £6.6 million. (excluding Primary substation costs)

Total = £46.6 million

To replace this network as ‘Y-type’.

440 * 0.9 at £24k per site = £9.5million, plus

440 *0.1 at 48k per site = £2.1million. (excluding Primary substation costs)

Total = £11.6 million

Therefore the capital replacement costs are circa £35million or 300% greater for ‘X-type’ network than ‘Y-type’ network. (cost breakdown in Appendix 2)

OPEX

In addition to the Capex costs for the initial build or replacement of the ‘X-type’ network there are additional operating costs associated with running the ‘X-type’ network over and above the traditional ‘Y-type’ network

These additional costs are again associated with the Civil costs associated with the solidly constructed substations, and the costs of maintaining the Unit protection components
For the purposes of this cost comparison the key costs are as follows:-

- The typical unit cost of a secondary substation maintenance is £476, there is no disaggregation of costs between the X & Y type secondary substation
- On a 1 in 12 year inspection regime the annual costs are (5060/12*£476)is £200k per annum

The work element of the ‘X-type’ substation is higher than that of the ‘Y-type’ due to the additional work on the Unit protection elements. However these costs can ‘by an large’ be offset by the additional preparation switching to allow access to a ‘Y-Type’ substation that is not required for a ‘X-type’ network:-

- Rearrange HV network to maintain supplies on non interconnected Y strings.
- Rearrange LV network or connect generator to provide or support lv back feeds to substation to maintain supplies to connected customers.
- Restore network to normal at the end of the day.

Therefore we can assume the costs of maintenance of the X & Y type secondary substation are broadly neutral.

Additional annual costs therefore of operating the ‘X-type’ secondary network can be broken down as follows:-

Battery replacement

- On a 1 in 6 year programmed replacement cycle plus a 15% reactive replacement of premature units failure we change 1000 units per annum @ £210 = £210k per annum
- Chargers have between a 25 and 40 year life and are replaced on failure rather than in a programme of work. Replacement costs are £828/unit. Failure rate at present is 100 per annum = £82.8k per annum. Ie site capital replacement programmes.

Pilot fault

- On average we repair 60 pilots (1.2%) of the asset base per annum at a cost of £300K per annum.
  (In order to repair a circuit with faulty pilots often more than one repair is required to improve the overall health of the pilot therefore a unit cost is not applicable and therefore costs are based on a total cost and run rate).
- As 11kV pilots are not supervised it is believed the current repair rate does not keep abreast of the actual failure rate. In ED1 we are proposing the increase the number of repairs (including minor overlays) to 70 repairs per annum at an average cost of £6.15k = £430 per annum

Post Fault Maintenance (PFM)

- At current run rate we carry out Post Fault Maintenance (PFM) to 120 units per annum @ £280 = 33.6k
  The majority of PFM will be on two circuit breakers per circuit fault in the X and interconnected Y network, and it not sensible to disaggregate this between the two network types, However in a true radial Y-Type network only one circuit breaker would control a circuit therefore the costs could be halved in a traditional Y network. Therefore the theoretical uplift is £17k per annum

Civil environment – approximately 350 secondary substation roofs and 450 substation doors are refurbished per annum at an average cost of £1.7 per unit = £1360K per annum. There is no real alternative to this or scope to reduce costs by converting X – Y network. The reduction is costs would only materialise if the substation is demolished and replaced with a GRP or other containerised housing. As the majority of these assets are in the community this would prove in the majority of situations to be unacceptable to our customers from an aesthetic perspective and it is unlikely we would gain the necessary planning consents. Therefore these costs are considered to be outside the scope of this comparison.

Total theoretical additional cost per annum of operating the ‘X-type’ network is

- Battery Cost - £293k/annum

- Pilot network - £430k/annum
- Pfm - £17k/annum

  Total - £740k/annum or £146/secondary circuit or 50p/customer per year .

Performance benefits

The 'X-type' network delivers frontier network performance, using DPRC5 performance to date there would be an average of 120 additional customer impacting hv cable faults per annum, impacting 104,000 per annum.

Based on an average time off or 85 minutes this equates:-
CI = 104000*£5.70 = £593k
CML = 104 * £0.17*85 = £1503k
Total IIS increase in penalties = £2096/Annum

Summary

The Capex Replacement of the SPM urban x type secondary network including HV customers would cost typically £239million over that of a traditional Y-type network over a 40 year asset life £6million per annum.

The Operating costs of the SPM urban x type secondary network costs typically £740k/annum to operate over and above a Y type network

The Performance advantages of the SPM urban network ensure 104,000 customers (7% of our customer base) are not subject to a power cut each year. Based on 85 minutes Average time of this equated to a saving of 6.9 CI and 5.9 CML's per annum over the performance of our Y-type network.

Appendix 1

1 Km of X or Y type 11kv ug network					
Asset	Class	Y type	X type	Delta	Comment
Building Civils	Secondary substation	8	20	12	Currently no approved GRP/container design for x type, Developers tend tom prefer to build substations which complement the aesthetics of the wider development however should we build a site the costs are roughly double for a brick building over a GRP
Transformer	Secondary substation	7.9	8.4	0.5	X type requires CT housing in TX long box Y type +£500
RMU	Secondary substation	3.6	4.7	1.1	X type has additional CT's/Ring switch Aux switches for ring test etc
Battery	Secondary substation		1.1	1.1	charger = £828 cells = £210
X type Protection	Secondary substation		9.5	9.5	9.5= local and remote end work
substation jointing & labour costs	Secondary substation	10.3	14.3	4	Crane/jointing/NRSWA/comm/traffic management
Cable	Network	111.68	111.68	0	per km
Pilot cable			8	8	per km based on 33 kv pilot material and jointing cost plus 50% lay - excludes excavation & reinstatement as this is in mains cable cost.
LV board	Secondary substation	4	4.6	0.6	LV board materials only used assume x type lv ACB = £600
		141.48	182.28	40.8	
				29%	

- Data source is Asset-02-004 used. Some costs stripped out from actual Unit cost to take account of Holistic replacement rather than unit by unit, possibly further efficiencies could be obtained
- Costs in £k

Appendix 2

HV customer connection X & Y type single feeder					
Asset	Class	Y type	X Type	Delta	Comment
Building Civils	Secondary Substation	10	20	10	Y string = GRP plus £2k for metering annex
11kV breaker	Secondary substation	4	41	37	Assume 3 Genie EVO
Battery charger	Secondary substation	0	2	2	Requires 48v charger and cells for panel board
House supplies	Secondary substation	0	0	0	Lights and battery chargers
X type Protection	Secondary substation	0	12	12	Required for network circuits
Substation jointing & labour costs	Secondary substation	10	25	15	Crane/jointing/NRSWA/comm
		24	101	76	
				314	%
HV customer connection X & Y-type 2 feeder					
Asset	Class	Y type	X Type	Delta	Comment
Building Civils	Secondary substation	20	26	6	Y string = GRP plus “3k for metering annex
11kV breaker	Secondary substation	8	68	60	Assume 3 Genie EVO
Battery charger	Secondary substation	0	2	2	Requires 48v charger and cells for panel board
House supplies	Secondary substation	0	0	0	Lights and battery chargers
X type protection	Secondary substation	0	12	12	Required for network circuits
Substation jointing & labour costs	Secondary substation	20	41	21	Crane/jointing/NRSWA/comm
		48	149	101	
				208	

- Data source is Asset-02-004 used. Some costs stripped out from actual Unit cost to take account of Holistic replacement rather than unit by unit, possibly further efficiencies could be obtained
- Excludes costs for SCADA which should be applied to X-Type to monitor battery condition as a minimum

Summary of REVISED Additional Costs for the SPM "Special Case"

This table summarises values and justification of additional costs taken from the original source documents provided by SP Energy Networks to Parsons Brinckerhoff for the review of the SPM "Special Case". During the development of the RIIO business plan, some of the source information has been refined to provide a more accurate assessment of the extra costs associated with the operation of an interconnected system. Updated cost estimates and justification are provided alongside the original estimates.

Alyn Jones/Malcolm Bebbington 26.02.2014

Asset	ORIGINAL ESTIMATE Additional Cost over ED1 period £million	ORIGINAL BASIS OF EVALUATION	**REVISED ESTIMATE Additional Cost over ED1 period £million**	**REVISED BASIS OF EVALUATION**
Capex 33 kV				
Primary transformers	£6.30	Based upon the need to replace 89 x 7.5MVA transformers in ED1 each costing £181k and a typical radial system of 37 x 12/24MVA transformers each costing £265k.	£5.65	Rational same but efficiencies applied to unit cost
Primary substation 33kV switchgear	£14.40	Based upon the need to replace 105 (6 indoor and 99 outdoor) oil circuit breakers in ED1 costing £110k each and £138.5k each respectively. 33kV switchgear would not normally be present in primary substations in a traditional radial system.	£7.79	Outdoor 33kV switchgear only
Primary substations33kV RMUs	£13.20	Based upon the need to replace 33 x 33kV Ring Main Units in ED1 costing £330 per site including civils and protections modifications. 33 kV RMUs are unique to the SPM system.	£11.76	All Indoor 33kV switchgear. Correction, Unit cost used in initial assessment (OD/d CB used instead of I/D CB)
33kV protection modernisation	£4.70	Based upon the plan to modernise 255 33kV protection installations in ED1. The protection requirements for an interconnected network are more onerous than in a radial system and an extra £18.5k is required per site.	£4.38	Updated costs for resubmission
BT21CN	£23.80	Based upon the plan to modernise 192 33kV protection units at £150k each in ED1 to operate with the new BT21CN communications services. There are significantly more units in the SPM system due to the requirements to protect the interconnected network (54 units at a derived £92k each in SPD).	£23.22	Updated costs for resubmission
33kV unit protection pilots	£3.30	Cost differential between SPM and SPD for overlaying pilot circuits.	£3.228	Updated costs for resubmission
Black Start Resilience at Primaries	£0	-	£0.91	New consideration for resubmission – installation of higher volumes of 72hr resilience at Primaries – therefore based on volumes differential between SPM & SPD – SDP used as a proxy for traditional industry New consideration for resubmission
RTU Replacement	£0	-	£6.37	New consideration for resubmission – replacement of higher volume of RTUs – therefore cost based on volumes differential between SPM & SPD – SDP used as a proxy for traditional industry
Ethernet Comms Infrastructure	£0	-	£4.75	New consideration for resubmission – replacement of higher volume of digital comms to service substation comms – therefore cost based on volumes differential between SPM & SPD – SDP used as a proxy for traditional industry
Substation Civils	£0	-	£6.34	New consideration for resubmission – based on higher volume of brick built substation for additional primary sites - therefore cost delta based on volumes differential between SPM & SPD – SDP used as a proxy for traditional industry, but SPD unit costs used as smaller footprint.
Sub-total	**£65.70**		**£**	**74.4**
Capex 11 kV				
11kV capex	£48.00	It is evaluated that the additional costs of replacing the assets in an interconnected network above the costs of a radial system are £239 million over the 40 year equipment life span. This equates to £6 million per year and £48 million for the ED1 period.	£0	Costs revised to only ED1 programme work See splits below
X type RMU	£0	-	£7.33	Based on cost differential of X-type RMU's over Y-type RMU's as per SPEN unit cost manual
X type transformer	£0	-	£0.17	Based on cost differential of X-type secondary transformer over Y-type transformers as per SPEN unit cost manual
Batteries at secondary substations	£0	-	£1	New consideration - X type secondary substations do not require tripping batteries Y- type do not. Therefore costs reduced over ED1 period to reflect SPD investment in batteries across at GM HV Substations as a proxy See CV3 row 51 on SPD & SPM CV tables
Substation Civils	£0	-	£10.13	New consideration for resubmission – based on higher volume of brick built substation over GRP/Open compound due to X-type requirements for secure well heated/ventilated building– therefore cost delta based on volumes differential between SPM & SPD – SDP used as a proxy for traditional industry, but SPD unit costs used as smaller footprint
Sub-total	**£48.00**		**£**	**18.64**

Opex 33 kV				
Primary substation maintenance	£1.32	Additional 33 kV switchgear at each substation	£1.82	SPM Volume issue on SPM 33kV primary substations maintenance per SPEN maintenance frequency with EHV switchgear for unit protected zones also covers PFM on 2 EHV circuit breakers rather than 1 per radial feeders PFM based on 120 units per annum costs at SPEN maintenance unit costs.
Primary substation post fault maintenance on 33kV circuit breakers	£0.52	Additional 33 kV switchgear at each substation		
Primary substation unit protection maintenance	£1.10	Protection associated with 33 kV switchgear	£0	Removed as indirect cost
Primary substation battery maintenance	£0.02	Protection associated with 33 kV switchgear	£.022	SPM discrete asset of translay batteries on Unit protection schemes = 2.715k per annum
33kV unit protection pilot repairs	£8.32	Repairs associated with pilot circuits	£3.36	Based on volumes issue for unit protection - volumes adjusted to SPD volumes and SPM unit cost as a proxy for traditional industry design without unit protection
33kV cable fault repairs	£1.26	Additional costs are associated with the length of cable being repaired in an interconnected system being 20-75% longer than the equivalent radial system. It is necessary to replace a longer length because the higher fault level leads to more cable being damaged around the site of a fault.	£0.97	Updated costs for resubmission
Substation civil maintenance	£1.46	Additional costs are associated with the greater number of substations within the SPM network.	£0.406	Primary plant civil' s volumes issue of primary plant volumes adjusted to SPD volumes and SPM unit cost as a proxy for traditional industry design without unit protection
33kV Rented Pilots	£0	-	£2.17	Based on higher volume of rented pilots to service 33kV unit protection over traditional industry – therefore cost delta based on volumes differential between SPM & SPD – SDP used as a proxy for traditional industry
Sub-total	**£14.00**		**£**	**8.74**

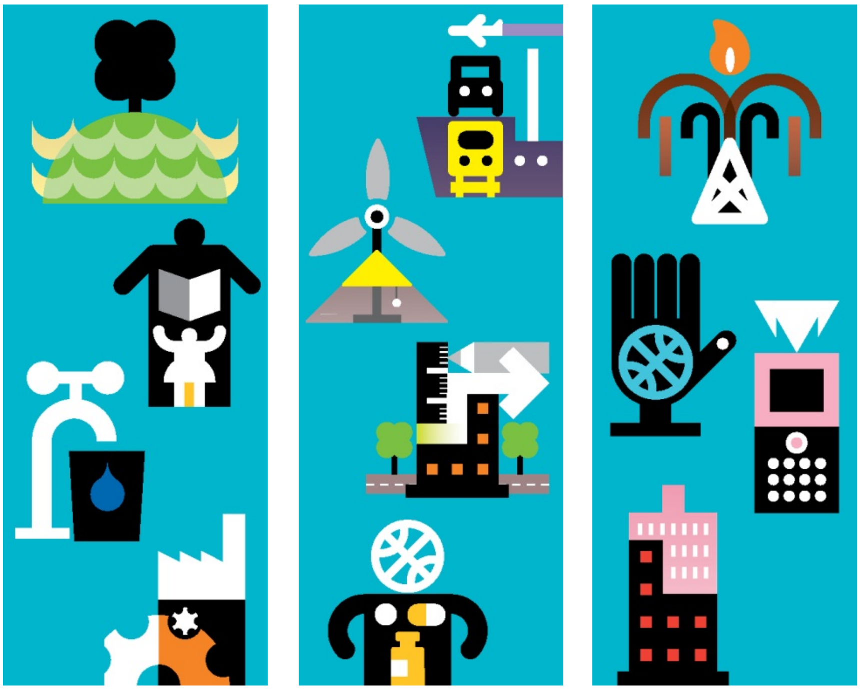
Opex 11 kV & 6.6kV				
Primary substation battery maintenance	£2.35	Based on costs of battery and charger replacement.	£	*Remove line*
Primary substation post fault maintenance on 11kV circuit breakers	£0.14	Based upon need to carry out post fault maintenance on an extra 60 units per year at a cost of £280 each.	£2.10	SPM Volume issue on SPM HV secondary substations maintenance per SPEN maintenance frequency with HV switchgear for unit protected zones also covers PFM on 2 HV circuit breakers rather than 1 per radial feeders PFM based on 200 units per annum costs at SPEN maintenance unit costs.
11 kV unit protection pilot repairs	£3.44	Based upon the repair of 70 pilots per year at an average cost of £6.15k each.	£0	*Remove line*
Substation civil maintenance	£10.88	Based upon the annual maintenance of 350 substation roofs and 450 substation doors at a cost of £1.7k per unit.	£0	Based on capex programme
X type RMU	£0			Delete line as costs in section above
Sub-total	**£16.80**		**£2.10**	
LV				
LV cable fault repair	**£6.06**		**£**	**1.83** Updated costs for resubmission - SPM unit cost issue due to second cut and test required on interconnected open circuit faults - SPM units used at SPD unit cost as proxy for traditional industry design

Original Source documents:

Title **(Filename if different to title)**	**Source**	**Comment**
SP Manweb Urban Networks (Manweb special case master v3.docx)	Email from M Bebbington 15th January 2014 15:35	A document comparing the design of the interconnected network with the more conventional radial networks of other DNOs.
Manweb 33 kV unit protected networks.docx	Email from M Bebbington 27th January 2014 16:58	A document quantifying the additional costs of modernising and operating unit protected 33 kV networks.
SPM 11kV Urban Network cost comparison (Manweb secondary x type network cost case.docx)	Email from M Bebbington 27th January 2014 16:58	A document quantifying the additional operational and asset replacement costs for an 11kV interconnected system.

B4 – PB Power Summary of REVISED Additional Costs for the SPM Special Case 25022014

7. Appendix B – Mott MacDonald (MM) Assessment of Special Case for SP Manweb Operating an Interconnected Network (February 2014)



Assessment of Special Case for SP Manweb

Operating an Interconnected Network

February 2014

SP Manweb

Mott MacDonald

Assessment of Special Case for SP Manweb

Operating an Interconnected Network

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Revision	Date	Originator	Checker	Approver	Description	Standard
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Summary and Conclusion

The distribution network built and operated by the Distribution Network Operator (DNO) SP Manweb and its predecessors over the past sixty years is fundamentally different from all other DNOs. Most distribution networks are organised radially, but the SP Manweb network is mainly designed and operated meshed at all voltage levels. Although more expensive to build and operate than radial systems, meshed networks offer better reliability and are more adaptable in response to changing load patterns. The background to the Manweb approach is reviewed in Chapter 1 of this report.

A comparison between these different approaches has been undertaken (see Chapter 2) in order to compare the costs associated with these designs and how these are affected by changes in loading, since it is anticipated that in the coming years distribution networks will have to develop to accommodate new loads and embedded generation with the introduction of Low Carbon Technologies (LCT). This comparison considered a trebling of the load density being supplied, which would cater for a significant introduction of low carbon technology (LCT) loads. Over this load increase the Manweb mesh design requires about 42% higher capital expenditure, but this is not uniform over the whole growth range. Each voltage level also shows different cost factors: at grid transformer level the cost is about 44% greater for the meshed design; at primary transformer level the cost is about 74% greater for the meshed design; and at the secondary level the cost increase is about 23%

Although generally more expensive than the radial system, because smaller growth increments are possible in the mesh design, network reinforcement can sometimes work out to be less expensive depending on the size of reinforcement necessary (see Figure 2.12). The smaller standard transformer sizes and single transformer substations largely account for this, but the cost per kVA is higher because larger substations benefit from 'economies of scale'. But the significantly higher utilisation achieved by the mesh design goes some way to offset this.

In a fully meshed and unit protected network, no supply is lost for the first fault that occurs, since there will always be a back-up route for supply which is already in service. It might be expected, therefore, that SP Manweb achieves higher reliability that other DNOs. The National Fault and Interruption Reporting System (NaFIRS) records details, provided by all the DNOs, of electrical faults and interruptions experienced by their networks; and from this information Customer Interruptions (CI) and Customer Minutes Lost (CML) statistics are derived and published by Ofgem. As shown in Chapter 4, SP Manweb has noticeably fewer CIs than all other DNOs except for the London DNO. London, of course, is a predominantly underground network, whereas a significant proportion of the SP Manweb system is overhead. Indeed the more rural parts of the SP Manweb 11 kV and LV systems operate radially. SP Manweb has carried out an analysis of NaFIRS statistics for just its urban areas which shows that CIs are even lower than those achieved by the London DNO.[1] CMLs, on the other hand, are not markedly lower than those of other DNOs, though they are significantly better than the average. Although customers

[1] SP Energy Networks 2015–2023 Business Plan Annex 2.10, SP Manweb urban network
http://www.spenergynetworks.co.uk/userfiles/file/201306_A2_10_SPEN_SP%20Manweb%20urban%20network.pdf

in SP Manweb's urban areas go off supply less often, there is anecdotal evidence that faults that interrupt supply can take longer to remedy than similar interruptions on a radial network.

The smaller equipment sizes used on the SP Manweb network are primarily the result of design decisions taken many years ago, and if those decisions were being taken today, given that there is much greater use of electricity than was envisaged back in the 1950s, it is certain that larger standard sizes of circuits, transformers and switchgear would have been chosen. The main components of an electricity network have a very long life, so SP Manweb has to live with its legacy. However, all equipment is replaced eventually, and so the design philosophy is changing.

On the SP Manweb 11 kV network there are two different ways that meshing is implemented, depending upon the type of 11 kV RMU (ring main unit) switchgear that is used: 'X-type' or 'Y-type'. The difference between these two networks is detailed in the reference[2], but the essential difference is that X-type RMUs allow unit protection to be used and the resulting network is fully meshed, with LV circuits able to interconnect between 11 kV feeders as well as along their length. Also, with Y-type RMUs, some types of fault can result in a loss of supply. For example, a fault on an 11 kV circuit can mean loss of supply to several substations on that circuit.

The fully unit protected approach clearly provides a more reliable supply, but at a price. At 11 kV the Y-Type design is less expensive, but would almost certainly result in more CIs and perhaps also in more CMLs. It has not been possible to quantify these changes, or whether they might be regarded as cost effective by the end user.

It should be noted also that the comparison in Chapter 2 has been done on the basis of 'conventional' network reinforcement. Radial networks are beginning to incorporate 'smart' design in order to approach the higher levels of utilisation and/or better reliability which are already provided by the meshed design; for example by introducing limited network interconnection (meshing) or by approaching it with auto-reconfiguration of the network following a fault outage. This will change the balance of costs in the future.

[2] SP Manweb Distribution Long Term Development Statement, for the years 2013/2014 to 2017/2018 http://www.spenergynetworks.co.uk/lt_statements/default.asp

1 Background and Introduction

During the first half of the 20th Century the demand for electricity in Great Britain doubled every seven to ten years. Electricity was provided by a large number of suppliers (both municipal and private companies) through a variety of distribution networks both AC and DC. In 1915 the government established Electric Power Supply Committee found that there were over 600 separate electricity supply undertakings across the country. That Committee recommended rationalisation of the system into district boards to generate and distribute within their areas. This did not happen straight away; initially generation and transmission was better coordinated – the Central Electricity Board was set up under The Electricity (Supply) Act 1926 which led to the development of the 132 kV national grid – and eventually, on 1 April 1948, the whole electricity supply industry (625 companies) was nationalised. In England and Wales twelve regional Electricity Boards were established for the distribution of electricity. One of these was the Merseyside and North Wales Electricity Board (MANWEB).

As well as bringing together all the different companies and systems within their respective areas, the Area Boards were also required to promote the provision of electricity to those without it; the process of 'rural electrification'. With the electricity demand continuing to grow at a rapid rate, the Area Boards had the opportunity to develop a unified system across their respective areas, since after a few years the majority of their network would be 'new'. MANWEB's first Chief Engineer was Peter Stowell, and he decided to adopt an interconnected and meshed distribution network design, which was quite different from any other Area Board. This philosophy he described in some detail in his Chairman's Address[3] to the Mersey and North Wales Centre of the Institution of Electrical Engineers (IEE) on 1 October 1957 – a revised and shortened version being subsequently published in the IEE Journal[4].

Area Boards were initially responsible for electricity distribution at voltages below 132 kV, and required to supply electricity over a wind range of load densities; from industrial, commercial and densely populated urban areas, to sparsely populated rural areas. The distribution systems developed as a hierarchy of networks at different voltages coupled via transformers. Typically three voltage levels would be adopted, for example: 33 kV, 11 or 6.6 kV and 415 V (now 400 V), i.e. 240 V (now 230 V) single phase. These were the voltage levels chosen by MANWEB, but different voltages were adopted by other Boards, for example: 22 kV, 66 kV.

1.1 Radial or Mesh Distribution

1.1.1 Radial (Traditional Design)

Nearly all Boards adopted a radial approach to distribution. In this arrangement, a substation might be supplied from the 33 kV network and transform the voltage down to 11 kV. One or more 11 kV feeders would radiate out from this substation, and supply several 11kV/LV substations which would be strung out along each feeder. This would normally be the most economical method of supply. Being operated radially, the amount of switchgear is minimised and protection simplified. But, as it stands, this is clearly not a particularly reliable system, since a single failure (transformer or feeder) would result in customers losing supply until the fault is repaired. To mitigate this, the 33/11 kV substation would have a minimum of two transformers (one to back-up the other) and the 11 kV feeders arranged to have switchable back-

[3] "A Review of Some Aspects of Electricity Distribution". Address given in Liverpool on October 1, 1956, by Mr. P. d'E. Stowell as Chairman of the Mersey and North Wales Centre of the Institution of Electrical Engineers.

[4] Peter d'Eyncourt Stowell; "Manweb Distribution"; IEE Journal, vol 4, no. 37, January 1958, pp 15-21

feeds, so that any interruption in service will only be as long as it takes to change over to an alternative supply. Clearly with the two transformers they need to be sized so that one of them is capable of meeting the entire load on the substation, which means that under normal conditions, neither transformer achieves a utilisation greater than 50%.

A similar arrangement obtains at the higher voltage level (132 kV to 33 kV), and also at the lower voltage level (11 kV to LV) where it is considered justified. It is not considered justified at LV where the load density is low, which is typically the case in rural areas. Here, single 11 kV/LV transformers will be supplied from an 11 kV overhead line, so a fault on either will result in a loss of supply until the fault is repaired. Transformers are reliable pieces of equipment, so failure is rare; and if it does occur, at this voltage level a spare will be readily available. Although overhead lines are more susceptible to faults, primarily due to adverse weather, these can be repaired relatively quickly, unlike faults on cables.

This practice conforms to the current distribution network planning standard, Engineering Recommendation (ER) P2/6, to which Distribution Network Operators (DNOs) have a licence obligation to plan and develop their systems. Essentially, relatively small amounts of load are permitted to lose their electricity supply for the time it takes to restore the network, but larger loads are required to be restored by switching, or even, if large enough, have continuous back-up.

With the radial approach, the loading on the distribution circuits decreases the further away from the infeeding substation, so it is usual to employ smaller conductor sizes (i.e. to ‘taper’ the network) towards the ends of the circuits. Although reducing the capital cost, this limits the capability to have a normally open interconnection at the end of these circuits to use as a backfeed. Also, it can make reinforcing the network, by adding a new infeeding substation, more expensive; since the existing circuit sizes in the vicinity of the new substation may too small and therefore have to be replaced or duplicated.

1.1.2 Mesh (MANWEB Design)

Whereas the majority of Area Boards adopted radial distribution, MANWEB was unusual, if not unique, in opting for a fully meshed system. Essentially, except for in rural areas, all feeders, at all voltage levels are supplied from both ends, and these ends always terminate at separate substations. The ground is effectively covered with a mesh of uniform circuits, more coarse at the higher voltages, with each mesh receiving distributed in-feeds from the voltage level above. The details of this arrangement are in the publications by Peter Stowell referred to at the beginning of this Chapter. An Annex to the SP Energy Networks business plan[5] describes the SP Manweb network design as implemented today at the various voltage levels; as also does the SP Manweb Long Term Development Statement[6].

To take full advantage of the built-in back-up capability of meshed networks requires more specialised protection and more switchgear, and is inevitably more expensive. However, this expense is mitigated to some degree by the fact that higher equipment utilisation can be achieved. In the radial system, generally only two transformers operate in parallel, but in a mesh system, three, four, five or even six transformers are effectively working in parallel. Equipment fault level ratings (switchgear and circuits) can prevent more than about five transformers actually being connected to operate in parallel, but this is not always the case. For example, the SP Manweb 33 kV network is interconnected all across North Wales and into Cheshire, because the longer circuit lengths in the rural and semi-rural areas keep the fault levels below limits. Similarly, LV networks, even in urban areas, can normally interconnect an unlimited number of 11 kV/LV

[5] SP Energy Networks 2015–2023 Business Plan Annex 2.10, SP Manweb urban network http://www.spenergynetworks.co.uk/userfiles/file/201306_A2_10_SPEN_SP%20Manweb%20urban%20network.pdf

[6] SP Manweb Distribution Long Term Development Statement, for the years 2013/2014 to 2017/2018 http://www.spenergynetworks.co.uk/lt_statements/default.asp

substations. But in practice, if the supply from a substation fails, only the transformers in the immediate neighbourhood can effectively provide back-up; though the ability to have 'unlimited' interconnection is advantageous, since the network planner is not forced to limit the size of an interconnected group.

So in a mesh network, equipment utilisation can easily be of the order of 80%, compared to 50% in a radial network. And an obvious advantage of the unit protected mesh system is that any single fault or failure will not result in any loss of supply, even for a short period of time. This is reflected in the Customer Interruptions (CI) and Customer Minutes Lost (CML) statistics published by Ofgem, as is considered in more detail in Chapter 5 of this report.

Another advantage is in meeting changing demand. In the mesh arrangement, overloaded feeders can be relieved by installing a new in-feed near the mid points, which reduces the spacing between in-feeds. Conversely, if demand falls in an area, substations can be decommissioned, and their equipment used elsewhere, provided that the longer feeding distances from the surrounding substations do not result in voltages outside of statutory limits. In radial networks, the introduction of new or larger substations can lead to circuits having to be replaced or reinforced due to the non-uniformity of the network.

However it should be noted that SP Manweb has adopted two differing approaches to interconnection at 11 kV: one, which employs the so called 'X-Type' Ring Main Unit (RMU) and the other a 'Y-Type' RMU. The connection details for these two RMU types are described in SP Energy Networks 2015–2023 Business Plan Annex 2.10[7]. Y-Type RMUs are connected in the traditional way with the HV/LV transformer connected to the transformer, and the HV feeder connected through the substation via the two isolators. The X-Type connection is 'turned around' with the transformer connected to one of the isolators and the HV feeder being connected through the substation via the other isolator and the circuit breaker. This means that 'unit protection' can be employed with the protection zone being bordered by three breakers: the RMU breakers at two adjacent substations on the HV feeder, and an LV breaker at the transformer between them[8].

With X-Type RMUs it is therefore possible to interconnect the LV between different HV feeders, whereas with Y-Type RMUs LV interconnection has to be limited to between substations on the same HV feeder, in order to avoid the possibility of backfeeding into a fault from an adjacent substation. The additional equipment and protection associated with the X-Type arrangement makes this a more expensive but more reliable option. Supply will be lost following a fault on a Y-Type HV feeder, until switching can take place to isolate the faulty section of circuit.

A similar style of unit protection has been employed by SP Manweb at 33 kV, however a suitable 33 kV RMU is no longer obtainable, and a three-panel switchboard has been adopted as an alternative – clearly a more expensive option.

[7] SP Energy Networks 2015–2023 Business Plan Annex 2.10, SP Manweb urban network http://www.spenergynetworks.co.uk/userfiles/file/201306_A2_10_SPEN_SP%20Manweb%20urban%20network.pdf

[8] Ibid.

2 Network Modelling

In order to compare the Manweb meshed design against the more usual radial distribution design, equivalent 'typical' sections of network were devised using each style. From these staring points the cost of increasing the capacity of the system could then be derived in terms of capital expenditure (CAPEX).

2.1 Initial Systems

All distribution voltage levels were considered in the analysis. The models developed can be seen in Figure 2.1. Only one sub-circuit is shown at each voltage level so as not to over clutter the diagram (it was assumed each instance of a sub-circuit was identical).

For the meshed system it was assumed that initially there would be three transformers operating in parallel at 132/33 kV and 33/11 kV. Meshing can be achieved with groups of between two and five transformers (limited by maintaining practical fault levels). The initial grouping allows 66% transformer utilisation (allowing for N-1 contingency). For 11 kV to LV it was assumed that full meshing would be installed on the LV system. The relatively high impedance of the LV cables was assumed to keep fault levels within design levels. The result of this assumption was that unlimited numbers of transformers could be connected in parallel allowing the 11 kV/LV transformer utilisation to be considered as 100%, since the on the loss of an individual transformer its load will be supplied from the surrounding transformers, and the transformers have a cyclic rating of 130%.

For the traditional system it was assumed that transformers would be operating in pairs throughout all voltage levels. This pairing of transformers means that only 50% utilisation (based on the emergency or cyclic rating) can be assumed in the best case when allowing for N-1 security. At 132 kV and 33 kV it was assumed that each substation (supplying two transformers) would be fed radially from the supply point. It is presumed that there will be two feeders to each substation (operating with normally open points) to continue the N-1 operating assumption. At 11 kV and LV it was assumed that the network would be configured in radial loops with built in open points. Throughout the system normally open points would be used to ensure separation of the network sections.

As twin feed from the super grid is standard it was used for both designs. Transmission is outside the scope of this study, therefore grid supply points were not considered in detail. It was assumed that the super grid transformers would have sufficient thermal capacity for all scenarios considered.

A key consideration in defining the number of substations throughout the system was the thermal rating of the transformers. The transformer ratings (typical for each network design) are summarised in Table 2.1. Based on the design assumptions already described the total numbers of each transformer type for each design style are summarised in Table 2.2.

Table 2.1: Assumed Transformer Ratings

Voltage Transformation	Transformer Rating (MVA)		Comment
	Traditional Design	Manweb Design	
Transmission/132 kV	-	-	Assumed to have sufficient capacity
132/33 kV	90*	60*	*Cyclic rating allows higher firm value
33/11 kV	12/24	7.5 (10)*	*Cyclic rating allows higher firm value
11 kV/LV	1	0.5	-

Table 2.2: Total Number of Transformers by Voltage Level

Transformer Voltage Step	Number of Transformers	
	Traditional Design	Manweb Design
132/33 kV	6	6
33/11 kV	24	42
11 kV/LV	504	735

To highlight the equivalence between the typical designs of each style, Table 2.3 summarises the power transfer capabilities to and from each of the voltage levels. The total load that can be supported is not the same for both designs, but each provides a starting point for comparing the incremental development of the two networks. Each starting position allows for a little headroom across all of the voltage levels.

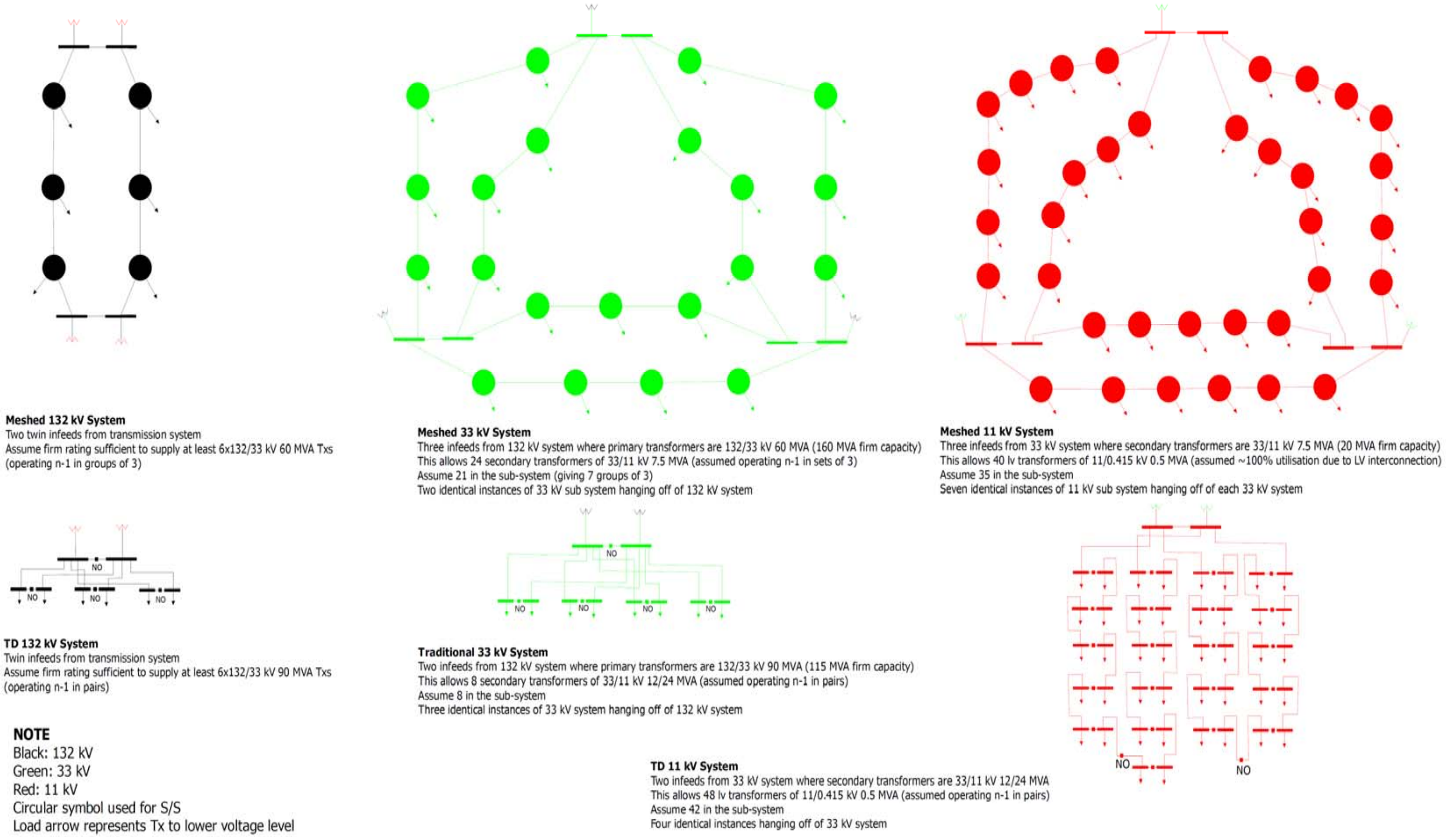
Table 2.3: Comparison of Capacities at Each Voltage Level[9]

Voltage Level kV	Traditional Design					Manweb Meshed Design				
	Firm Capacity Incoming Per Sub-Set	Firm Capacity Outgoing Per Sub-Set	No. of Sub-Sets	Total Firm Capacity Incoming	Total Firm Capacity Outgoing	Firm Capacity Incoming Per Sub-Set	Firm Capacity Outgoing Per Sub-Set	No. of Sub-Sets	Total Firm Capacity Incoming	Total Firm Capacity Outgoing
132	∞	345	1	∞	345	∞	320	1	∞	320
33	115	96	3	345	288	160	140	2	320	280
11	24	21	12	192	252	20	17.5	14	280	245
LV	1.0	1.0	252	252	252	245	245	1[10]	245	245

9 In the context of this table, incoming capacity is referring to the thermal limit on the transformers in feeding from the level above (allowing for N-1). Similarly outgoing capacity refers to the thermal capacity of the transformers feeding the voltage level below (allowing for N-1). It is important to note for the meshed system that the assumption was 3 transformers operating in parallel.

10 The assumption made was that the LV system would be fully interconnected. The result being that the incoming capacity is simply the combined rating of the transformers. In reality only the 6 closest transformers at most are likely to feed load on the LV system due cable impedances.

Figure 2.1: 'Typical' Distribution Designs, Manweb (Meshed) [top] and Traditional (Radial) [bottom]



2.2 Expanding the System

For both system designs it was assumed that traditional solutions would be applied to the system. This allows for a direct comparison between the distinct network types. Traditional solutions involve simply expanding the system by the addition of more plant as the load requires it.

To expand the capability of the either system the first step would be the installation of additional secondary (11 kV/LV) transformers. In the meshed design, following the original full meshing assumption on the LV system, each new 500 kVA transformer would allow a further 500 kVA of load (capacity). There is initially room for 16 new transformers on each 11 kV subset of the system. For the traditional design it has been assumed that twin 1 MVA transformer substations will be added. There is initially room for 3 new substations on each 11 kV subset of the system. The expanded meshed and traditional systems can be seen depicted in Figure 2.2 and Figure 2.3 respectively.

Figure 2.2: Expanded Meshed 11 kV System

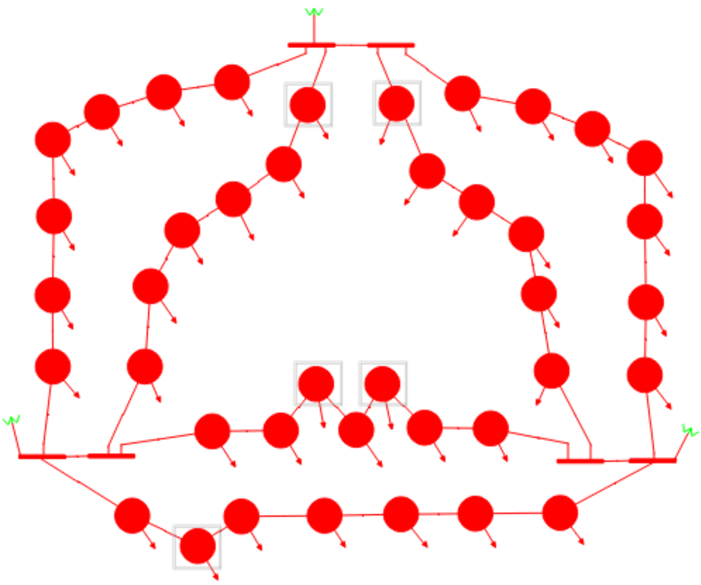
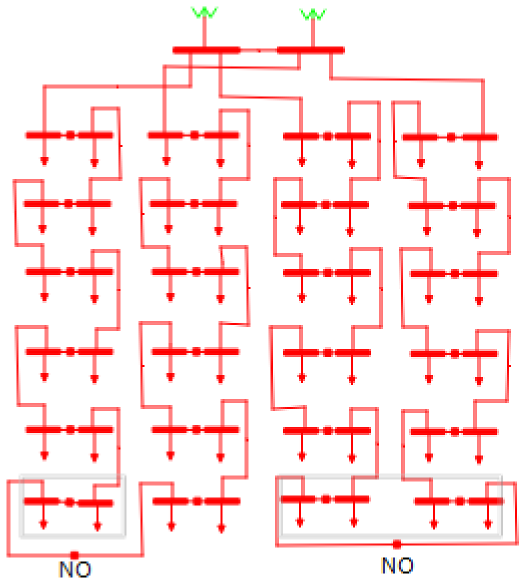


Figure 2.3: Expanded Traditional 11 kV System



As the capacity of the existing primary (33/11 kV) transformers became fully utilised new ones would be added. This would allow further secondary transformers to be added to the 11 kV systems. For the meshed system this would involve increasing the groups of three transformers to groups of four by adding additional 7.5 MVA 33/11 kV transformers. This would in turn allow the addition of 20 new 0.5 MVA 11 kV/LV transformers to the associated 11 kV system (assuming the higher firm rating of 10 MVA for the primary transformers). The initial system has headroom to allow for 2 of these additions per subset. In the traditional design no new 12/24 MVA twin transformer substations could be added as there was not enough available headroom on each of the 33 kV systems.

Figure 2.4: Expanded Meshed 33 kV System

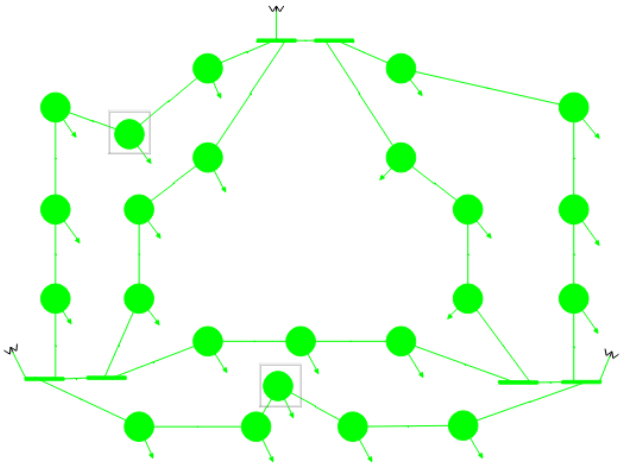
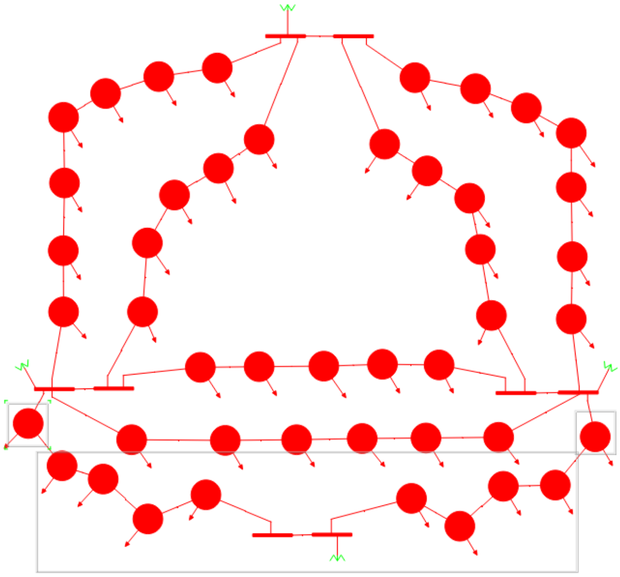


Figure 2.5: Further Expanded Meshed 11 kV System



At the point where the 33 kV system runs out of headroom, additional 132/33 kV transformers are required. In the meshed system, as discussed, this would mean increasing the number of transformer in each group feeding each sub system. For the traditional design it has been assumed that a twin transformer substation will be added allowing the construction of further new substations to be created downstream.

Figure 2.6: Expanded Meshed 132 kV System

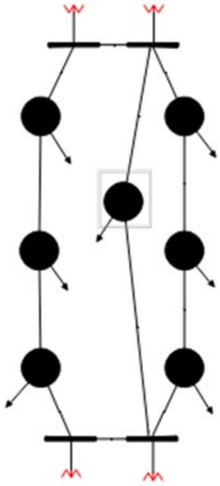


Figure 2.7: Expanded Traditional 132 kV System

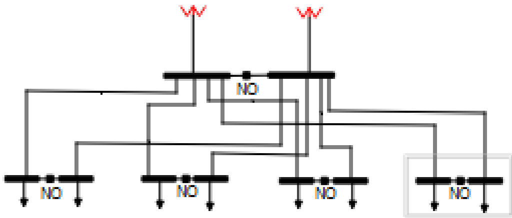


Figure 2.8: Further Expanded Meshed 33 kV System

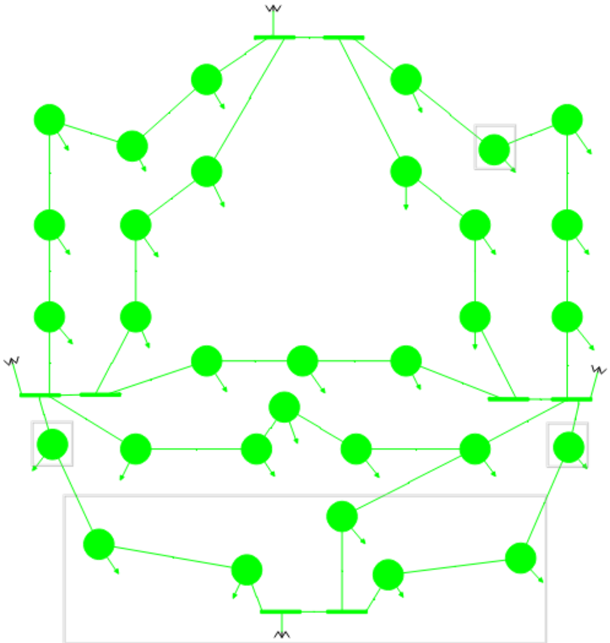
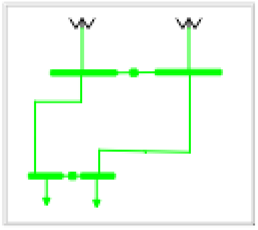


Figure 2.9: New Traditional 33 kV System



This process of adding transformers to the meshed system to increase capacity can be repeated, adding new transformers at each voltage level as required, increasing the group size until the maximum of 5 is reached. Groups larger than 5 can exceed equipment fault level rating when substations are relatively closely spaced. As the number of transformers in the group increases so does the potential utilisation of those assets. A 4 group would allow 75% utilisations and a 5 group would allow 80%, allowing for N-1. Once a group reaches the limit of 5 infeeding transformers it is necessary to split the group up in order to add more transformers. This process requires that, in order to increase capacity and retain the same level of security, two transformers must be added unlike the one normally required by the mesh system[11]. When splitting a group it is important to bear in mind that the downstream transformers need also to be sensibly split between the two new groups.

2.3 Capital Expenditure (CAPEX) Costing

The capital expenditure was based on unit costs built up in a similar manner for each design type. It has been built up to allow for all civil works as well as the new power system hardware and protection. The main cost differentials are associated with the number of transformers and the method of protection. The unit costs allowed for per step type and the resultant capacity increases for both the meshed and traditional designs are summarised below in Table 2.4.

[11] This is a worst case assumption, since it may be possible to involve adjacent groups in a wider regrouping exercise in order to achieve higher utilisation levels overall.

Table 2.4: Capital Expenditure (CAPEX) Costs

Type	Description	Design	Cost (k£)
A	New secondary unit protected transformer with associated LV and 11 kV cabling	Meshed	160
a	New twin secondary non-unit protected transformers with associated LV and 11 kV cabling	Radial	260
B	New primary unit protected transformer with associated 11 kV and 33 kV cabling	Meshed	1800
b	New twin primary non-unit protected transformers with associated 11 kV and 33 kV cabling	Radial	3000
C	New grid unit protected transformer with associated 33 kV cabling and 132 kV OHL	Meshed	5900
c	New twin grid non-unit protected transformers with associated 33 kV cabling and 132 kV OHL	Radial	6500

The costing is sensitive to the lengths of cable and overhead line (OHL) associated with each new substation. OHL line was assumed for the 132 kV system with cables used throughout the rest of the system. Typical lengths of HV and LV cables associated with a new secondary transformer were used to form the basis of these numbers. The traditional radial design has double the length associated with it due to the necessity for twin feeders. Average circuit length data was used when deciding lengths for other new substation types. The lengths used are summarised in Table 2.5.

Table 2.5: Lengths (in m) of Cable/OHL Associated with Each New Substation Type (and Cost in £/m)

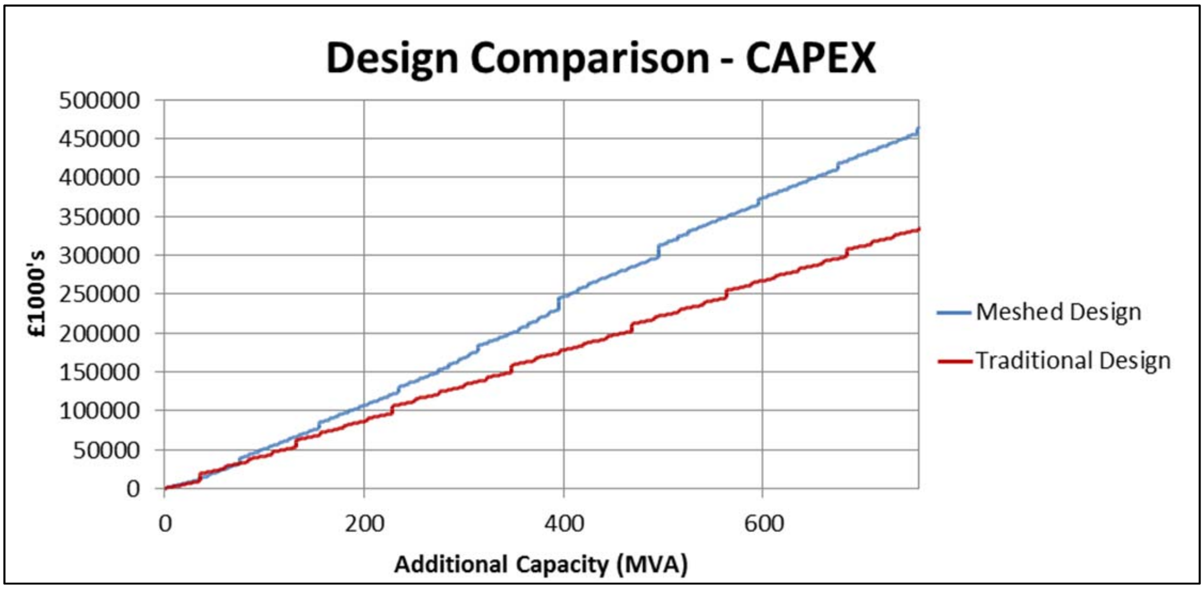
Type	132 kV OHL	EHV Cable	HV Cable	LV Cable
A	-	-	400	100
a	-	-	800	200
B	-	1840	2560	-
b	-	3700	4200	-
C	6700	2300	-	-
c	10000	3700	-	-
(Cost)	(105)	(250)	(140)	(120)

2.4 Study Results

Using the methodology described in section 2.2, the system was expanded from the initial system described in section 2.1. The study was expanded to the point where each of the designs would have thermal capability sufficient for approximately 3 times the initial load (a 756 MVA increase in capacity). Expanding to this extent allows for discussion: around and beyond foreseeable load growth; the effect of the requirement to split groups.

The cumulative CAPEX cost for increasing capacity for each design type is shown in Figure 2.10. The total CAPEX required for the meshed design was £464m compared to £332m required for the traditional design. This would imply that the meshed design is approximately 42% more expensive to expand, with regards to CAPEX, when compared to the traditional design. Over the total 756 MVA range this would average out as an additional £174k per 1 MVA capacity added to the system.

Figure 2.10: Cumulative CAPEX Costs



The cumulative total cost difference and the cost difference per 1 MVA added capacity are shown in Figure 2.11 and Figure 2.12 respectively. The cumulative cost difference is not a perfectly straight line; this is reflected in the cost difference per 1 MVA added which shows large differences across the range. This is due not only to the different cost of upgrades for each of the designs but the frequency at which they become necessary due to the different ratings of equipment.

Initially the difference is £60k per MVA. This is simply the difference between one new twin traditional secondary substation and two meshed secondary substations. This is consistently the difference until the thermal headroom in one of the 11 kV systems is fully utilised. This happened first for the traditional design, triggering the need to reinforce the system with the addition of a primary substation. As the traditional design requires major reinforcement earlier, it in fact becomes more expensive when compared to the meshed system for a brief period of the expansion.

At the point where an additional 36 MVA has been made available, the thermal capability of the grid substations has been used, in the traditional design. Beyond this, with the addition of a new grid transformer, 4 new primary substations can be added each allowing 24 secondary substations. This pattern could then repeat indefinitely (due to the assumption of unlimited rating of super grid transformers).

As discussed in section 2.2 expansion of the meshed system cannot happen in such a linear form. At the point where an additional 275 MVA had been added each of the original groups of three primary transformers had been expanded to groups of five. This resulted in the necessity of beginning the process of splitting the groups. The effect of this was to require (as explained in section 2.2) the addition to two primary substations because of the lower utilisation achievable in smaller group sizes. At this point the cost difference per MVA markedly increases. This splitting of the primary groups continues until around 525 MVA of additional capacity has been added. Beyond this point, the new groups are expanded as before, building up to groups of 5. There were also two instances where the grid groups required to be split (this happened at the steps from 395 MVA and 495 MVA), these resulted in relatively large step changes in the cumulative cost difference.

Figure 2.11: Cumulative Cost Difference Between Designs (Shows Indication of Stage of Meshed System Expansion)

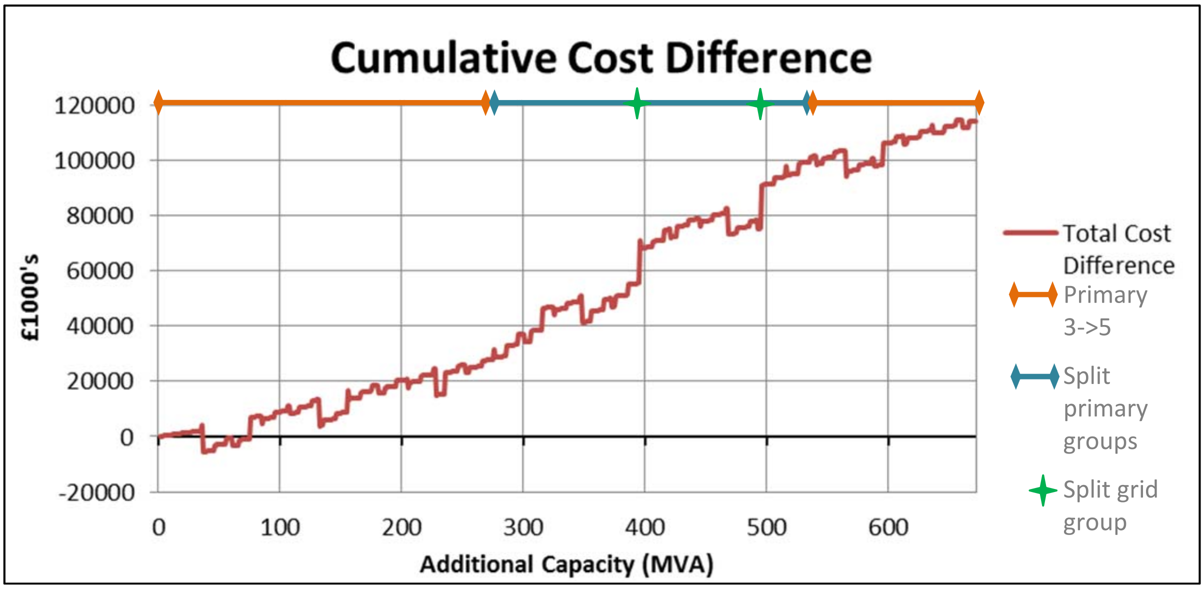
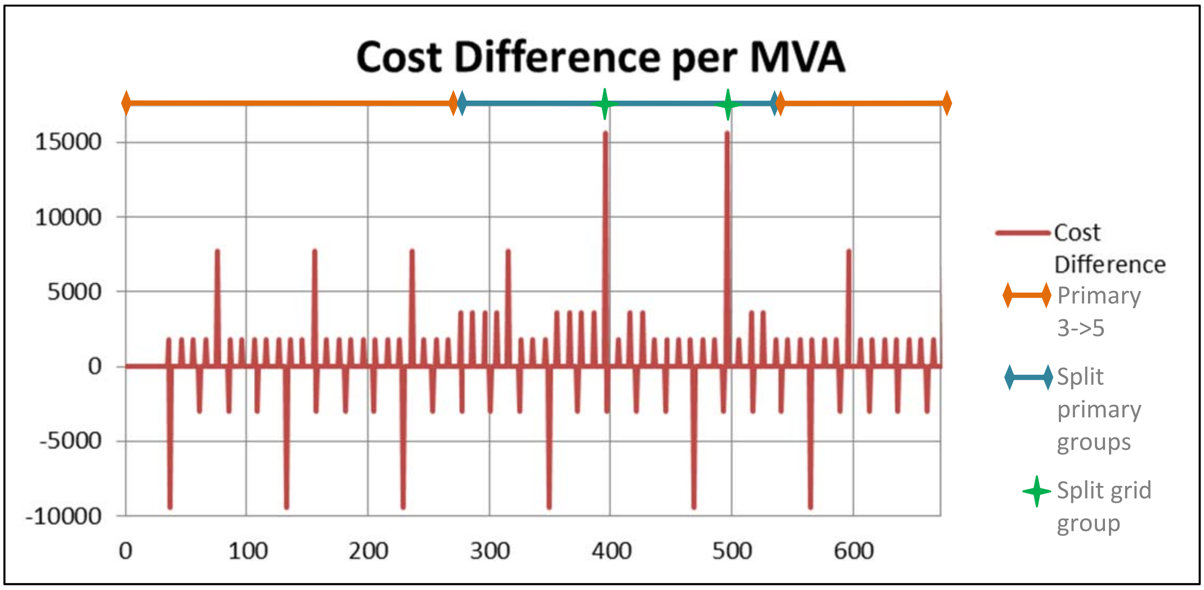
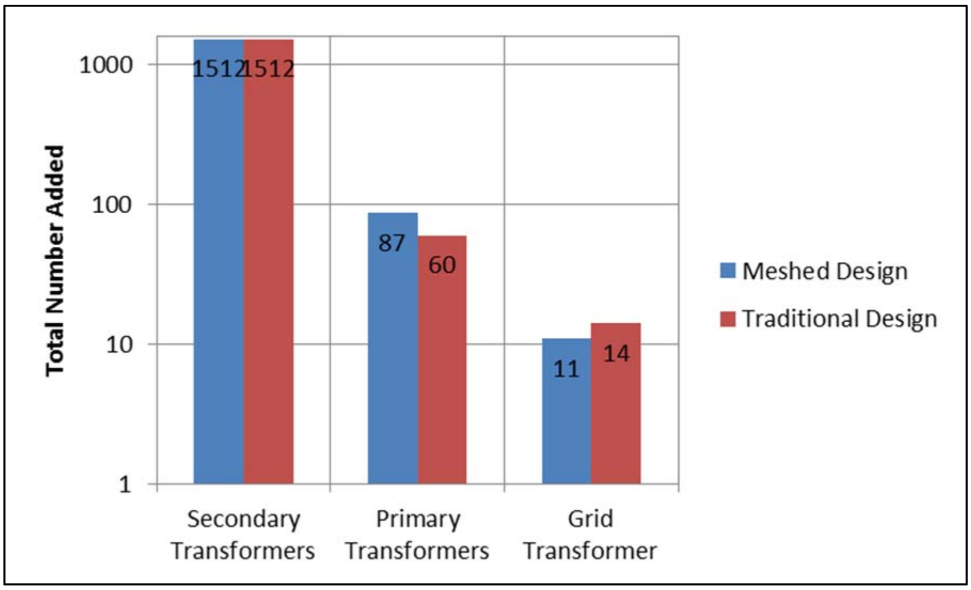


Figure 2.12: Cost Difference for Each MVA Step (Shows Indication of Stage of Meshed System Expansion)



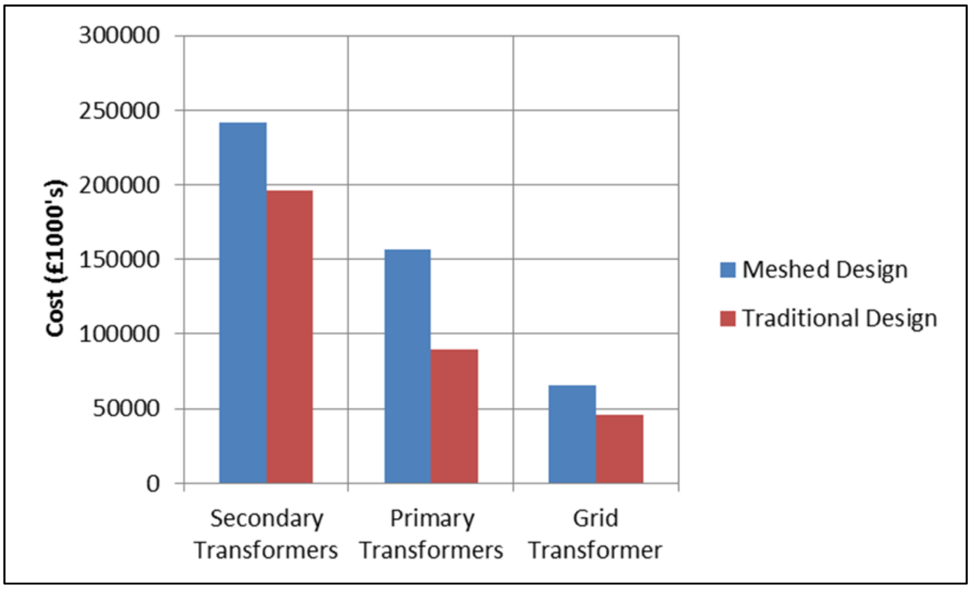
The numbers of new transformers added (by type) to achieve four times the initial capacity is summarised in Figure 2.13. Note that for the traditional design there were assumed to be two transformers per substation. Therefore the number of substations is half the number of transformers. For the meshed design however the number of transformers is equal to the number of substations. The increased utilisation factors of the transformers working in groups offsets the discrepancy in the thermal ratings between the designs. For secondary and grid transformers this is most noticeable as the number added to each design is very similar. For primary transformers (where the majority of the group splitting has taken place) almost half as many again of the number of primary transformers was required for the meshed design.

Figure 2.13: Total Number of Transformers Added, By Type
(For Traditional Design, Number of Substations Will be Half the Number of Transformers)



Totalling the amount spent on each design for each new substation type (including the associated cabling) highlights where the cost differences come from: at grid transformer level the cost is about 44% greater for the meshed design; at primary transformer level the cost is about 74% greater for the meshed design; and at the secondary level the cost increase is about 23%.

Figure 2.14: Total Spent, By Transformer Type (Price Includes Associated Cabling)



The spread of the investment is quite different depending in the design style used. For the traditional design, even though unit costs increase with voltage level, total spend decreases due to the volumes involved. For the meshed design the majority of the expenditure was required at both the secondary and the primary voltage level.

The costs associated with each transformer type as total system capability increases are shown in Figure 2.15, Figure 2.16 and Figure 2.17. These graphs highlight the frequency of investment required at each level.

Figure 2.15: Capital Expenditure at the Secondary Level

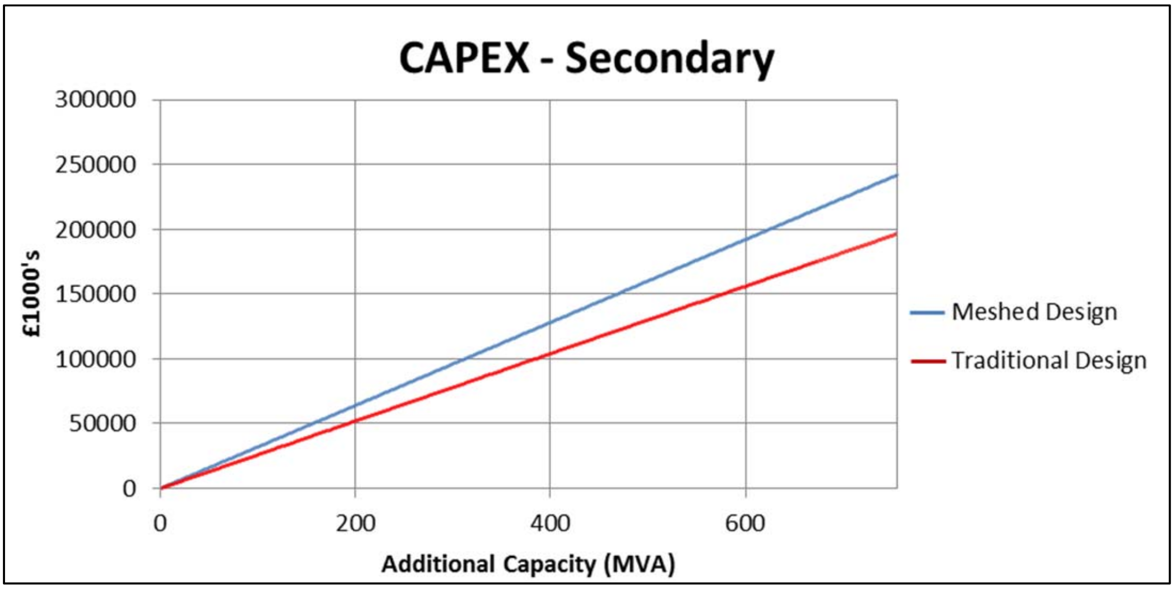


Figure 2.16: Capital Expenditure at the Primary Level

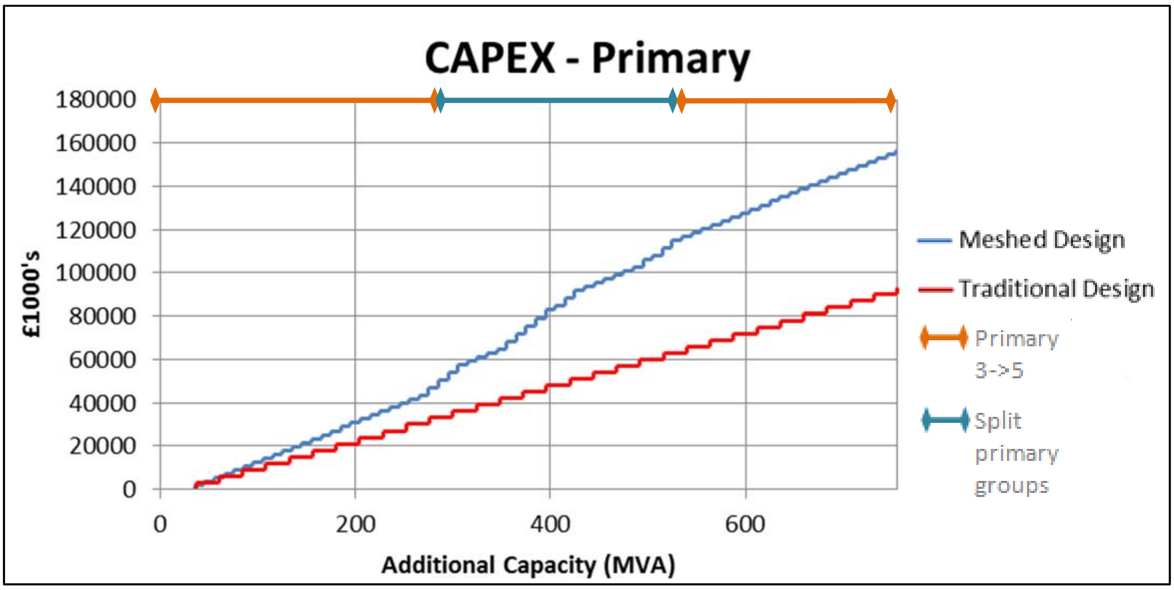
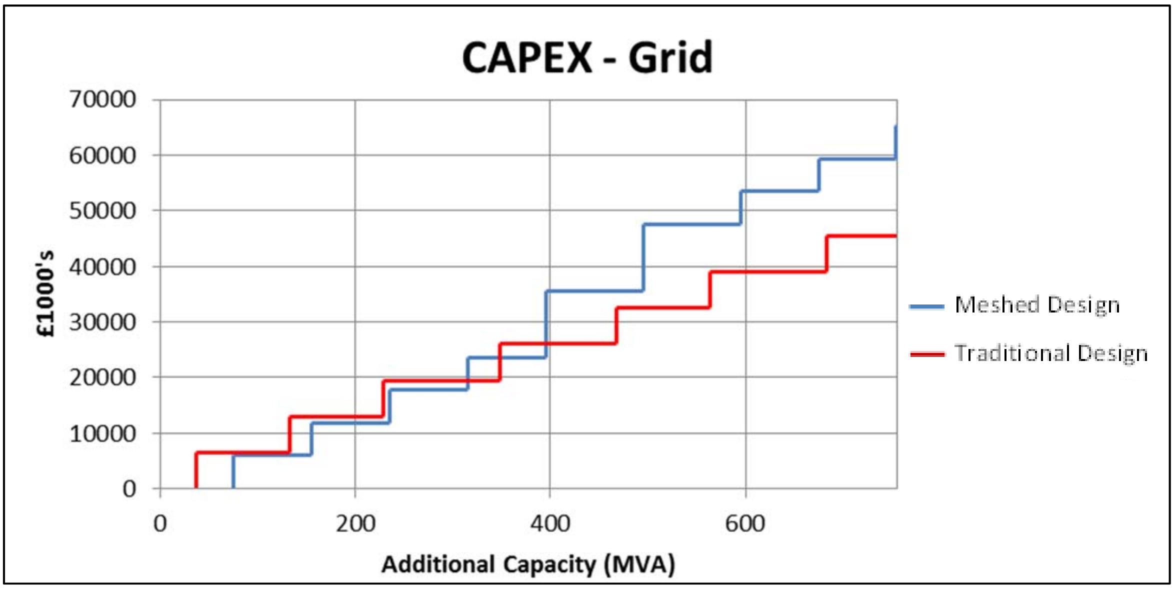


Figure 2.17: Capital Expenditure at the Grid Level



2.4.1 Summary and Effects of Key Assumptions

The assumptions used can have a major effect on the outcome of the studies. Assumptions have been applied equally to the traditional and meshed designs.

The main assumptions were made with regards to the load. It was assumed that all loads were connected on the LV network and evenly split across all transformers with a uniform demand profile. This assumption meant that capacity at each voltage level could be considered purely in terms of the summation of the ratings of the transformers connected to the lower voltage level compared to the summation of the ratings of the transformers connected to the higher voltage level (allowing for N-1). It also meant that when expanding the systems, when a new primary transformer was added it required a secondary transformer added downstream to unlock capacity.

It was also assumed that load would expand equally across the system. This affected the order in which the upgrades were required. Changing the order of the upgrades (i.e. progressing one half of the network before the other) would have affected the rate of change of cost in some instances. The differences would though balance out across the entirety of the system upgrades considered.

A number of assumptions was made around the expansion of a five-group. For the primary transformer groups (as the secondary transformers were not considered in groups) it was simply assumed that the secondary transformers could be split proportionally between the new groups. When expanding the grid transformer groups, there were a number of different sized primary transformer groups connected downstream that had to be considered in more detail. They were split between the two new grid groups; with more primary ones being placed with the new grid four-group, but with as equal a split of different sized primary groups across each sub system as possible. In reality, due to geographical and other issues, it may not be possible to split the groups in this manner. Other costs may be associated with these splits not entirely captured in this analysis. The reason that downstream systems must be split across unique upstream ones is to avoid back feeds during outage conditions.

With regards to the allowing groups of 5 infeeding transformers at 132 kV and 33 kV, it may be somewhat optimistic. In urban areas where the cable impedance is low, fault levels would become too high for groups of that size so splitting may have to occur earlier. This would increase the cost for the meshed system as more splitting would have to take place which requires more transformers to be added.

As previously mentioned an N-1 allowance was made when considering capabilities. This assumption was made due to this being a standard planning rule to allow some level of redundancy in the system, allowing for single outages.

3 Load and Generation Growth

One of the advantages of the meshed distribution network, as outlined by Peter Stowell[12], is its flexibility in adapting to changing load. Chapter 3 has already compared how radial and meshed networks need to be developed in response to load growth. How load is expected to change in the coming years has been considered by the DECC/Ofgem Smart Grid Forum in Work Stream 3, which has analysed the effects of a number of Low Carbon Technologies that will impact on the development of distribution systems within the UK[13].

3.1 Work Stream 3

The key drivers identified in Work Stream 3 are new electrical loads in the form of heat pumps and electric vehicles, and distributed generation in the form of photovoltaic sources.

For the planning of supplies to housing areas it is currently typical for DNOs to plan on the basis of between 1 to 2 kW of load per household during peak times for non-electrically heated homes[14]. This loading is referred to as the After Diversity Maximum Demand (ADMD), and the value used depends on the nature of the housing, for example, house size and the fuel used for cooking and heating. Indeed, if the houses in an area have off-peak electric storage heating, or other forms of electric heating, the ADMD used will be markedly higher, say 4 to 8 kW[15].

The effect of new LCT loads on the overall ADMD in any particular location is dependent on the times when these various load curves peak. For electric vehicle charging it is possible to influence the time of day when charging takes place through the use of suitable tariffs and/or ‘smart’ technology, which should enable electric vehicle charging to be accommodated within existing network arrangements. However the impact of heat pumps cannot be similarly managed and they could therefore more than double the network loading in locations where the penetration of heat pump usage approaches 100%.

During the RIIO-ED1 price control period (2015-2023), SP Manweb is predicting an overall load growth of about 10%, a combination of some general load growth and new LCT load. In the ED2 period LCT loads are expected to increase much more rapidly.

[12] Peter d’Eyncourt Stowell; “Manweb Distribution”; IEE Journal, vol 4, no. 37, January 1958, pp 15-21

[13] Work Stream 3 Phase 2 Report: “Assessing the Impact of Low Carbon Technologies on Great Britain’s Power Distribution Networks” Available on the ENA website at: http://www.energynetworks.org/electricity/smart-grid-portal/decc/ofgem-smart-grid-forum/work-stream-3.html

[14] SP Energy Networks: “Framework for Design & Planning of LV Housing Developments, Including Networks and Associated HV/LV Substations”, ESDD-02-012, Issue No 5.

[15] Ibid.

3.2 Radial vs Mesh Expansion

Chapter 2 presents a detailed comparison of the expansion of radial (traditional) and mesh (SP Manweb) distribution networks to meet additional load.

The expansion has been taken to about three times the initial loading, and on average over this range the Manweb mesh approach has a capital expenditure about 40% higher. However this difference is not uniform over the load range and for some load changes the traditional radial design can be more expensive to reinforce. This is mainly because the mesh design can be usually reinforced in smaller increments.

4 Network Reliability

Since on a fully meshed network, clearance of an initial fault does not result in any loss of supply, it seems obvious that a meshed distribution will be more reliable than radial distribution.

4.1 Customer Interruptions (CI) and Customer Minutes Lost (CML)

The National Fault and Interruption Reporting System (NaFIRS) records details, provided by all the DNOs, of electrical faults and interruptions experienced by their networks; and from this information Customer Interruptions (CI) and Customer Minutes Lost (CML) statistics are derived. CIs are the average number of customers whose supply in interrupted over twelve months per 100 customers, and CMLs are the average durations for which a customer loses supply over the same period. These statistics ignore all faults and interruptions that are less than three minutes long. CIs and CMLs for all of the DNOs are published by Ofgem[16], and the latest numbers and in the table below.

Table 4.1: Comparison of DNOs by Customer Interruptions and Customer Minutes Lost

	CI		CML
LPN	24.4	SWales	32.4
SPMW	39.3	LPN	42.4
ENWL	47.8	SWest	42.6
SPD	50.7	ENWL	47.3
SWales	58.4	SPMW	47.5
SWest	61.5	SPD	49.4
EMID	61.7	EMID	54.9
SSES	63.6	SSES	64.1
NPGN	65.2	NPGY	68.2
NPGY	69.9	NPGN	71.1
SSEH	74.0	EPN	72.4
SPN	76.9	SPN	73.2
EPN	86.0	SSEH	78.4
WMID	102.2	WMID	89.5

Source: Ofgem Electricity Distribution Annual Report for 2010-11

SP Manweb has noticeably fewer CIs than all other DNOs except for the London DNO. London, of course, is a predominantly underground network, whereas a significant proportion of the SP Manweb system is overhead. Indeed the more rural parts of the SP Manweb 11 kV and LV systems operate radially. SP Manweb has carried out an analysis of NaFIRS statistics for just its urban areas which shows that CIs are even lower than those achieved by the London DNO[17]. CMLs, on the other hand, are not markedly lower than those of other DNOs, though they are significantly better than the average. Although customers in SP Manweb's urban areas go off supply less often, there is anecdotal evidence that faults that interrupt supply can take longer to remedy than similar interruptions on a radial network.

[16] "Electricity Distribution Annual Report for 2010-11", Ofgem. https://www.ofgem.gov.uk/ofgem-publications/46553/electricitydistributionannualreportfor201011.pdf

[17] SP Energy Networks 2015–2023 Business Plan Annex 2.10, SP Manweb urban network http://www.spenergynetworks.co.uk/userfiles/file/201306_A2_10_SPEN_SP%20Manweb%20urban%20network.pdf

8. Appendix C – Original Fast Track published Annex

2.10 Annex

SP Energy Networks 2015–2023 Business Plan

SP Manweb urban network

SP Energy Networks

June 2013

SP ENERGY NETWORKS

Scope

This annex to the SP Energy Networks 2015-2023 Business Plan provides background information specific to the SP Manweb licence area.

Here we outline the fundamental design differences between traditional electricity distribution networks in the UK, and the Manweb urban network design. We discuss capital and operational costs and compare and contrast performance. This annex also comments on previous operational efficiency reviews, the implications of change and our current philosophy on continued operation of the Manweb urban network design.

Comment is provided on the SP Manweb ED1 expenditure proposals in relation to the continued stewardship of the urban network.

Introduction

SP Manweb provides electricity to 1.5 million customers across a diverse geographical foot print that encompasses both large urbanised areas of Merseyside together with rural areas of Cheshire, North & Mid Wales and Shropshire

Over 66% of our customers live in the major urbanised conurbations of Merseyside and the Wirral, together with other large towns and cities across Cheshire, where the electricity network is primarily constructed from underground cables. Our remaining customers across our semi urban and rural networks are connected to our network which more generally comprises of a mix of overhead lines and underground cables.

It is recognised that not all electricity networks are the same. At industry privatisation in 1989 our shareholders inherited an electricity distribution network that is unique in the UK and overall delivers the highest customer performance outside central London; it can be argued that the design of the urbanised network delivers the best customer performance in Great Britain.

The SP Manweb urban network was designed and built throughout the 1950-1970s with a design philosophy of high transformer utilisation to target lowest economic costs based on commodity price forecasts at that time. Smaller transformers than industry standard are run constantly interconnected at all voltages and standard cable sizes are used throughout.

To supply our customers over our geographical footprint around 55% of the SPM network is designed and run as an “X-Type” network, solidly interconnected at 33kV, 11kV and LV. Of the remaining, 23% of the network is designed as a “Y-type” network, solidly interconnected at 33kV and 11kV but less so at LV and 22% is designed as a radial network with single transformers feeding a non-interconnected 11kV and LV.

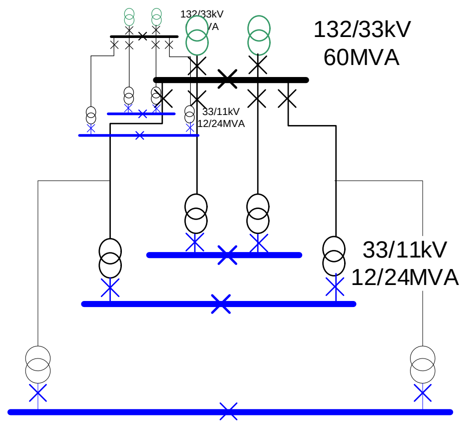
This annex describes the electricity network that supplies the SP Manweb customers in the urban areas (X Type Networks).

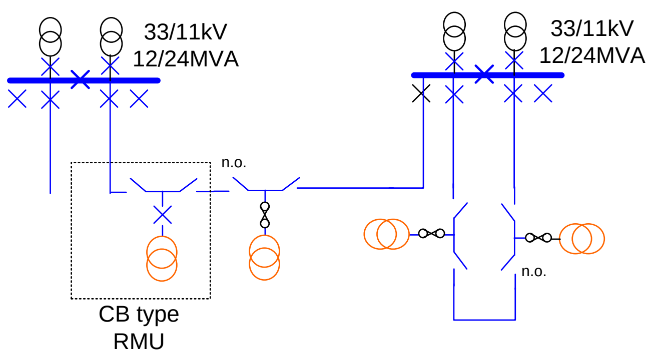
Traditional Industry Network Design

Before considering the SP Manweb Urban Network philosophy it is worth while briefly summarising the traditional network design in use across the wider GB network (including SPD).

The accepted industry wide design is based on duplicate radial transformer feeders, operated in parallel as show below.

At 132 and 33kV, the transformers can be connected singularly or banked with multiple transformers (at up to 3 substations) connected to the higher voltage or source circuit breaker.





33kV networks tend to radiate outwards from 132kV bulk supply points, similarly 11kv networks tend to radiate outwards from primary substations. Historically companies will have tapered the network cables, as the cable travels further form the supplying transformer, but more recently uniform (standardised) cables have been employed.

11kV networks fed from primary substations can be constructed as radial ‘or looped’ circuits back to the same substation, or can be built as an interconnector to an adjacent primary substation to provide post fault support and resilience. In all cases the circuit must be run with a split or ‘normal open point ‘at an electrically convenient point on the circuit.

The LV network whilst having the capability to offer interconnection will in all cases be run radially with fuses or links removed at substations, LV surface mounted pillars or beneath ground link boxes.

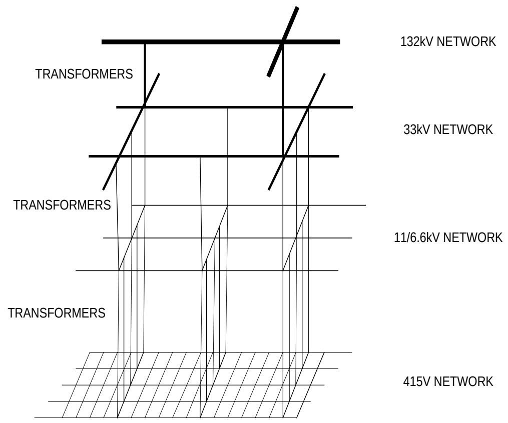
The recognised benefits of this network philosophy are in its simple design, simple protection arrangements, requiring less distributed switchgear and protection with consequential reduced capital and operating costs.

Some of the pertinent limiting factors of this design are that of Fault Level management, transformer utilisation factor is limited to 50%, triggering reinforcement and hence capital expenditure at earlier point of overall load growth, and customer interruptions (CI’s) are increased over that of an interconnected network design. It is recognised however that advances in network controllable points and automation algorithms has improved the quality of supply performance on these networks in recent years.

Cables emanating from large substations are often non-uniform along their length, and are often tapered as the distance from the substation increases. By nature these networks are not readily extended without considerable effort and expenditure to develop a new substation, and laying more cable to increase the circuit capacity, therefore they are not considered as “Smart ready” as interconnected networks.

SP Manweb Urban Networks

The origins of the Manweb Urban Network design can be traced back to the period shortly after the electricity industry was nationalised in 1947, and it was developed and expanded over the next 30 years and continues to be modified and extended today. The design methodology varies significantly from the traditional industry network design described above of duplicate radial networks, emanating from transforming stations, and is based on a design philosophy of high transformer utilisation, where smaller transformers than industry standard are run interconnected at lower voltages and standard cable sizes are used throughout. Each voltage layer providing support to the voltage layer immediately above (LV, HV, EHV and 132kV) offering a fully integrated and interconnected network



SYSTEM OF NETWORKS FOR DISTRIBUTION OF ELECTRICITY

The design was developed by Peter d’E Stowell the former Manweb Chief Engineer, and whilst there are elements of similar design in restricted parts of Edinburgh, and throughout the Central London area, the SP Manweb urban network is considered unique in the UK.

The underlying principle of the Manweb urban network is to maximise the utilisation factor of high voltage transformers supplying any given load group through the combination of 3 key features, uniformity, interconnection and unit protection.

Uniformity

The uniformity of the Manweb network design takes two separate forms, uniformity of equipment ratings and uniformity of application.

Although design and specifications of component parts of the Manweb network have evolved throughout the last 50 years, the ratings of these component parts have remained extensively the same.

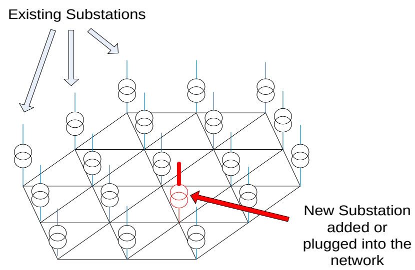
Typical ratings are as follows:-

- 60 MVA grid transformers (132/33kv), with 20MVA 33kV circuits
- 7.5 MVA primary transformers (33kV /hv) with 3.5MVA hv circuits
- 500kVA hv/lv secondary transformers (hv/0.415kV) with 170kVA lv circuits ,

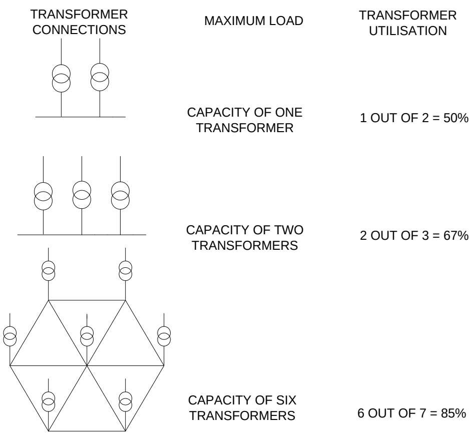
At each voltage level therefore there is a standard rating for circuits, between each voltage level there is a standard transformer rating, and at each voltage layer there is a standard design covering switchgear, protection and relay settings.

This uniformity of equipment and ratings provides opportunity for expansion in line with network growth and facilitates reinforcement by the addition of a new transformer with minimal cable laying and no change to protection or settings. This was a key driver through the expansion period of the electricity network in its early years and is equally pertinent today as it delivers a scalable solution to meet the demands for the anticipated load growth on the distribution networks as we migrate to, and accommodate Low Carbon technologies.

Interconnection



DISTRIBUTED INFEEDS TO A NETWORK



TRANSFORMER UTILISATION

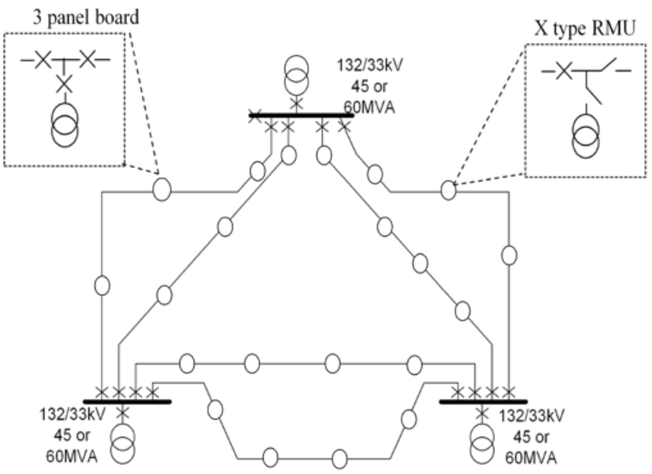
The benefits of uniformity can be applied to any network configuration however when a uniform network is configured to operate in an interconnected manner then the benefits can be multiplied. Interconnection in this context means the circuits of each voltage layer run from one infeeding substation to another substation and are predominately operated with all intermediate switches in the circuit 'closed' position.

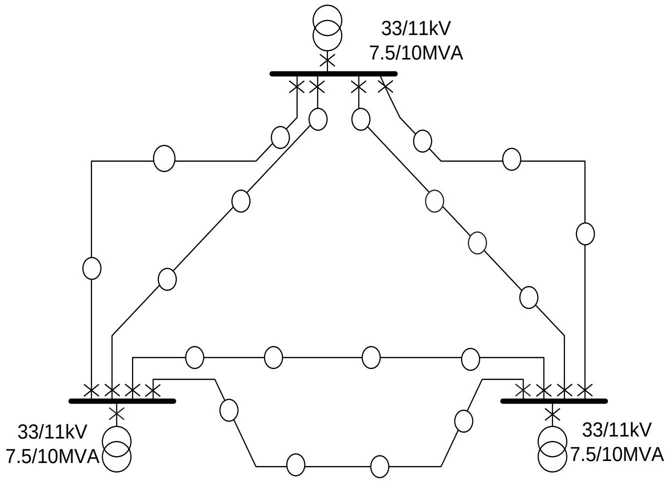
In the early development of the cable network at each voltage level, it was important to install uniform sized cables rather than employ tapered networks, in order to establish the grid or lattice interconnected network for the future, facilitating the connection of additional transformers due to load growth.

Equally during the depressions of the 1980's and more recently, as load centres move, then underutilised transformers can simply be unplugged and re-established closer to the new load with minimal network alteration.

By operating interconnected networks between in feeding substations it is possible to increase the utilisation factor of high value (and cost) transformers. By operating smaller than industry standard transformers in this manner it is possible to reduce the physical foot print and therefore cost of associated plant and civil accommodation.

In an ideal network, utilisation factors of up to 85% are possible. However in order to operate the equipment on the Manweb Network safely within its design fault level parameters then it is normal to operate via interconnected cables up to 4* 60MVA Grid Transformers, or 5 * 7.5MVA primary transformers. This still achieves utilisation factors of 75% and 80% respectively but maintains fault level within the design criteria of 750MVA and 250MVA. It is equally permissible to interconnect secondary substations via the LV network, with the limiting factor that no lv circuit can be controlled by more than 3 fuses from separate substations. Beneath ground LV link boxes are used extensively on the LV network to split up the LV interconnected network to achieve this requirement.





With higher utilisation factors incremental load growth can be absorbed more efficiently before reinforcement is triggered. When the group load reaches its maximum then a further transformer can be simply added or ‘plugged in’ to the network or the transformer group can be reconfigured by the movement of network split points.

Ring Main Units (RMU’s) were originally installed at the primary substations and secondary substations along the interconnectors between infeeding substations. These RMU’s comprise of 2 ring switches and a circuit breaker or fused switch in a single unit of switchgear.

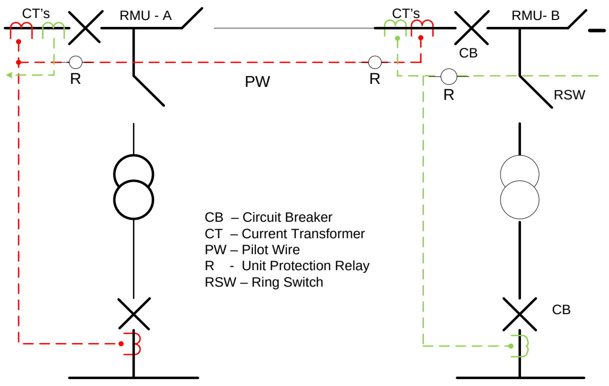
In the Urban network design the RMU is configured as an ‘X-type’ and is illustrated above, with one ring switch connected to local transformer, the other ring switch and the circuit breaker being connected to the incoming and outgoing cables along the interconnector. At 33kV suitable RMU’s are no longer manufactured therefore the design and application has evolved to comprise of a 3 panel switchboard again illustrated above.

There is a Circuit Breaker on the lower voltage side of the transformer.

Unit Protection

Unit protection in its simplest form utilises the *Merz Price* principle, which effectively checks that load current entering a protected zone is equal to the load current leaving the protected zone. As long as this is the case then the protection remains in balance and does not operate. Should a fault develop in the protected zone then the current entering the protected zone will be the sum of the load current plus the fault current, the current leaving the protected zone will be the load current only, therefore the protection becomes out of balance and will operate a protection relay, which in turn will operate the controlling circuit breakers for the protected zone, and the circuit will be safely disconnected from service.

Unit protection as applied to the SP Manweb network interconnected distribution network, whilst generally based on the basic principle above is more sophisticated and has been developed to protect substation, transformers and its feeding cables. A simplified representation of unit or ‘zone’ of protection as applied to the SP Manweb Urban network is illustrated in the figures below.



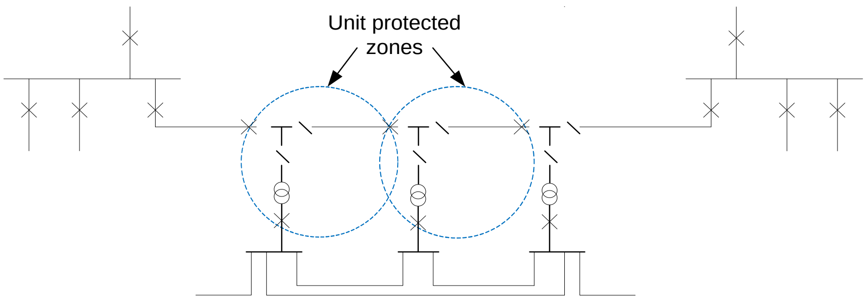
A simplistic illustration of unit protection as applied to the SP Manweb urban network is shown opposite purely to illustrate the additional components required over and above those employed in traditional network designs.

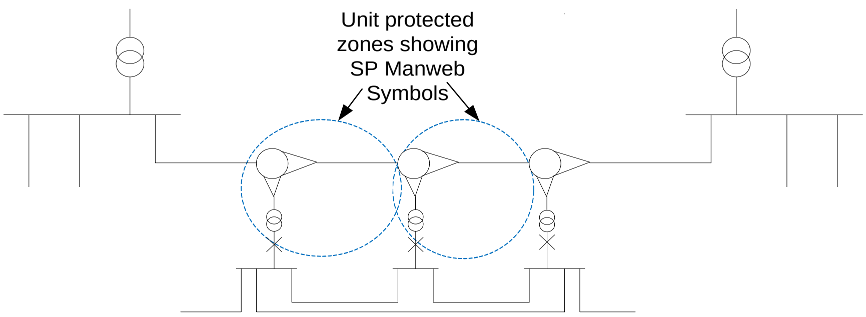
At RMU-A Current transformers (CT's) are installed and connected locally to summate the current on the incoming cable and the outgoing load of the locally connected transformer; this current is in effect balanced against the outgoing current at the remote end of the circuit at the adjacent RMU-B.

The summated output of the pair of CT's at RMU A and the output of the CT's at remote RMU B are connected via communication cables commonly referred to as 'Pilot Wires' run alongside the main distribution cable between substations - illustrated by the red section of the drawing above.

Under normal circumstances the load current entering the unit protected zone at RMU B will balance with the load current of the local transformer at RMU-A together with the outgoing load current along the remainder of the interconnector, and the protection relays connected to the pilot wires will remain stable.

If a fault occurs within the unit protected zone on the distribution cable between the two RMU's or on locally connected transformer at RMU A, then the normal load current entering and leaving the protected zone will be incremented by the fault current entering the protected Zones at RMU A and RMU B, and will not balance. Therefore the protection relays connected to the pilot wires will operate, and cause the controlling circuit breakers to operate and remove the faulted zone. The protection relays connected into Pilot Wires are powered by DC battery systems.





By overlapping unit protected zones along the interconnector, a fault or outage in any given unit protected zone can be occur without disconnecting customers, as these supplies will be maintained by the adjacent network via the interconnecting cables from neighbouring substations. In the more traditional 'Y' type networks used elsewhere in SP Manweb on semi urban and rural networks and the wider GB electricity network as a whole, a similar fault will result in loss of supplies to the entire customer base connected to the interconnector, or radially operated circuit, with as a consequence a poorer customer performance.

Unit Protection on interconnected networks as applied to SP Manweb networks operating at 33kV is generally comprised of 'Translay' Protection and at 11kV, 'Solkor' Protection. Whilst their operation can be traced back to the fundamental principles outlined above each of these protection schemes are much more sophisticated and reference to manufactures literature, or support documentation should be made if a detailed understanding of the individual protection scheme is required.

Performance

It has already been stated that the Customer Performance of the SP Manweb network as a whole is second only to that of Central London. (UKPN LPN), with customers in SP Manweb likely to see a power interruption once in every 2 years, lasting typically 63 minutes, and customers in Central London once in every 3 years lasting a similar duration. It is also true that with an average of 53 customers interrupted per fault on SP Manweb network; this is the lowest number of customers impacted by a fault (and therefore the best performance) on any electricity network in Great Britain (Data taken from Ofgem - Electricity Distribution Annual Report for 2010-11)

	2010/11 - CUSTOMER INTERRUPTIONS PER 100 CUSTOMERS:		2010/11 - CUSTOMER MINUTES LOST	
DNO	Target	Performance	Target	Performance
LPN	33.4	24.4	41	42.4
SPMW	45.6	39.3	61.1	47.5
ENWL	52.9	47.8	55.6	47.3
SPD	60.1	50.7	65.5	49.4
SWales	79.5	58.4	44.6	32.4
SWest	73.6	61.5	51	42.6
EMID	75.7	61.7	69	54.9
SSES	73.8	63.6	69.1	64.1
NPGN	68.3	65.2	71.3	71.1
NPGY	75.3	69.9	76	68.2
SSEH	77	74	75.1	78.4
SPN	85	76.9	87.6	73.2

Table ranked on CI performance

The statistics above relate to total network performance for individual Distribution Network Operators.

Looking at the SP Manweb values in more detail it is clear that they are a combination of both our urban and rural networks performance, which due to the prominence of the west coast weather systems is exposed to extremes in weather conditions and consequently a greater fault rate than that experienced by the relatively benign urban networks.

As described above the design of the SP Manweb urban network is such that for any 33 kV or HV network fault the CI's should be zero, as the faulted circuit is protected by unit protection and customer supplies are maintained by the wider interconnected network. In reality there are interruptions to customer's supplies on these networks due to a combination factors, such as:-

- Second circuit faults occurring simultaneously with the first circuit fault leaving sections of network stranded or islanded.
- Failures of unit protection systems to operate correctly due to faulty relays or faulty/damaged pilot cables.
- Failures of circuit breakers to operate correctly
- 'Designed in' customer losses such as radially fed HV customers or IDNO's, or elements of radial networks embedded within the urban network
- Failures on the fringe of the urban areas where the overall circuit can be configured using a mixture of Urban X-type and Semi Rural Y-Type network
- More recently developments in organised 3rd party interference/intervention – Metal theft

For faults on LV interconnected networks then for the majority of fault conditions only a small percentage of the customers connected to the LV cable circuit will be interrupted as fuses at one end of the circuit only will trip to remove the fault, with supplies to the remaining customers connected to the LV circuit maintained from the remote ends of the 2 way or 3 way interconnected circuit.

The Central London electricity system of LPN consists entirely of underground urban networks, and is operated in an interconnected mode, therefore it is appropriate to compare the SPM urban network directly with the performance of LPN as a whole, in order to demonstrate the performance advantage of the SP Manweb urban network design.

By extracting the customer performance for the SP Manweb urban networks for the same reporting year as shown above (2010/11), the CI per 100 customers is 13.22 and the CML per 100 customers is performance is 22.0 minutes, this equates to customers connected to the SP Manweb urban networks likely to see a power interruption once in every 8 years, some 2.5 times better performance than that of LPN network, with the interruptions affecting less customers per fault and lasting on average for shorter periods.

This SP Manweb urban network has demonstrated consistently over time its frontier network performance in terms of CI and CML

Network Design and Efficiency Reviews

The SP Manweb Urban network is unique in design and delivers frontier network and customer performance as discussed in the previous sections, a heritage as an organisation that SP Energy Networks is rightly proud of. However it is recognised both within SP Energy Networks and the wider industry that this network has greater complexity, involves more components and is more expensive to construct and maintain than the recognised industry network design, (Y Type).

This is something that SP Energy Networks is continually aware of and has reviewed and evaluated on a number of occasions both internally and externally by engaging independent consultants, in order that we can consider if it remains viable to continue to propagate the SP Manweb urban networks 'X type', and to consider alternative network designs and solutions.

These reviews were conducted as follows

External : -

- Merz and Mclellan 1998
- ABB 2000

Internal :

- Martin Deehan 1998
- Jane Wilkie 2006.

The engineering aspects of these reviews remain unchanged over time and common threads of these reviews can be summarised as follows:

- Urban LV interconnected networks should if designed and operated correctly provide better performance than traditional radial networks but are expensive as they are generally longer networks
- Urban 11kV interconnected network design delivers frontier customer performance, but at a cost premium over traditional radial networks with or without automation. However it's not cost effective/or desirable to convert wholesale to 'Y-type' networks
- It is considered that urban 33kV interconnected network provides little or no customer performance benefit and is significantly more expensive than traditional dual radial transformers operated in parallel configurations, due to additional switchgear requirements. (*Author Comment - whilst the benefits of a development of a dual radial transformer solution may be true for green field developments, the various reports have failed to recommend substantial proposals of how we would complete a migration from the existing interconnected network. Both in terms of the additional network reinforcement, or the more onerous task of acquiring suitable 'larger' sites for the development of additional urban substations. Analysis of SP Manweb 33KV customer performance indicates major contributors to CI/CML are from faults affecting rural radial primary transformers or radial urban transformers. Occasional malfunctioning equipment on the SP Manweb urban network does incur customer interruptions; however this is the exception rather than the rule.)*
- The SP Manweb urban 33kV and 11kV cable networks utilise standardised and uniform cable sizes. Migration to industry designs would in many locations leave stranded assets as the cable sizes and rating would be inadequate.

- The SP Manweb urban networks utilisation factor is very much higher than for traditional networks, implying that our network is working harder in our SP Manweb area, leaving less spare capacity than on traditional networks. *(Author comment - through the introduction of the UK network Load Measure, we will reduce our trigger point for reinforcement by 20%. We will also continue our programme to uprate our high voltage network from 6.6kV to 11Kv, releasing latent capacity in our HV cable networks throughout ED1).*
- The SP Manweb urban network represents the most cost effective network, both in cost per kVA of capacity and maximum demand. However, the incremental cost of SP Manweb's urban network arrangement is approximately 30% more expensive in terms of total cost per unit of network capacity.
- No reports deal adequately with the consequential reinforcement of Bulk Supply points as a consequence of breaking up 33kV network, and reducing the currently high utilisation factor of Grid transformers at Bulk Supply Points.

In summary the advantage of the SP Urban Network is confirmed as offering frontier CI performance over that of traditional radial networks. The network design is also inherently "smart" as the network is designed to accept power flowing in either direction, and alternative paths are available when there is a fault. The network is more ready to facilitate customer uptake of low carbon technologies and the associated costs are lower as reinforcement is facilitated in the main by 'plug in' substations and minimal cable lying.

The disadvantage of the SPM Urban Network design is that it is more expensive to build, as it requires more switchgear and unit protection which in turn requires a means of reliable communication network between substation sites and a more robust building construction.

The design reviews have confirmed that the size and complexity of the existing network does not allow wholesale change to the network design in urban areas, without a major impact on the performance of the network to existing customers and significant capital spend.

Whilst savings could be made by developing less complicated 'Y-Type' networks these savings would be offset by additional capital expenditure and future operating costs required to supplement the existing transformer capacity within the network as a whole, as current high utilisation factors on which the network was fundamentally designed over the last 60 years or so would be brought down to the industry norm of 50%

Internal estimates based on the last five years of data supplied to Ofgem through the quality of supply reporting scheme indicate that for the 11kV network alone should it be converted to 'Y-Type' network, the result would see an additional 104,000 or 7% of our customers experience a power cut each year.

We believe that this would be unacceptable to our customers who, through stakeholder engagement across the Manweb licence area (including an event held in Liverpool) have told us they want to experience less power cuts.

We therefore have no feasible alternative when replacing existing assets in interconnected areas other than to replace like for like, and to maintain the existing network arrangements.

However we recognise that it is more cost effective to build new networks using a more traditional design, and therefore when SPEN, or an Independent Connection provider (ICP) are designing new networks or connections on our network , we will build a non-interconnected design where possible, provided this will not impact or compromise on existing customer performance.

Key Costs in ED1 to maintain the SP Manweb Urban Networks

SP Manweb have outlined in its RIIO- ED1 submission a number of areas of expenditure specifically related to the continued successful operation and integrity of the urban network, over and above expenditure for the areas of its more traditionally designed networks.

Specific details are contained in the relevant CV tables, however key activities and threads are itemised below :-

- Ongoing maintenance of substation environment to provide a safe, watertight environment for X Type substations, this will not only ensure safe operation of primary equipment but will safeguard the integrity of the associated unit protection equipment.
- Ongoing maintenance and repair of the 11kV and 33kV network communications system (Pilot Wires), without which the integrity of the associated unit protection systems will deteriorate, with significant reduction in performance of the protection systems and consequential decrease in customer performance.
- Maintenance and inspection of LV link Boxes (including confirming network configuration of the internal switching points) utilised in the operation and control of LV interconnected network.
- Ongoing maintenance of 33kV RMU's used extensively on X-type interconnected 33kV networks
- Replacement of 25 'end of life'HI5, 33KV RMU's with 3 panel switchboards (33KV RMU's are now out of production).
- Ongoing maintenance of secondary substation (11 or 6kV/LV substation) battery systems associated with X-type networks – Simple Y-type secondary substations are generally battery free.
- Continue our 6.6kV network updating programme to 11kV to release more capacity from the current interconnected cable networks.
- Continue to install remote control facilities (SACDA) on Urban Networks as part of Asset modernisations schemes to allow better monitoring of interconnected network performance

A summary of our key costs and investments for the ED1 period can be found in our 2015-2023 Business Plan – Expenditure Chapter.