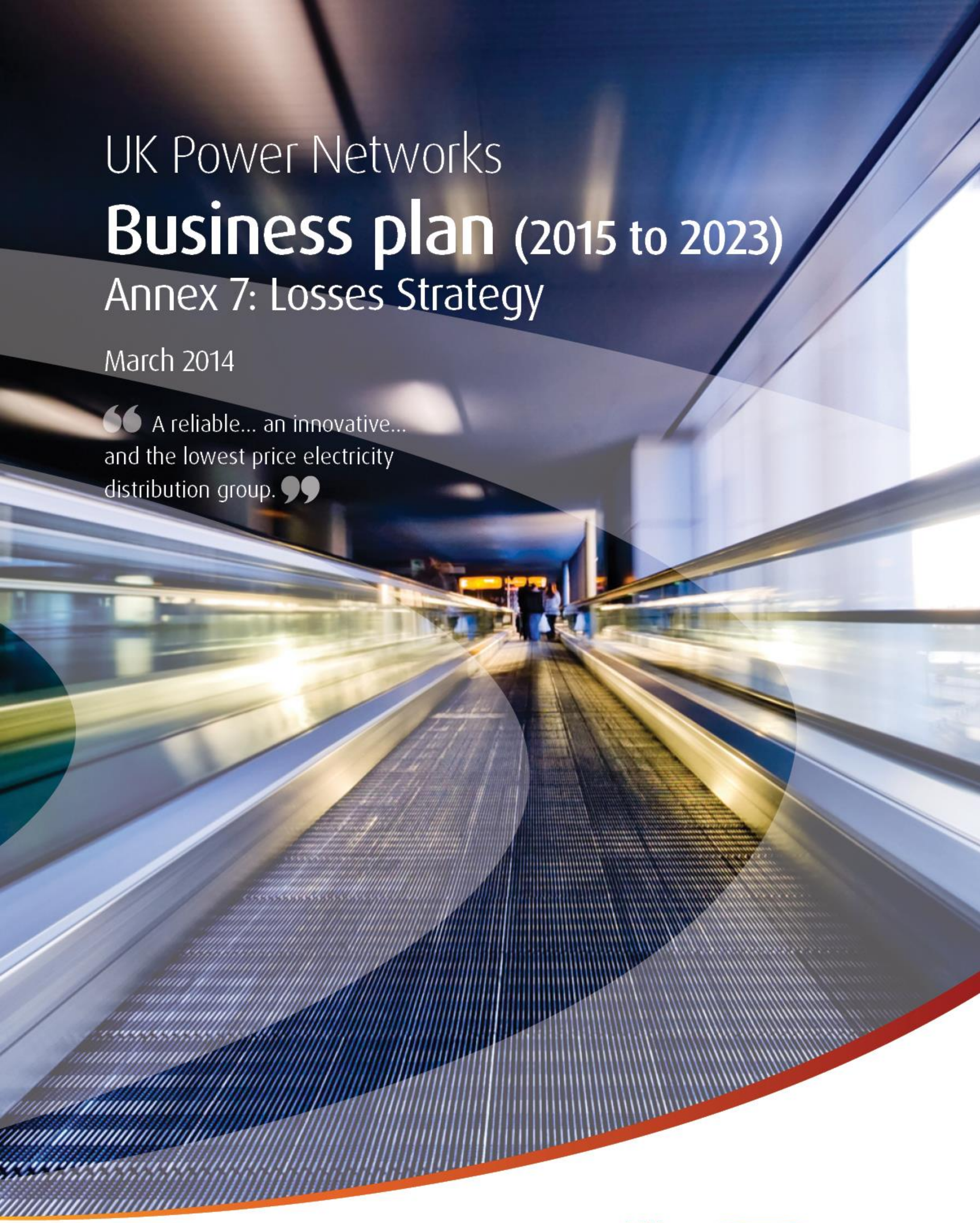

UK Power Networks

Business plan (2015 to 2023)

Annex 7: Losses Strategy

March 2014

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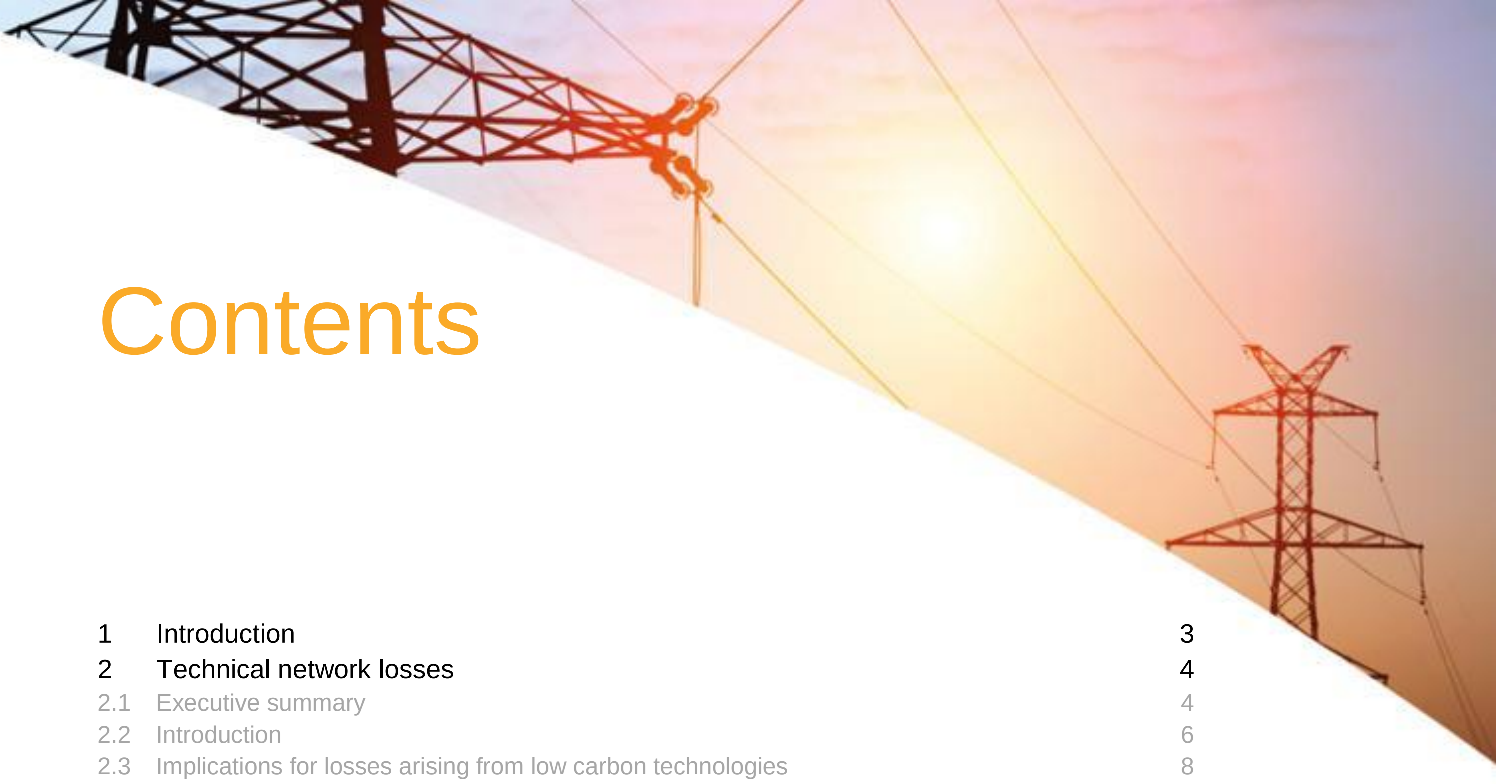

Contents

This annex has been updated to reflect UK Power Networks' March 2014 business plan. We have a tracked change version for the purpose of informing Ofgem of all revisions to July 2013 business plan, should this be required.

1 Introduction

The UK Power Networks losses strategy combines the following two distinct areas:

- Technical Network Losses
- Electricity Theft

For the purposes of this document, these subjects are separated out into individual chapters. The first chapter (Technical Network Losses) sets out our plans for managing network technical losses with the aim of controlling losses in an economically justifiable manner; the second chapter (Electricity Theft) discusses UK Power Networks' strategy for tackling theft of electricity from its distribution networks.

2 Technical network losses

2.1 Executive summary

This chapter summarises UK Power Networks' strategy for managing network technical losses with the broad strategic objective of controlling losses at a level that is economically justified. Economic justification of measures to mitigate losses will be determined through cost-benefit analysis based on Ofgem's RIIO ED1 guidance which, as well as valuing the energy cost of supplying losses also recognises the real, but declining, carbon impact arising from electricity production.

UK Power Networks' strategy, as described in this document, is to factor-in appropriate loss mitigation measures to all categories of network investment. This approach which we describe as 'opportunistic' will give rise to greater and more cost-effective opportunities for losses mitigation since the consideration will be largely a matter of incremental cost over that required to meet a given investment driver. For example, the incremental cost of installing a higher rated cable to serve a new development might be small compared with the value of the reduced losses benefit, whereas overlaying an existing adequately rated cable for no other reason than to reduce losses would be unlikely to be cost-effective. The approach to cost-benefit analysis will therefore primarily be based on incremental cost-benefit comparing the NPV of intervention options and factoring-in the discounted value of losses (and any other on-going costs and benefits) in the overall investment appraisal.

This document describes a range of opportunistic measures to reduce losses and these are summarised in the annexe to this document. In broad terms these measures fall into the following categories:

- System management
- Optimised transformer specifications
- Rationalised and economically optimised cable conductor sizes
- Network architecture and voltage rationalisation
- Legacy network design rationalisation
- Voltage and power factor management
- Power Quality management
- Improving phase balance on HV and LV networks
- Energy usage at operational sites
- Demand side response
- Active network management
- DG support
- Emerging smart grid technologies

The strategy recognises that pressures to cost-effectively accommodate new low carbon technologies will result in networks being driven harder. Under DECC's 'central' generation scenario and 4th Carbon Budget demand scenarios, distribution networks will need, by 2030, to accommodate up to 20GW of Solar PV generation and distribute up to 66GWh of additional electrical energy (a 19% increase over today) due to electric vehicle charging and heat pumps. It follows that in MWh terms losses will inevitably increase as a direct consequence of the increased energy flows. Moreover, the unmitigated usage of low carbon technologies (i.e. in terms of time of day of usage) is likely to give rise to network peak demands increasing disproportionately to the underlying increase in electrical energy distributed. This in turn would have a further disproportionate impact on circuit losses which vary with the square of the electrical current passing through the conductors.

Taking all these factors into account, a challenging target would be to maintain losses as a percentage of energy distributed at current levels. It is generally assumed that across Great Britain, distribution network technical losses are around 6% but with variations of between 4.5% and 9% for urban and rural networks. However, there is considerable uncertainty over the current level of technical losses. This is due both to inaccuracies inherent in the current electricity market reconciliation assumptions and the fact that 'measured' losses comprise both technical and non-technical losses. The reconciliation issues should be addressed to a large extent by information available from the national smart metering system once rollout is completed in 2020. At that time, it should be possible to derive not only a more accurate assessment of the overall level of losses actually being incurred on distribution networks but a greater insight into which parts of the network are giving rise to the highest losses and the solutions that might be available.

Notwithstanding that the figures will need to be recalibrated once smart metering data becomes widely available, UK Power Networks' ambition is to maintain losses in percentage terms broadly at current levels (2012/13 outturn) over the RIIO ED1 period despite the anticipated increase in network power flows. The ED1 outturn ambition is shown below along with our estimate of the level of unmitigated ED1 outturn losses that we would anticipate due to forecast load growth over the RIIO ED1 period in the absence of this strategy.

Network	DPCR5 Average Losses (GWh)	Anticipated ED1 Outturn Unmitigated Losses (GWh)	EDI Outturn Ambition Losses (GWh)
EPN	2,475	2,495	2,396
LPN	1,773	2,120	2,031
SPN	1,462	1,411	1,370

A consequence of our opportunistic approach is that we attribute no costs to implementing this strategy and hence no expenditure in our business plan categorised as 'technical losses management'.

Whilst costs will be incurred in terms of additional network studies to evaluate opportunities, we expect to absorb these as part of the process improvements we are delivering through our current Business Transformation project.

In terms of network investment, whilst it is probable that our incremental cost-benefit approach will lead to additional investment (where this shows a positive NPV of losses saved) again we anticipate absorbing these additional costs within the overall levels of LRE and NLRE investment included in our business plan.

Similarly, if studies suggest that higher procurement costs - for example associated with a bias towards larger LV cables (Section 2.7.2) - are justified by the resulting capitalised value of losses saved, again we will absorb these additional costs. In the case of Ecodesign transformers designed to meet the requirements of a proposed new EU directive (Section 2.7.1) the implications for transformer tender prices are as yet unknown but our interim working assumption is that once the EU directive comes into effect standardisation should drive prices to a level broadly comparable with the current UK Power Networks standard based on ENATS 35-1.

Through this strategy, UK Power Networks anticipates delivering, at potentially no additional cost to consumers, savings in losses rising to a cumulative present value benefit of £46.9m over the RIIO ED1 period. Along with the societal benefits of reduced CO_2 emissions, these benefits should flow through to consumers in terms of lower energy prices.

2.2 Introduction

2.2.1 Background

This chapter summarises UK Power Networks' strategy for managing network technical losses in order to meet the following objectives:

- To be consistent with our Electricity Act (statutory) obligation and Distribution Code / Distribution Licence obligation to 'permit the development, maintenance and operation of an efficient co-ordinated and economical system for the distribution of electricity'
- To demonstrate a proactive approach towards economic, social and environmental sustainability through our management of electricity distribution network efficiency
- To manage our carbon footprint

This strategy is implemented across UK Power Networks through an internal Engineering Instruction which provides guidance to planning, design and operations staff responsible for managing the network assets and through UK Power Networks' internal compliance auditing procedures.

2.2.2 Scope

This strategy is concerned with the economic minimisation (i.e. optimisation) of network technical losses and includes:

- 'Variable' or Copper (Cu) losses which are due to the electrical resistance of conductors and hence have a non-linear (quadratic) relationship with the current passing through the conductor (i.e. losses = I^2R, where I represents current and R represents the resistance of the conductor)
- 'Fixed' or Iron (Fe) losses (also known as 'no load' losses) which are incurred as a result of the magnetising forces involved in transforming electricity. The main component is the hysteresis loss which is incurred each time the direction of the magnetic field in the transformer core is reversed (100 times per second for a 50Hz AC system). The losses are 'fixed' in the sense that, unlike variable losses, the losses are not a function of the load current passing through the conductor (i.e. transformer windings); they are present and virtually constant so long as the transformer is energised, even when supplying no load[1]
- Other less significant forms of technical losses including: corona[2], skin effect[3], cable sheath and dielectric leakage losses (i.e. in conductors and insulators), 'stray' losses which relate to flux leakage from the intended magnetic path within the transformer core and eddy current[4] losses (i.e. in transformer cores and windings)
- Energy involved in running network ancillary equipment such as transformer cooling fans and pumps which are required to dissipate the heat produced as a consequence of transformer losses, and other auxiliary energy supplies directly associated with electricity distribution (including substation heating, lighting, ABCB air compressors, tunnel cooling systems, etc.)[5]

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[1] Note however that transformer iron losses do vary with core flux density. Nominal values for iron losses therefore apply only when operating at rated secondary voltage. Typically, a 1% increase in secondary voltage produces a 2.5% increase in iron losses.

[2] Corona losses are generally significant only in the case of EHV overhead line conductors. They result from breakdown in the air (insulation) surrounding the conductor due to very high voltage gradients.

[3] Skin effect describes the tendency of an alternating current to distribute itself within a conductor so that the current density near the surface of the conductor is greater than that at its core. The impact is to increase the effective resistance of the conductor giving rise to higher variable losses. Being a function of AC frequency the impact will be greater if significant levels of higher order harmonic currents are present.

[4] Eddy current losses are a function of variable losses in a transformer but also vary with the square of the frequency. Hence the presence of harmonics in the transformer windings will have a proportionally greater impact on the eddy current loss component.

[5] For the purpose of this strategy, this includes all electrical energy associated with the electricity distribution network assets that is not delivered to consumers - including electricity metered, or otherwise taken into settlement, and not therefore actually recorded as 'losses' per se: for example substation power supplies.

2.2.3 Overall strategic objectives

It has long been recognised that managing distribution network technical losses is integral to good distribution engineering practice. However, from a network design perspective (which will naturally assume the optimal day to day operation of the network with regard to overall efficiency and security), optimising losses is essentially a trade-off between up-front investment (for example in lower loss equipment and/or additional network capacity) and the longer term cumulative benefits of reduced losses. In pure business terms, the optimum design from a losses perspective is that which delivers the highest NPV of incremental cost-benefit in terms of initial investment and longer-term benefits arising from reduced losses.

Reducing losses to the most economic level has the following consumer and wider societal benefits:

- It maximises the available capacity of plant and equipment to deliver useful energy (i.e. rather than supply losses)
- By the same token, it also reduces the amount of generation required purely to supply network losses. In the case of variable losses, due to their non-linear relationship with current (i.e. variable losses are proportional to the square of the current passing through a conductor) it follows that a disproportionate level of less efficient (and generally higher carbon footprint) generation will be called upon to supply losses at times of peak demand. Reducing reliance on the less efficient fossil-fuelled power stations therefore has a direct ‘carbon benefit’
- If losses are minimised, then lower levels of capital and operational expenditure will be incurred in providing, maintaining and reinforcing generation, transmission and distribution assets (there is also a carbon benefit in terms of avoided material extraction, manufacturing and transportation costs)
- Lower resistance-induced voltage regulation along LV distributors which will enable a wider effective voltage bandwidth to be deployed and/or a lower substation voltage set-point to be established – both of which will enable higher network capacity utilisation

2.3 Implications for losses arising from low carbon technologies

2.3.1 DECC forecasts

Under DECC's Central scenario, some 20.6GW of small scale (up to 5MW capacity) renewable generation will be in commission across GB by 2030, the bulk of which (some 19.7GW) will be solar PV. In production terms, these figures equate to 19.8TWh and 15.9TWh p.a. respectively. Under DECC's High scenario, there will be 38.2GW of small scale renewable generation of which 29.5GW will be solar PV along with 2.2GW of waste-derived generation.

DECC has also produced a range of scenarios for heat pump and electric vehicle take-up over the period to 2030. These scenarios are designed to meet the requirements of the 4th Carbon Budget. Under the highest of these scenarios, electric vehicle charging and heat pumps would respectively give rise to some 16TWh and 49.5TWh of additional electricity consumption by 2030. This equates to an increase in electricity consumption of 19% compared with current levels.

2.3.2 Implications for electricity demand

Taken together, connections of significant volumes of these electricity generation and demand technologies will create higher two-way power flows than LV networks have hitherto experienced or been designed for. Moreover, the times at which electricity is likely to be generated and used by these technologies is not well correlated and hence this will give rise to new, potentially more extreme, daily and seasonal demand profiles. This has significant implications for network variable losses.

By way of illustration: Solar PV production might be expected to peak during summer afternoons when electricity demand is low. This may well give rise to reverse power flows and (high) voltage control issues[6]. Electric vehicle recharging (home-based) and heat pump usage is more likely to peak during early evening periods, particularly in winter. This coincides with the current time of system peak demand - at which time, there will be no production from Solar PV generation to offset the increased LV network demand. This is likely to challenge thermal ratings of LV networks and/or lead to (low) voltage control issues.

Unmitigated, the combined impact of low carbon technologies on daily demand shape would be to suppress mid-afternoon demand in summer, potentially to a level below the national production capacity of wind generation leading, potentially, to wind generation output having to be curtailed. Conversely, the winter weekday evening peak demand might rise substantially - indeed disproportionately to the overall net increase in electricity consumption - requiring the dispatch of low carbon-merit peaking generation and hence leading to a high carbon cost of network losses at such times.

2.3.3 Implications for losses

Given the non-linear relationship between variable losses and electricity power flows it will be apparent that a 'peakier' demand profile would give rise to a disproportionate (to demand) increase in losses because loss load factor would deteriorate. It would also imply a disproportionate requirement for investment in additional network capacity (i.e. disproportionate in the sense that capacity investment would be driven by a deteriorating load factor rather than an increase in electricity consumption per se).

Even assuming that load factors could be maintained at current levels through demand shaping, in the absence of investment in additional network capacity, an additional 66TWh of electricity consumption across GB would give rise to an increase in variable losses from around 14.7TWh p.a. to 20.8TWh p.a. (an increase of some 40%).[7]

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[6] Micro-CHP is less likely to be problematic in this respect as, being heat-led, production is more likely to coincide with periods of relatively high electricity demand.

[7] For the purposes of this illustration it is assumed that, in the absence of additional network capacity, fixed losses remain constant.

It follows from the above that there would be benefits in terms of avoided investment in capacity and reduced (increases in) losses if the potential increase in peak demand could be suppressed through peak-shifting - i.e. either through direct controls, intelligent autonomous controls (or smart appliances) or simply time-of-use tariff incentives to encourage consumers to avoid peak demand periods where practicable. For example home charging of electric vehicles could generally be restricted to night-time off-peak periods (ideally excepting consumers with electric space and water heating, or served by parts of the network which are already night-peaking such as off-mains gas areas) without loss of convenience. This concept is discussed further in Section 2.8.1 of this document.

2.4 Overall approach to losses optimisation

2.4.1 Typical apportionment of losses over a distribution network

For a typical distribution network, around 30% of technical losses will be due to fixed losses and 70% due to variable losses (though there will be regional variations in this ratio). In terms of how these are distributed across a typical distribution network: some 55% of fixed losses will typically be due to HV/LV distribution transformers and 20% due to EHV/HV transformers. For variable losses, some 45% will typically be at the LV network level and 25% at HV (generally 11kV) level[8]. Overall, LV losses typically account for around 45% of total losses and HV losses for around 25%. EHV losses (including 132/33kV transformers and other EHV/EHV variations) account for around 25% of fixed losses and 30% of variable losses; and 30% of losses overall.

Overall, technical losses for GB distribution networks are estimated to be currently around 6%[9] of the electrical energy distributed. Given the current GB annual electricity consumption of around 350TWh, and assuming 6% technical losses (i.e. net of non-technical losses) for distribution networks, the current level of distribution network technical losses is approximately (350 x 6%) = 21TWh p.a. of which variable losses will be approximately (70% x 21) = 14.7TWh and fixed losses (30% x 21) = 6.3TWh.

2.4.2 Losses optimisation – practical limitations and opportunities

Notwithstanding regulatory incentives and our vision, as a respected corporate citizen, to support sustainability and contribute to reducing greenhouse gas emissions, the opportunities for cost-effectively achieving reductions in technical losses are limited to those which are economically viable. This is because any significant sustainable reductions in technical losses would require substantial changes to our network architecture and plant and equipment which, in terms of economics and practicality, could be embedded only over an extended period of time.

We could not, for example, justify replacing a high loss (but otherwise perfectly serviceable) system transformer with a low loss unit purely on the basis of reduced losses benefit. At best, we might justify bringing forward the replacement of an old high loss transformer at a substation that required reinforcement in the foreseeable future in order to maintain ER P2/6 compliance. In such a case the correct approach would be to undertake an investment appraisal taking account of future (discounted) cash savings arising from reduced losses and any other revenue benefits such as (say) reduced tap-changer maintenance.

2.4.2.1 Impact of high plant and equipment utilisation factors

It must also be recognised that since variable losses are a function of the electrical resistance of the electrical plant and equipment through which an electrical current passes and the square of that current, then maximising the utilisation of our assets (rather than reinforcing the network) will inevitably result in a tendency for variable losses to increase. Given the relative economic buoyancy of the part of the country that characterises our three licensed distribution areas (at least under less recessed economic times) and the consequences for load growth, the economic pressure to manage overall investment through high levels of plant and equipment utilisation will continue to weigh against the case for investing to minimise losses such that wherever these two drivers are in conflict, the latter will generally give way to the former.

One of the consequences of the transition to smarter, more actively managed networks will be a shift of emphasis towards probabilistic (rather than deterministic) standards. By way of an example, dynamic plant and equipment ratings informed by the wider use of modelling, monitoring and state estimation will increasingly displace deterministic cyclic, distribution and emergency ratings. The benefit will be to maximise sustainable levels of utilisation; the downside will be increased variable losses. It is important however to acknowledge that there is a potentially significant embedded carbon saving in deferring or avoiding reinforcement of serviceable assets.

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[8] This apportionment includes variable losses on the associated lower voltage windings of transformers.

[9] Estimates for GB distribution network losses vary between 4.5% for urban networks and as high as 9% for rural networks.

2.4.2.2 Exploiting synergies

Notwithstanding limitations for cost-effective reductions in losses, opportunities to incrementally reduce losses will arise as a natural synergy with our overall investment programme and as a result of our harmonised network design standards and technical specifications. Moreover, there will undoubtedly be opportunities for reducing losses at minimal outlay, for example by optimising network running arrangements (e.g. optimising normal open points).

It follows from the above that our strategy for optimising technical losses should be based primarily on an ‘opportunistic’ approach using incremental cost-benefit analysis to determine the justification for additional network expenditure above the minimum required to address other investment drivers (for example investment to address a load or non-load related asset condition or a request for a new connection). This approach will give rise to greater opportunities for cost-effective reductions in losses than one seeking to justify investment based solely, or primarily, on the reduced losses benefit.

This approach applies equally to the derivation of plant and equipment specifications and design standards where the capitalised value of losses might justify a lower loss option (for example a lower loss transformer specification or a network design standard based on larger cross-sectional area cable conductors).

2.4.3 System management opportunities

As part of any review of regional development, asset renewal, or reinforcement strategy, specific consideration will be given towards opportunities to cost-effectively reduce losses through load flow rerouting and/or circuit reconfiguration.

There will also be an on-going review of (especially 11kV and LV) circuit configuration and running arrangements to determine whether changing positions of normal open points and even cross-jointing of cables could lead to an improvement in variable losses, and potentially some freeing-up of circuit capacity.

System management can be a resource-hungry activity but the benefits in terms of overall network efficiency are attractive, particularly where studies are directed towards parts of the network that are experiencing above normal load growth due to new development activity or low carbon technology penetration.

2.4.4 Major project opportunities

Major asset renewal / reinforcement programmes can reveal opportunities for beneficial circuit reconfiguration in order to both optimally distribute, and reduce the overall distances of, power flows. This in turn will minimise variable losses as well as improving overall utilisation of plant and equipment.

In some cases, however, the emphasis might need to be towards minimising any *increase* in losses, for example where load transfer is being carried out in order to relieve an existing main or primary substation. The existing substation may be ideally located in terms of proximity to the load centre and any load transferred to the relieving infrastructure could therefore result in power being distributed over an increased distance which may then have consequences for variable losses. The example in 2.4.5 indicates how the value of losses should be incorporated in our overall approach to project investment appraisal.

2.4.5 Consideration of losses as part of an overall project appraisal

Options for reinforcing an urban 11kV network might include further 11kV injection by means of additional 33/11kV transformer capacity or, alternatively, a rationalisation of voltages by replacing existing 33/11kV transformation with 132/11kV direct transformation. This might be a particularly attractive option where the existing 33/11 transformers are old high loss units and both the transformers and the associated switchgear have a relatively low health index (it may be possible to redeploy the ‘redundant’ 33kV cables at 11kV at which voltage any aging of the cable insulation will be less of a concern). In such a case, the relative impact of the two options on losses might be a significant factor in determining the most economic NPV solution. Relevant factors in the losses equation will include:

- The benefit of retiring high loss transformers in favour of modern low loss units
- The further benefit of avoided transformer iron and copper losses arising from rationalisation (i.e. elimination of the 33/11kV transformation stage) resulting in fewer transformers overall
- Any detriment in terms of increased variable losses arising from extended distribution at 11kV in lieu of 33kV

It will be apparent from this illustrative example that the cost-benefit analysis will be very specific to the particular network concerned and will require detailed load flow studies to determine the net impact on losses and hence the value of the losses contribution to the overall investment appraisal for the project.

2.4.6 General approach

The purpose of this document is to identify the circumstances under which an evaluation of losses should be undertaken; the methodology to be applied in determining such evaluation; and the measures which should be considered. These circumstances include:

- Network projects undertaken to satisfy investment drivers where losses might make an important contribution to the overall NPV of the project and/or the evaluation of options
- Network design standards where losses will be a factor in determining the economic optimisation of network architecture (for example economic loadings of power cables)
- Plant and equipment specifications used for tendering purposes where the capitalised value of losses will be a factor (for example transformers)
- Implementing each of these measures in accordance with this document will provide a high level of assurance that UK Power Networks is taking all practical opportunities to cost-effectively optimise losses

2.5 Principles of evaluation of losses benefit

2.5.1 Rationale for undertaking losses evaluation

Ofgem has confirmed in its March 2013 Strategy Decision Document that the form of losses incentive applied during DPCR4 but discontinued over DPCR5 will not be reintroduced for RIIO ED1. Regulatory assurance will however be effected through four components: licence obligation, loss reduction expenditure in the business plans, annual reporting and a possible discretionary reward.

This UK Power Networks document recognises the wider economic, environmental and societal importance of managing distribution network technical losses irrespective of the presence or otherwise of a target-based regulatory incentive.

For the reasons outlined in 2.4.2, this strategy is primarily ‘opportunistic’ in nature. Sections 2.7 and 2.7 of this document describe the practical measures that UK Power Networks will take to optimise losses over the course of ED1 and beyond. UK Power Networks’ ambition for losses over ED1 is based on a high-level cost-benefit analysis in support of this strategy, the results of which are summarised in 2.6.2 which includes an estimate as to the contribution which each of the measures described in this Strategy will make towards savings in network losses. In practice, the contribution from each measure will depend on the scope for any given part of the network to benefit from that measure which will generally need to be determined through power system modelling.

2.5.2 Valuation of losses

In accordance with Ofgem’s RIIO ED1 guidance on cost-benefit analysis, the present valuation of benefits associated with measures to reduce losses will be based on the annualised saved costs of electricity production and carbon emissions, the latter valued at the current traded price of carbon but assuming a declining forward profile of annual power sector emissions reflecting anticipated progress in decarbonisation of generation.

Valuing losses fully over the lifetime of the asset, and using this on-going value (adjusted as necessary to reflect forward variations in ‘real’ - i.e. non-inflated - costs of losses) to 'capitalise' losses in our network design and investment analyses, will tend to give rise to a lower value of specified losses in our plant and equipment technical standards. The basis of determining the value of any measure will therefore be based on DCF analysis using the discount rates stipulated in Ofgem’s RIIO ED1 guidance[10] and reflecting the anticipated load growth and changing load and loss load factors for that asset or network over its lifetime.

Given the opportunistic nature of the strategy, the most cost-effective measures for reducing losses will generally be those implemented either in conjunction with network interventions driven by other investment drivers or in determining standards for network design, and specifications for plant and equipment. It follows that the most appropriate approach to valuation in most cases will be through NPV-based *incremental* cost-benefit analysis, i.e. comparing the incremental cost of any supplementary network investment, or enhancement to a specification or standard, with the present value of the resulting savings in losses over the lifetime of the associated assets.

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[10] 3.5% pre-tax real up to 30 years; 3.0% beyond 30 years

2.6 DPCR5 and RIIO ED1 perspectives

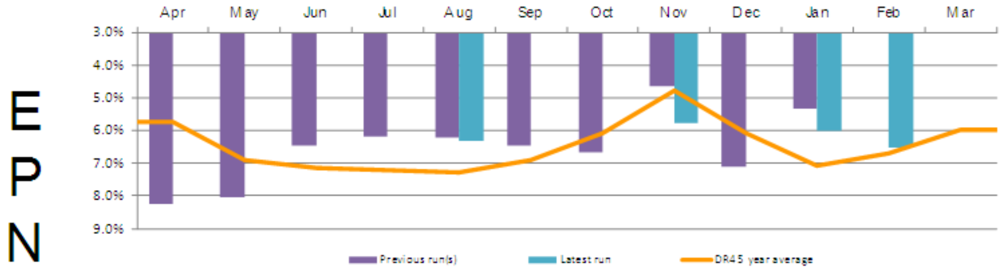
2.6.1 DPCR5 performance

Although Ofgem has decided not to activate a target-based losses incentive for DPCR5, UK Power Networks has nevertheless continued to monitor the losses performance, as determined by the methodology developed for the non-activated DPCR5 losses incentive, for its three licensed networks. The chart overleaf illustrates the DPCR5 rolling performance for each of our three licensed networks as determined by this methodology.

This methodology is dependent on settlements data which, as can be seen, is extremely volatile. The monthly variations in losses performance as determined by this methodology do not reflect actual losses performance of our networks which will vary to a very much less extent (tending to increase during winter months and reduce during summer due the relationship between demand and variable losses).

The average DPCR5 losses performance values shown in the table in section 2.6.2 are based on the settlements methodology and will therefore include non-technical losses. These values are not therefore directly comparable with the ED1 losses performance figures in this table which are based purely on assessed technical losses performance.

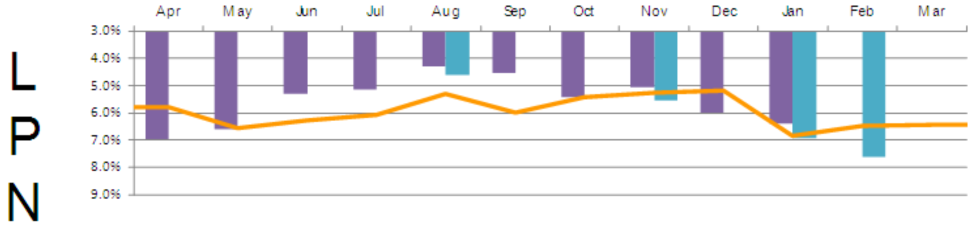
Figure 1 2012/13 Losses Performance



Losses Performance

Cumulative Loss	6.70%
DR4 5 Year Average	6.45%

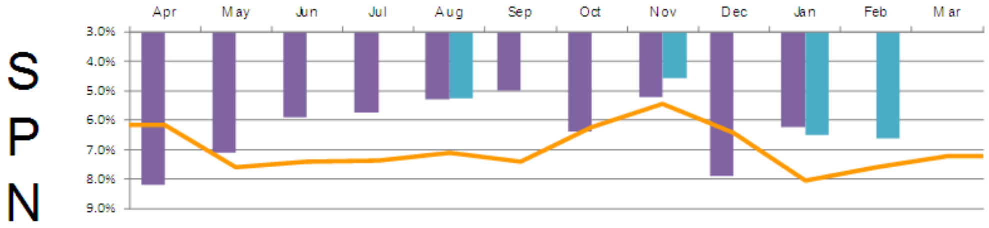
The EPN R2 run for November 2012 has increased >1% aganst the previous run, which has added the the April / May months to push the cumulative loss further above the DR4 average.



Losses Performance

Cumulative Loss	5.90%
DR4 5 Year Average	5.98%

The SF run for February 2013 gives high losses in LPN and there are minimal rises are noted with the R1, R2 and R3 reconciliations, LPN has a cumulative loss for 2012/13 which is still performing better against the DR4 average.



Losses Performance

Cumulative Loss	6.35%
DR4 5 Year Average	7.00%

SPN has seen improvement in the R2 losses reconciliation in November. January and August both stand relatively steady against the previous run and remain below the DR4 average

2.6.2 RIIO ED1 outlook and CBA

Notwithstanding the proactive attention to network losses described in this document, a priority for all DNOs over the RIIO ED1 (and especially ED2) period will be the efficient accommodation of new low carbon technologies whilst at least maintaining current levels of network security, asset health and quality of service.

For the reasons described under 2.3, meeting this objective without incurring either significant network reinforcement or a disproportionate increase in technical losses will be a major challenge which will rely increasingly on the successful application of smart grid solutions and consumer incentives with regard to peak demand management as described later in section 2.8.

The rollout of smart meters scheduled for completion in 2020 will give new insights into the actual level of technical losses incurred on distribution networks, as well as vital information regarding LV network load flows and voltage levels which will be of great value in determining options to reduce LV network losses. It follows that any consideration of targets for network losses will need to be informed (or reviewed) in light of this information since the assumed level of losses for distribution networks (around 6% as suggested in 2.4.1) may be shown to be incorrect, or at least the information might indicate significant variations in losses between networks of different characteristics (for example between networks serving rural, urban, suburban, industrial and central business district areas).

Give the inherent risk that low carbon technologies will not only give rise to higher load flows and therefore higher losses in absolute (i.e. MWh) terms, the potential for these technologies to disproportionately increment peak demand and hence degrade load factor means that losses may also increase in relative (i.e. percentage of energy distributed) terms.

Moreover, whilst smart grid technologies will confer significant investment savings over conventional reinforcement solutions by releasing network capacity to enable higher asset utilisation, there will be trade-offs in some cases for losses. A classic example is the application of real-time thermal ratings which allow conductors to operate at higher temperatures but with the obvious consequence that heat loss (driven by 1^2R losses) is increased. Applied to transformers, the use of real-time ratings in lieu of reinforcement also precludes or defers the opportunity for installing a modern low loss transformer in place of an older high loss unit.

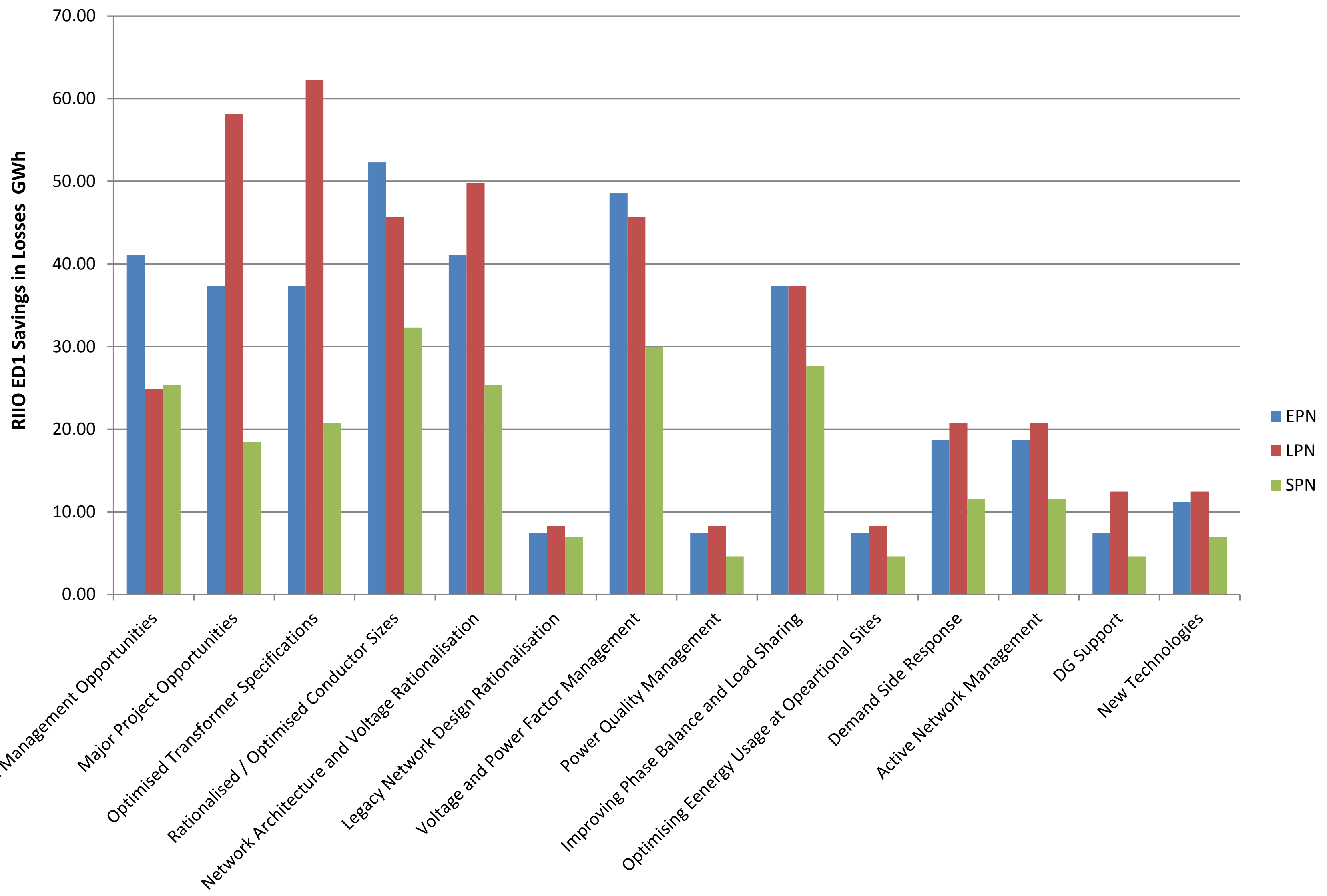
On the other hand, active network management and other smart grid solutions aimed at optimising voltage levels and power sharing will have the beneficial effect of reducing (or at least containing increases in) losses. Demand side response initiatives aimed at shifting or reducing peak demand will be of particular value in both releasing network capacity and reducing losses.

It follows from all the above that setting quantified targets for losses performance for the RIIO ED1 period at this time is not straightforward. A stretching target would be for losses to be contained in percentage terms at DPCR5 levels (recognising that active measures to mitigate losses in accordance with this strategy are already being implemented) subject to ‘recalibration’ once smart meter information becomes fully available from the end of 2020.

Notwithstanding that the figures will need to be recalibrated once smart metering data becomes widely available, UK Power Networks’ ambition is to maintain losses in percentage terms broadly at current levels (2012/13 outturn) over the RIIO ED1 period despite the anticipated increase in network power flows. The ED1 outturn ambition is shown below along with our estimate of the level of ED1 unmitigated outturn losses that we would anticipate due to forecast load growth over the ED1 period in the absence of this strategy.

Network	DPCR5 Average Losses (GWh)	Anticipated ED1 Outturn Unmitigated Losses (GWh)	EDI Outturn Ambition Losses (GWh)
EPN	2,475	2,495	2,396
LPN	1,773	2,120	2,031
SPN	1,462	1,411	1,370

The chart overleaf provides an indication as to the expected contribution that each of the measures described in this strategy will make towards the anticipated savings in network losses (in GWh) over the RIIO ED1 period. Whilst it is possible to make an informed estimate as to how each of the measures will contribute, this needs to be treated with caution since each will depend on the scope for any given part of the network to benefit from such measures which, in the absence of detailed measurements coupled with in-depth modelling, is impractical to gauge with certainty.


RIIO ED1 Savings in Losses GWh
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
System Management Opportunities
Major Project Opportunities
Optimised Transformer Specifications
Rationalised / Optimised Conductor Sizes
Network Architecture and Voltage Rationalisation
Legacy Network Design Rationalisation
Voltage and Power Factor Management
Power Quality Management
Improving Phase Balance and Load Sharing
Optimising Eenergy Usage at Opeartional Sites
Demand Side Response
Active Network Management
DG Support
New Technologies
EPN
LPN
SPN

A consequence of our opportunistic approach is that we attribute no costs to implementing this strategy and hence no expenditure in our business plan categorised as ‘losses management’.

Whilst costs will be incurred in terms of additional network studies to evaluate opportunities, we expect to absorb these as part of the process improvements we are delivering through our current Business Transformation project.

In terms of network investment, whilst it is probable that our incremental cost-benefit approach will lead to incremental investment (where this shows a positive NPV of losses saved) again we anticipate absorbing these additional costs within the overall levels of LRE and NLRE investment included in our business plan.

Similarly, if studies suggest that higher procurement costs - for example associated with a bias towards larger LV cables (Section 2.7.2) - are justified by the resulting capitalised value of losses saved, again we will absorb these additional costs. In the case of Ecodesign transformers designed to meet the requirements of a proposed new EU directive (Section 2.7.1) the implications for transformer tender prices are as yet unknown but our interim working assumption is that once the EU directive comes into effect standardisation should drive prices to a level broadly comparable with the current standard ENATS 35-1.

A summary of the overall cost-benefit analysis is shown in the following table.

	Units	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
Losses	£m	2.39	3.50	4.33	5.26	6.25	7.33	9.19	11.09
Total societal net benefits	£m	2.57	3.78	4.67	5.69	6.79	8.41	11.06	13.94
Net benefits	£m	2.53	3.76	4.66	5.68	6.77	8.40	11.05	13.92
Discount factor	=1/[(1+SRTP)^n]	0.97	0.93	0.90	0.87	0.84	0.81	0.79	0.76
Discounted net benefits	£m	2.45	3.51	4.20	4.95	5.70	6.83	8.68	10.57
Cumulative discounted net benefits	£m	2.45	5.96	10.16	15.11	20.81	27.64	36.32	46.89
Reduced losses	MWh	49,397	72,380	89,330	108,569	129,170	151,443	189,697	228,991
Reduced emissions associated with losses	tCO2e	24,838.98	35,346.80	42,329.67	49,872.25	57,463.24	65,176.40	78,889.87	91,912.26

Through this strategy, UK Power Networks anticipates delivering, at potentially no additional cost to consumers, savings in losses rising to a cumulative present value benefit of £46.9million over the RIIO ED1 period. Along with the societal benefits of reduced CO_2 emissions, these benefits should flow through to consumers in terms of lower energy prices

2.7 RIIO ED1 – conventional approaches to losses management

The following opportunistic approaches will be taken to reduce network losses where incremental cost-benefit analysis suggests a positive NPV.

2.7.1 Optimised transformer specifications

A significant aspect of losses evaluation is determining the capitalised losses (both iron and copper losses) for transformers. This is an important element of our technical specification since it informs manufacturers tendering for the supply of transformers as to the optimum design/cost trade-off.

A consequence of this approach is that all new transformers purchased by UK Power Networks are now 'low loss' units[11] - the specification for which includes the use of laser-etched steel cores which have the characteristic of producing lower iron losses compared with conventional cold rolled grain-orientated steel-cored transformers and of course earlier hot rolled steel-cored transformers[12].

The term 'low loss' relates primarily to the level of transformer iron losses (i.e. more so than copper losses). Although the iron loss in a transformer is much lower than the 'rated' copper loss (i.e. the losses when the transformer is operating at its rated capacity) the fact that the former is permanently incurred while the transformer is energised means that iron loss is generally the more important consideration and the one which is most influenced by technological development. In the case of EHV/HV transformers, due to the relatively low utilisation level implicitly required by ER P2/6, the average load on a system transformer is generally much less than it's rated capacity. The non-linear relationship between copper loss and current (load) in turn means that the average copper loss will be much less than the rated copper loss.

Amorphous steel-cored transformers which have an even lower level of iron loss (but usually a marginally higher copper loss) than low loss transformers have been available for some time, and indeed a few have been installed on UK Power Networks' system. Amorphous steel is (by definition) non-crystalline and hence there are no grain boundaries to orientate. This results in a higher value of permeability. However, amorphous steel is difficult to manufacture in large plate sizes (not least because it is brittle) and is generally available only for smaller distribution transformers. Moreover, the cost is considerably higher than for laser etched / cold rolled conventional steel-cored transformers. The following table provides a comparison of iron and copper losses for a typical range of 315kVA distribution transformers:

Variant	Fe Loss (watts)	Cu Loss (rated watts)
315kVA (standard)	735	4,800
315kVA (low loss)	380	4,100
315kVA (amorphous)	145	4,800

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[11] Power transformers are specified according to IEC 60076-1 with cold rolled steel cores to IEC 60404-1; ground-mounted distribution transformers are specified according to ENATS 35-1.

[12] Cold rolling of the steel used in the transformer core allows the crystalline steel grain boundaries to be directionally orientated which, when combined with the addition of certain impurities such as silicon, gives rise to higher permeability and hence an easier path for the magnetising flux (it also increases electrical resistivity in the steel core). The result is lower hysteresis and eddy current losses, and hence lower iron loss. Laser etching of the steel core further improves the grain orientation.

For the time being, the use of amorphous steel-cored transformers cannot be justified for general application. However, a 'watching brief' will be maintained so that should the techniques and economics of production change significantly, consideration can then be given to including amorphous steel-cored transformers as an option – especially for (say) pad-mounted distribution transformers. For comparison, the specified target values of losses for ground-mounted distribution transformers as currently purchased by UK Power Networks based on ENATS 35-1 are shown below:

2.7.1.1 Ecodesign transformers

It is expected that a new EU Directive - 2009/125/EC - will mandate the adoption of 'Ecodesign' transformers for distribution networks in two phases - from 2015 and 2020. The proposed Ecodesign requirements in respect of copper (load) and iron (no load) losses are shown in the table below.

Rated Power (kVA)	Tier 1 (from 1 January 2015)		Tier 2 (from 1 January 2020)	
	Maximum load losses (Watts)	Maximum no-load losses (Watts)	Maximum load losses (Watts)	Maximum no-load losses (Watts)
25	Ck (900)	Ao (70)	Ak (600)	Ao-10% (63)
50	Ck (1100)	Ao (90)	Ak (750)	Ao-10% (81)
100	Ck (1750)	Ao (145)	Ak (1250)	Ao-10% (130)
160	Ck (2350)	Ao (210)	Ak (1750)	Ao-10%(189)
250	Ck (3250)	Ao (300)	Ak (2350)	Ao-10% (270)
315	Ck (3900)	Ao (360)	Ak (2800)	Ao-10% (324)
400	Ck (4600)	Ao (430)	Ak (3250)	Ao-10% (387)
500	Ck (5500)	Ao (510)	Ak (3900)	Ao-10% (459)
630	Ck (6500)	Ao (600)	Ak (4600)	Ao-10% (540)
800	Bk (7000)	Ao (650)	Ak (6000)	Ao-10% (585)
1000	Bk (9000)	Ao (770)	Ak (7600)	Ao-10% (693)
1250	Bk (11000)	Ao (950)	Ak (9500)	Ao-10% (855)
1600	Bk(14000)	Ao (1200)	Ak (12000)	Ao-10% (1080)
2000	Bk (18000)	Ao (1450)	Ak (15000)	Ao-10% (1305)
2500	Bk (22000)	Ao (1750)	Ak (18500)	Ao-10% (1575)
3150	Bk (27500)	Ao (2200)	Ak (23000)	Ao-10% (1980)

Note: options for load and no-load loss values range from Ak and Ao (lowest) respectively to Dk and Do (highest)

Applying Ofgem's RIIO ED1 CBA approach to compare the Ecodesign specification with our current UK Power Networks specification shows, for most transformer ratings, a significant present value benefit in terms of saved losses in respect of the 2020 specification. In terms of whether this represents a positive *net* present value will depend on the yet to be determined market price for Ecodesign transformers. Notwithstanding the present value of losses saved, it will therefore be important to monitor the impact on transformer tender prices of adopting the Ecodesign specifications. Our interim working assumption is that once the EU directive comes into effect, standardisation should drive prices to a level broadly comparable with the current UK Power Networks standard based on ENATS 35-1.

UK Power Networks currently installs in the order of 1,000 ground mounted distribution transformers p.a. and around 450 pole mounted transformers. Grid and Primary transformer installation rates vary typically between 8 to 14 and 16 to 30 per annum respectively. In round figures, UK Power Networks spends around £10m p.a. on average in purchasing ground mounted distribution transformers.

Not until the EU confirms its intention to direct adoption by member states of the Ecodesign will clarity begin to emerge as to the market price for compliant transformers. UK Power Networks will review its current procurement policy once it becomes clear that the expected benefits of standardisation are being reflected in market prices sufficiently to justify procuring Ecodesign transformers in advance of the directive coming into effect.

By way of example, our analysis indicates that for a 2015 Ecodesign 1,000kVA distribution transformer to be cost-effective, the price would need to be within 25% of our current contract price. In the meantime, it is interesting to note that our current specification for 500kVA distribution transformers stipulates lower Iron and copper losses than the proposed 2015 Ecodesign and marginally lower iron losses than the 2020 design.

2.7.2 Rationalised range of standard cable / conductor sizes

Continuing to standardise on a rationalised range of cable sizes will enable UK Power Networks to leverage economy of scale benefits with suppliers.

Limiting the range of available options will naturally lead to larger overall cable sizes since (at LV) 'tapering' options will be constrained, and at higher voltages it will be necessary to default to the 'next size up' (either for thermal or fault level rating purposes) in cases where a previous 'ideal' size would have been available. Nevertheless, the price leveraging and optimised stock holding opportunities (including in terms of joints and terminations) surrounding standardisation outweigh the cost implications of larger overall cable sizes, especially bearing in mind that excavation, installation and reinstatement costs, which are generally the most significant elements of the overall cost, are largely unaffected by cable size.

From a losses perspective, there are considerable spin-off benefits associated with increasing overall cable sizes (i.e. reducing conductor resistance) particularly at LV where circuit loadings are relatively peaky and utilisation levels are relatively high. Careful consideration will therefore be given during the planning / design phase of any project towards the selection of 'economic' cable / conductor sizes (rather than necessarily the minimum size from a thermal rating, voltage gradient, earth loop impedance or fault level perspective) taking account of the marginal cost of installing a cable with a larger cross sectional area conductor compared with the incremental value of lower losses.

The table below summarises the more commonly used standard conductor sizes at LV, 11kV, 33kV and 132kV and (where relevant) the sizes which have more recently been discontinued from common usage. It will be evident that the discontinuation of certain cable / conductor sizes will result, overall, in larger conductor sizes being employed for a given current carrying duty.

Table 1 Standard UK Power Networks Cable / Conductor sizes

Voltage / Type	Standard Conductor	Discontinued Conductor
LV U/G Service (concentric)	35mm^2 Al/Cu	25mm^2 Al/Cu
LV U/G Main (waveform)	95mm^2 Al	35mm^2 & 70mm^2 Al
	185mm^2 Al	120mm^2 Al
	300mm^2 Al	
LV O/H Service	35mm^2 Al ABC	25mm^2 Al/Cu
LV O/H - see note (1)	50mm^2 Al ABC	50mm^2 HD Al
	95 mm^2 Al ABC	100mm^2 HD Al
	120 mm^2 Al ABC	
11kV U/G (XLPE s/c triplex)	95mm^2 Al	
	185mm^2 Al (direct buried only)	150mm^2 Al
	300mm^2 Al	
20kV U/G (XLPE s/c triplex)	300mm^2 Cu	
	400mm^2 Cu	
11kV O/H	50mm^2 ACSR	
	100mm^2 ACSR	
	50mm^2 BLX	
	120mm^2 BLX	
33kV U/G (XLPE single core)	300mm^2 Al	185mm^2 Al or Cu
	500mm^2 Al	400mm^2 Al
	630mm^2 Al	400mm^2 Cu
	630mm^2 Cu	500mm^2 Cu
	800mm^2 Cu	
33kV O/H	100 mm^2 ACSR (Dog)	

Voltage / Type	Standard Conductor	Discontinued Conductor
132kV O/H	200 mm^2 ACSR (Jaguar)	
	200 mm^2 AAAC (Poplar)	
	175 mm^2 ACSR (Lynx)	
	300 mm^2 UPAS	
	500 mm^2 UPAS	400 mm^2 (Zebra)

Note (1): Where 100mm^2 HD Al or 0.1 ins^2 Cu lines are to be reconductored, 95mm^2 ABC will generally be used in rural / low density locations except where thermal rating or voltage regulation dictates the use of 120mm^2 ABC. For urban / higher density locations, where feeder loadings may be higher, consideration should in any case be given to using 120mm^2 ABC if the incremental cost is justified by reduced losses.

Note (2): 132KV XLPE cables are subject to individual tender.

2.7.3 Network architecture and voltage rationalisation

2.7.3.1 Voltage rationalisation

Investigating opportunities for voltage rationalisation, both in conjunction with major asset renewal / reinforcement strategies and also as part of an on-going system management review as advocated in 2.4.3 above, might lead to opportunities for significant savings in terms of both fixed and variable losses.

Each transformation stage introduces fixed losses and, where multiple voltage transformations are used (e.g. 132/33kV; 33/11kV; 11kV/LV or 66/22kV; 22/6.6kV 6.6kV/LV) the cumulative iron losses can be disproportional to the level of demand being supplied, especially under light load conditions. The example in 2.4.52.4.4 illustrates how voltage rationalisation options might be considered as part of a major reinforcement or asset renewal project. Similar opportunities for voltage rationalisation, optimisation and standardisation will be considered as part of a longer-term system development strategy.

2.7.3.2 Direct 132/11kV transformation

Direct 132/11kV transformation provides an opportunity to eliminate a stage of transformation and hence a source of iron losses. On the other hand, this approach can lead to larger 11kV switchboards serving wider geographic areas and potentially longer 11kV feeders. Hence a potential consequence is increased variable losses in the 11kV cables. Nevertheless, given the requisite analysis, overall savings in losses can generally be achieved.

2.7.3.3 11kV Circuit Configuration

The guiding principle governing the economic configuration of 11kV circuits is that of compliance with ER P2/6 in respect of which the requirement for Class B Group Demand determines the extent to which switched alternative supplies need to be incorporated. Albeit a legitimate option under P2/6 for class A (<1MW) demands, there has been a general move away from using teed spurs on 11kV underground cable networks (i.e. usually to supply a single distribution transformer typically protected by a free-standing switch fuse or circuit breaker). This is because of concerns over quality of supply (CI/CML) implications in the event of an in-section 11kV fault. In particular, the use of teed connections was considered inconsistent with the now discontinued Overall Standard OS1a which required a specific percentage of customer interruptions to be restored within 3 hours.

However, the exclusive use of looped connections leads to an overall increase in aggregate 11kV circuit cable length which, apart from leading to some small additional risk of a network fault, will also give rise to increased losses[13]. This is particularly so where relatively long loops are installed close to the source of the 11kV feeder where the circuit loading will be relatively high.

It follows that an overall consideration of economics, taking account of both losses and potential quality of supply impact, is the correct approach, rather than a rigid application of a ‘no tees’ policy. In particular, consideration needs to be given to the fact that the mean time to failure of a specific 11kV cable section with a teed connection will be many years; whereas the additional losses resulting from an alternative looped connection will be incurred immediately, and continuously thereafter.

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[13] The use of a larger csa cable associated with a loop connection will only marginally mitigate this impact due to the higher load carried by the loop – especially close to the source end of the 11kV feeder.

2.7.3.4 V Network Tapering

In terms of preparing for a future that might involve significant levels of heat pumps, electric vehicle chargers and micro-generation as outlined in 1.1 it is important to consider now the future impact that such low carbon technologies might have on LV networks, since retrospective corrective action might prove expensive and largely impractical.

LV networks have traditionally been designed on the basis of 'economic tapering' of cable sizes to reflect the fact that the demand on an LV distributor gradually falls from a maximum level at the substation LV busbars to virtually zero at the end of the distributor (i.e. either a pot-end or LV link box normal open point). The exception to tapering has been where the LV distributor is providing an LV backfeed capability from an adjacent substation. From a losses perspective, the economic benefit of tapering has historically been considered to outweigh the economic impact of increased losses albeit the adoption of rationalised cable sizes referred to in 2.7.2 above has reduced the scope for tapering.

However, with the prospect of increased levels of low carbon technologies, consideration needs to be given to the impact on LV network loadings and voltage profiles. At times of low electricity demand, micro-generation will tend to 'spill' onto the LV network[14]. In isolated cases, this would be of little consequence; however, where clusters of micro-generation are connected to the same LV distributor, the cumulative effect could be significant in terms of the voltage profile along the LV distributor. The particular concern would be that voltage levels could rise above the upper statutory limit (or indeed the G83 high-voltage trip setting) especially if the whole of the LV network served by a distribution transformer was, at times, to export onto the 11kV network. Conversely, heat pumps and electric vehicle charging might reasonably be expected to increment LV network loading at times of current peak demand – i.e. typically between 5 and 6pm on winter weekday evenings for suburban or rural networks serving mainly residential areas with available mains gas supplies.

Ideally, the impedance of the individual LV distributors would be reduced. In practice this would mean a combination of shorter length and larger sized LV cables, and would therefore be a difficult and prohibitively expensive corrective measure to apply to an existing network. A more practical retrofit option would be the use of larger distribution transformers and/or transformers fitted with on-load tapchangers. The use of modern in-line voltage regulators is another, potentially cheaper, option where a particular LV circuit (rather than the whole of the LV network served by a particular transformer) is experiencing voltage regulation issues.

2.7.3.5 New LV Networks

Where new LV networks are being installed, and particularly where the type of development might be regarded as susceptible to a future high take-up of low carbon technologies, consideration will now be given to limiting the length of individual LV distributors, and also to specifying larger cable sizes than would be necessary from either a thermal capacity perspective or to maintain voltage above the lower statutory voltage limits under conventional one-way power flows and current methods of assessment of after-diversity maximum demand (ADMD).

A further beneficial impact of shorter LV distributors and larger cable sizes will of course be lower electrical resistance and hence lower variable losses. Whilst each individual case should be considered on its merits, since the incremental cost of installing larger cable sizes on new networks is small, there is a strong prima-facie case for now adopting 300mm^2 CNE cable as the standard cable size for the spine of a typical LV distributor. In terms of cost impact (based on UK Power Networks' current contract prices): 300mm^2 CNE aluminium cable is 24% more expensive than 185mm^2 CNE cable but has 64% lower phase conductor electrical resistance[15] (and hence would deliver 64% lower losses for a given balanced electrical load).

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[14] For example, micro CHP units in residential properties might export onto the LV network in the early hours of winter mornings when householders are pre-heating their (gas heated) homes but using very little electricity. Similarly, photovoltaic generation might spill onto the LV network during the daytime on summer weekdays when householders are at work and using little electricity.

[15] 300mm^2 CNE cable has a reduced cross-section copper concentric neutral having the same electrical resistance as a 185mm^2 CNE aluminium cable; hence neutral losses due to load imbalance would be the same as for a 185mm^2 CNE cable.

2.7.4 Legacy non-standard network designs and voltages

The remaining networks operating at the now discontinued voltage levels of 22kV and 6.6kV will gradually be replaced through natural evolution and investment synergies. In general, this will provide losses reduction opportunities due to the (higher) standard voltages now employed, i.e. 33kV (or 132kV) and 11kV. However, there are, in addition, discrete pockets of non-standard network architecture which, due to their age and component obsolescence, are the subject of more specific asset replacement programmes. These will provide further opportunities to reduce losses albeit subject to practical limitations inherent in their legacy designs.

Examples of such networks include:

- The LPN LV interconnected 11kV network
- The SPN 2kV and 3.3kV networks
- The SPN LV network served by Scott-connected transformers, predominantly around Croydon

2.7.4.1 LPN LV interconnected 11kV network

The meshed configuration of the LPN LV interconnected network provides for a natural real-time optimisation of LV power flows which is broadly consistent with the minimisation of losses[16]. The issue from a losses perspective is simply that parts of this network are now highly loaded (and hence give rise to a relatively high level of variable losses). However, the more pressing renewal drivers are the lack of operational flexibility arising from the need to maintain the integrity of discrete 11kV feeder groups (a design concept which significantly limits Main Substation load transfer capability) and the now limited thermal capacity headroom of parts of the LV interconnected network which can lead to cascade LV fuse operation in the event of an 11kV fault. ‘Radialisation’ of these networks (where appropriate in conjunction with system automation to meet quality of supply expectations) may give rise to higher LV losses, as well as higher harmonic voltages (due to increased source impedance). However, in economic terms, this is generally outweighed by the improved plant utilisation that is inherent in maintaining the 11kV feeder group configuration. A possible future opportunity subject to economic justification is that surrounding the use of LV Soft Normal Open Points (SNOPs – see 2.8.4).

2.7.4.2 SPN 2kV and 3.3kV networks

Albeit a relatively small component of the SPN system there is an asset renewal driver arising from the increasing obsolescence of the SPN legacy 2kV and 3.3KV networks network components. Replacement with a conventional 11kV network using standard cable / conductor sizes will reduce variable losses. Using modern, relatively low loss, distribution transformers will also reduce iron losses.

2.7.4.3 SPN Scott-connected network

Part of the SPN network, largely localised around Croydon is based on Scott-connected transformers. The network is a legacy of the now long discontinued DC system. However, unlike a conventional Scott connection where the LV output is traditionally 2-phase with the phases displaced by 90deg, in this case, a hybrid configuration is used which effectively provides a 4-phase system (each phase displaced by 90deg).

The LV network served by these transformers is a 3-wire system comprising either triple concentric or 3-core (conventional) cable. The cables are each served by 2 - 180deg displaced phases providing a 460/230V LV system, not unlike an LV network served by a single phase (2-wire) 11kV network. As with the SPN 2kV and 3.3KV networks, obsolescence of the network components (and the fact that it is largely impractical to meet the requirements of consumers wishing to be provided with a 3-phase supply) is a strong renewal driver. However, whilst replacement with a conventional 11kV network using modern, relatively low loss, distribution transformers would reduce iron losses, the legacy 3-wire cable network will preclude the possibility of a balanced 3-phase system, leading to higher neutral losses and possibly higher variable losses overall.

2.7.5 Voltage and power factor management

There are specific requirements under ESQC Regulations, EU Legislation (BS EN 50160), Grid and Distribution Codes, and Engineering Recommendations covering these aspects of power system design and operation. However, there are implications for losses too as described below.

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[16] Load flows in a meshed network will be determined by the route of lowest impedance rather than lowest resistance, but given that X/R ratios for an entirely underground network with a limited range of standard cable sizes will be reasonably constant, the two are broadly equivalent.

2.7.5.1 Voltage management

Optimising voltage at all voltage levels will provide the best assurance of meeting statutory obligations under ESQC Regulation 27 (3) (b), (c) and (d). Maintaining voltage at the lowest permissible level within the statutory limits will also ensure that variable losses (as a percentage of energy supplied) are minimised[17]. In practice, determining busbar voltage set points is a compromise between achieving the ideal voltage level from an energy efficiency perspective and practical considerations regarding the need to ensure adequate automated voltage control (AVC) relay operating bandwidths and operating time delays[18].

11kV/LV transformers are generally equipped only with off-load tapchange switches (or internal reconfigurable links) which are set according to the anticipated 11kV voltage gradient along the HV feeder serving the substation, taking account of the impact of Line Drop Compensation (LDC) where installed at the upstream primary substation.

The increasing penetration of decentralised generation (DG) into our distribution networks (particularly at 11kV and LV) will challenge traditional approaches to voltage management. For example, the GenAVC[19] approach which was the subject of a UK Power Networks Registered Power Zone can in some cases be employed in order to optimise system voltage in the case where a generator connects to a remote part of the network and would otherwise give rise to a potential voltage rise issue[20]. A further option for optimising system voltage is that afforded by the SuperTAPP n+ voltage control relay marketed by ‘Fundamentals’. This relay has the additional advantage of being able to optimise voltage set points of individual (and possibly dissimilar) system transformers operating in parallel across a network so as to minimise circulating currents and hence reduce losses.

Whilst these novel voltage control devices can provide additional DG ‘headroom’, it is important to recognise the consequent impact on LV voltage profiles which might in some cases already be operating close to upper voltage limits at certain periods of the day/year but may in future be operating close to lower voltage limits at certain times of the day.

A further ‘DG’ scenario is that concerned with concentrated penetrations of micro-generation which may give rise to voltage rise issues on LV networks under low demand conditions. Under such circumstances, it is possible that consideration may need to be given to more dynamic forms of LV voltage control, e.g. by equipping 11kV/LV transformers with on-load tapchangers coupled with a limited-range AVC function.

It will be important to give particular attention to the management of voltage as DG and micro-generation penetration increases. Given the overall impact of low carbon technologies on daily and seasonal LV network voltage profiles (described in 1.1) it will be essential to exploit the statutory voltage bandwidth of 400/230V +10% / -6%. Setting the voltage as low as practicable consistent with maintaining voltage within statutory limits will generally give rise to lower losses since, although there will be some loss of diversity, there will generally be a reduction in peak demand and indeed overall consumption. It follows that variable losses will generally be reduced.

Smart meter functionality incorporating half-hourly RMS voltage recordings and configurable high / low voltage alerts will greatly assist the monitoring of voltage levels on LV networks.

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[17] For a given circuit and load impedance, decreasing voltage will cause a lower current (I) to flow - and hence an even lower value of I^2. However, for a given amount of energy supplied, a lower supplied voltage will require (for fixed impedance electrical appliances) a given current to flow for a longer period which will adversely impact diversity. Nevertheless, the overall impact is that load factor and loss load factor will be improved and hence losses (as a percentage of energy supplied) will be lower. Note however, that for appliances with significant inductive impedance (e.g. electric motors) the effect of lowering voltage will generally be to increase reactive current flow inducing higher circuit losses.

[18] Too narrow a bandwidth and/or too fast a response time would create excessive tapchanger operation and, in the extreme, could result in ‘hunting’ if the voltage step change dictated by transformer tap intervals was to approach that of the relay operating bandwidth. Recommended tap interval / bandwidth ratios and relay operating time settings are included in relevant UK Power Networks Engineering Instructions.

[19] GenAVC was the commercial product name of a system originally promoted by Econnect Ltd. for modifying conventional AVC / LDC schemes so as to take account of measured and/or state-estimated voltages at various points on a system which includes 11kV connected (generally asynchronous) generation.

[20] In the case of a synchronous generator, operating in ‘constant voltage’ (PV) rather than ‘constant power factor’ (PQ) mode can mitigate this impact; in the case of an asynchronous / induction generator the impact will be mitigated to some extent as the generator will import VArs while exporting real power.

2.7.5.2 Use of traditional phase balancers and voltage regulators

Phase balancers, often in conjunction with voltage regulators, have historically been used on a very selective basis to maintain voltage within statutory limits on ‘long’ rural LV feeders where achieving phase and voltage balance has otherwise proved to be problematic[21]. Such traditional devices produce losses in their own right and, particularly in the case of moving-coil voltage regulators, incur an on-going maintenance cost. The opportunity will be taken during ABC reconductoring and 11kV overhead line resilience programmes to remove these devices wherever practicable through optimisation of transformation points and/or improved balancing of LV service connections.

The use of modern voltage regulators on 11kV rural overhead line networks may however become a necessary option in future as a result of the impact of DG on 11kV feeder voltage regulation - i.e. where active management of system 11kV voltage through the use of either conventional AVC schemes or the more active forms of voltage control described above prove impractical or insufficient. Modern power electronics based voltage regulators may also become necessary on some LV networks where high penetrations of micro-generation are experienced.

2.7.5.3 Power factor management

The impact of poor (less than unity) power factor is that for a given level of demand (in kW) a higher current (I) will be required. This higher current will then have the effect of increasing variable (I^2R) losses due to the electrical resistance in the supplying circuits and transformers. These losses are given off in the form of heat and hence directly affect the ability of plant and equipment to supply a given electrical demand (in kW) within its electrical rating.

Power factor is of particular concern where high (and especially peak) demands occur during the summer months. Air cooling installations (compressors fed by induction motors) if not compensated will give rise to lagging power factors in the supplying distribution networks. The demand for air cooling systems may grow and studies have shown that personal computers (which in an office environment can contribute significantly to the need for air cooling) may also have poor power factors. For summer peaking substations, at the very time that the high ambient temperature will reduce the effective rating of the transformer, this additional heating current in the transformer windings will further reduce the effective rating of the transformer.

Improving power factor closer to unity would therefore not only reduce losses, but also reduce the risk of a winding temperature trip of a heavily loaded system transformer under an outage (N-1) condition[22]. The most effective way of improving power factor is for reactive demand to be compensated at source – i.e. at the consumer’s premises. This can be ‘incentivised’ through DUoS pricing mechanisms, though this incentive might need to be reinforced through direct contact with the consumer (through his Supplier where appropriate) to raise awareness of the benefits of power factor correction where power factor is a particular ‘network’ issue. For large power consumers, poor power factor will be evident from half-hourly metering information.

An alternative (or complementary) approach is to also consider the scope for compensation to be applied directly to UK Power Networks’ system, especially where power factor is seasonally low. This can be achieved through simple switched capacitor banks (automatic switching could be triggered via a power factor monitor). Alternatively, where finer control is required and/or to avoid frequent mechanical switching, consideration could be given to the installation of power electronic devices such as SVCs or Statcoms[23].

In the case of LV networks, the greatly increased household ownership of personal computers and an even greater growth in mobile phones and other digital devices has undoubtedly contributed not only to continued domestic load growth but potentially a worsening power factor, exacerbated by the fact that some ‘high efficiency’ (compact fluorescent) light bulbs also have a poor power factor. The impact of new low carbon technologies such as heat pumps might further degrade power factor in future.

Smart metering, the rollout of which (to all residential consumers and most SMEs covering profiles 1 to 4) will be completed in 2020, will enable power factor to be closely monitored by virtue of the fact that smart meters will measure 4-quadrant flows on a half-hourly time-series basis.

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[21] A balanced voltage supply might be particularly necessary where a consumer’s installation includes three-phase motors and the presence of NPS voltages might otherwise exceed P29 limits.

[22] Power factor can be derived at the EHV and EHV/HV system level from Pi data where the necessary transducers have been installed.

[23] Devices are now available that are compatible with distribution (as opposed to transmission) networks. Note however that power electronic devices generate their own ‘losses’ (and harmonics) and these should be taken into account when evaluating their potential benefit.

2.7.6 Power quality management

Management of power quality within certain stipulated 'planning' limits / levels is both the subject of specific Engineering Recommendations and a Distribution Code (and hence Distribution Licence) requirement[24]. From a losses perspective, the two aspects of power quality that are most relevant are:

- Unbalanced or negative phase sequence (NPS) voltage
- Harmonic background levels

NPS voltages are a consequence of unbalanced load. Other important considerations are single phase connections at higher voltages, the NPS impact of which will be reflected in the lower system voltage levels leading not only to higher losses but also potential damage to electric motors which have low negative phase sequence impedance. In particular, attention should be given to the possible NPS implications of arc furnace connections and railway AC traction supplies.

2.7.6.1 Management of harmonics

As well as potentially causing interference with communication and electronic protection systems, the presence of harmonics in distribution lines and/or transformer windings will directly contribute to variable I^2R losses (as well as effectively de-rating plant and equipment[25]). Also, the presence of harmonics in transformer windings will increase hysteresis and stray losses, and especially eddy current losses which are proportional to the square of the AC frequency.

Transformers produce harmonics as a result of the non-sinusoidal nature of the AC magnetising current. However, these are generally 'triplen' harmonics (3rd, 9th, etc.) and since, in a 3-phase system, these triplen harmonics are all in phase with each other, then provided the transformer has a delta winding, the magnetising current triplen harmonics will circulate around that winding and no triplen harmonic voltages will appear in the lines of the 3-phase system.

If however, triplen harmonics are generated by devices connected to an LV network, the harmonic currents in the neutral conductor will not cancel (as with the fundamental) but will be additive, leading to additional copper losses even in a 'load-balanced' network. In LV distribution networks, the lower order (non-triplen) harmonic (e.g. 5th and 7th harmonic) background levels may already be approaching G5/4 planning limits.

Notwithstanding the localised impact of distorting loads associated with industrial processes (for example arc furnaces) the growth of compact fluorescent lighting and digital appliances, and a potential exponential trend in the take-up low carbon technologies, has the potential to increase system harmonic levels significantly. Looking to the future, the main causes of harmonics in distribution networks are expected to be:

- PV micro-generation inverters
- Electric vehicle chargers
- Heat pump soft-start systems
- Variable speed motor drives
- Switch mode power supplies (associated with personal computers and modern TVs)
- DC railway traction supplies (particularly in the SPN region which supplies part of Network Rail's extensive 600V and 750V '3rd rail' DC system)

The emergence of 'vehicle-to-grid' (V2G) systems which allow electric vehicles to export real or reactive power to the grid would create a potential further challenge in the future. Maintaining control of harmonics is essentially a 'damage limitation' exercise but effective application of G5/4 when assessing new non-linear loads to be connected to the network will provide the best opportunity for containing harmonic background levels within G5/4 limits.

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[24] In particular: G5/4, P28, and P29 (covering: harmonics, voltage fluctuation and negative phase sequence voltage planning limits respectively).

[25] Harmonics can also lead to over-voltages – i.e. due to the voltages generated by harmonic currents flowing through impedances. This can lead to equipment failures (capacitors being particularly susceptible).

2.7.6.2 Managing harmonic resonance risk

A particular avenue of concern with regard to harmonics is that of harmonic resonance. Because series impedances of higher voltage distribution networks (and transformers at all voltages) are primarily due to inductive reactance (and hence proportional to AC frequency), the higher frequencies associated with harmonic voltages means that harmonic currents are limited by proportionally higher impedances. This provides a natural barrier to excessive harmonic current levels. However, a particular condition which can arise is that of harmonic resonance which can lead to the creation of a low impedance path for harmonic currents.

This phenomenon is the result of shunt capacitance between the conductors of distribution networks. Shunt capacitance gives rise to circuit susceptance which increases with AC frequency. Hence, the higher the order of the harmonic voltage, the less capacitive reactance will be presented to harmonic currents in distribution lines. If the level of shunt capacitance is abnormally high, then a resonant condition can occur whereby, at a given frequency, the series inductive reactance and shunt capacitive reactance balance[26] and so present low overall impedance to currents at this resonant frequency. With sufficient shunt capacitance, the resonant frequency can approach that of the lower order harmonic currents resulting in high harmonic voltages and currents. Apart from high losses caused by these currents flowing through the circuit resistance, this can lead to significant voltage stressing and de-rating of plant and equipment.

In practical terms, this condition is most likely to arise with abnormally long underground cables. These may be a consequence of large scale undergrounding of overhead lines. However, an increasingly likely scenario is the laying of a long 11kV cable extension to connect a remote power station such as a wind turbine or wind farm[27].

2.7.7 Improving phase balance and load sharing on LV and HV networks

Poor phase balance gives rise to higher than necessary currents in one or more phase conductors of a cable or overhead line and hence higher than necessary I^2R losses overall. On LV networks, where balance is traditionally poor due to the lower level of ‘real-time’ demand diversity, the effect is further exacerbated due to the residual current in the neutral which gives rise to further variable losses[28].

2.7.7.1 LV underground networks

In the case of underground cables, it would be impractical and certainly not cost-justified to attempt to rebalance loads by re-jointing service cables (even assuming that sufficient information could be derived regarding individual service cable loadings). The opportunity is therefore largely limited to ensuring that for all new developments, single phase services are jointed so as to achieve the best possible balance along a given LV distributor. This is not simply a case of ensuring that a roughly equal number of services are connected to each phase. There is an optimum sequence of connection of services along the route of an LV distributor (assuming that each service will have a similar load characteristic) which can be depicted as follows: R-Y-B-Y-B-R-B-R-Y (whereupon the sequence restarts at R-Y-B and so on). This sequence of service connection should therefore be adopted for all new developments, including those installed by ICPs and, since it will have an impact on upstream losses, those installed by IDNOs too. Where multiple services are taken from a single joint, the precise sequence is obviously less critical, but the above principle should still be adhered to.

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[26] For a circuit represented by the classic T or Π equivalent circuit, resultant reactance = $\Sigma(2\pi fL - 1/2\pi fC)$ where L and C are the series inductance and shunt capacitance elements (respectively) of the circuit.

[27] A further consideration is the impact of additional shunt capacitance on 11kV Arc Suppression Coil (ASC) systems where the overall system capacitance may rise to a level beyond the tuning range of the coil.

[28] Even where load may appear balanced when averaged over a period of time (for example over a half hour period as measured by a substation maximum demand recorders or from aggregated smart meter half-hourly profiles) at a more granular level the impact of short-term loads such as electric cookers, kettles, electric showers, toasters, etc. will give rise to significant short-duration neutral currents.

2.7.7.2 LV overhead line networks

For conventional LV ‘4-wire’ overhead lines there has been a tendency in the past for load imbalance to arise due to an unequal sharing of service connections across the three phases of the line. In particular, the lower (blue) phase being conveniently close to the (bottom) neutral conductor tends to be more heavily populated with service connections. This is also potentially problematic in terms of conductor regulation since a heavily loaded blue phase conductor is more likely to sag and clash with the adjacent neutral conductor which will sag less under heavy loading, even under minor unbalanced loading conditions. Where the imbalance is dynamic, i.e. varies between conductor phases over the daily load cycle, improvements can be obtained by the use of LV balancers used in conjunction with LV voltage regulators. However, these devices are in themselves a source of losses and their use has been virtually discontinued other than as stop-gap measures pending local system reinforcement.

Where the imbalance is more constant, benefits can be achieved relatively easily by disconnecting and reconnecting overhead (or underground polymeric) services adopting the sequence described above. This action can be readily incorporated when services are transferred (or renewed) as part of an ABC reconductoring project. Given the extensive reconductoring programme which has been embarked upon in order to improve LV network storm resilience and to meet ESQCR requirements for clearances, this presents an ideal opportunity to reduce losses on LV overhead networks[29].

2.7.7.3 LV link box NOPs and renewal programmes

UK Power Networks’ condition-based LV link box renewal programme provides an opportunity for the positions of LV NOPs to be reviewed, with the prospect of improved load sharing between electrically adjacent LV feeders and substations. Smart meter data (half-hourly time-series aggregated power flow and nodal half-hourly time-series voltage data) will provide a useful indicator as to where the positions of existing LV NOPs might be suboptimal and hence where replacement link boxes might be better positioned. Addressing this opportunity will result in released capacity headroom and lower network losses.

2.7.7.4 Opportunities arising from 11kV overhead line resilience works

A characteristic of UK Power Networks’ 11kV overhead line (mechanical) resilience programme is that small cross-section (typically .025 and .04 sq. inch) copper conductors (and other non-standard material conductors such as cadmium copper, Silmalec[30] and steel) will be replaced with larger cross-section conductors; i.e. 100mm^2 ACSR (or 120mm^2 BLX)[31] for main lines and 50mm² for spurs[32].

ACSR conductors have higher tensile strength than equivalent copper conductors and, due to their lower weight, lower sag characteristics than copper conductors. They are therefore less prone to mechanical failure (e.g. due to windborne material and ice accretion) and less liable to incur tree contact due to sagging (typical under abnormal feeder loading conditions). A minor downside is that being of larger diameter than the copper equivalent conductor they have a higher wind loading which needs to be taken into account in terms of support diameters. From a losses perspective, the larger diameter also marginally reduces corona loss albeit this is not a significant consideration at 11kV. The main losses benefit arises from the fact that the larger ‘copper equivalent’ size of conductor used will have a significantly lower value of resistance than the small cross-section conductor it is replacing.

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[29] This opportunity extends also to 3-wire LV (460/230V) networks.

[30] Silmalec is an aluminium alloy which includes small quantities of silicon and magnesium.

[31] BLX uses an aluminium alloy (not ACSR) conductor. 185mm^2 BLX is also available, mainly as a 33kV option.

[32] Note: metric overhead conductor sizes - a 100mm^2 ACSR conductor has roughly the same electrical resistance as a .1 sq. inch copper conductor.

A further opportunity arising from the resilience programme is that it will afford opportunities to ensure that any phase imbalance due to the connection of single phase spurs to 3 phase lines is minimised – either by ensuring an equal sharing of single phase (two-wire) spur connections across the three phases of the main line or ideally converting single phase lines to 3-phase construction as part of the refurbishment / resilience improvement works. This does not imply that single phase transformers need be replaced; merely that they are connected so as to be shared as equally as possible across all three phases[33]. Hence, except in the case of extensive single-phase sub-networks, the conversion from single to 3-phase 11kV construction can often be achieved at a relatively small incremental cost to the resilience improvement works. Additional benefits include improved operation of arc suppression coils due to better balancing of system shunt capacitance.

2.7.7.5 Co-ordination of 11kV overhead line resilience and LV ABC works

An opportunity arising from the co-ordination of 11kV overhead line resilience and LV ABC reconductoring works is the potential for optimising the number and location of 11kV/LV transformation points. It is probable, particularly in the case of rural networks, that since the substations and LV networks were originally installed, consumer demand profiles and overall levels of demand will have changed. This in turn means that not only might the positions of LV open points be suboptimal, but also might be the numbers, sizes, and locations of (generally pole-mounted) substations serving a particular rural community.

It follows that where both 11kV overhead resilience works and LV ABC reconductoring works are planned for a given rural area there might be considerable advantage from both a losses and investment efficiency perspective (and even from a quality of supply perspective) in reviewing the positions and sizes of teed and in-line pole-mounted transformers, the degree of LV interconnection, and the positions of LV NOPs.

2.7.8 Optimising energy usage at operational sites

Whilst not generally considered in the context of ‘pure’ technical losses, energy used to operate cooling fans and pumps (i.e. for OFAF transformers) and other auxiliary energy supplies directly associated with electricity distribution (including substation heating, lighting, ABCB air compressors, tunnel cooling systems, etc.) can be considered a further source of losses in the sense that this represents energy used in the distribution of electricity[34].

In considering the possibility for reducing energy demand at operational buildings, careful consideration needs to be given to the need to continue to protect the fabric of the building and the operational equipment it houses. This is particularly relevant to indoor switchgear which may exhibit discharge leading to eventual catastrophic insulation failure in damp conditions. The use of dehumidifiers may provide a lower-energy option than heating in some cases. There may also be the potential for heat pumps to provide the low grade heat required.

A further option is to consider the possible re-use of energy (heat) emitted by operational equipment – e.g. transformer coolers at grid, main and primary substations, especially where, for other reasons, a heat exchanger is used to water-cool the transformer oil. Alternatively, there may be opportunities for exporting this heat off site, say to an adjacent commercial complex. Exactly such a system has been commissioned at Bankside substation in London, where waste heat from the system transformer cooling system is used to provide low grade heat to the adjacent Tate Modern Gallery. Whilst this will not reduce electrical losses per se, it does mean that the energy is not in fact ‘lost’ but usefully reused with consequential carbon offsetting benefits.

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[33] Note that small 3-phase transformers are inherently less tolerant of LV phase imbalance than equivalent single phase units, leading to excessive LV voltage regulation and/or thermally induced failure.

[34] Whether or not the usage is metered is academic from a carbon footprint perspective; the fact remains that this is energy used in the operational distribution of electricity and in essence is no different to other technical losses.

2.8 RIIO ED1 – smart grid approaches to losses management

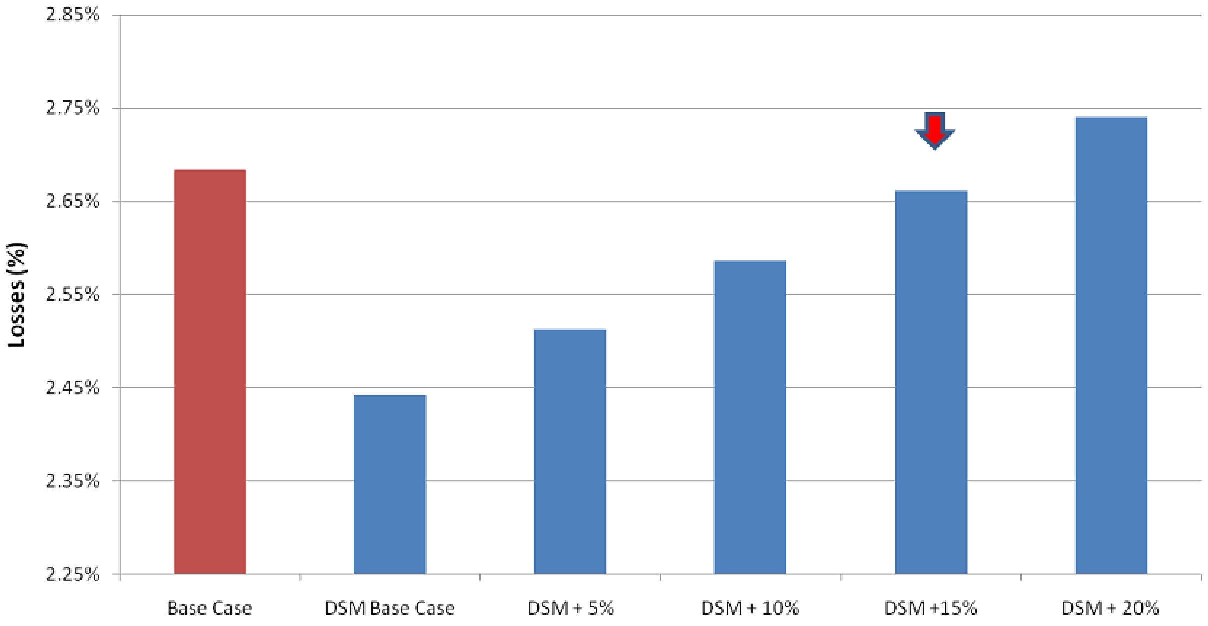
2.8.1 Demand side response

Section 2.3 above noted that there would be benefits in terms of avoided investment in capacity and reduced increases in losses if the potential increase in peak demand could be suppressed through peak-shifting - i.e. either through direct controls, intelligent autonomous controls (or smart appliances) or simply time-of-use tariff incentives to encourage consumers to avoid peak demand periods where practicable. For example, home charging of electric vehicles could generally be restricted to night-time off-peak periods (ideally excepting consumers with electric space and water heating, or served by parts of the network which are already night-peaking such as off-mains gas areas) without loss of convenience.

The potential beneficial impact of demand shifting on losses is illustrated by the following chart which is the result of a study undertaken by Imperial College London looking into the impact on future network loadings arising from electric vehicles and heat pumps and their impact on 11kV/LV transformer and LV network losses.

The chart suggests that at current levels of demand (the base case) a reduction in losses of around 0.25 percentage points at this voltage level would theoretically be possible through improving load factor through demand-side measures. The chart also suggests that, alternatively, up to a 15% increase in energy delivered, if accompanied by optimum levels of demand side management to maximise network load factors (i.e. flattening the daily demand curve), could be accommodated on existing networks whilst maintaining 11kV/LV transformer and LV network losses at current levels. It follows that the 19% increase in consumption due to electric vehicle charging and heat pumps (as described in 1.1) could theoretically be accommodated with only a relatively small increase in distribution network losses through effective demand-side measures.

In practice, Demand Side Response is not a measure that DNOs can currently implement independently of other industry parties – in particular Suppliers (in respect of domestic and SME consumers) and Commercial Aggregators (for larger industrial and commercial consumers) – without either compromising the integrity of the current electricity market and/or underutilising the potential role of demand side response in providing wider market or system benefits.



At the domestic (and to a lesser extent SME) level smart metering will provide the facility for simple or sophisticated[35] time of use (ToU) tariffs. Such tariffs incorporating adequate price incentives could be effective in reducing (or shifting) peak demand and hence improving load and loss load factor. However, for the price signal to be sufficiently strong it would need to reflect the impact of peak demand on the marginal cost of electricity production and not simply the marginal cost of electricity distribution network capacity.

The chart overleaf illustrates some early findings from the dynamic day-ahead ToU tariff trial that is being conducted as part of UK Power Networks' 'Low Carbon London' LCNF project. Some 1,100 domestic consumers are participating in the trial and each consumer has a smart meter which enables the project team to record their half-hourly time-series consumption. The tariff is a critical peak price tariff with three price bands. The price bands are not fixed to specific periods of the day; instead consumers are notified one day ahead of the prices and time bands that will apply over the following day. The charts show the averaged impact of the tariff on the electricity demand profile of the trial participants compared with a control group whose consumption patterns are monitored through the same smart metering system but who are supplied via a conventional single (or in some cases simple two-rate) tariff and are not participating in the ToU trial.

The chart provides an indication of the potential for peak demand reduction through active demand side management (noting that no smart appliances or external switching of demand is involved in the trial). The ability to reduce peak demand in this way will become increasingly important as a means of mitigating the impact of electric vehicle charging and heat pump loads on peak demand. Given that a 19% increase in electricity consumption due to electric vehicles and heart pumps could give rise to a 40% increase variable losses (Section 2.3), the benefits of effective peak demand reduction in terms of avoided investment in network capacity and reduced distribution network losses could be considerable.

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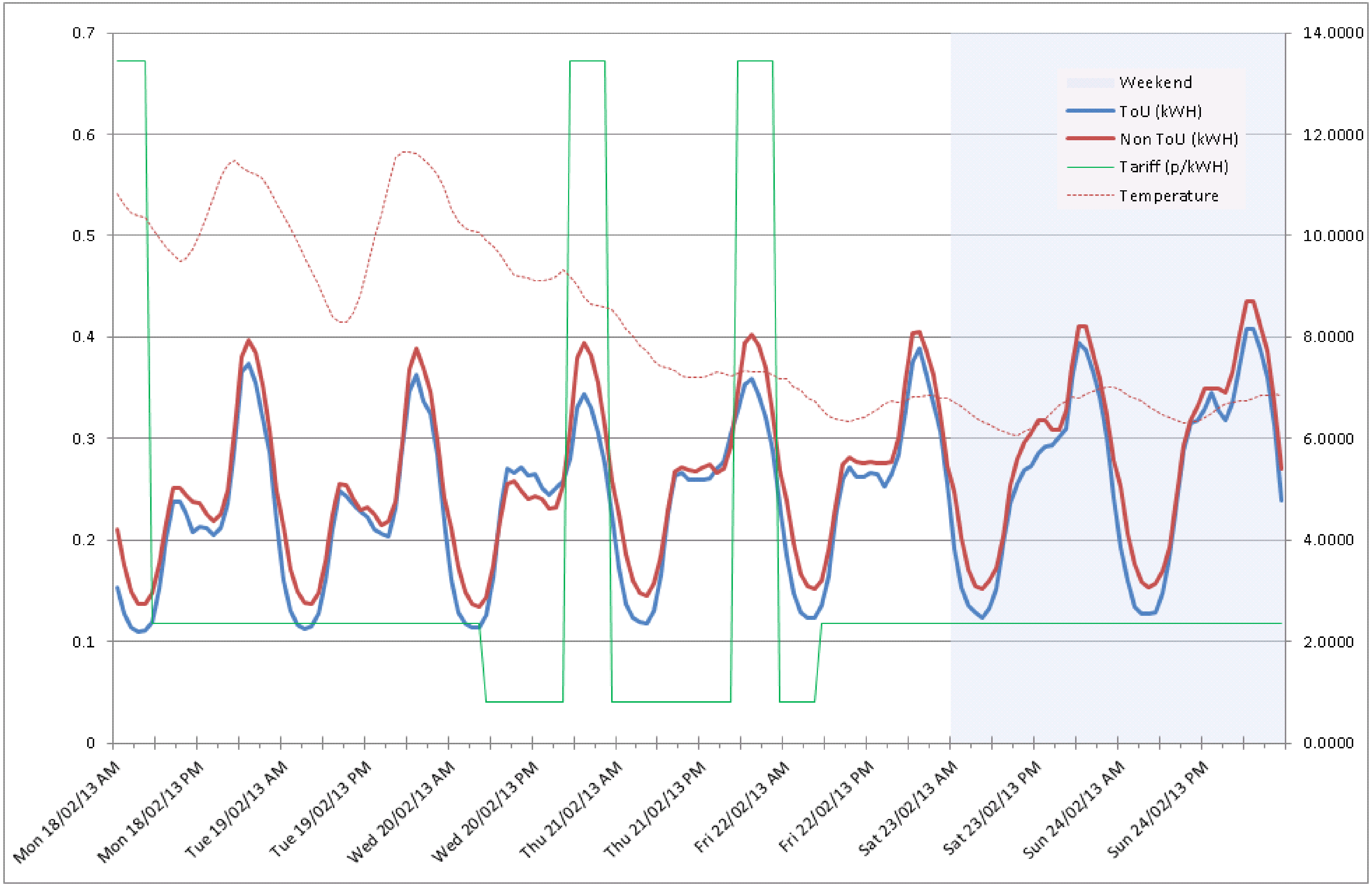
[35] A simple ToU tariff would typically have fixed price and time bands (blocks); a more sophisticated tariff might have variable (dynamic) prices or time bands with (say) day-ahead notification (dynamic tariffs would be more suited to optimising demand patterns to align with the output of intermittent generation).


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
14.0000
12.0000
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
Weekend
ToU (kWH)
Non ToU (kWH)
Tariff (p/kWH)
Temperature
Mon 18/02/13 AM
Mon 18/02/13 PM
Tue 19/02/13 AM
Tue 19/02/13 PM
Wed 20/02/13 AM
Wed 20/02/13 PM
Thu 21/02/13 AM
Thu 21/02/13 PM
Fri 22/02/13 AM
Fri 22/02/13 PM
Sat 23/02/13 AM
Sat 23/02/13 PM
Sun 24/02/13 AM
Sun 24/02/13 PM

2.8.2 Active network management

Although currently limited, there will in future be opportunities for reducing losses by optimising network running arrangements closer to real time. The following are examples of possible strategies:

- Changing normal open points on 11kV networks on a seasonal basis if there are significant differences in the natural null point between two circuits between summer and winter
- Moving open points at weekends where (say) the load on a circuit serving an industrial complex falls off significantly, whereas the load on an adjacent circuit remains constant or even increases (e.g. due to a leisure / shopping complex load)
- Optimising open points where prolonged network outages (e.g. due to major diversion works) are being undertaken (though supply security will be the primary consideration in such circumstances)
- Moving open points even closer to real time to reflect variation in outputs of distributed generators (DGs) – especially intermittent generators such as wind farms
- Converting radial networks to unit-protected which, in addition to the obvious supply security benefits, will then create a natural 'null' point on the ring obviating the need for dynamic switching of NOPs to optimise losses and/or DG export[36]
- Reviewing the strategy of placing 11kV NOPs at primary substations in order to provide rapid infeed reinforcement or restoration in the event of 33kV circuit outage (which might for example be necessary to meet the requirements of ER P2/6)[37]. Given the now wider availability of automation across the 11kV network, there might be scope for such NOPs to be placed at optimum positions from a losses perspective or switched dynamically as described above
- Switching out of single system transformers during light load periods (e.g. summertime) in order to save iron losses. This strategy of course needs to take account of the fact that copper losses on the adjacent (then more heavily loaded) transformer and transformer feeder will increase with the square of the increased current. It follows that only very lightly seasonally loaded substations are likely to present this opportunity and, even here, consideration needs to be given to the management of a number of inherent risks
- For example, it will be important to 'test' the de-energised circuit at regular intervals in order to ensure that no fault has appeared since the circuit was last energised. Experience has also shown that where a system transformer has been de-energised for some time, there is a heightened risk of a Buchholz protection operation, either as a consequence of lower (cold) oil levels or as a result of any sudden release of accumulated trapped gases in the tank which can cause a Buchholz surge operation. Not least of the issues to be considered is the increased risk of customer interruptions and possible power quality issues arising from reduced fault levels

Whilst some of the above examples may seem extreme from a traditional network management perspective, the wider installation of remotely controlled (and even automated) switchgear will greatly facilitate opportunities such as those described above. Such opportunities should be explored in conjunction with the on-going 'system management' review described in 2.4.3. In all cases, account must be taken of any additional wear and tear on switchgear that might ultimately outweigh any reduced losses benefit in financial terms. The availability of 'frequent use' switchgear (as being tested under UK Power Networks' 'Flexible Plug and Play Networks' LCNF project at 33kV) will be a key factor in the viability of adopting such a strategy.

2.8.3 DG challenges and network support

Notwithstanding the micro-generation challenges and voltage management issues outlined in 2.3, the presence of much greater levels of larger scale generation on our distribution networks (more generally connected at 11kV or 33kV) will give rise to further challenges

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[36] The null point will be determined by impedance rather than resistance, but for a typical underground unit protected ring, the X/R ratio will generally be largely constant.

[37] This will be particularly relevant to 'single transformer' sites.

For example, a current significant downside to high volumes of 11kV connected CHP plants based on conventional synchronous generation is the limited fault-level headroom on (particularly urban) 11kV networks designed to a 13.1KA (250MVA at 11kV) fault level. Parts of the central LPN network are now unable to absorb any significant additional contributions to symmetrical three-phase fault levels. The position can be exacerbated during (132kV and 66/33kV) transformer feeder outages whereupon 11kV busbars are paralleled resulting in a higher 'G74'[38] contribution and, in the case of the classic 33/11kV 4 x 15MVA configuration, a lower busbar source impedance due to the paralleling of three transformers. Fault Current Limiters (see 2.4) have the potential to resolve this issue albeit they are more easily accommodated when designed-in to the architecture of a new network rather than as a retrofit option.

Provided the voltage and fault-level management issues surrounding DG can be economically overcome, DG will provide opportunities for improved network management, including management of losses. For example, DG could help optimise power flows by achieving a better overall balance between generation and demand and hence help to flatten network demand profiles. Even where a suboptimal level of balance might cause a localised increase in losses, the overall impact might still be to reduce losses overall due to reductions in upstream power flows required to serve downstream demand. Moreover, if more of the losses are being supplied by renewable energy sources, then the overall carbon footprint of losses will be reduced. Whilst the responsibility for dispatch of generation is unlikely to fall on DNOs in the foreseeable future, this does not preclude a DNO entering into contractual relationships with DG operators to provide ancillary services such as network support or as part of an agreed curtailment arrangement.

2.8.4 New and emerging network technologies

A number of emerging network technologies have the potential to improve operational flexibility and efficiency. Some of those which have the potential to beneficially impact network losses are briefly described below. Emphasis will be given to further developing these technologies including through IFI or LCNF projects.

2.8.4.1 Fault current limiters

An opportunity that will become available in the foreseeable future is that of Fault Current Limiters (FCLs). These devices have been under development in various guises for some time and embrace a wide range of possible technologies[39]. The ideal application of these devices would be in series with bus sections / bus couplers where fault level is currently approaching plant and equipment limits or could in future approach design fault levels due to higher levels of distributed synchronous generation.

FCLs would have the advantage of maintaining the benefits of high fault levels (e.g. power quality benefits such as lower harmonic voltages and reduced voltage flicker) whilst limiting fault currents in the event of a network fault. For example, notwithstanding physical accommodation limitations, it is possible to envisage that the standard LPN 3 x 60MVA Main Substation could one day be operated with all bus sections and couplers closed (in series via FCLs) with the considerable advantage of improved busbar load sharing and network security. This in turn would be beneficial in terms of reducing network losses. An important consideration with FCLs will be to ensure continued protection operation and discrimination.

2.8.4.2 Energy storage

Given the fact that electricity cannot readily be stored in any large central pool (other than through pumped storage hydro-electric schemes such as Dinorwig and Ffestiniogg power stations) there would be clear benefits in terms both of efficient generator despatch and network capacity management if local storage schemes could be implemented to smooth load profiles and effectively improve generator and/or network load factor. Improving load factor would in turn reduce variable network losses (albeit the overall efficiency of the AC/DC/AC conversion cycle would need to be taken into account).

Storage could be in the form of demand-side devices (including heat storage) or network-connected installations. A potential application of the latter would be to balance the output of intermittent generators such as wind turbines. In terms of cost-justification, it is likely that the system balancing potential of storage in addition to losses reduction or reinforcement deferral would be a key investment driver. UK Power Networks is currently engaged with two LCNF projects exploring the potential benefits of grid-connected electrical energy storage.

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[38] ER G74 provides guidance on assessing the contribution from spinning induction motors to transient and subtransient fault currents.

[39] Is limiters are already available but concern has been expressed by the Health and Safety Executive concerning their fail-safe reliability. These devices are not currently approved.

A Li Ion based storage device at Hemsby, Norfolk will test the benefits of co-ordinated operation with a local wind farm while a larger planned installation at Leighton Buzzard[40] will enable UK Power Networks to explore ancillary market opportunities.

In both cases, the impact on losses will be monitored. For example, although the AC/DC/AC conversion losses will be not insignificant, the Leighton Buzzard device connected directly to the 11kV busbars at the primary substation eliminates the copper and iron losses that would have been incurred as a result of otherwise having to construct a third 33kV circuit and install a third 33/11kV transformer.

The power electronics associated with AC/DC/AC conversion will generally have the capability of filtering harmonics and controlling power factor, thereby potentially conferring a further losses benefit.

2.8.4.3 Soft Normal Open Points (SNOPs)

An emerging technology is that of power electronics-based ‘soft’ normal open points. These enable effective meshing of circuits and hence provide the potential for reduced variable losses[41] due to improved load sharing (subject to reasonable matching of circuit reactance) whilst retaining the quality of supply benefits of discrete protection zones. SNOPs have a potential application on both 11kV and LV networks: the latter as an alternative to radialisation of already meshed networks (for example in Central London – see 2.7.4).

2.8.4.4 Superconductivity

As discussed earlier, variable losses in conductors occur due to resistance, which varies with temperature. At absolute zero temperature, conductors would be perfect conductors, i.e. they would have zero resistance. In practical terms, superconductors are conductors which comprise compounds that exhibit very low electrical resistance at very low temperatures.

Although USA and Denmark have already installed very short ‘high-temperature’ superconducting power networks[42] as feasibility trials, wide-scale deployments of such networks will be limited in the foreseeable future by the high cost (including energy cost) and impracticality of cooling long lengths of cables to cryogenic temperatures.

The most likely future applications of superconductors from an electricity distribution perspective include:

- Superconducting magnetic energy storage systems (SMES)
- Superconducting Fault Current Limiters
- Generators, transformers and motors which would use ‘high temperature’ superconductors

Opportunities for economic deployment on distribution networks of superconducting distribution cables are likely to be limited to applications where a particularly high conductor current carrying capacity is required over a relatively short cable route length due to physical constraints in accommodating a number conventional cables to provide equivalent capacity. A further application could be where heat emissions are potentially problematic. It follows that from a UK Power Networks perspective one of the more likely applications where both of these criteria could be relevant is the use of 132kV superconducting cables in London’s cable tunnels.

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[40] ‘Hemsby Storage’ is the subject of an IFI / LCNF Tier 1 project; Leighton Buzzard is the site associated with UK Power Networks’ third LCNF Tier 2 project - ‘Smarter Network Storage’.

[41] This is subject to the network losses reduction being greater than the power conversion losses.

[42] ‘High-temperature’ superconductors are materials that exhibit superconducting properties at temperatures well above the typical range normally associated with superconductivity – e.g. typically 35K but as high as 150K.

2.9 Summary of strategic measures

It will be evident from the this chapter that the management of network technical losses is not a discrete activity; it is a function of many aspects of electrical power network engineering and management, ranging from network design, plant and equipment specifications, maintenance and testing, major project activity, new connections activity, quality control, strategic and tactical asset management (including real-time asset management), research and development, and network abnormality management. As such, the purpose of this chapter is to describe UK Power Networks' strategic framework for the efficient management of network technical losses. Nevertheless, a number of priorities are self-evident and these are briefly summarised below, cross referenced to this chapter.

Key Action	Importance / Potential	Doc. Ref.
In conjunction with regional development strategies and as part of an on-going system management review, studies will be undertaken to ascertain optimum circuit configurations and load flows.	High	2.4.3
In conjunction with major asset renewal / reinforcement programmes opportunities will be explored for beneficial circuit reconfiguration in order to both optimally distribute, and reduce the overall distances of, power flows	High	2.4.4
Opportunities will be investigated for savings in fixed and variable losses arising from voltage rationalisation associated with major asset renewal / reinforcement strategies and also as part of an on-going system management review.	High	2.4.3 2.4.4
The economic valuation of losses (including capitalised valuations) will be continuously reviewed to ensure that transformer technical specifications are optimally aligned.	High	2.7.1
The specification for the Ecodesign transformer will be adopted as soon as it is evident that market prices have stabilised and the lower capitalised losses justify any increase in purchase price.	High	2.7.1
Opportunities will be taken for economic reductions in losses arising from rationalised cable / conductor sizes and from application of 'economic' ratings as well as thermal, voltage (including flicker) and fault level considerations.	High	2.7.2
Opportunities will be taken for reductions in transformer fixed (Fe) losses arising from voltage rationalisation, and potential savings included in the economic assessment of alternatives.	Medium	2.7.3
Options for direct (132/11kV) transformation will take into consideration the potential impacts on Fe and Cu losses	Medium	2.7.3
Holistic economic assessment will be applied to the selective use of tees on 11kV networks, recognising the increased copper losses arising from 'long' loops serving downstream demand vs. the marginally enhanced CI/CML risk.	Low	2.7.3
For new LV networks (serving new developments) the value of losses will be fully reflected in the overall network design (for example comparing the marginal cost of larger csa cables and/or reduced tapering compared with the losses savings that would accrue).	High	2.7.3
In designing new networks, the impact of future penetrations of micro-generation, electric vehicles and/or heat pumps will be taken into account where the type of development might lead to such deployment. This might typically result in shorter route lengths and less 'tapering' of LV distributors.	High	2.7.3
Albeit constrained by legacy design issues, opportunities for addressing losses will be taken into consideration as part of the overall business case for updating non-standard networks.	Low	2.7.4
AVC systems will be managed in accordance with documented policies, regularly reviewing optimum 33kV and 11kV busbar voltage set points and selection of distribution transformer tap settings.	Medium	2.7.5
For LV networks, distribution transformer tap positions will be set to provide the most optimal profile that can be achieved to exploit the available statutory bandwidth of 253V - 216V. In particular, operating at the lower end of the bandwidth will generally give rise to lower losses	High	2.7.5
Voltage issues will be investigated thoroughly, identifying and addressing root causes. Smart meter functionality incorporating half hourly time-series RMS	High	2.7.5

Key Action	Importance / Potential	Doc. Ref.
voltage recordings and configurable high / low voltage alerts will greatly assist this objective		
Consideration will be given to the voltage optimising opportunities surrounding new AVC technologies (such as GenAVC and SuperTAPP n+) particularly for networks with significant Distributed Generation.	Medium	2.7.5
The use of traditional LV phase balancers and voltage regulators will be discontinued wherever practicable, especially where opportunities arise to review numbers, positions and sizes of PMTs, and positions of LV NOPs, as a result of 11kV and LV OHL resilience and ABC reconductoring works.	Low	2.7.5
The use of modern voltage regulators on 11kV overhead line and LV networks may become necessary in future as a result of the impact of DG and micro-generation on 11kV and LV feeder voltage regulation.	Medium	2.7.5
Power factor will be selectively monitored at 11kV and LV system level where Pi data is available. Instances of poor power factor will be addressed either at source (where known – e.g. through hh metering data) or through use of switched capacitors / SVCs / Stacoms (etc.) where practical and economically beneficial.	Medium	2.7.5
Monitoring power factor at more discrete 11kV and LV voltage levels may become increasingly important with the wider proliferation of DG, heat pumps, digital appliances, and low energy (CFL) light bulbs. 4-quadrant power flow data from smart meters (rollout completion scheduled for 2020) should be monitored to check for deteriorating power factor.	Medium	2.7.5
Effective power quality management has beneficial consequences for losses; in particular, ensuring as far as practical that NPS voltages do not exceed P29 limits (for example at the point of common coupling where large single phase loads are supplied).	Low	2.7.6
Steps will be taken to ensure that, as far as practicable, connections of new non-linear loads or applications involving AC/DC/AC conversion (including photovoltaic generation, electric vehicle chargers and heat pump soft start systems) do not give rise to background harmonic levels higher than those specified under G5/4 planning guidelines.	Low	2.7.6
Steps will be taken to avoid risk of harmonic resonance, in particular due to rural 11kV undergrounding projects and long 11kV underground cable extensions to serve DG installations.	Low	2.7.6
All newly installed LV networks (including those installed by IDNOs and ICPs, particularly those served from our LV networks or distribution transformers) will be balanced in terms of evenly phase-distributed service connections.	High	2.7.7
Opportunities will be taken to improve LV network load balance during renewal works – e.g. by ensuring evenly phase-distributed service connections during ABC reconductoring and LV overhead line service renewal programmes.	High	2.7.7
In conjunction with LV link box renewal programmes, opportunities will be taken to assess the optimum positions of link boxes and NOPs to optimise power sharing and hence losses	High	2.7.7
Opportunities will be taken during 11kV OHL resilience works to economically upgrade single phase (2-wire) spurs to 3 phase and achieve equal phase distribution of connected single-phase transformers and any 2-wire sub-spurs.	Medium	2.7.7
Particularly where LV ABC and 11kV OHL resilience works are planned for the same area, the numbers, positions and sizes of Pole Mounted Transformers will be reviewed, as will the degree of LV interconnection and positions of LV NOPs.	Medium	2.7.7
Energy usage at operational sites will be optimised and opportunities for economic export of waste heat explored	Medium	2.7.8
Emphasis will be given to cross-industry initiatives aimed at developing attractive demand side management and response products.	High	2.8.1
Consideration will be given to opportunities surrounding active network management to optimise normal running arrangements with respect to losses, without significantly compromising CI/CML performance. Subject to risk assessment, this will include opportunities for de-energising system transformers	Medium	2.8.2

Key Action	Importance / Potential	Doc. Ref.
during periods of light load.		
Consideration will be given to applying automated / remote control dynamic switching solutions to optimise losses (and optimise circuit utilisation) in real time.	Medium	2.8.2
There will be a continuous review of opportunities for losses optimisation arising from the increasing penetration of DG, and the evolution of active network architecture.	Medium	2.8.3
Emphasis will be given to developing new network technologies which have the potential to improve network operational flexibility and efficiency (including lower losses). Examples include fault current limiters, superconducting cables, energy storage systems and power electronics based devices such as Stacoms and Smart Normal Open Points	Medium	2.8.4

3 Electricity theft

3.1 Executive summary

UK Power Networks is determined to actively tackle theft of electricity from its distribution networks. Our actions, whether direct or through the provision of services to suppliers, help ensure that we operate efficiently and avoid honest consumers 'picking up the tab'. Reducing theft also helps protect our customers from dangerous situations, disrupts criminal drug production and serves to promote energy efficiency.

In the RIIO-ED1 period we will be focusing on three key areas:

Theft from Suppliers

These are situations where the premises have a supplier appointed but the occupier seeks to avoid charges by tampering with their meter, installing hidden bypasses or connecting directly to the cut-out.

Our Key Commitments:

- In RIIO-ED1 we will continue to offer a Revenue Protection Service that will collate leads, carry out investigations and provide comprehensive reporting
- UK Power Networks will develop and implement arrangements to incentivise the reporting of possible theft
- All activity will be in accordance with industry Codes of Practice

This service will be offered to all suppliers and funded by a full cost recharge to suppliers taking up the service.

Theft in Conveyance

These are situations where there is no supplier associated with the premise. Illegal services are installed or legitimate services are energised with direct-to-main connections or false meters.

Our Key Commitments:

- In RIIO-ED1 we intend to develop new and innovative techniques for the identification of theft cases
- Heading into the ED1 period we will maintain and refine our detailed analysis of cases to best understand trends and focus targeting
- We plan to build upon our experience in previous theft and data management activities
- As UK Power Networks transitions to Ordnance Survey's "AddressPoint" standard it will be possible to cross-reference missing premises
- A combination of office-based investigations coupled with a programme of site visits will serve to identify rogue connections
- We plan further use of distributor's statutory powers whereby customers are routinely charged for the electricity assessed as stolen
- We wish to explore opportunities to prosecute selected cases to provide a stronger deterrent effect

It is anticipated that only limited sums will be recovered from customers so this activity will require part-funding through DUoS.

Under-declaration of Unmetered Supplies

Certain items such as streetlights, advertising hoardings and cable TV infrastructure are not individually metered since they represent modest and predictable loads. Energy bills are based upon the declared inventory of equipment connected to our network and electricity may be “lost” where the customer unintentionally loses track of what’s installed.

Our Key Commitment:

- In RIIO-ED1 we plan to conduct physical on-street audits together with accompanying desktop analysis to ensure that customers tender data that meets expected standards and fully covers the electricity they consume

There is scope to recover some money from customers but it’s unlikely to cover all costs. The net costs will require funding through DUoS.

UK Power Networks believes that policies to address theft must be fair, consistent and encompass all customers and circumstances encountered. Those choosing to steal electricity must have a real expectation of detection and face genuine costs and penalties when that occurs. In tackling Theft in Conveyance we will be mindful of vulnerability issues and people’s ability to pay in the way we approach the resolution of instances of theft. However on-going abstraction, whether deliberate or accidental, is to the detriment of every legitimate customer and thus theft-related activities must be suitably recognised and funded.

3.2 Introduction

This chapter provides a high level summary of UK Power Networks proposed strategy for countering electricity theft in the ED1 period. Within the electricity industry theft related activities are generally referred to as Revenue Protection (RP) and this terminology is used in the chapter.

Levels of electricity theft in the UK do not compare with the endemic proportions encountered in some developing economies. It's nevertheless something that UK Power Networks needs to actively tackle, in conjunction with other parties, in order to fulfil its current obligation *"to develop and maintain an efficient, co-ordinated and economical system of electricity distribution"*.[43] Undetected theft adds to the costs borne by legitimate consumers and, with little incentive to be energy-efficient, such individuals may also use far more electricity than normal contributing to environmental concerns.

In its March 2013 strategy decision on RIIO-ED1, Ofgem determined that they would create new obligations for tackling electricity theft outside of the losses reduction mechanism and in addition to the general duty. There were three strands to the decision:

- Ofgem proposed to amend the Standard Licence Conditions of the Distribution Licence to require DNOs to tackle theft where a supplier is "not responsible"
- Ofgem indicated that they expected suppliers and DNOs to implement measures for tackling theft through the existing industry code governance arrangements over and above the baseline regulatory obligation
- Ofgem required that prior to implementing their revised approach DNOs were expected to maintain their current levels of activity in identifying and resolving unregistered premises

In addition to this there are risks stemming from the potential for poorly installed wiring to create dangerous situations. Such activity constitutes a criminal offence and where electricity is stolen for cannabis production such theft is supporting organised criminal networks. Instances of theft involving DNOs can be divided into several broad categories.

3.2.1 Theft from suppliers

This covers circa 90% of the currently identified theft cases on our network. These are cases where electricity is stolen and consumed at a premise for which a supplier is appointed. Typical methods include mechanically tampering with the meter to cause under-recording, the use of switched neutral arrangement to prevent units being accrued, utilising a false powerkey or wholly bypassing the meter and tapping either the cut-out, the incoming service cable or a passing main.

3.2.2 Theft in conveyance

This covers cases where electricity is taken at a premise for which no registered MPAN exists. It's typically via a legitimately installed service for which no supplier has been appointed (either connected direct-to-main or with the installation of a 'false' meter) or via wholly illegal connections made by parties known or unknown.

3.2.3 Under recording of unmetered supplies

These represent a final category of connections which, whilst not necessarily outright theft, can nevertheless be a source of loss from our distribution networks. Unmetered Supplies are permitted for various types of street furniture with modest and predictable loads for which it is uneconomic to install individual meters. Examples include streetlights, traffic signals, bus shelters and CCTV cameras. The customers are required to maintain accurate inventories and report these regularly to the DNO in its role as the Unmetered Supplies Operator (UMSO). The UMSO then calculates the annual consumption on the basis of this information. Losses would typically stem from accidental under-reporting where customers lose track of what is fitted although in rare cases deliberate under-reporting may occur to minimise electricity bills. Whilst Unmetered Supplies account for less than 2% of total electricity consumption the reliance on record-keeping by customers does create a greater propensity for mistakes to occur.

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[43] Electricity Act 1989 Section 9.

3.2.4 Current theft statistics

The tables below show actual performance over the last three years with ‘successful investigations’ being those where a field visit has taken place, theft established, and evidence gathered and a report compiled. There is a clear trend of increased numbers of Domestic and Commercial cases with the latter virtually doubling over the period. Whilst Cannabis cases have edged downwards the overall trend is very much up. Average assessments of stolen units have declined slightly for Domestic and Commercial but very notably for Cannabis sites. This is thought to reflect production trends towards smaller ‘grows’ in residential premises but may also reflect the sites being identified more quickly.

		2010-11	2011-12	2012-13
Successful Investigations	Domestic	3,297	3,768	4,012
	Commercial	427	602	811
	Cannabis	861	719	637
		4,585	5,089	5,460

		2010-11	2011-12	2012-13
Units Assessed (GWh)	Domestic	38	36	37
	Commercial	42	53	51
	Cannabis	65	37	23
		145	126	111

		2010-11	2011-12	2012-13
Average Assessment per Investigation (kWh)	Domestic	11,581	9,447	9,227
	Commercial	99,193	88,024	63,326
	Cannabis	75,264	51,493	35,810

Looking ahead we anticipate that successful cases will remain around the 5,500 level.

3.3 Interaction with wider industry developments

Ofgem is presently sponsoring a raft of industry improvements concerned with tackling theft in both gas and electricity, including changes to Licence Conditions, the establishment of gas and electricity Theft Risk Assessment Services (TRAS) and potential supplier incentive mechanisms. In parallel a DCUSA Working Group[44], including UK Power Networks representation, is reviewing and updating the Electricity Revenue Protection Code of Practice. This will set minimum standards for theft investigations and, more importantly, outline industry best practice. UK Power Networks will operate any Revenue Protection activities in line with this Code.

UK Power Networks will work with Ofgem and other industry parties in developing and implementing wider improvements to tackling theft. Some of the decisions on the industry mechanisms will affect and re-direct our company strategy.

An example of this is incentive mechanisms to reward and encourage the reporting of possible theft. We consider this an essential element and the best solution may be a national “Crimestoppers” style approach (perhaps TRAS led or administered) funded by all parties. However, if such a scheme was either not developed by the industry or was proposed but rejected under industry governance then UK Power Networks would develop and implement a standalone scheme covering our network areas.

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[44] Distribution Connection and Use of System Agreement Change Proposal No. 054.

There are both similarities and differences in the approach required to tackling each of the three types of theft we have identified because of the different parties involved. Theft from Suppliers and Unmetered Supplies both involve suppliers and registered customers but require different approaches because of the different Settlement arrangements and the involvement of the UMSO. Theft in Conveyance does not directly involve suppliers although they pick up the resulting Settlement error and ultimately pass it back to customers in the same manner as any other Settlement error arising. This paper will now explore our strategy for these three areas in more detail.

3.4 Theft from suppliers

In the interests of tackling this category of theft UK Power Networks has for many years provided a regional Revenue Protection service which continues to be utilised in full by the majority of suppliers. This presents an efficient procurement option and is particularly essential for smaller suppliers or those with limited market-share in particular regions who might otherwise struggle to make appropriate Revenue Protection arrangements. Indeed, even amongst the minority of suppliers who have ‘opted out’ and chosen to organise their own Revenue Protection activities some continue to rely on UK Power Networks for difficult cases or immediate ‘make safe’ situations.

3.4.1 Our revenue protection service

Our Revenue Protection offering includes a full end-to-end service compliant with the current Code of Practice with both a substantial, highly-trained field force and an extensive back-office support unit. The operation of this service is briefly summarised below.

The RP service acts as a regional hub for the receiving and processing of leads indicating possible theft of electricity in progress. These can arrive from a variety of sources including leads called in by Police, local authority personnel, meter readers and members of the public or generated through their own proactive investigations. Leads are firstly risk assessed and then sorted into those to be actioned by UK Power Networks or those to be passed to suppliers who use alternate RP service providers.

The risk assessment considers whether there is evidence of a potential safety hazard on site (so it requires a priority call), whether there is likely to be theft occurring (not all leads can justify a field investigation), whether it is likely to be safe for the RP Officer to carry out work (individually, as a team or with attendance of the police) and whether any alternate service provider will not be able to attend a safety case within the time required in the Code of Practice[45].

A field investigation will then be conducted which may involve liaising with Police and other agents such as Meter Operators, locksmiths, dog handlers, etc. It may also require attending court for warrant applications and executing warrants. The RP service will make safe any dangerous situations it comes across in conjunction with the investigation. Field investigations span all premise types from flats and houses to commercial offices, shops, factories, caravans and non-postal pillars, cabinets and compounds.

A field report is completed and sent to the supplier for each investigation analysing what has occurred. If theft has taken place it will include assessments of the volume of electricity that has been abstracted and who is responsible together with evidence such as photographs to support the case. Other physical evidence such as meters subject to interference are collected and retained in accordance with the Police & Criminal Evidence Act should they be required later in court.

This provides the suppliers with all the facts to help them resolve the situation. In many cases the Revenue Protection staff will, in addition to ensuring that everything is made safe, further assist the supplier by immediately fitting a new meter. Depending on the type and severity of interference encountered this may be important in ensuring that the customer remains on supply. Alternatively, if the supplier prefers we will refer the job back to them to arrange for their Meter Operator to fit a new meter.

During the 2012-13 year our Revenue Protection service conducted 8,500 field investigations with 5,500 theft instances discovered. As demonstrated by the images below (showing the distribution by electoral wards) successful cases are heavily London-centric. The following image provides a magnified view of the Greater London region.

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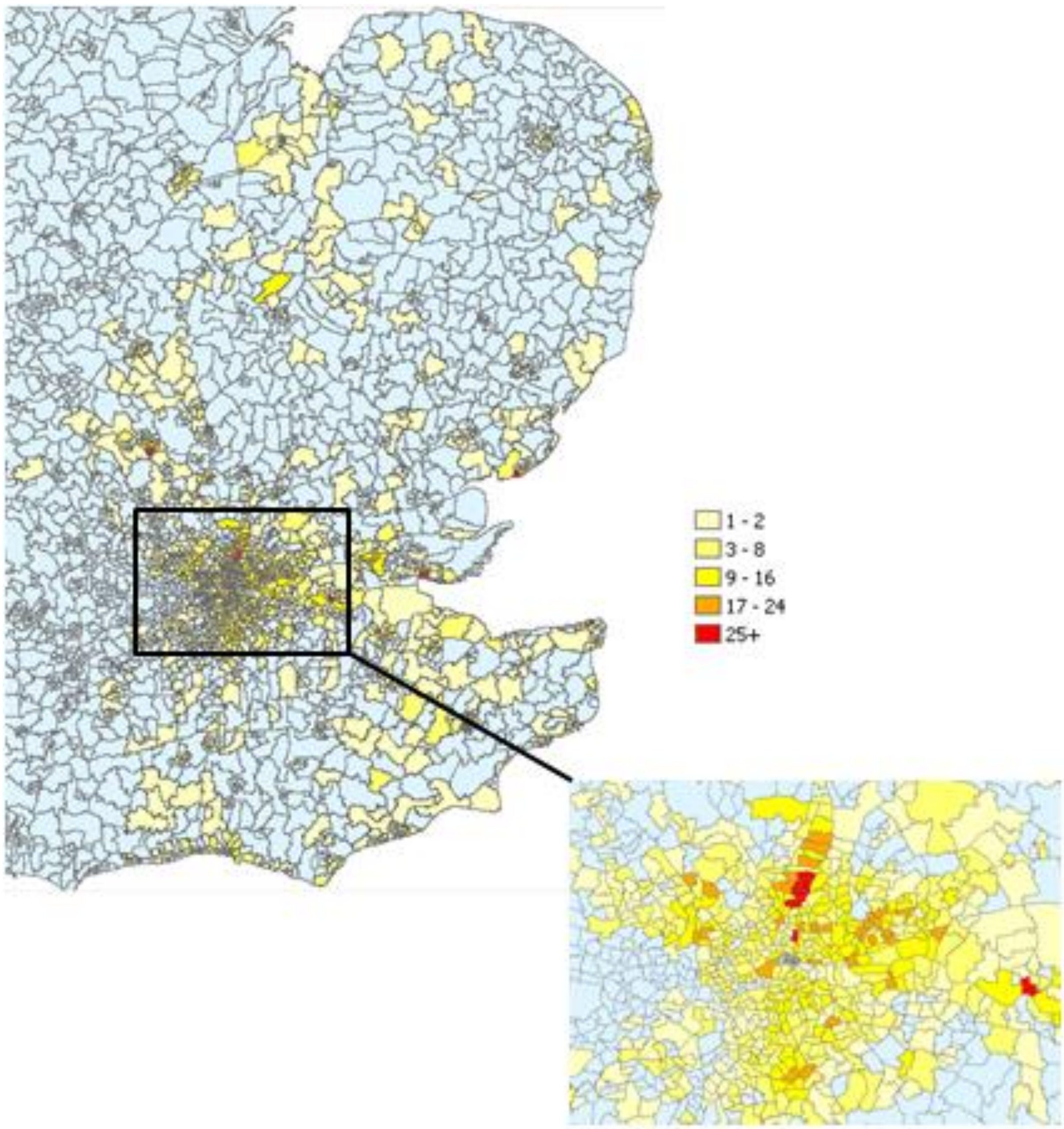
[45] UK Power Network operates a 24 hour a day 365 days a year service, not all service providers do so.



3.4.2 The RIIO-ED1 period

In RIIO-ED1, recognising our unique position as network operator, we shall continue to offer this regional RPU service. There are always likely to be some suppliers for whom alternative arrangements are unrealistic and we are committed to facilitating their adherence to their Revenue Protection obligations via the provision of this comprehensive and high-quality service.

We expect the current levels of Revenue Protection activities will need to be maintained throughout the ED1 period. Whilst we will work to eradicate theft wherever possible it is inevitable that innovation within the criminal community will bring fresh challenges in keeping overall theft levels under control. The planned incentive arrangements should serve to encourage suppliers to tackle theft amongst their customer base by providing a real financial benefit. Whilst a ‘moral obligation’ has generally seen suppliers authorising investigations where reasonable suspicions exist Ofgem’s proposed arrangements can engender a more fundamental change of mindset and approach.

3.5 Theft in conveyance

Cases where there is no registered supplier are subject to the same lead mechanisms with third parties (the police, councils, etc.) unaware whether a particular suspicious premise will involve a supplier or not. These leads are analysed and investigated by our Revenue Protection service in exactly the same manner as normal supplier cases with a mixture of proactive and reactive visits to premises of all types. Some situations are adjudged sufficiently unsafe that supplies are promptly de-energised by the Revenue Protection officers but a majority present no immediate risks and are left on-supply. The completed report is then forwarded to UK Power Networks for further action and resolution.

3.5.1 New lead generation techniques

In RIIO-ED1 we intend to develop new and innovative techniques for the identification of theft to operate in addition to the leads directly generated by our Revenue Protection service. Our thinking is already being influenced by recently instigated improvements in the statistical data we collect. This is helpful in assessing the sorts of premises that are more likely to harbour theft cases and it is teaching us the most likely techniques to be employed (e.g. genuine meters obtained from other premises installed on illegal connections such that nothing looks obviously wrong to the casual observer). We are also able to analyse geographical patterns via Geographic Information Systems (GIS) and even at this early stage we are seeing significant concentrations in particular areas. It is our intention to maintain and further develop such analysis.

A number of sources of potential leads have been identified and going forward we intend to undertake significant work to develop lead generation approaches and to assess the ‘hit-rates’ generated by each technique and how best those ‘hit-rates’ may be maximised.

Ordnance survey ‘addresspoint’ matching

As UK Power Networks transitions to mapping to Ordnance Survey’s “AddressPoint” standard it should prove increasingly feasible to cross-reference data searching for premises lacking Meter Point Administration Numbers (MPANs) via the Unique Property Reference Number (UPRN). Almost any recognised address should have a matching MPAN and any that don’t warrant further investigation.

Multiple occupancy sites

Ordnance Survey’s datasets highlight premises which are subdivided into two or more separate dwellings. In higher-risk Post Code zones (as evidenced from our historical data) it is potentially feasible to manually compare OS data, Royal Mail Data and Council Tax records with our own MPAN listings. This will serve to highlight properties lacking MPANs. It’s significantly more manually intensive than routine address-matching but, if conducted in the right areas based on good intelligence, should prove effective relative to the resource employed. In some cases there may be a communal supply but the remainder will constitute high-quality leads and it will be sensible to conduct a site visit in order to assess the situation.

Unaccepted new connection quotations

Every year UK Power Networks provides detailed quotations for new connections which are not taken up. Some projects may simply not have progressed and some may latterly be delivered via Independent Connection Providers or constructed as Independent Distribution Networks. However, anecdotal evidence suggests that a proportion of those jobs do indeed take place but via unauthorised, third-party contractors. A combination of office-based investigations coupled with a programme of site visits will serve to identify rogue connections.

Connection types warranting enhanced checks

We also plan to build upon our experience in previous theft and data management activities to focus not just on specific leads but rather those broader types of connection that traditionally cause more trouble and incur greater incidences of unregistered services. Further exploration will be necessary but certain targets have already been identified:

a) Shopping centres / Industrial estates with their continual redevelopments and re-numbering of units present opportunities for enhanced checks. Where desktop activities reveal apparent shortfalls in expected MPANs then site visits will be undertaken to investigate the actual network connectivity situation

b) Supplies to feeder pillars whether for such purposes as large advertising hoardings or electric vehicle charging present increased risks of direct-to-main connections. This may stem from a misplaced belief that anything on the highway may be ‘unmetered’ in the manner of regular street lighting columns for which special arrangements exist to pay for the energy consumed

c) Landlords' supplies have a disproportionate propensity to be improperly connected and constitute Theft in Conveyance. These tend to serve lighting in stairways and other communal areas such as car parks and bin stores together with lifts and electronic entry systems. In the case of converted properties landlord supplies may sometimes borrow the service cable for the original property, the MPAN for which has been logically disconnected. In the case of new build they may borrow what was a Temporary Builders Supply for which the MPAN has been similarly logically disconnected. In most cases the landlord is discharging their responsibilities through a succession of managing agents and in such circumstances it is unlikely that anyone will query the absence of electricity bills

3.5.2 Resolution options

As a Distribution Network Operator we are more restricted than our supplier counterparts in what we can do to resolve these cases. UK Power Networks does not itself have a supply agreement with the customer and nor can it seek to establish such arrangement on their behalf as this step is wholly at the volition of the customer. The installation of a prepayment meter (a universally popular option for suppliers) also falls outside of the distributor's remit. Meanwhile, provided that the cabling is safe, then a policy of immediate de-energisation is not clearly permitted for under relevant legislation. In any event this could affect homes occupied by vulnerable persons and others who may be largely blameless with their landlord having been the instigator of the deception.

UK Power Networks has traditionally opted to provide its Revenue Protection service with a suite of template letters specific to the circumstances they encounter on-site. These lay out what has been discovered, what the customer needs to do to legitimise their supply and the possible implications if they fail to do so in clear, easy-to-understand language. We aim to further improve and strengthen these controls. Such revised policies are already the subject of early-stage discussions particularly with regard to how customers will be encouraged to comply with requests to rectify the situation and settle sums owed.

We will be looking at the necessary resourcing implications and assessing how that is most economically and effectively delivered. In addition to our Revenue Protection service we have hundreds of highly trained individuals across our business who have the skills to conduct technical and safety assessments on-site. We also have the operational staff able to effect more complex de-energisation (e.g. by the removal of the fuse carrier and heat-shrink wrapping of the conductors) or full disconnection via the permanent below-ground termination of the supply cable in appropriate circumstances.

3.5.3 Development of deterrent mechanisms

At present there is little deterrent to the theft of electricity. There is some confidence around not getting caught and only limited penalties and sanctions if the worst happens. Detecting and publicising a greater volume of cases will provide some warning to those engaged in these activities. We will also use our powers under Schedule 6, Paragraph 4 of the Electricity Act whereby customers are routinely required to pay for consumption assessed as having been stolen together with the costs of the investigation.

We will also explore the opportunity to actively prosecute certain cases – something that is rarely attempted either by distributors or suppliers. This will place great demands in terms of evidence-gathering and associated administration but once processes are established and refined it will be easier to prosecute further deserving cases subsequently. The key factor will be ensuring that prosecutions are suitably publicised demonstrating that theft is not a risk-free choice and providing some measure of deterrent. We would seek to make use of our website, arrange for our Press Team to place stories in the local and regional press and engage with trade associations such as the UK Revenue Protection Association.

3.6 Unmetered supplies

UK Power Networks has undertaken a series of physical audits on large unmetered supply customers. These all showed an under-recording of true consumption and in several cases uncovered very significant shortfalls. In addition to inventory rectification works by the specific auditees the knowledge of such checks taking place prompted many other customers to ‘get their house in order’ in possible anticipation of being ‘next on the list’. The audits thus have a very positive impact on improving the accuracy of energy allocation for unmetered supplies generally.

Our actions led to a series of meetings between representatives of distribution businesses and representatives of customer organisations. The result was a ‘Best Practice’ document covering both inventorisation standards by customers and audit approaches by distribution companies. This was widely endorsed by Elexon, The Electricity Networks Organisation, The Institute of Lighting Professionals and The Association of Directors of Environment, Transport & Planning. It provides an excellent framework for future audits which can be clearly understood by all concerned.

We intend to continue with a programme of physical on-street audits of unmetered supply inventories. These may include both random checks of larger customers and targeted checks of any customers where analysis via desktop and GIS resources suggests potential problems. Audits may also be employed against customers who routinely and consistently fail to provide inventory updates despite repeated requests.

3.7 Funding countering-theft activities

The provision of our regional Revenue Protection service for suppliers will continue to be operated on a cost-neutral basis. We would set our ES5 Revenue Protection charges to suppliers consistent with our internal and external costs of providing the service. There is obviously scope over the eight-year span of the ED1 period for volumes to change both on an underlying basis and through changes in supplier's policies for tacking theft. Factors such as the aforementioned TRAS and the mass-rollout of Smart Meters can also be expected to have some impact. The intended pricing structure will ensure that any actual variation in the take up of our services will result in a parallel variance in costs and Excluded Services Revenue and so be cost neutral to Customers.

UK Power Networks anticipates that that it will need to spend an average of 15p per customer per annum during the ED1 period to deliver the Theft in Conveyance and UMS actions proposed by this strategy (net of costs recovered from offending parties). We consider that this reflects very favourably against industry estimates that theft adds £15[46] to the average customer's electricity bill each year. Our modelling forecasts that this will equate to around £1000 per case investigated or £1500 per case successfully resolved. A successful case may be defined as one where past theft has been confirmed but actions taken to stop further recurrence.

An average Theft in Conveyance case identifies annual theft of around 12,000 kWh. On this annualised basis the wider customer base sees payback benefit within a one year period as set out below. It must also be recognised that without substantive activity on our part and with no supplier involved such theft will otherwise likely persist for an indefinite period accruing 12,000 kWh year-on-year.

Average Cost Per Successful Case	**£1,500**
Average Theft EAC (kWh)	12,000
Assumed market value of each kWh	14p
Market 'Payback' Period (Years)	0.9

Industry experience is that the costs of tackling theft typically exceed the value recovered thus making countering theft a net direct cost to industry parties. The indirect value of a deterrent effect may partially offset this but is difficult to quantify. In its wide ranging proposals for improving the tackling of energy theft Ofgem have acknowledged this commercial disincentive and is proposing incentive funding arrangements for suppliers in both gas and electricity.

For the reasons already expressed it will be important to attempt to recover monies from customers identified as having committed Theft in Conveyance. The receipt of an invoice issued under Schedule 6 detailing the value of electricity assessed as stolen together with the reasonable costs of investigation serves as a form of penalty and deterrent. This is all the more important when considering that we will generally seek to avoid taking people off supply unless safety concerns come into play. In practice we would expect that perhaps only two thirds of successful cases will be invoiceable and even if pitched conservatively we estimate that on average less than half of the sums invoiced will actually be recovered.

The complications will be numerous and wide-ranging. There are likely to be disputes between landlords and tenants as to responsibility, particularly in terms of 'electricity being included within the rent' within house-flat conversions and even where such arrangements aren't claimed the party responsible for the original illegality (e.g. installation of a false meter). Landlords may be difficult to trace with many discharging affairs through the numerous unregulated lettings agencies which have burgeoned in the past decade. Such agencies have frequently proved unwilling to release names and addresses of the landlords whom they represent. Tenants in such premises are more likely to be transient with short tenancies and frequent turnover reducing the timescales for which payment may be demanded. A significant proportion of tenants may qualify as vulnerable in terms of income, apparent poverty or other factors and some may find it more difficult to understand proceedings on account of English not being their first language. Premises where cannabis cultivation has taken place and criminal prosecutions are on-going are unlikely to offer realistic prospects of financial recovery. Even where there is full clarity as to the party responsible and no obvious factors to claim as mitigation we would not anticipate a likely willingness to pay. Coupled with all of the above distributors lack the established debt-recovery arrangements, experience and personnel which are a fundamental part of a supplier's daily operations.

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[46] Estimate of GB Theft, £400m (UK Revenue Protection Association, 2012).

UK Power Networks forecasts significant effort and resources in resolving Theft in Conveyance cases. Beyond the initial investigation by our Revenue Protection service we may need to dispatch engineers to assess safety aspects and conduct more thorough inspections of services, especially where adapted or extended by third party contractors as part of building conversions. In some circumstances, whether in order to maintain supply to vulnerable persons or where culpability cannot be established, we may have to repair damaged services without any prospect of recovering the costs associated. The next steps will involve significant administration and correspondence with the customer which may be complicated by a variety of factors including denial, evasion and attempts to offload responsibility onto other persons. In addition to postal and telephone contact further visits in person may be needed to expedite progress. As previously mentioned some customers may have a poor command of English and potentially require translation services with others in straightened financial circumstances wishing to seek assistance from charitable bodies or local authorities with whom we may need to engage. Each case will be genuinely individual and few are anticipated to prove straightforward. With the ultimate sanction of disconnection avoided wherever possible, and particularly in domestic situations, cases are likely to take lengthy periods to conclude.

In terms of forecasting the costs of operating the proposed anti-theft strategy, we anticipate that we will spend around £600k per annum on field investigations initiated both by third party notifications and by leads generated from within the office based analysis team. We anticipate a further £100k per annum to be spent on unmetered supplies audit programme. Office costs cover a wide range of activities including the implementation of the lead generation techniques and the significant effort to effectively apply the resolution techniques outlined in this strategy together with more traditional back office support of the field operation. We also anticipate that we will incur costs from undertaking safety resolution and disconnection work and legal costs in pursuing compensation from offending parties. These are summarised in the table below.

Costs (£k)	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**20/21**	**21/22**	**22/23**
Field operations – theft	600	600	600	600	600	600	600	600
Field operations - UMS audits	100	100	100	100	100	100	100	100
Office investigation & follow up	500	500	500	500	500	500	500	500
Other	200	200	200	200	200	200	200	200
Total	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400

Taking into account the issues with cost recovery described above we forecast income recovery from third parties of £200k per annum across ED1. Implementation of the strategy will therefore require funding of the gap through DUoS. This will be £1.2m per annum or the approximately 15p per customer described above.

Revenue (£k)	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**20/21**	**21/22**	**22/23**
Recovered from third parties	200	200	200	200	200	200	200	200
Funded through DUoS	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Total	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400

The above tables exclude income & costs for work undertaken at the request of suppliers. As previously stated such work is forecast to be undertaken on a full cost recovery basis.

3.8 Conclusions

A regional Revenue Protection service provides a ready means for suppliers to fulfil their responsibilities permits a central resource for the management of leads and offers the scale and volume to really understand what is happening on our distribution networks. At the same time it in no way precludes those Suppliers who choose to make their own direct arrangements whether for some or all cases involving their customers. Mechanisms and processes to transfer leads and hand off 'make safe' cases are already well-established. With our current pricing model this service can be provided on a transactionally funded basis with no impact on our Allowed Revenue.

UK Power Networks believes that policies to address Theft in Conveyance must be fair, consistent and encompass all customers and circumstances encountered. They must ensure that those still choosing to steal electricity have a realistic expectation of detection and face genuine costs and penalties when that occurs. Customers, particularly at the more vulnerable end of the spectrum, must be provided all reasonable assistance in legitimising their supplies and there must be due consideration of their means to pay. However, long-term consumption outside of normal industry Settlement arrangements cannot be tolerated. Whilst the focus must be on metered supplies the unmetered customer base remains a small but relevant sector to encompass within an anti-theft programme.

UK Power Networks must be adequately funded and rewarded for its activities in detecting, resolving and deterring electricity theft recognising the substantial benefits ultimately accruing to customers in the form of lower bills, enhanced electrical safety and the disruption of criminal activities.