Strategy for losses

February 2018, version 2.1

Northern Powergrid's Approach to Energy System Losses

No system can be 100% efficient and electricity networks are no different. The losses on an electricity network are made up of fixed losses, variable load losses and also theft from the network. Northern Powergrid naturally seek to minimise losses where is it economic to do so and this report sets out to our customers and stakeholders how we plan minimise losses.

Making decisions which change network losses in isolation from other aspects of technical and economic performance is seldom achievable. The electricity system is complex and different parameters are interrelated within a given network and across network and operator boundaries. Losses on distribution networks are a major component of the overall losses within the UK's energy system but because of this whole system interrelationship Northern Powergrid recognises that management of losses should not just be limited to consideration of its distribution network but should involve a system wide perspective, taking into account actors in the rest of the electricity network.

This is important because the transition to a low carbon economy involving the electrification of transport and heat has the potential to increase system losses as network equipment is more highly utilised. Any such increase needs to be weighed against the carbon reduction benefit arising from this transition. The move towards a distribution system operator role may offer market based and smarter solution based opportunities to manage losses, and will be facilitated by better losses visibility and more potential for losses control, for example maximizing the ability of zero-carbon generators to dispatch. Such solutions themselves may involve local increases in losses but again deliver a net carbon reduction benefit. Conversely a smarter flexible energy system with large amounts of distributed generation offers the prospect to actively manage power flow to minimise the need to move power over long distances. Whole system thinking will be important so that overall benefits maximised and costs minimised across the energy system. Northern Powergrid believes losses management is not only about reducing losses, but also includes taking account of the financial and carbon cost of losses to our customers being factored into any new and smarter solutions, be they technical or market based. In this fast changing environment, Northern Powergrid has adopted an approach of fully integrating this whole system understanding of losses within all its Asset Management decision making and planning processes.

Against a backdrop of increased consumption and complexity, Northern Powergrid defines its losses philosophy as "a whole system approach that ensures network decisions are made using techno-economic analysis so that losses are appropriately valued to provide best aggregate benefit to customers in carbon reduction as well as economic terms."

Guidance for the reader

The purpose of this document

This document describes the processes, technologies and engineering solutions that we are adopting in the 2015-23 period to ensure electrical losses on our system are as low as reasonably practicable, since losses are a source of inefficiency and waste. This is a requirement of Standard License Condition 49. We also set out the range of alternative options that we have considered to reduce losses, and our assessment of which options deliver the best value for money for customers. In version 2 of this document we've also provided a progress update on these options; how we have adjusted our strategy based on learning from our own and other DNO losses projects and changes to the external environment; and updates on delivering the actions.

The document covers both electrical losses and electricity theft.

It includes as appendices:

- a history of the updates and the reasons that drove them, and
- the proposed action plan through which this strategy will be implemented

Our target audience for this document

This document can be used to help guide any interested reader or stakeholder through our strategy for ensuring losses are as low as is economic and reasonably practicable.

It represents a summary of internal working documents that are continually reviewed and updated by our staff. In order to provide full information for stakeholders we have inevitably included in the document some concepts and terminology that may not be familiar to the general reader.

Relationship with our Losses Discretionary Reward

Our losses discretionary reward (LDR) submission complements our losses strategy, providing a greater emphasis on understanding, modelling and disseminating information about losses. The losses strategy places an emphasis on our business-as-usual decisions, with any learning from the LDR influencing future updates to our losses strategy. Therefore the strategy for losses is intended to be distinct from our losses discretionary rewards submission.

Contents

1 Summary

Our strategy for the 2015-23 period can be summarised as follows:

- To seek losses management through the selection of equipment and installation designs across the full range of our engineering activity. In general we are not bringing forward work programmes **solely** to target losses reduction since we do not believe it is justified by the cost/benefit analysis we have undertaken[1],
- To use the information flows from smart meters and substation monitoring as they become available to better understand and measure losses and to target both the use of demand side response (DSR) to reduce peak loads and existing reinforcement programmes thereby reducing losses.
- To review network configuration, both in design and operation, to establish whether the network can be configured to reduce losses and when necessary make these changes.
- To work within our relevant powers with suppliers and police forces in our region to disconnect illegal and/or unsafe connections.

Electrical losses

Variable electrical losses from our network are the natural effect of wires heating up when they conduct electricity. It is not possible to distribute electricity without this effect and it is reasonable to consider losses as the energy required to transport electricity. However, just as road vehicles can be more or less efficient, so electricity networks can use more or less energy in transporting electricity.

From our initial forecast, shown in Table 1, is that losses from our electricity network will reduce in the 2015-23 period by 230GWh (based on the benefits of all investment including customer driven) from an estimated opening level of 2,369GWh (a 9% reduction)[2]. The forecast profile of losses across the period initially rises slightly with load growth, before falling from 2018 driven mainly by our strategy for reducing technical losses and our expectation that the roll-out of smart meters has the potential to significantly affect system losses by changing consumer behaviour to reduce load on the system at peak times in response to new tariffs from suppliers. This projection is subject to significant uncertainty since it is highly sensitive to variables that are outside our control. In particular, we do not know how quickly, if at all, energy suppliers will implement time of use tariffs that send strong signals to customers, how customers will respond to those signals and how reported losses under the industry's billing and settlement arrangements will be impacted by the advent of smart meters.

The expected uptake of low-carbon technology may increase losses from the network in some situations, due to the heavier loading it causes that will be required to accommodate it. Throughout 2015-23 we will continue to look for innovative ways of minimising electrical losses, and we will implement them where there is a clear benefit to our customers from doing so.

[1] Where there is a combination of investment drivers such as deteriorating asset condition and poor losses performance we look to accelerate replacement

[2] V2 update: In 2015/16 losses were 11% lower than in the original forecast. This is thought to be due to a much reduced consumption from our customers the we originally forecast.

	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23
	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh
Opening balance	2,368,517	2,374,046	2,374,017	2,368,727	2,353,929	2,330,452	2,290,663	2,227,455
Background changes								
Load growth	11,843	11,870	11,870	11,844	11,770	11,652	11,453	6,785
General historical rate of reduction	-1,184	-1,187	-1,187	-1,184	-1,177	-1,165	-1,145	-679
Smart grids & LCTs	253	-1	207	-3,805	-6,942	-337	-764	507
Smart meters	-	-	-	-	-	-17,333	-34,667	-52,000
Technical losses strategy								
GM Transformer	-3,873	-7,833	-11,840	-15,848	-19,855	-23,863	-27,871	-31,878
PM Transformer	-161	-214	-366	-518	-671	-825	-979	-1,134
HV cables	-178	-372	-557	-743	-929	-1,117	-1,306	-1,496
LV cables	-1,170	-2,292	-3,416	-4,544	-5,673	-6,801	-7,929	-9,057
Closing balance	2,374,046	2,374,017	2,368,727	2,353,929	2,330,452	2,290,663	2,227,455	2,138,503
Actual	2,129,162	*2,029,000 (estimate)*						

Table 1- Forecast losses movements

In particular, we will ensure that electrical losses feature in our investment decisions. Losses are built into our procurement and policy decisions alongside safety and reliability considerations, so that we systematically consider the costs and benefits of investing in new low-loss technology when we replace our assets. This assessment means that we install assets (such as low-loss transformers) that are more efficient at conducting electricity, and therefore result in lower losses. However, we will not do this regardless of cost, bearing in mind that our customers want us to keep their costs down, as such all losses investment decisions are at a worst case cost-neutral to the customer.

External Environment

Since the first version of this strategy published in 2013 there have been significant changes to the wider environment which will affect losses decisions. These factors have created more uncertainty in valuing future losses than was the case in 2013. However Northern Powergrid remains confident its robust cost benefit analysis methods will inform least regret investment decisions in spite of the external changes. The changes which have had most affect are:

- Brexit has also resulted in considerable uncertainly around what rules and regulations we will have to comply with in the future. For example Northern Powergrid (along with other DNOs) has assumed that the EU's Eco-design directive will be incorporated into UK law post Brexit.
- 2040 Electric Vehicle targets. Due to increased pressure on urban air pollution the UK government has placed further emphasis on phasing out internal combustion engines. The projections Northern Powergrid used for future load growth are being reviewing in light of these new targets.
- Smart Meter delays. The smart meter programme has being delayed several times, meaning any benefit of ToU tariffs has also been delayed. The minimum level of aggregation of

consumption data required for data protection purposes will also reduce the utility of smart meter data to calculate losses[3].

Electricity Theft

We consider electricity theft to be an important issue, as it is linked to organised crime and the production and distribution of illegal drugs. For example, cannabis is very often farmed in houses filled with lights to stimulate growth of the plants. The drugs gangs often take the dangerous step of bypassing the electricity meter in order to draw power directly from the network without it being measured or paid for.

We take our responsibilities in this regard very seriously and we maintain a 24-hour fast-response service to support the police when they need technical help in their investigations.

We have been a key player in increasing the focus on electricity theft within our industry and will continue our active engagement on this issue. For example, we have representatives on the Home Office's Cannabis Cultivation and Power Companies Working Group, and we worked with industry colleagues to develop the National Electricity Revenue Protection Code of Practice.

Electrical loss reduction as part of our wider carbon footprint reduction

We have been monitoring our carbon footprint since 2007 and have successfully achieved a 7.3% reduction in carbon emissions over the past three year.[4] In 2015-23, we are aiming to reduce our carbon emissions by 10%. Alongside non-electrical measures such as speed limiters on our operational vehicle fleet, electrical loss reduction is part of this. In particular we are assessing energy use in our operational buildings (which is classed as electrical losses) and seeking to reduce usage with solutions such as innovative humidistats to reduce the temperature (and hence electricity consumption) at our substations (see section 1.3.2 and annex 1.6 of our published business plan).

Smart Meters

The roll-out of smart meters will provide us with an opportunity to access network data at lower voltage levels of our network than ever before. In the 2015-23 period we will use the new smart meter data to understand how best to measure losses on networks where low carbon technologies are becoming more commonplace. As a result, we will be able to make more targeted investments to reduce electrical losses. And in the future, the more accurate measurement of losses would enable our regulator to re-establish a financial incentive on us to reduce losses further.

We will continue to develop our own processes, and help to develop the processes for the industry as a whole, to ensure that we are well positioned to collect data from smart meters as soon as they are installed.

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[3] CIRED 2017: Analyzing the ability of Smart Meter Data to Provide Accurate Information to the UK DNOs (http://cired.net/publications/cired2017/pdfs/CIRED2017_0654_final.pdf)

[4] Our carbon footprint is now published in our annual environmental report: http://www.northernpowergrid.com/asset/1/document/3581.pdf

In 2015-23 we intend to use smart meter demand data to more effectively plan and develop our network to meet the future challenges from the connection of LCTs, targeting the use of DSR and investment in reinforcement.

It should be noted that the benefits in this area are dependent on the availability of both data for decision making and, in the DSR area, agreements on how decisions might be implemented. For this reason loss reductions are subject to:

- A swift and successful roll out of smart meters;
- Availability of consumption data at a sufficiently granular level and low customer aggregation; and
- Methods of passing cost signals or device management signals to customers at a reasonable cost - this will depend on suppliers being minded to facilitate this.

2 Scope

Energy is lost on the distribution network whenever power is transported from the Grid Supply Points or embedded generators to the end customer. The energy lost is driven by the following general mechanisms:

- Inaccuracies in metered and unmetered data;
- Theft from the system;
- Electrical energy loss from network asset components due to variable resistive losses (associated with the passage of current through a resistance) and fixed losses (associated with the applied voltage to equipment); and
- Electrical energy consumed in the course of network operation and control.

For the purposes of this document, electrical losses are characterised by the latter two mechanisms.

This document details our approach to electrical loss reduction and to electricity theft reduction. It considers:

- Electrical energy losses;
- Electrical energy consumed by network operations;
- Electricity theft; and
- The possibilities raised by and expected benefits from smart meters.

It details the approaches we will pursue including existing strategies and initiatives for new techniques. These initiatives will drive changes to our design and to a lesser extent operational policies which will ensure that development and operation of our network and specification of assets minimise technical losses within the context of designing an economic, efficient and co-ordinated network.

The document does not cover inaccuracies in metered and unmetered data, although it may be noted that the smart metering roll out will have an impact upon this.

3 Electrical losses

Electrical losses occur when energy is transferred across electrical networks, the magnitude of which defines the total network efficiency. Losses are well understood process and the economic reduction of losses is embedded within Northern Powergrid historical and existing design codes and procurement policies.

There are three areas of electrical losses:

- variable resistive losses (associated with the passage of current through a resistance);
- fixed losses (associated with the applied voltage to equipment); and
- Electrical energy consumed by network operations, for example heating and lighting at a substation.

The picture for losses going forward is mixed. However the future predicted changes in the nature of electrical demand, primarily through the use of low carbon technologies (LCTs), are likely to lead to increased networks losses but an overall carbon reduction for the economy. Furthermore as the cost of wholesale energy and price of carbon are factored into loss reduction cost benefit analysis, there is a greater incentive to reduce losses than would otherwise be the case.

Around two thirds of total system losses are on the LV and HV network. At these levels of network, solutions are introduced on an incremental basis in a proactive manner. This paper details our approach to technical loss reduction, through existing strategies and new initiatives developed over the ED1 period. These initiatives will drive changes to our design policies which will ensure that development of our network and selection of plant and cable, minimise technical losses within the context of designing an economic, efficient and co-ordinated network. We are also looking to implement new technologies such as power factor correction and carbon neutral substations as part of business as usual in future.

We will continue to develop and update the actions proposed in this document to reflect European developments, learning from industry projects and progress on our initiatives, so that our losses strategy remains calculated to ensure losses are as low as reasonably practicable, and based on up-to-date cost-benefit analysis.

3.1 Electrical energy losses

The energy lost in this manner can be normally characterised as either:

- Fixed losses; or
- Variable losses.

Fixed losses are incurred on an electrical system by virtue of it being energised and are independent of the loading conditions.

- Cables incur these losses in the form of dielectric losses which are most significant at 33kV and above, at 11kV and below these losses are generally negligible.
- Overhead lines incur these losses in the form of corona discharge, both audible and visible, but this is considered negligible in terms of network voltages used by Northern Powergrid.

- Transformers incur these losses in the form of iron losses within the transformer core and are significant at all voltage levels.

Variable losses are incurred due to the load on a system and are proportional to the load squared.

- Cables and overhead lines incur these losses due to the resistance of the conductor cores and the energy is lost as heat. The calculation of the loss is given by the formula $P = I^2R$. This means that for a doubling of current flowing the losses will increase by a factor of four.
- Transformers also incur variable losses due to the resistance of the copper HV and LV windings and the energy is again lost as heat. This is the same mechanism as line and cable resistance losses.

3.2 Electrical energy consumed by network operations

The auxiliary transformers at our major substations provide power supplies to support the command and control and general substation facilities on site. The demand on site typically comprises of:

- Battery charging;
- Opening and closing of switchgear;
- Transformer cooling fans and pumps;
- Heating & lighting;
- Security lighting, alarm systems, CCTV and powering security fences;
- Remote measurement and control systems (Supervisory Control And Data Acquisition (SCADA) telemetry and supervision Remote terminal Unit (RTU) consumption including communications);
- Protection and intertripping pilot schemes; and
- Voltage control relays e.g. AVCs, and tap changer operation.

For example, an EA technology report carried out to study the power consumption at our major substations suggests that the annual consumption of the primary distribution network substations may be in excess of 11 000 MWh for the Yorkshire license area alone. Of the energy consumed, the largest consumption is from space heating of the substation buildings.[5] A more detailed assessment of the unmetered electricity consumption has been undertaken and will be impact over the short term by installation of substation dehumidifiers.

3.3 Calculation of electrical losses

Fixed losses are calculated based on physical principles using manufacturers or standard loss data on a per asset basis for transformers or on a per km basis for cables and overhead lines verified over

[5] EATL "Energy Efficient Substation" S5195_2.

time using measurement on the system. This type of loss can therefore be robustly assessed either on an individual asset or total network basis without the need for onerous detailed calculation.

Variable losses have a complex relationship to customer demand, the customer maximum demand, the customer load profile and the load profile of system load. Since all four of these vary with time of day and time of year, it is only possible to predict how losses will change with any one parameter by considering all four.

Losses are calculated by calculating the overall efficiency of the network. This is by subtracting the energy leaving the system from the energy entering the system. The metering accuracy at the entry and exit points is critical in ensuring losses are accurate. As most exit points (domestic meters) have an accuracy which is similar to the proportion of losses experienced, it is therefore not possible to calculate losses to within an accuracy level of measurement or monitoring that could inform an efficiency initiative. Accurate measurement of real time electrical losses on the distribution system is not and may not be achievable for many years to come, and will depend on the eventual profile and final extent of the smart meter roll out programme[6] and how pervasive measurement on various parts of the network becomes. Current methods of calculating losses are based upon crude models that simply allocate the difference between energy purchased and distributed across the network assets in an educated way. Having long recognised that that movement in this loss figure is very insensitive to investment that Northern Powergrid make but very sensitive to the data accuracy and the behaviour / efficiency of customers; we cannot influence it significantly and demonstrably. We will investigate how the future smart metering infrastructure for domestic customers, covering 50% electrical demand, can be used to improve our understanding of network electrical losses. This will enable us to better target improvements in loss performance.

Since the first version of this document the roll out of smart meters has suffered delays and no smart meter data is currently available. In mitigation Northern Powergrid has published[7] cost benefit analysis templates to be used for designers, planners and standards engineers that draw on other data sets and knowledge. These templates use findings about load shape from our Customer Led Network Revolution project data to more accurately predict losses for a future asset. We've also funded a project[8] to look into the effect data aggregation and time resolution has on the accuracy of calculating losses.

3.4 Overall distribution of electrical losses

Figure 1 below gives an indication of how the total system losses are distributed across the network assets. These figures are based on the Northern Powergrid Yorkshire license area, but the distribution of losses is similar to that of the Northeast license area and other DNOs networks. It can be seen that over two thirds of the energy lost on the system is at HV and below.

[6] Even when the smart metering roll out is complete the accuracy of smart meters is of the same order of magnitude as the proportion of the overall losses (i.e. 2% accurate meter readings used to calculate losses values which are around of 5% of the total energy consumed). Furthermore any data aggregation requirements will make losses calculations less robust.

[7] Code of Practice for the Methodology of Assessing Losses, IMP/001/103 July 2016

[8] CIRED 2017: Analyzing the ability of Smart Meter Data to Provide Accurate Information to the UK DNOs (http://cired.net/publications/cired2017/pdfs/CIRED2017_0654_final.pdf)

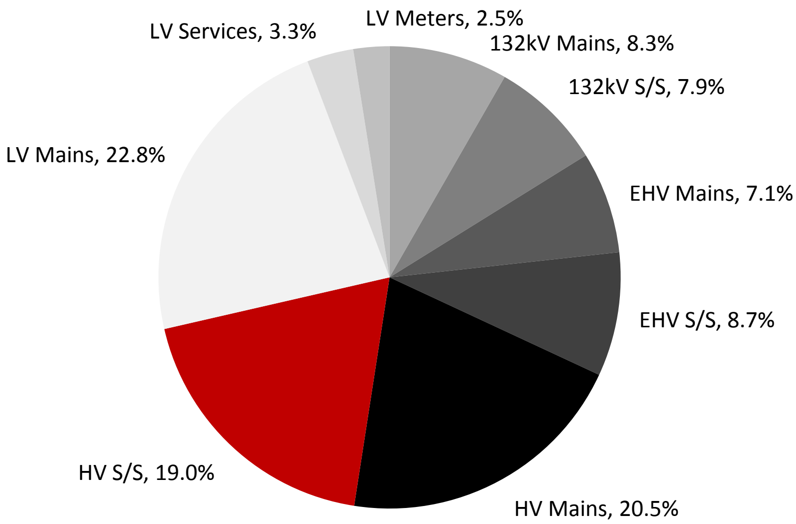

Figure 1: Typical overall distribution of percentage losses (adding up to 100%)

3.5 Wider environment

Figures on losses over the DNOs' networks in Great Britain are thought to be around 5-6% of total electricity generated[9]. This represents the largest component of the DNOs Carbon footprint, for example this represents 93% of Northern Powergrid's carbon footprint[10] . Broadly this translates to around 0.84 MTonnes of CO2 emitted due to losses on the Northern Powergrid network.

Reducing losses on distribution networks can have a significant effect on overall CO_2 emissions for the country. For example electrical losses on distribution networks are estimated to contribute approximately 1.5% of GB's overall greenhouse gas emissions[11] , and although reducing losses to zero is not possible, any significant reduction in losses could make an important impact on the overall emissions of the UK as long as doing its not at the expense of greater savings elsewhere on the energy system.

3.5.1 EU targets and directives

2020 targets

One of the five 2020 headline targets agreed across the EU relates to Climate Change and Energy. These are split into an overall reduction in greenhouse gas emissions of 20% from 1990 levels; 20% of energy from renewables; and 20% increase in energy efficiency.

These targets have been translated into national targets by the EU which takes into account the different situations and circumstances of each member state. The UK has been set a target of a reduction in greenhouse gas emissions of 16% from 1990 levels and 15% of energy from renewables (no level of energy efficiency has been mandated for the UK at this time).

9 Ofgem (2010). Factsheet "Electricity Distribution Units and Loss Percentages Summary"

10 NPg (2016-2017). Environment Report" http://www.northernpowergrid.com/asset/0/document/2724.pdf

11 http://www.ofgem.gov.uk/Networks/ElecDist/Policy/losses-incentive-mechanism/Pages/index.aspx

BEIS carbon budget

To meet the European targets, the UK has placed a legally binding restriction on the total amount of greenhouse gases the UK can emit over a five year 'carbon budget' period. Under each budget every tonne of greenhouse gas emitted will count towards the overall restriction up to 2050. Total emissions are capped using the EU Emissions Trading System, with any rises in one sector, meaning another sector will have to reduce emissions.

Losses on the electrical distribution system are not directly stated within the budget; however they have an indirect effect on the targets for the UK. This is because as losses are reduced, less input from generators is required, and overall carbon emissions are lowered.

Ecodesign and energy labelling policies

The Ecodesign Directive (2009/125/EC) establishes a framework to set ecological requirements for energy-using and energy-related products sold in all 27 EU Member States.

The requirements to be introduced in three tiers: 2015; 2020 (and 2025 for larger pole mounted transformers) and include:

- minimum energy performance requirements for medium power transformers,
- peak efficiency requirements for large power transformers, and
- product information requirements.

Northern Powergrid transformers can be split into four Ecodesign categories as shown in table:

Ecodesign Category	Equivalent Northern Powergrid Category	Method of losses measurement	Expected impact on Northern Powergrid
Medium Pole Mounted Transformers ≥160kVA & ≤315kVA	'Large' Pole Mounted Transformers (200kVA and 315kVA)	Maximum load and no load loss level specified (more lenient and increased timescale due to weight limitation of poles)	Tier 1 are similar in terms of total losses as existing capitalised cost. Tiers 2 & 3 more stringent, however cost increase uncertain.
Medium Power Transformer <4MVA; HV ≤24kV; LV≤1.1kV	Ground Mounted Distribution Transformer (315kVA, 500kVA, 800kVA & 1000kVA)	Maximum load and no load loss level specified.	Tier 1 are similar in terms of total losses as existing capitalised cost. Wilsons Power Solutions estimate to increase the efficiency of their Tier 1 transformer offering to an Amorphous Core Tier 2 compliant transformer the price would increase by 50%
	'Small' Pole Mounted Transformers (25kVA, 50kVA & 100kVA)		Single phase transformers were not in scope in Tier 1 and are being considered for inclusion in Tier 2.

Ecodesign Category	Equivalent Northern Powergrid Category	Method of losses measurement	Expected impact on Northern Powergrid
Medium Power Transformer Rated > 4MVA; 24kV < HV ≤ 36kV; 1.1kV < LV ≤ 24kV	33kV CER Primary Transformer (i.e. 33/11kV)	Maximum load and no load loss level specified.	Tier 1 & 2 perform slightly worse given Northern Powergrid's estimated load loss factors and utilisation rates. Existing stock has better iron losses, but worse copper losses than both Ecodesign tiers. Ecodesign minimum performance appears to be optimised for highly loaded transformers.
Large Power Transformer Rated > 5MVA; HV > 36kV;	66kV CER Primary Transformer (i.e. 66/11kV) & CMR System Transformers	Chosen on calculation of peak efficiency.	Similar methodology to existing practices.

Table 2 : Transformer Ecodesign categories

The directive references the performance categories described in EN50464-1:2007. Figure 2 below shows how existing ground mounted distribution transformers compare against the expected minimum requirements for the Ecodesign directive.

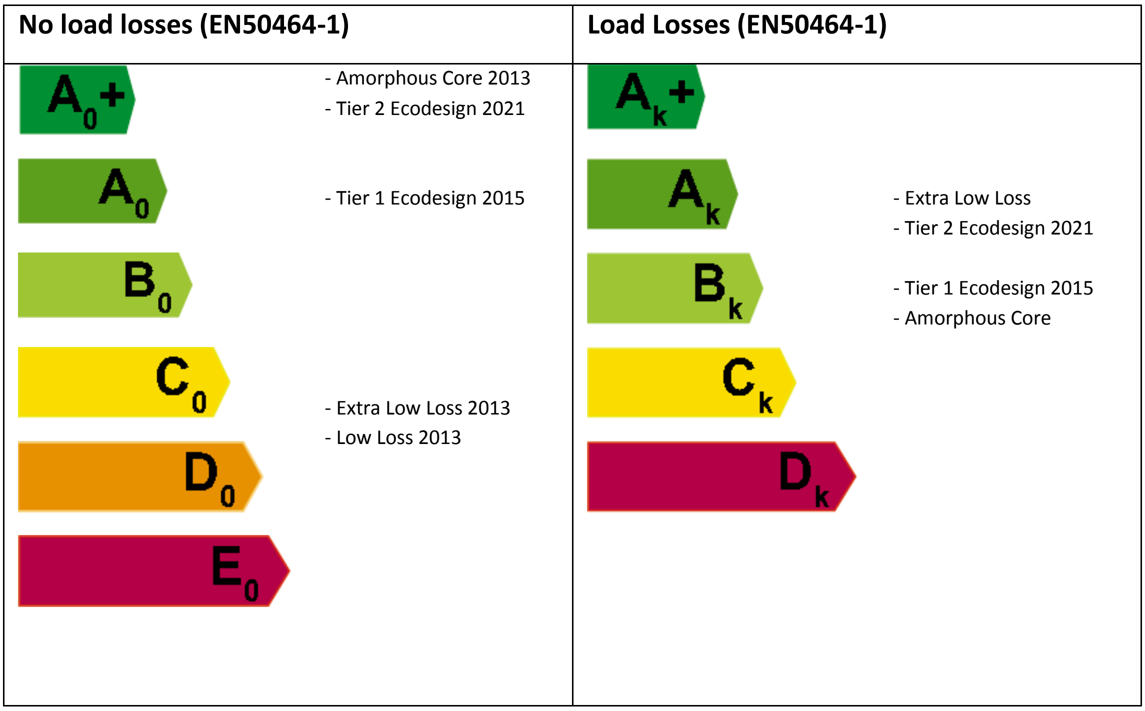

Figure 2: Existing ground mounted distribution transformers

Since of the first version of this strategy was published we have started to install Tier 1 compliant transformers which have higher unit costs and larger equipment sizes. However the typical cost uplift between pre and post Tier 1 standards of equipment in terms of size and cost has small as manufacturers have been able to meet the new requirements with improved designs using existing materials and manufacturing techniques. It remains to be seen if manufacturers can meet Tier 2 in a similar manner, or whether more complex designed and more expensive materials such as Amorphous steel cores will be required.

EU network codes

The European Network of Transmission System Operators for Electricity (ENTSO-E) represents 41 transmission system operators (TSOs) from 34 European countries.

ENTSO-E's Network Code on Demand Connection will help to facilitate cross-border network issues and market integration issues across the EU. The code helps to establish a secure interconnected transmission system through close co-operation between generators, transmission network operators and distribution network operators.

Article 16 of the code places a restriction on Reactive Power flows at the transmission-distribution interface. The existing reactive power range is not specified by the Grid Code. These limits have been implemented primarily from a stability perspective; however they will inevitably have a positive effect on system losses.

Within this code it places an emphasis on the cost benefit analysis to justify the whole system savings. If reactive power equipment was installed at the interface with National Grid, the only cost savings would be on National Grid's transmission system but potentially paid for by Northern Powergrid. However installing power factor correction on the lower voltage networks would have benefits for Northern Powergrid and National Grid.

3.5.2 BHE environmental policy

As part of Berkshire Hathaway Energy (BHE), Northern Powergrid's environmental policy supports and upholds the principles and objectives of BHE's global environmental policy (known as "Environmental RESPECT").

Specifically under 'Efficiency', the RESPECT policy states: -

"We will responsibly use natural resources and pursue increased efficiencies that reduce waste and emissions at their source.

We will develop sustainable operations and implement environmental projects designed to leave a clean, healthy environment for our children and future generations".

As losses are the largest component of Northern Powergrid's carbon footprint, losses are should continue to be actively reduced to lower overall emissions to uphold and support the RESPECT principles.

3.5.3 Historical performance

Due to the inherent difficulties in comparing losses over time, the graph below should be used for illustrative purposes only. Nevertheless, there is little overall downward trend on the Northern Powergrid network, and the losses picture looks relatively stationary despite falling consumption in the same period[12]. Northern Powergrid, have similar losses as most of the other DNOs, with an

[12] Since 2000-01 to 2015-16 overall consumption in the Northeast has fallen by 12.2% and Yorkshire by 7.9%

overall losses trend over time similar to the industry average. This graph highlights how inaccuracies in settlement can have a significant effect on measured losses. It is envisaged that in terms of actual losses, there is less variance between the years. Year 2009-10 shows an example of how metered data inaccuracies can skew the measured losses significantly.

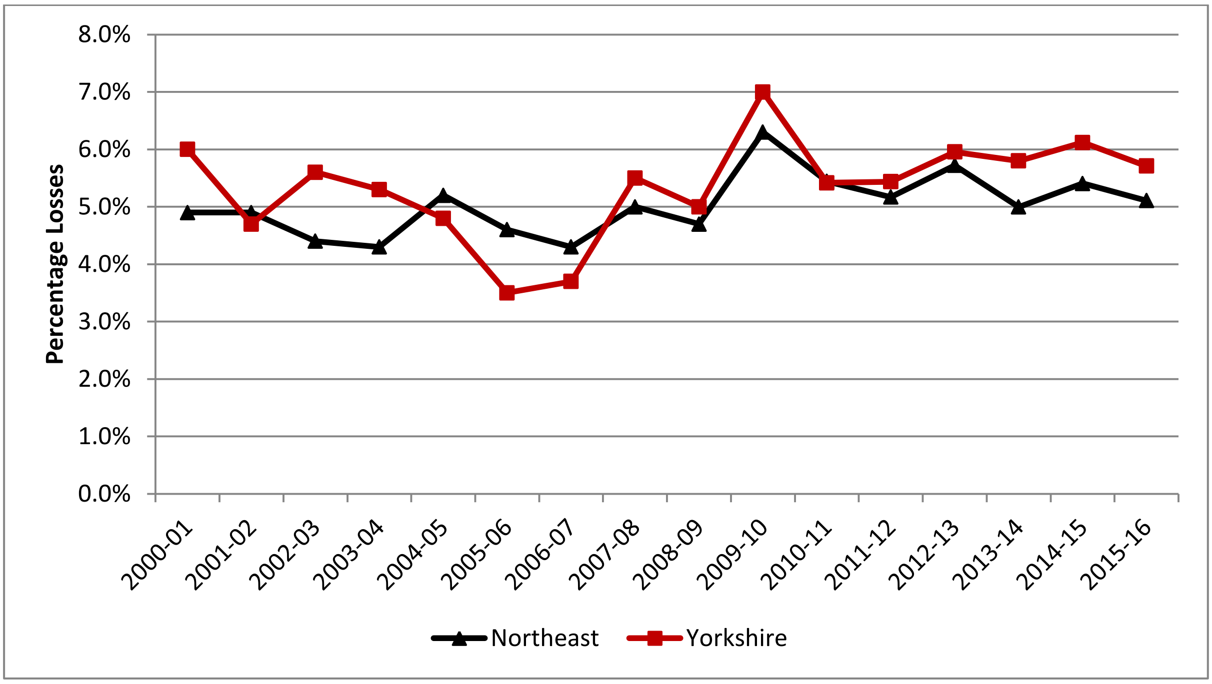

Figure 3: Comparison of Northeast and Yorkshire percentage losses from 2000-01 to 2015-16

3.6 Present policy on managing and reducing losses

This section captures the present policies that underpin our business plan assumptions. The various elements of product specification and product application embedded in our design policies have been justified using cost benefit analysis. More recently these cost benefit analyses have been reviewed and updated using the Ofgem CBA framework for the 2015-2023 business plan.

3.6.1 Product specifications

Transformers

Northern Powergrid typically specifies four main types of transformer for use on the system (technical specification identifier in parenthesis): -

- Continuous Maximum Rated Transformers (NPS/003/021);
- Continuous Emergency Rated Transformers (NPS/003/012);
- 11kV & 20kV Ground-Mounted Distribution Transformers (NPS/003/011); and
- 11kV & 20kV Pole-Mounted Distribution Transformers (NPS/003/034).

The specifications for all of these transformer types include a requirement that the manufacturer works out the lifetime cost of the transformer using the following formula: -

Lifetime Cost = Purchase price + (No load loss kW x No load £/kW) + (Load loss kW x Load loss £/kW)

The values for the no load £/kW and load loss £/kW are given in the Code of Practice for the Methodology of Assessing Losses (IMP/001/103). The latest figures (2016) are shown in the table below:

Transformer Type	No Load Loss £/kW	Load Loss £/kW
System Transformers (CER & CMR)	£11,980	Calculated on a bespoke basis
Distribution Transformers (Ground mounted)	£11,980	£1,443
Distribution Transformers (Pole mounted)	£11,980	£723

Table 3 : No load loss £/kW and load loss £/kW

As expected the no load losses on a per kW basis are the same for all transformer types as they are the steady state condition of the network. The difference in load loss values are attributed to differing load loss factors and utilisation factors. With the 2016 update of IMP/001/103, distribution transformers have been split with separate copper loss values for ground mounted and pole mounted. Also the capitalised copper loss values for system transformers are now calculated on a bespoke basis. This allows Northern Powergrid to better target it's expenditure on reducing losses on assets which are more highly utilised.

Cables

Cables are procured to Northern Powergrid standards which in-turn reference national standards which specify minimum resistivity of conductors, and variance from nominal conductor size. From a loss reduction perspective, the selection of cable size as dictated by the design policy has a greater impact than the equipment standard.

3.6.2 Design policy

In designing and operating an efficient power network, Northern Powergrid has historically embedded a low loss policy within design practices.

Cable selection

The benefits of low loss design have usually been in the form of oversizing conductors (relative to existing utilisation levels), which can have the added benefit of improving network performance (i.e. voltage drop, current carrying capacity and earth loop impedance).

At low voltage (230/400V), the use of 300mm^2 aluminium cables has been adopted as standard cable size for all mains other than spurs carrying less than 120A per phase[13].

[13] NPg (2017). IMP/001/911 – "Code of Practice for the Economic Development of the LV System"

Since the first version of this document the standard cable size used on distribution feeders at 11kV is now 300mm^2 aluminium (changed from 185mm^2). Following a review of our 20kV standard cables, the size remains at 185mm^2 for distribution feeders[14]. For HV overhead lines, the use of 100mm^2 and 175mm^2 AAAC is specified for Main Line circuits and 50mm^2 and 100mm^2 AAAC for tail end circuits are specified. The choice of these conductor sizes is dependent on the load of the circuit. Since the first version of the losses strategy the standard of AAAC has been changed from AL3 to the lower resistance AL5 conductor, which will reduce load losses.

Transformer sizing and selection

Historically for distribution transformers, the 'economic' sizing for a transformer is generally based upon not exceeding an initial maximum design loading of 95% of the nameplate rating for typical domestic load curves and transformers up to 1000 kVA. Since the first version of this document economic loading has been reviewed and guidance tables included in IMP/001/911. This allows design engineers to appropriately size transformers to optimise losses in a consistent manner.

System transformers are sized to match the load, and that selection of cables and overhead lines shall be based on technical and engineering aspects on System Configuration[15].

3.6.3 Network operations

Optimising customer numbers

Open points on the high-voltage network are positioned to optimise customer numbers and load, but also to reduce switching operations under first circuit outages. Moving an open point to optimise customer numbers between two or more feeders usually results in the optimisation of load and losses, however this is not guaranteed.

Substation ambient temperature

In all major substations (primary substation, supply and grid supply points) indoor equipment rooms are temperature controlled. This is usually in the form of resistive electric heaters, controlled via a thermostat to allow switchgear and associated control equipment to function correctly.

There is an existing initiative being delivered to install dehumidifiers at all major substation sites this will have a variable impact due to present practice in the setting of temperature controls.

3.6.4 Promoting the efficient use of electricity

Power factor correction

For customers connected to the LV network, customers are encouraged to aim for a power factor of between 0.95 lagging and unity on their electrical systems[16] in order to reduce reactive power flows and hence load losses. Northern Powergrid's Statement of Use of System Charging, stipulates that half hourly metered customers are charged for excess reactive power consumption (kVArh)[17].

[14] NPg (2017). IMP/001/912– "Code of Practice for the Economic Development of the HV System

[15] NPg (2015). IMP/001/913 – "Code of Practice for the Economic Development of the EHV System"

[16] NPg (2012). IMP/001/ 010 – "Code of Practice for Standard Arrangements for Customer Connections"

[17] NPg (2013). LC14 – "Statement of Use of System Charging" – NPgN & NPgY.

The excessive reactive power charge was introduced for HV and LV half hourly metered customers in April 2010.

Power quality

The nature of loads over recent decades has changed from passive current using devices (i.e. incandescent lamps and directly connected motors), to switched mode power supply connected devices (Compact Fluorescent Lamp (CFL)/Light Emitting Diode (LED) lamps, and Variable Frequency Drive (VFD) motors). These non-linear connected devices draw non-sinusoidal currents which in turn create harmonic voltages distortions for other customers. These harmonics increase the iron losses in the upstream transformer core and eddy current (resistive) losses in the transformer windings and cables.

As such Northern Powergrid stipulates that where this is likely to occur, the connection design should take into consideration the requirements of Engineering Recommendations G5/4 as appropriate to mitigate any issues.

3.7 Impact of future networks on losses

The transition to a low carbon economy involving the electrification of transport and heat is likely to increase demand on the system and therefore in turn losses as network equipment is more highly utilised.

3.7.1 Increased parasitic losses

During RIIO-ED1 smart meters will replace manually read gas and electricity meters in homes and small businesses. These meters are designed to record consumption of energy (electricity and gas) and relay the information to the energy suppliers automatically. Due to the increasing functionality of the new meters, the parasitic losses from these meters are generally greater than existing metering. The energy supplied to these meters is on the Northern Powergrid side of the meter, (as per existing meters) and hence are classed as a system loss.

The table 4 shows an estimate of smart meters parasitic (from maximum permitted losses stated in the Metering Instrument Directive) against existing meters: -

Meter Type	Existing Metering Losses	Smart Meter Losses	Increase in Losses
Gas Meter	0W Electrical (Gas pressure driven)	1W	1W
Single Phase Single Element Electricity Meter	2W	3W	1W
Single Phase Twin Element Electricity Meter	2W	3W	1W
Poly Phase Electricity Meter	5W	7W	2W
In Home Display	0W	0.6W	0.6W
Communications Hub	0W	1W	1W

Table 4 : Estimate of smart meters

As can be seen in table 4 the parasitic losses from a typical household will increase from around 2Watts to over 5Watts (Gas meter, Single phase meter, in home display and communications hub).

The existing electricity meters on our network are estimated to contribute to around 2.5% of the overall losses; therefore smart meters could conceivably increase this proportion significantly. Assuming that smart meters do not adjust customers' behaviour and load remains static, smart metering is estimated to add a steady state load of 18MW to system losses across both licences[18].

3.7.2 Embedded generation

Small and medium generation connected to the LV and HV networks is envisaged to be mainly from Photovoltaic (PV) and small scale Wind Generation. There are varying predictions and scenarios from BEIS about the future uptake of these technologies, our 2015-2023 forecast that across both license regions, the number of PV and Wind installations is expected to increase by around three times the 2012 penetration levels by 2020.

On a network feeder when embedded generation is exporting energy, the load on a feeder will be reduced. As the net power flow on the respective feeder tends to zero (i.e. local generation matches local load), thus the variable losses on the feeder and on the upstream transformer will be also tend to zero. However, these scenarios are unlikely to often coincide with maximum demand on the system, where variable losses on the system are highest. As such embedded generation is likely to reduce system losses overall particular if it paired with storage so its utilisation of the networks can be shaped to optimise overall system efficiency.

3.7.3 Electrification of transport and heat

In a similar vein to increased generation, BEIS are also predicting an increase in heat pumps and electric vehicles being connected to the network. Northern Powergrid's interpretation of the BEIS and National Grid future energy scenarios indicate that across both license regions, the expected number of installations may increase significantly over the coming decade. Northern Powergrid is investigating how these scenarios will be felt on a more granular level using our low carbon technology forecasting tool[19]. These loads if not properly managed will significantly increase the load on the network and the associated resistive losses will increase quadratically.

3.7.4 Impact of future time of use tariffs

The variable losses are proportional to the square of the load therefore for given amount of energy transferred over a fixed time period; a flatter load profile has fewer losses than the same energy transferred with a 'peakier' load profile.

The introduction of time of use tariffs will aim to flatten the load profiles by creating real-time charging mechanisms. This will charge customers more for electricity at peak times, and will encourage customers to use electricity at other off-peak times, which will flatten the load profile. The smart metering roll out is key to the introduction of these tariffs for domestic consumers.

Although the aim of the time of use tariffs is not solely for a reduction in variable losses, (primarily to match generation with demand); it should nevertheless help to reduce overall losses on the network.

[18] Based on 6.6Watts on 75% Smart Meter coverage on 1.5m domestic customers in Northeast and 2.1m domestic customers in Yorkshire.

[19] In 2017, we concluded an innovation project aimed at improving how well we can forecast customer electricity use, based on roll-out scenarios for electric cars, heat pumps and distributed generation. We are now in the process of finding out how we can adopt this tool in our normal working methods.

3.8 Options for further loss reduction

This section describes a range of potential options for reducing technical losses, split into three sections – expand existing loss reduction techniques; new technologies; and changes to network operations.

3.8.1 Expand existing loss reduction techniques

It is important to note that due to the incremental nature of the asset replacement programmes and network reinforcement, any improvement in losses implemented in this manner will be gradual. It is also worth noting that a reduction in losses at lower voltage levels on the network can also have benefits on losses further upstream at higher voltages.

Increasing cable sizes/plant sizing

Cables and overhead lines

Losses in LV and HV circuits represent around half of all system losses on the network. With no real scope in improving cable performance in the short term, the only way to make any significant progress is to review design policies on cable and overhead line selection.

For low voltage distribution, the policy states using 300mm^2 aluminium for all mains except for small tees. To increase the cross sectional area above 300mm^2 is not straight forward or practical as it would involve manufacturers modifying equipment and limitations on bending radius for installation, for example for LV feeder pillars the maximum size is 4c300mm^2 . An alternative may be to change the conductor material from aluminium to copper, however as copper is currently around three times the price of aluminium (kg to kg) this would be unlikely to be recovered in terms of losses over the lifetime of the cable.

For 11kV design, 185mm^2 aluminium was the prominent cable size used for network feeders, except for 300mm^2 for first leg from primary. Analysis of our network has shown the average feeder load on an underground, distribution 11kV feeder is 136A, has a loss load factor of 20% and is 3.9km long. Cost benefit analysis for this average feeder shows it is beneficial to install 300mm^2 over 185mm^2 in losses savings alone. The increased current carrying capacity and reduced voltage regulation by upsizing the cable has not been valued, however is a significant added benefit. Following this analysis IMP/001/912 was updated to reflect this for 11kV feeders. For 20kV feeders analysis has shown it is not cost benefical to increase cables size from 185mm^2 to 300mm^2 because of the lighter loading and increased cost between the two sizes compared with 11kV.

For HV overhead lines, the designer has the choice between 50mm^2, 100mm^2 and 175mm^2. The construction of 50mm^2 and 100mm^2 lines is similar; however there is a step change in construction cost at 175mm^2 to cope with additional weight of conductor.

The policy limits the use of 50mm^2 to tail end spurs with less than 700kVA of load. A cost benefit analysis suggests the figure of 700kVA remains appropriate in terms of losses savings.

At EHV the cable is selected on a more bespoke basis, where the cost of losses is factored in, for the purposes of this review EHV cable size selection are considered appropriate.

Transformers

Oversizing transformers is not guaranteed to reduce losses, as under low load conditions, the fixed iron losses of a large transformer may be greater than the sum of the iron and copper losses of a smaller one. Nevertheless, this scenario is rare for most network load profiles and it is usually beneficial to oversize transformers relative to load.

Figure 4 below shows some pre 2015 distribution transformers procured for Northern Powergrid under various loads. When the transformers are lightly loaded the baseline iron losses are dominant in total losses and the smaller rated transformers fair best in terms of efficiency. As the load picks up the copper loss component quickly becomes more dominant in efficiency and using a higher rated transformer reduces losses.

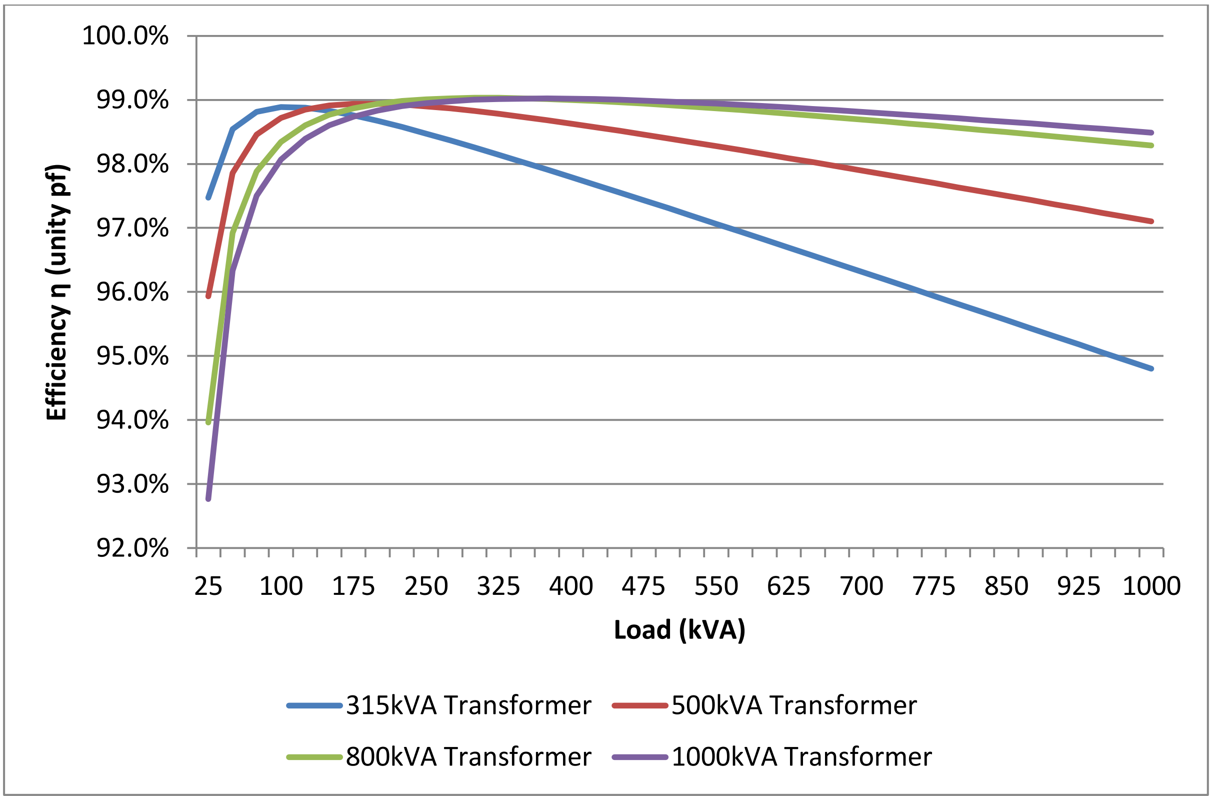

Figure 4: Approximate efficiencies against load for typical Northern Powergrid transformers

Since the first version of this document IMP/001/911 has been updated to include guidance for sizing of Tier 1 distribution transformers to optimise their loading.

We will be carrying out an economic loading assessment of these new Ecodesign Tier 2 compliant transformers against design load based on pricing information from manufacturers.

Network configuration

There has been a drive within the business to reduce customer numbers on LV and HV feeders to reduce the respective CIs and CMLs. The knock on effect of this is that the load on these circuits is also reduced, as fewer customers are connected. The existing guidance states there should be no more than 120 customers on an LV feeder and 2,000 on an HV feeder.

Ultimately, reducing load on feeders by splitting customers will reduce variable losses. We are reviewing the customer numbers figures on the each feeder to factor in likely losses, or specifically limit design load on feeder at HV and LV, and the influence of ED1 IIS regime.

Power factor correction

The most efficient power transfer takes place when the power factor of the demand on the network operates at unity.

The general benefits of installing power factor correction (PFC) would be: -

- Overall network power consumption reduced (VA)
- Electrical energy transmission efficiency maximised
- Transformer and distribution equipment losses reduced
  - Circuit fixed losses & transformers iron losses remain same
  - Upstream circuit variable losses reduced
  - Transformer copper losses reduced
- Higher utilisation of existing equipment capacity
  - Potential reduction in reinforcement needed
- Network voltage conditions improved
- Potential future ENTSO-E compliance

Possible draw backs on a case by case basis could be:

- Capacitor banks are resonant with the system at harmonic frequencies;
- Pre-existing harmonic conditions on the network are magnified or exacerbated;
- Transient in-rush currents and voltages occur; and
- Reliability of equipment and consequence of failure on voltage, max demand and harmonics.

PFC could be installed at various points of the system. The most efficient use of PFC is at the load end. Traditionally for bulk customers this is often at the customer's switchboard and at the consumer level within certain devices (such as adding a capacitor in parallel with the magnetic choke in fluorescent light fittings).

The use of PFC in residential installations is unlikely to be technically or financially feasible, except as required within manufacturing standards for consumer products. There could be the option of installing PFC at distribution substations, which would bring HV power factor towards unity. This would add an additional degree of complexity from an operational perspective, may lead to capacitors being underutilised and may prove difficulty to install spatially in existing substations.

As mentioned earlier, adding PFC at Grid Supply Points (on the DNO side), would provide no real benefits for Northern Powergrid. The most cost effective location for PFC would likely be at primary substations; this would reduce losses upstream of the primary (33/66/132kV) and would help any potential future compliance with the ENTSO-E code requirements for the transmission/distribution NGC interface. An approximate cost benefit analysis indicates that a 5MVAr capacitor banks installed at a primary substation, would be cost beneficial if the initial installation cost was the order of £20 000 per MVAr installed.

Transmission companies such as National Grid make use of Mechanically Switched Capacitors (MSC) or Static VAR compensators (SVCs) to support the voltage under certain network conditions by reducing the flow of VARs on the network or even reversing the flow under certain circumstances. This is done at 400kV, 275kV and 132kV substations and several large wind farms. These devices are also being deployed as part of a few LCN projects[20] to assess their benefits on distribution networks

[20] Such as WPD's "STATCOM Effectiveness on Rural Networks" and UKPNs "Energy Storage System Project"

Power quality

Harmonics

Non-linear connected loads such as rectifiers can cause voltage and current distortions to the power system waveform. As well as disturbing adjacent customers supply, this can cause increased losses on the network.

Although the individual devices are usually compliant with existing manufacturing product standards the individual harmonics may be outside of limits when the currents from several devices are aggregated., The management of harmonic emissions from domestic connections (less than 16A per phase) is done at a product level based on EN standards however there is no limit to the emissions from an individual connection whereas for larger connections we managed emissions from the connection in line with G5/4.

For industrial customers, detailed assessments of the connected load are usually carried out to comply with the levels stipulated in G5/4. However for residential loads, this would prove more difficult as the individual customers may be within harmonic limits, however it may not be evident at the connection stage that the sum of the customers harmonic currents may be outside limits. The solution for this could be to install filters (again akin to PFC) at distribution substations or primary substations where issues are identified.

The effect of harmonics on losses it not thought to be as significant as poor power factor, however this is envisaged to increase as more load is fed via switched mode power supplies.

Load Imbalance

LV networks are designed such that single phase customers are balanced across the three phases of an LV main. In an ideal LV network the steady state current flowing along the neutral conductor is zero. When the loads are not balanced it leads to increased losses and voltage drop on the affected phases.

Our design policy specifies that for new developments the single phase loads should be equally distributed across the three phases. However for existing installations the level of imbalance is not measured and only becomes apparent when a fuse operates on an overloaded phase, or when there is voltage measurement on the phase.

The balancing of customer numbers on LV feeders would help to reduce load imbalance, however this assumes that all customers take equal load. A further step would be to measure the three phase currents on each LV feeder to balance load rather than customer numbers. Where the load imbalance is outside of acceptable limits action could be taken to move customers from a loaded phase to a less loaded one.

Since version 1 of this document we have begun to roll out LV substation monitoring, which will measure both total harmonic distortion and unbalance. This information will help us to quantify the harmonic and unbalance for future losses decisions.

3.8.2 New technologies

Superconductors

Superconductors are materials that can have zero electrical resistance at certain conditions, namely relatively lower temperatures. The latest generation of superconductors, can exhibit superconductivity at relatively high temperatures, such as (77K or −196°C) and can be cooled more easily with readily available refrigerants such as liquid nitrogen. The advantages of superconductors on electrical networks are:-

- Reduction in resistance with a corresponding reduction in I^2R copper losses.
- A reduction in voltage drop.
- Increased loading capacities per cross sectional area of material relative to conventional conductor material.
- Reduced network voltages required to transmit similar power levels as existing cable systems.

The disadvantages are: -

- Cost
- The increased complexity of installation and additional cooling apparatus
- The cooling apparatus itself consumes energy.

In the past decade there have been several trial cable projects around the world which have used superconductors. These have been at several power ratings from 574MW (Long Island, New York) to 40MW (Essen, Germany). However, the capital cost of these projects has been significant, and these projects have been subsidised by research grants from government energy departments.

We do not envisage superconducting cable being installed on the network in the short to medium term. Any future superconductor projects on the network are likely to be at the EHV network level, where capital is spent on fewer, high capacity, high value assets.

Since the first version of our losses strategy Western Power Distribution commissioned a feasibility study to look into Superconducting Cables. Following their closedown report it was suggested the technology was significantly more expensive than conventional solutions. However superconductor technology costs were falling year on year and forecasts suggest potential cost parity with other solutions within five to ten years. Northern Powergrid will keep this situation under review but we believe that superconducting technologies may not be cost beneficial until RIIO-ED2.

Low Loss Transformers

Transformers procured on the Northern Powergrid network are approximately 98-99% efficient at rating. However, to transport energy from a generator to the end user, this energy on average will pass through five transformers on a network. Hence transformers account for approximately a third of the losses on the network.

The definition of low loss transformer varies between manufacturers, however if we assume that the existing population of transformers on the network are of 'standard loss' design, reduced loss designs can be benchmarked against them. The following low loss designs assessed are:

- Low Core Loss Transformers (including Amorphous Core)
- Reduced winding resistance transformers
- Cast resin transformers
- Power electronic transformers

Low core loss transformers employ core materials such as Amorphous steels, laser etched high permeability core steel and microcrystalline steels to reduce the iron losses. Amorphous core transformers have the lowest iron loss of any core material in the market place (see figure 5). Historically these transformers have been popular in the USA as the wound core method used in the USA lends itself to one piece cores, rather than the stack produced cores of European manufacturing methods. However due to their impressive iron loss performance, Amorphous core transformers are becoming more popular in Europe.

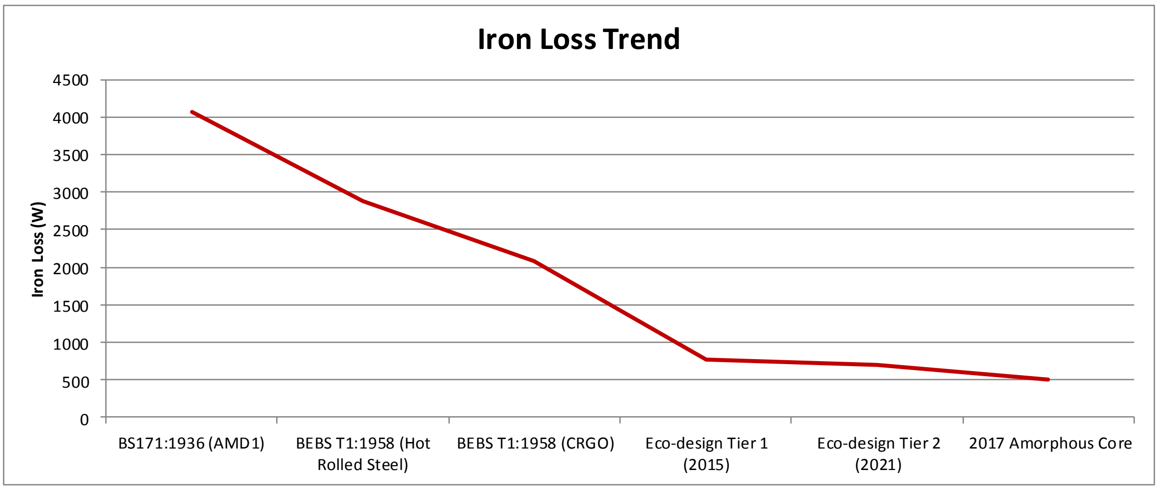

Figure 5: 1000kVA transformer iron loss trend from 1936 to 2017

Reduced Winding Resistance

A method of reducing copper losses is to reduce the resistance of the windings. This can be either by reducing the resistivity of the winding material, increasing the cross sectional area or reducing the number of windings[21] (see figure 6).

However there is a trade-off when reducing winding resistance, such as increasing core size to accommodate the larger windings which in turn leads to increased iron losses in the core. This then influences the X/R ratio of the unit and can lead to more onerous network fault level requirements.

[21] Heathcote [1998] – "J&P Transformer Book".

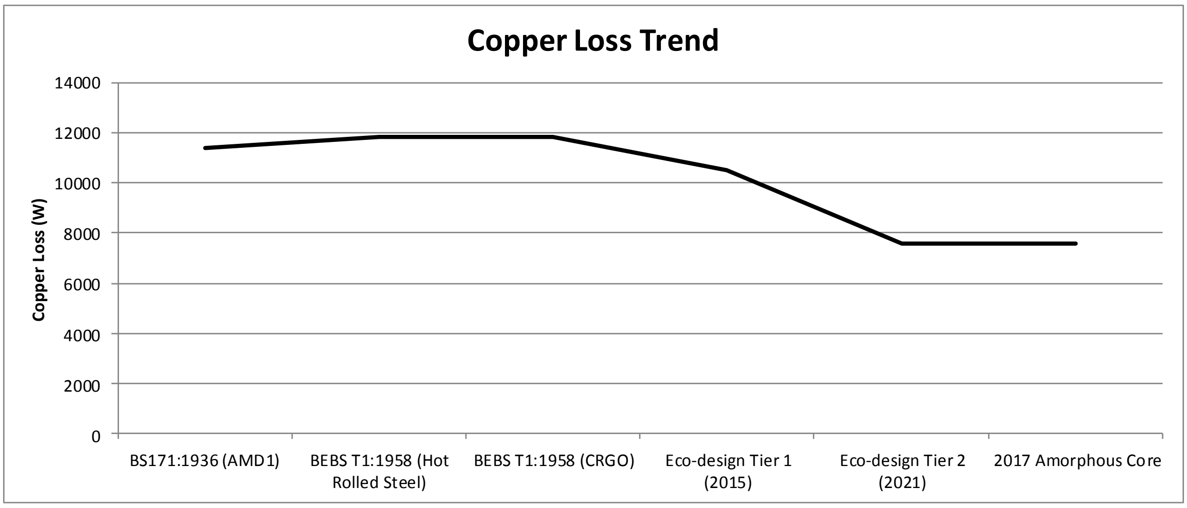

Figure 6: 1000kVA transformer copper loss trend from 1936 to 2017

Cast Resin Transformers

Instead of using oil as a dielectric medium, an epoxy resin is used to encapsulate the windings. The main advantages of cast resin transformer are they are virtually maintenance free, moisture resistant, flame retardant and self-extinguishing. This makes them ideal for integration within buildings, where the risk of fire is a primary concern.

The losses from cast resin transformers follow similar principles to oil filled transformers, namely core and winding losses. However, as cast resin transformers can be placed within buildings they can often be located closer to the load centre which reduces losses in LV sub mains cabling. As Midel oil filled transformer have similar fire performance properties and efficiencies to cast resin, the use of cast resin transformer is not thought to be of any cost benefit to Northern Powergrid.

Power Electronic Transformers

The use of power electronic ‘transformers’ has been increasingly used in consumer electronics for charging mobile devices and in powering computers. There are different technologies available for this, included the basic AC/AC buck, to high frequency modulated devices. The benefits of using solid state devices for distribution transformers are a reduction in weight, better power quality, power factor correction ability, elimination of oil and reduction in losses[22]. Commercially, there are no power electronic utility transformers on the market from manufacturers; however ABB have created a traction power electronic transformer rated at 1.8MW and 25kV. This device operates at several voltage inputs and frequencies to allow international operation of rolling stock. It is not envisaged that a power electronic distribution transformer will enter the market for some time and will be a premium product for specialist application when it does. In 2017 Scottish Power Distribution have registered their ‘LV Engine’ as an NIC bid to look into solid state transformers.

Impacts of low loss transformers

Several manufacturers now offer low loss transformers such as ABB, Siemens and Schneider, however there is a significant premium.

[22] E.R. Ronan [2002] - “A Power Electronic-Based Distribution Transformer” IEEE Transactions on Power Delivery

There is also concern that due to lower iron losses in the transformer core that ferroresonance can occur more readily[23].

Cast resin transformers have shorter thermal time constraints, which lowers their overload capacity.

Power electronic transformers may have a limited fault current contribution, which may lead to problem achieving disconnection times on the LV network. There is also a concern with regards to the robustness to environment, as the electronics are more sensitive to temperature and humidity than standard transformers.

Low loss and cast resin transformers are often much larger than a similarly rated standard oil filled transformers. Cast resin transformers also require extra ingress protection when place outdoors. The table below shows the extent to which the size increases for 1000kVA ground mounted transformers for different technology types. The Ecodesign Directive has recognised this issue and as such has given pole mounted transformer designs longer to comply with this standard, as there are concerns that the larger pole mounted transformers may be too heavy to be accommodated on a pole.

1000kVA 11/.433kV Transformer (Schneider Electric estimates)						
Type	**Mass (kg)**	**Increase in Mass from Standard %**	**Length (mm)**	**Width (mm)**	**Height (mm)**	**Increase in Volume %**
Standard	3135	-	1680	1170	1710	-
Ecodesign Tier 1 (laser etched high permeability core steel)	4450	42%	1825	1175	1830	16%
Ecodesign Tier 2 (laser etched high permeability core steel)	6080	94%	1935	1215	2075	45%
Amorphous	6000	91%	2300	1450	1700	68%

Table 5 : Schneider Electric 2013 estimates

Since version 1 of this document, manufacturers have developed Tier 1 and Tier 2 compliant transformers which are more compact than the 2013 estimates above, but are still larger than pre eco design.

Carbon Neutral Substations

Carbon neutral substations have been investigated by EA Technology for Northern Powergrid, which looked at several case studies of the energy lost at major substations. The report[24] makes recommendations to investigate several options for reducing losses, some of which are described below.

Heat recovery from transformers at major substations to heat substation buildings

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[23] R. A. Walling [2003] - "Ferroresonance in Low-Loss Distribution Transformers" PESGM 2003 - IEEE

[24] EATL "Energy Efficient Substation" S5195_2

As has been discussed previously, transformers are between 98-99% efficient. However the 1-2% heat losses are still significant in terms of actual heat output. A typical 15/30 CER transformer loaded to 15MVA, has copper losses of 80kW and iron losses of 8.5kW[25].

Major substations (primary, supply and grid supply), have control rooms and switch rooms which are temperature controlled to avoid condensation within equipment. The heating is usually supplied via resistive heaters mounted on the walls.

A typical primary substation constructed in the 1970's has an annual heating requirement of about 3.2MWh and a peak requirement of about 5.7kW. The electricity supplied to the heaters is supplied by the auxiliary supply and classed as a system loss.

In theory the heat output from one of the primary transformer's iron losses alone, would be enough to heat the substation building and the lowest outdoor ambient temperatures often coincides with high demand on the transformers, where the copper losses are the highest.

Modern distribution substation design takes advantage of this method, where the switchgear and transformer are in close proximity, in one room or enclosure. The heat output from the transformer is sufficient for the switchgear and separate resistive heaters are not required.

The methods for extracting the heat from the transformers would require a separate study but could be in the form of a heat exchanger on the transformer and radiators/fan coil unit within the substation building.

The use of low level waste heat from substations and other areas of high electrical losses such as Data Centres have been used before for district and amenity heating. For example in Switzerland, the low level waste heat (27-40^{o}C) from an IBM data centre has been used to heat a local swimming pool[26]. The details of how revenue could be generated from this waste heat would have to be assessed, or whether it would be 'gift' to the local community.

Although there would be limited scope for us to heat public amenities from substations this proves the concept that low level waste heat can be effectively 'recycled'. Since Version 1 of the strategy we've mobilised a project to look at the feasibility of the re-use of heat at substations within our LDR.

Solar heating at major substations to heat substation

An alternative to the previous example - the use of solar heating technology could also be explored as an alternative to using the waste heat from substations.

Use of local renewable generation to support substation auxiliaries

It is noticeable that other public and private organisations have become more aware and active in recognising applications for these technologies and implementing projects. Examples are: petrol stations, supermarkets, office blocks, road signs and parking meters.

The use of PV and of wind power could be used to offset the energy used by substation auxiliaries. According to DECC, in July 2012, the cost of small scale PV per kW is £2,493, has a return on investment of 6.3%, has a 20-25 year lifetime and requires minimum maintenance.

There are also synergy benefits with substation battery charging and black start capability or other prolonged loss of EHV substation supply.

Design of the energy efficient substation to be carbon neutral

[25] Brush Transformer Test Certificate

[26] http://www-03.ibm.com/press/us/en/pressrelease/23797.wss

A previous government energy policy set out plans for all new homes to be carbon neutral by 2020. An initial entry point for us may be to start plans to introduce a mirror of the carbon neutral homes initiative in terms of developing plans and designs for the carbon neutral substation. A method of reducing energy consumption would be to increase the U value of the building fabric for new substation buildings to reduce the heating demand. This could be embedded into the design specification for new substation buildings and retrofitted to existing ones.

By increasing the insulation U value to the substation buildings it is estimated that energy consumption could be reduced by up to 2.5GWh over a licence area or a saving of £325k per year[27].

3.8.3 Changes to network operations

Voltage reduction at night

Historically voltage reduction has had been used to reduce demand, as much of the load has been ‘voltage dependent’ (tungsten lamps and resistive heating). As the resistance of these devices is fixed, applying a lower voltage reduces the current drawn, less power is transferred and hence overall load is reduced. However, increasingly more load is ‘voltage independent’, as it is fed via a switched mode power supply, which effectively changes its impedance based on voltage (such as HF fluorescent, LED, PCs and VFD fed motors)[28]. Therefore lowering voltage may not lead to the demand savings as desired and could actually increase I^2R losses.

The risk of mal-operation or network voltage conditions being inadvertently placed outside of statutory limits would also have to be factored in.

Since version 1 of the strategy we’ve investigated this as part of our investigation into losses on the customer side of the meter within our LDR.

Switching out under-utilised plant

At times of low load at twin transformer major substations, the combined iron and copper losses of the two transformers can be higher than the equivalent iron losses and copper losses of one transformer. At these times losses could be saved by switching out one of the transformers and re-energising it when the load increased. The implementation of NMS APRS v5 will enable the switching out of under-utilised plant to be achieved more easily.

The disadvantages of this would be security of supply, as if there was a fault on the single transformer, the de-energised transformer would have to be re-energised and loaded up. This would not be instantaneous, and may prematurely age the transformer as the rate of change of temperature would be more rapid than usual. Other problems may be circuit breaker wear, as they would be operated more regularly than under normal conditions. SSEPD are investigating this as an (LCNF) Tier 2 project called ‘LEAN’. We will wait on the findings of this project before proceeding.

3.8.4 Smart Meters

The roll-out of smart meters will provide us with an opportunity to access network data at lower voltage levels of our network than ever before. In the 2015-23 period we will use the new smart meter data to understand how best to measure losses on networks where LCTs are becoming more commonplace. As a result, we will be able to make more targeted investments to reduce electrical

[27] EA Technology - Andrew Bower et al (2013). S5195_2 - “Energy Efficient Substation”.

[28] Carbon Trust [2011] – “Voltage Management” Technology Guide (CTG045)

losses. And in the future, the more accurate measurement of losses would enable our regulator to re-establish a financial incentive on us to reduce losses further.

We will continue to develop our own processes, and help to develop the processes for the industry as a whole, to ensure that we are well positioned to collect data from smart meters as soon as they are installed.

In 2015-23 we intend to use smart meter demand data to more effectively plan and develop our network to meet the future challenges from the connection of LCTs, targeting the use of DSR and investment in reinforcement.

The smart meter data will be used to measure and reduce losses.

We are committed to using demand-side response in 2015-23, and our modelling, drawing on the ENA's commissioned work on network benefits of smart meters, leads to our conclusion of a reduction in system losses (compared with the position with no DSR) of £54m and a reduction in future costs of £49m. This will arise from suppliers being able to offer customer's time of use tariffs to encourage them to shift demand from the peak periods which in turn reduces network losses.

The roll-out of smart meters creates an opportunity for us to access half-hourly performance data on our network. This data will be invaluable in helping us to understand the complex interactions (at lower voltages particularly) between network losses and increasing densities of low-carbon technologies. As mentioned in section 2.7.1 of our published RIIO-ED1 business plan, increasing our understanding in the 2015-23 period is essential in order to support the potential future reintroduction of a financial incentive for us to reduce network losses.

Our planned smart-grid investment includes low-voltage monitoring at substations being installed over the 2015-23 period (see annex 1.9 smart-grid development plan). When combined with the smart meter data, this new monitoring data will help us accurately target losses measurement at specific and critical points on our network. The understanding we gain in the 2015-23 period will help us manage the additional complexity introduced by low-carbon technologies and help develop a range of tools to manage losses effectively in future periods.

3.8.5 Cost benefit analysis of practicable investment options

As part of our business plan submissions for the RIIO-ED1 review we tested the economic practicability of the options for losses investment that were technically practicable. This was done using Ofgem's prescribed cost benefit analysis (CBA) template which puts a social value on the reduction of losses.

The results of such cost/benefit analyses will vary as the input parameters change; the scope of investment to which they apply will also change. The analyses were done with regard to the typical load parameters on Northern Powergrid's licensed networks now and may not be applicable to other networks or to loading patterns which may come to exist in the future. This is worth noting as higher loads associated with electrification of heat and transport may drive higher losses and high levels of loss management investment.

Given that some of the recommended actions in this document are to investigate promising areas of loss management, we would expect that this will develop some new technically practicable investment areas over time thereby expanding the scope of investment to be considered. It should also be noted that our investment choices will also be influenced by external forces such as European directives.

We have reviewed the CBAs and are content that they remain valid at this time. We would expect that they will change over ED1 as certain plant and equipment contracts are renegotiated and investment costs change as a result.

It should be noted that the CBAs were undertaken on a sample of work in line with our asset replacement proposals. The outputs in the tables are still in line with this as the purpose of the tables is to convey the most appropriate action. The volumes and benefits however are based on the full investment work we expect to undertake including asset replacement, reinforcement and customer driven work. There is clearly a degree of uncertainty in this forecast, particularly in the customer driven work, but it represents the best view available.

Pole Mounted Distribution Transformers:

Options considered		Decision	Northern Powergrid Combined NPV			
			16 years £m	24 years £m	32 years £m	45 years £m
Baseline	Cheapest acceptably rated asset	Rejected	-	-	-	-
1	Capitalised Cost Transformer (current policy)	Adopted	0.04	0.07	0.09	0.11
2	EcoDesign 2015 Minimum Transformer	Rejected	-0.10	-0.13	-0.15	-0.16
3	EcoDesign 2021 Minimum Transformer	Rejected	-0.20	-0.21	-0.21	-0.22

We considered the minimum functionally acceptable transformer against the two stages of Ecodesign transformer and our current capitalised cost transformer specification (where the cost of losses over the transformer's life is added to the capital cost of the transformer when the contract evaluation is done).

The current specification provides the greatest benefit in Ofgem's CBA model and it also meets the present EcoDesign requirements.

Our plan is to install 3,517 units over the 2015-23 period, a benefit of 4.9GWh over 2015-23.

Ground Mounted Distribution Transformers:

Options considered		Decision	Northern Powergrid Combined NPV			
			16 years £m	24 years £m	32 years £m	45 years £m
Baseline	Cheapest acceptably rated asset	Rejected	-	-	-	-
1	Capitalised Cost Transformer (current policy)	Adopted	6.40	10.16	12.83	15.57
2	EcoDesign 2015 Minimum Transformer	Rejected	5.70	9.67	12.50	15.40
3	EcoDesign 2021 Minimum Transformer	Rejected	4.77	9.12	12.24	15.43

We considered the minimum functionally acceptable transformer against the two stages of Ecodesign transformer and our current capitalised cost transformer specification (where the cost of losses over the transformer's life is added to the capital cost of the transformer at the tender evaluation stage).

The current specification provides the greatest benefit in Ofgem's CBA model and it also meets the present EcoDesign requirements.

Our plan is to install 3,317 units over the 2015-23 period, a benefit of 142.9GWh over 2015-23.

Power factor correction:

Options considered		Decision	Northern Powergrid Combined NPV			
			16 years £m	24 years £m	32 years £m	45 years £m
Baseline	No mainstream investment at present (current policy)	Adopted	-	-	-	-
1	PFC installed at three PSS	Rejected	-0.08	-0.06	-0.04	-0.02

We considered the potential for installing power factor correction at specific substations to reduce losses.

At present Ofgem's model shows that this is marginally of less benefit than taking no action. However we expect that power factor correction may become cheaper to install in future as equipment process fall and we are intending to trial some such equipment around the mid part of this regulatory period.

300mm^2 waveform LV cable in preference to 185mm^2 waveform on cable overlays:

Options considered		Decision	Northern Powergrid Combined NPV			
			16 years £m	24 years £m	32 years £m	45 years £m
Baseline	Overlay 185mm^2 with 185mm^2	Rejected	-	-	-	-
1	Overlaying LV cable with 300mm^2 Wf (current policy)	Adopted	0.35	0.84	1.20	1.56

When we install new LV mains cables the Ofgem CBA shows a clear benefit in utilising 300mm^2 even though 185mm^2 would carry the load current. We are pursuing this option in our investment plans and will install 2,569 km over the 2015-23 period, a benefit of 40.9GWh over 2015-23.

300mm^2 Triplex HV cable in preference to 185mm^2 for second leg and beyond out of primary (already 300mm^2 on first leg):

Options considered		Decision	Northern Powergrid Combined NPV			
			16 years £m	24 years £m	32 years £m	45 years £m
Baseline	185mm^2 on second leg and beyond	Rejected	-	-	-	-
1	300mm^2 for all 11kV network feeders	Adopted	-0.31	-0.11	0.05	0.24

When we install new 11kV cables the Ofgem CBA shows a clear benefit in utilising 300mm^2 even though 185mm^2 would carry the load current. We are pursuing this option in our investment plans and will install 2,669 km over the2015-23 period, a benefit of 6.7GWh over 2015-23.

We have done the same analysis for 20kV cables, but due to the lighter loading of the 20kV system this is not cost beneficial. Therefore our design policy still stipulates 185mm^2 for 20kV.

33/11kV Transformer:

Options considered		Decision	Northern Powergrid Combined NPV			
			16 years £m	24 years £m	32 years £m	45 years £m
Baseline	Cheapest acceptably rated asset	Rejected	-	-	-	-
1	Capitalised Losses Transformer (current policy – identical unit to baseline in this instance)	Adopted	0.00	0.00	0.00	0.00

We considered the minimum functionally acceptable transformer our current capitalised cost transformer specification (where the cost of losses over the transformer's life is added to the capital cost of the transformer when the contract evaluation is done).

The current specification provides the greatest benefit in Ofgem's CBA model and it meets the present EcoDesign requirements. We are pursuing this option in our investment plans and will install 51 units over the 2015-23 period. We are not claiming any benefit in this area as it is in line with our practice for many decades.

66/11kV Transformer

Options considered		Decision	Northern Powergrid Combined NPV			
			16 years £m	24 years £m	32 years £m	45 years £m
Baseline	Cheapest acceptably rated asset	Rejected	-	-	-	-
1	Capitalised Losses Transformer (current policy)	Adopted	-0.03	-0.01	0.00	0.02

We considered the minimum functionally acceptable transformer our current capitalised cost transformer specification (where the cost of losses over the transformer's life is added to the capital cost of the transformer when the contract evaluation is done).

The current specification provides the greatest benefit in Ofgem's CBA model and it meets the present EcoDesign requirements. We are pursuing this option in our investment plans and will install 23 units over the 2015-23 period. We are not claiming any benefit in this area as it is in line with our practice for many decades.

Use 100mm^2 Al 11kV conductor on spurs in preference to 50mm^2

Options considered		Decision	Northern Powergrid Combined NPV			
			16 years £m	24 years £m	32 years £m	45 years £m
Baseline	50mm^2 Al 11kV OHL (current policy)	Adopted	-	-	-	-
1	Using 100mm^2 11kV OHL for spurs	Rejected	-0.32	-0.36	-0.37	-0.39

We considered using 100mm^2 conductor on 11kV spurs in preference to 50mm^2. However due to the typical loading on such circuits the losses savings do not presently justify the increased investment costs.

This is a particular area which may change in future though. Electrification of transport and heat may lead to significantly higher loads on circuits of this type, particularly in semi-rural areas such as commuter villages. Such changes in load may make 100mm^2 conductors viable and we will review the CBA as electric transport and heat penetration rises.

4 Non-Technical Losses and Electricity Theft

The management of the impact of non-technical losses and theft on our networks is a primary concern for us and below are a number of initiatives we have put in place

Theft in conveyance

Under the terms of its Distribution Licence specifically Standard Licence Condition 49 (SLC49) Northern Powergrid undertakes all reasonable cost-effective steps within its power to resolve any cases of Relevant Theft of Electricity from its distribution system to ensure that losses are minimised. We fully support the initiatives of the Crime Stoppers “Stay Energy Safe” campaign, the “Theft Risk Assessment Service” (TRAS) and the “Energy Theft and Tip Off Service” (ETTOS). A dedicated office based support team under our Shared Services function take reports and notifications received from outside the business concerning theft of electricity and where appropriate arrange for suitably qualified field personnel to visit the properties in question to investigate and where a tamper has been detected then we would always in the first instance make this safe. The reports and tip-off’s may come from various sources including; General Public, Police, Meter Operator agents, Revenue Protection agents, the Company’s field operatives and the ETTOS. We will firstly establish if there is a Meter Point Administration Number (MPAN) and a registered electricity supplier (or former supplier if recorded as disconnected) using systems such as the Electricity Central Online Enquiry Service (ECOES) or the Outage Management System (OMS) to determine which party is responsible for the site investigation. If an MPAN exits (or has existed) then in conjunction with Section 6 of the Electricity Act we have a managed process where we coordinate with the Supplier and their Meter Operator (or Revenue Protection team) would follow up to ensure that again the illegal connection is made safe and further losses are prevented. If no MPAN exists then NPg will take responsibility to ensure that all losses are minimised and will work within our code of practice as well as within the relevant licence conditions as well as the Law if a criminal act has been determined.

Unregistered connections (untraded MPANs)

Some consumers are using electricity which they are not paying for because their supply has not been registered because the Supplier’s registration processes have failed. However, the units these unregistered consumers use add to distribution losses and the cost of these lost units is consequently spread across all customers. Getting these unregistered consumers registered with a Supplier will reduce overall system losses, improve efficiency and reduce overall cost to customers.

While Northern Powergrid is well placed to identify unregistered system users on their networks, they are not able to register them. Registration can only be achieved by a Supplier first agreeing a supply contract with a customer. Hence, in 2014 Northern Powergrid raised a formal Distribution Connection and Use of System (DCUSA) change proposal DCP209 ‘Resolving Un-registered Customers’. This change was raised specifically to improve communications with unregistered customers, set out best practice processes for managing unregistered customers up to, but excluding, the registration process itself and where necessary place new obligations on other parties such as Suppliers. This change was approved by Ofgem on the 30 August 2016 and implemented on 1 October 2016.

In addition, we have invested in technology and resource to tackle this issue; field operative staff physically act on information received and carry out premise inspections working in conjunction with key back office support staff such as our Call Centres and a dedicated team operating within our Registration Services function. Obviously our primary concern is, and always will be, safety but as unregistered customers do not fall into this category they are still taken seriously and in line with Schedule 27 of the DCUSA and, as a last resort, customers can be disconnected.

Field visits to unoccupied and high risk premises

Management of assets in unoccupied and high risk premises is a function that has been carried out by Northern Powergrid for a number of years. The main business driver is safety in ensuring Suppliers are adequately discharging their obligations under their Supply conditions (condition 12) where they should take reasonable steps to detect and prevent, theft or illegal abstraction, damage and or meter interference with these inspections covering parts of the Distribution Network Operator's (DNO) equipment. Generally, inspection provides assurance that neither degradation nor wilful interference has created a hazard. The process links back office support directly with Field Operatives where work is scheduled as 'cold call' appointments.

Unmetered Supplies (UMS) Connections - ensuring accurate inventories

To help and minimise non-technical losses all customers with Unmetered Supplies are required to maintain a detailed and accurate inventory of all equipment and provide a copy to Northern Powergrid as agreed with the customer, usually a minimum of annually for non-half hourly (NHH) connections and monthly for half-hourly (HH) connections and when requested on an adhoc basis. In addition, Northern Powergrid carries out process audits and will work on a regular basis with Local Authorities to ensure that the information provided is correct and complete. Process audits are undertaken in line with the Managing Unmetered Electricity Street Lighting Inventories (MUESLI) document as endorsed by a number of authorities including Elexon and the Electricity Networks Association (ENA). In carrying out the role of the Unmetered Supplies Operator (UMSO) we take the role incredibly seriously as we recognise that this can be a complex area for those outside of the industry such as the Local Authorities. For that reason we have a small dedicated team looking specifically at this subject and who regularly meet with the Local Authorities to discuss various UMS topics. Northern Powergrid have also added a downloadable fact sheet from their website that provides key information covering topics such as the accuracy of inventories to areas where efficiencies can be made.

Urgent Metering Services

Although Electricity suppliers are not obligated to provide a 24/7 Urgent Metering Service (UMetS) many suppliers do provide a 24/7 Contact Centre and very few offer a 24/7 field service. As DNO's we are aware this causes a problem for our field operatives in the event of a metering equipment fault outside the normal field service working hours and if not rectified as soon as possible would adversely impact losses. Recognising this and the impact on customer service especially vulnerable customers, we now provide a 'limited' Urgent Metering Service for all electricity suppliers. The service is aimed at restoring a supply for vulnerable customers and rectification of other minor issues for all customers in the event of a metering equipment issue when our field staff is already out at site.

5 Recommendations

This loss reduction strategy has highlighted a multi-layered approach to reducing losses. Several of the existing loss reduction techniques are straight forward to implement and are incorporated into everyday asset replacement and reinforcement schemes. We have identified additional elements of our design policy that will be reviewed in light of new information and our intention is to complete these investigations in line with the dates shown in Appendix 2.

Other proposed techniques are on a project specific level, where detailed measurements of the problem (such as power factor) and site surveys will have to be carried out before implementation. Due to the need to investigate potential operational problems it is proposed that these solutions are trialled on our network or alternatively we understand the learning from trials in other DNOs if appropriate.

Clearly the EU Ecodesign Directive will have the greatest impact and we will continue work to understand the wider implications of this legislation. We will continue to work with manufacturers to ensure better cost certainty and technical differences to existing stock are understood prior to mass adoption. At present we are assuming that cost efficiencies driven by the legal requirements will make compliant distribution units more economic than distribution units of a higher specification. For power transformers we are assuming we will continue to purchase to existing specifications which appear at present to be in-excess of the Ecodesign requirements on the basis that we not make a retrograde step in performance.

We will, through the existing innovation knowledge sharing process, continue to disseminate the findings of any work we do associated with network losses and identify best practice learning from other DNOs.

A summary of the different strategies and actions is shown in the following table. A more detailed view can be found in Appendix 2.

	Ease of deployment	Actions	Version 2.0 Progress Update
Existing loss reduction techniques			
Increasing cable sizing	Straight forward	Implement the policy of installing a minimum cable size of 300mm^2 at 11kV where practical (e.g. if bending radii and termination arrangements allow). Carry out cost benefit analysis for 20kV feeders. Continue to install a minimum of 300mm^2 mains LV cables that are of a larger capacity than the minimum size option having taken into account capitalised electrical losses in the assessment of lifetime cost within our	**Complete (2017)** IMP/001/912 (Code of Practice for the Economic Development of the HV System) published February 2017 now states 300mm^2 Al Triplex is the standard size. The 20kV cost benefit analysis has been carried out. It is not cost beneficial to increase the cross sectional area of the 20kV cables and the standard remains

		designs.	185mm^2 Al Triplex. (IMP/001/912 section 3.6.6)
Transformer loss specification	Straight forward	We will continue with our current policy to purchase transformers that have lower electrical losses than the minimum cost units available based on having taken into account capitalised electrical losses in the assessment of lifetime cost rather than simply purchase price. Market test the likely costs and availability of lower loss units that may become viable using Ofgem's prescribed cost benefit analysis and fixed data.	**Complete (2017)** IMP/001/103 (Code of Practice for the Methodology of Assessing Losses) published July 2016 defines capitalised loss figures based on Ofgem's cost benefit analysis template. These are split into Iron and Copper losses for pole mounted, ground mounted and system transformers (IMP/001/103 appendix 5)
Increasing transformer sizing	Straight forward	We will continue with our current distribution transformer oversizing policy. We will review this in light of the Ecodesign Directive and carry out cost benefit analysis of economic sizing of low loss transformers and update our design policy as necessary.	**Complete (2017)** IMP/001/911 (Code of Practice for the Economic Development of the LV System) published February 2017 gives guidance on the economic loading of transformers (IMP/001/911 section 3.5.2)
Network configuration	Straight forward	Review design policy on the optimal loading of circuits by assessing the impact on losses, customer numbers and taking into account operational constraints. Implement changes to the policy where necessary and mobilise a project to effect operational network configuration changes to the existing network where justified.	**Ongoing (2015)** Since 2015, much of the HV network has been assessed to optimise open points to balance load and customer numbers. In turn this should reduce losses.

Power factor correction	Moderate	Commission trial installation of power factor correction equipment at distribution S/S and primary S/S. Capture learning from other innovation projects to combine with our own experience with a view to establishing a firm design policy.	**Awaiting data from LV substation monitoring (2020)** Following our Smart Grid enabling investment into installing wide spread LV board monitoring, it is planned for the power factors of distribution substations to be analysed to determine if power factor correction is economic. Initial analysis from our DS3 project shows our LV load has a power factor very close to unity.
Power quality	Moderate	Commission trial installation of harmonic filters at distribution substations and primary substations as part of innovation projects with a view to gaining experience and establishing a firm design policy.	**Awaiting data from LV substation monitoring (2020)** Following our Smart Grid enabling investment into installing wide spread LV board monitoring, it is planned for the total harmonic distortion of distribution substations to be analysed to determine if installing harmonic filters is economic.
Load imbalance	Moderate	Commission trial installation of equipment to improve phase imbalance as part of innovation projects with a view to gaining experience and establishing a firm design policy. Mobilise project to understand how smart metering data can be used effectively to understand phase loadings. Establish an enduring process that identifies	**Awaiting data from LV substation monitoring (2020)** Following our Smart Grid enabling investment into installing wide spread LV board monitoring, it is planned for phase imbalance at distribution substations to be analysed to determine if

		the worse imbalances and take corrective action.	phase re-allocation is economic.
Loss measurement	Difficult	Evaluate methods for assessing network losses using domestic smart metering data and contribute to developing an output based losses incentive for RIIO-ED2.	**Project Started in LDR (2021)**
Theft Reduction	Straight forward	Continue to offer a full revenue protection service for those electricity suppliers that wish to take it up	**Complete (2017)**
Legacy plant and networks	Straight forward	Building on WPD's approach of an early replacement of high loss pre-1958 ground mounted transformers, we'll investigate the losses cost of older primary and grid transformers. Aligning with UKPN's strategy we'll also look at our split phase legacy networks (triple concentric cables and ground mounted split phase transformers). The results of these investigations will inform our investment plans for the ED2 period.	**New Action V2.1 (2023)**
Voltage Rationalisation	Difficult	Building on UKPNs losses strategy and our losses consultation we plan to raise this at the ENA Losses Working Group, as we feel this issue should be looked collaboratively across the DNOs in the first instance.	**New Action V2.1 (2018)**
New techniques			
Superconductors	Difficult	Monitor the development of low temperature superconductors and research projects in the next	**Complete (2023-2031)** WPD's Superconducting Cables – Network

		regulatory period. Pursue the most promising developments via innovation projects to understand their potential exploitation.	Feasibility Study suggests superconducting cable is not at cost parity with conventional conductors but may be within the next decade. To be re-investigated during RIIO-ED2.
Low Loss transformers	Moderate	Implement findings from the EcoDesign Directive. Assess whether it is economic to purchase units with a specification in excess of the Ecodesign Directive requirements. Assess the implications on our network fault levels and ferroresonance of using low loss transformers that have a different X/R ratio than our current units. Establish guidelines for their application and incorporate these into our design policies.	**Tier 1 complete and Tier 2 ongoing** We now procure EcoDesign Tier 1 transformer and are awaiting the for Tier 2 transformers offerings from manufacturers. The Capitalised losses figures may lead us to procure more efficient transformers than Eco-design minimum where economic. The X/R ratios have not yet led to any problems with protection or with ferro resonance.
Design of the energy efficient substation to be carbon neutral	Moderate	We led an innovation project in 2011/12 to gain an understanding of the electrical and thermal energy demands of EHV substations in relation to their local climate. Learning from this project will be used to develop Ecodesign solutions that reduce the net energy requirement of both existing and new substations. An immediate example of this is to review the substation building	**Project Started in LDR (2018)**

		fabric specifications such that the use of higher thermal insulation levels may be incorporated into the design policy where economically beneficial.	
Changes to network operations			
Voltage reduction at night	Moderate	No action as unlikely to reduce losses but watching brief on ENW project.	**Awaiting roll out of AVCs** Following our Smart Grid enabling investment into installing smart AVCs at major substations, there is a facility to send remote voltage setpoints and to apply line drop compensation – this will reduce voltage under light loading conditions including at night. A guidance document on applying LDC has been published.
Switching out under-utilised plant	Moderate	Investigate the effects of frequent switching of plant and how network performance will be affected once our new Network Management System is implemented and incorporate findings into our operational policies.	**Awaiting outcome of LEAN** SSEPD are investigating this as an (LCNF) Tier 2 project called 'LEAN'. We will wait on the findings of this project before proceeding.

Table 6 : Strategies and Actions

6 Update process

Our Smart Grid Implementation team are responsible for updating this losses strategy as necessary driven by changes to the inputs to our strategy. However events that would be expected to trigger changes going forwards would include the following scenarios

- The strategy will be reviewed following the annual revision of our investment plans. Any change to the investment plan may require a revision to our actions to implement the losses strategy and also our overall view of losses movements.

- The strategy will be revised following major changes to the contracts through which investment with losses impacts are delivered. Input price changes will affect the degree to which we should be pursuing losses management investment.
- The strategy will be reviewed should the penetration of electric transportation and heat change significantly.
- The strategy will be reviewed in light of learnings from other DNOs from ENA Technical losses working group we participate in, the DNOs' respective losses strategy updates and their losses discretionary reward submissions. Any relevant recommendations are then recorded in the appendices 3 and 4.

As a result of these scenarios, a review of the losses strategy would be expected annually as a minimum, and possibly more frequently at times.

The review would take the form of an internal expert review and engagement with stakeholders to confirm direction and actions remain appropriate.

Revision of the strategy would be undertaken following this review incorporating changes as appropriate, but in the event of no changes being required then as a minimum a statement that the previous strategy remains valid should be expected.

Appendix 1 – Change Log

Version	Changed section	Detail
Version 1.0		
July 2013		Business plan submission
Version 1.1		
July 2015	Guidance for the reader	Updated to reflect the change from 2015-2023 business plan document to standalone losses strategy
July 2015	Summary	Completely re-written to reflect inclusion of theft and greater emphasis on smart metering and the status as a standalone document
July 2015	Scope	Completely re-written to reflect inclusion of theft and greater emphasis on smart metering and the status as a standalone document
July 2015	Electrical losses	Minor update to improve clarity
July 2015	Calculation of electrical losses	Minor update to reflect changes to the smart meter roll out
July 2015	Ecodesign and energy labelling policies	Updated to reflect the progress in the Ecodesign directive
July 2015	Network operations	Minor change to improve clarity
July 2015	Impact of future time of use tariffs	Minor update to reflect changes to the smart meter roll out
July 2015	Transformers	Updated to reflect the progress in the Ecodesign directive
July 2015	Smart meters	New section added in line with feedback from Ofgem · Highlights the opportunities · Lays out the techniques that will be pursued · Level of perceived benefit and alignment with previous perceptions of benefit · Reference to the ED1 Business Plan – Annexes 1.4 and 1.9 in particular · A discussion of the benefits, dis-benefits and prerequisites of smart metering
July 2015	Electricity theft	New section added covering other kinds of losses (not just those that arise because of electrical impedance) · Discussion of the issues around theft and the

		problems caused by it · Description of the actions we are taking along with Crimestoppers and energy suppliers
July 2015	Strategy summary table	Entry on theft added
July 2015	Change Log	New section detailing the versions and (at a summary level) the changes made
Version 1.2		
Jan 2016	Guidance for the reader	Reference to the appendices on changes, plans and progress added
Jan 2016	Summary	Strategy reviewed to add additional methods of utilising smart meter data and network configuration to manage losses Level of losses movements reviewed in light of the full range of investment with will affect losses (reinforcement and customer driven in addition to asset replacement). Table of forecast losses movements added
Jan 2016	Cost benefit analysis of practicable investment options	Anew section added indicating the results of the CBAs undertaken, the implications and the actions and benefits that flow from them.
Jan 2016	Non-Technical Losses and Electricity Theft	A new section replacing the Electricity Theft section from the July 2015 revision. The scope is similar to, but slightly wider than, the previous version and the content has been fully revised in line with the thinking that has been emerging since the start of the 2015-23 period.
Jan 2016	Update process	A new section describing the events that would trigger update of this strategy and the likely frequency thereof has been added
Jan 2016	Appendix 1 – Change log	The change log has been updated
Jan 2016	Appendix 2 – Actions to implement the losses strategy	A new section detailing the action plan that flows from the losses strategy, including asset related investment, policy changes, procedural changes and R&D.
Jan 2016	Appendix 3 – Report on previous year's actions	Blank at this time, this section will in future revisions contain information on our progress with the action plan
Version 2.0		
Nov 2017	General update for consultation	General update driven by changes in external environment; changes to our code of practice for valuing losses, codes of practices for LV and HV

		design, upgrading cables sizes, updates from manufacturers on eco-design, updates to the smart metering programme and updates to our non-technical losses strategy.
	Philosophy	New Philosophy section added
	Smart meter programme	Updates to smart metering programme
	Losses forecast	Actual losses figures for 2015/16 and 2016/17 added to forecast
	Eco-design	Updates from manufacturers on Eco-design compliant transformer and learning from Tier 1 procurement.
	Percentage Losses	Updates on percentage losses values
	Codes of practice	Updates to the Code of Practice for the Methodology of Assessing Losses, IMP/001/103 (regarding new methods and capitalised values), Code of Practice for the Economic Development of the LV System, IMP/001/911 (regarding transformer loading guidance) and Code of Practice for the Economic Development of the HV System, IMP/001/912 regarding reduced conductor resistances.
	Other DNOs losses strategies	New section on other DNO's losses strategies
	Other DNOs losses innovation projects	New section on other DNO's losses innovation projects
Version 2.1		
Feb 2017	General	Minor wording changes for consistency with other NPg strategy documents.
Feb 2017	Recommendations	Aligned actions with LDR Tranche 2.
Feb 2017	Recommendations	Legacy plant and networks action added
Feb 2017	Appendix 4	BHE Projects added.

Appendix 2 - Actions to implement the losses strategy

The actions to implement the losses strategy fall into two categories: ongoing programmes and one-off improvements.

Ongoing programmes

Action		Units	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23
Increasing cable sizing	Implement the policy of installing a minimum cable size of 300mm^2 at 11kV where practical (e.g. if bending radii and termination arrangements allow).	Metres 11kV cable	324	343	336	339	336	329	331	331
	Continue to install a minimum of 300mm^2 mains LV cables that are of a larger capacity than the minimum size option having taken into account capitalised electrical losses in the assessment of lifetime cost within our designs.	Metres LV cable	332	318	319	320	320	320	320	320
Transformer loss specification	We will continue with our current policy to purchase transformers that have lower electrical losses than the minimum cost units available based on having taken into account capitalised electrical losses in the assessment of lifetime cost rather than simply purchase price.	66kV Ground Mounted Transformers	4	-	1	7	2	1	6	2
		33kV Ground Mounted Transformers	6	2	12	7	9	7	3	5
Increasing transformer sizing	We will continue with our current distribution transformer oversizing policy.	HV Pole Mounted Transformers	499	165	470	473	474	477	478	481
		HV Ground Mounted Transformers	403	412	417	417	417	417	417	417

Appendix 3 - Report on other DNO's losses strategies

The losses strategies of the DNOs have much in common and so there is little value in summarising their entire strategies here, however the table below shows the salient points:

DNO	Section	Description	Relevance to NPg
ENWL	3.1.1	Pre 1990 > 750kVA transformers	Assuming these units are early CRGO steels, NPg would find it difficult to identify a cut off date from the transformer nameplate.
SPEN	7.3.2	100mm^2 as standard conductor HV overhead	NPg's stance was to use 100mm^2 on mainlines and 50mm^2 on spurs. However we will we look into the associated increased mechanical reliability benefits of using 100mm^2 within the the losses cost benefit analysis.
SSEPD	3.3 & 6.1	6.6kV to 11kV upgrade is cost effective in certain circumstances	We have recently upgraded our Kingeo Primary Substation from 6.6kV to 11kV. We've also been gradually upgrading our Darlington network to 11kV. To be considered for ED2.
SSEPD	6.2	Static Balancers on LV networks	Static balancers are used on the legacy NPg networks. However we will keep a watching brief SSEPDs progress.
WPD	3.4 (2017)	Early replacement of pre-1958 GM Transformers	We've completed a CBA and implemented a similar policy to WPD within our asset health indices. We also plan to carry out an CBA looking in the cost effectiveness of the early replacement or high loss on our older grid and primary transformers.

WPD	7.2.8 (2017)	HV phase balance correction using PV inverter	Interesting development. We will keep a watching a brief and raise the issue with our distributed generation stakeholders
UKPN	5.3.5.1	Voltage Rationalisation	This point was also raised as part of our losses consultation in November 2017. We think this is worth considering on a national level and we'll raise this as part of the ENA Losses working group.
UKPN	5.3.5.2	Non-standard networks	Like UKPN we have some legacy triple concentric cables, and split phase transformers. We plan to holistically we will review our these networks against modern networks to identify if any action to reduce losses is cost effective.

Appendix 4 - Report on other DNO innovation projects in relation to losses

Organisation	Section	Relevance to NPg
Sohn Associates Report [29]	*Recommendation 1: The network modelling and analysis tools used in the study are based on calibrated representative network models data. Given the increasing importance of losses, it would be appropriate that DNOs establish the capability of modelling and evaluating loss performance of their present and future networks, under different future development scenarios*	We should look to ensure that we can model losses in our power system tools by incremental improvements to the existing tools and by incorporating this requirement into the specification for the future replacement of those tools.
Sohn Associates Report	*Recommendation 2: DNOs to consider carrying out more systematic data gathering associated with power factor to assess the materiality of the issue and to enhance the understanding of the costs and benefits of power factor correction at consumers' premises. The business case for power factor correction may then be developed.*	We should explore use of power factor correction via either our own innovation project or other DNO projects e.g. LV capacitors in ENW Smart Street project. We should explore using the smart metering data and SCADA data to identify network locations with a poor power factor i.e. less than 0.9.
Sohn Associates Report	*Recommendation 3:*	As part of our rollout of LV monitoring we

[29] "Management of electricity distribution losses" report by Imperial College London and Sohn Associates

	Further work is required to assess the extent of the imbalance problem and to test various solutions, which will not only reduce losses but deliver many other benefits of a well-balanced network. It may be appropriate to develop policies and working practices for avoiding excessive imbalance in future.	should examine the amount of phase imbalance we have an opportunity for improving network losses & increasing capacity. We should strengthen the requirement in our LV design policy for avoiding future excessive imbalance. This will improve over time as we confirm on which phase existing customers are actually connected.
Sohn Associates Report	*Recommendation 4: The inaccuracy of loss calculation using half-hourly data at the edges of the LV network should be recognized when conducting network studies*	The work behind this recommendation backs up our decision not to taper the LV network and aligns with the work done by the Sheffield University PhD on assessing losses using smart metering data.
Sohn Associates Report	*Recommendation 5: As the benefits of peak demand reduction may be material, an assessment of the opportunities enabled by alternative smartgrid techniques to achieve this should be carried out.*	We should monitor the impact on losses from the supplier rollout of Time of Use tariffs enabled by the smart metering programme. Our future work on DSR should incorporate consideration of losses if appropriate.
Sohn Associates Report	*Recommendation 6: As the benefits of active voltage control in LV distribution network may be significant, comprehensive assessment of the opportunities to further reduce network losses should be*	Our voltage reduction programme at primary substations to reduce LV voltages, rollout of smart AVC units and voltage management policies align with this recommendation.

	carried out.	
Sohn Associates Report	*Recommendation 7: When considering active network management solutions and technologies to facilitate low-carbon connections, the impact on losses should be given full consideration*	We should ensure that network design policy changes are made in line with our ED1 licence obligation on losses. We need to ensure that our design engineers follow our policy guidance on losses assessment for EHV design solutions.
Sohn Associates Report	*Recommendation 8: There is a clear case for fundamentally reviewing cable and overhead line ratings to ensure that future loss costing has been included in the economic rating calculation. This could be based on Ofgem's loss investment guidelines or on loss-inclusive network design standards.*	We should continue to incorporate losses considerations in our production of network design policy on standard equipment ratings.
Sohn Associates Report	*Recommendation 9: The transformer loss calculations indicate that the benefits of investing in low-loss transformers may be significant and this should be considered further to establish or otherwise the low-loss transformer business case in line with UK energy and carbon policy*	We should continue to purchase transformers manufactured in line with the requirements of the Ecodesign directive and activity participate in the debate on the requirements for Tier two of the Ecodesign directive.
Sohn Associates Report	*Recommendation 10: In future losses may drive early asset*	We should assess the accelerated replacement of older poorly performing distribution transformers.

	replacement of transformers when economically efficient. If early replacement programmes are economically justified and capable of being funded, appropriate resources would need to be made available to facilitate delivery of such programmes.	
Sohn Associates Report	*Recommendation 11: Network designers may consider the option of installing additional distribution transformers to minimise LV network reinforcement cost and reduce network losses*	We have in the last iteration of our HV & LV design policies considered the optimal loading of individual distribution transformers. We should in the next review of those policies consider the guidance we provide for evaluating the overall cost effectiveness including losses impact of new HV transformers verses the extension of existing LV networks.
Sohn Associates Report	*Recommendation 12: In the light of future developments, particularly in relation to the integration of low carbon demand and generation technologies, it may be appropriate to reconsider long-term distribution network design. This may take a strategic view of future voltage levels and include consideration of losses in the decision-making.*	This is an interesting and wider reaching recommendation that may need to be explored in national level thinking due to the impact on regulatory allowances. However at a local level we should continue to extend the 20kV network and evaluate whether it has further use as a replacement for 11kV at strategic locations.
Sohn Associates Report	*Recommendation 13: In order to reduce losses and provide future flexibility within LV networks, LV tapering policy may be re-examined.*	Done already and expanded to consider opportunities at HV.

Sohn Associates Report	*Recommendation 14: A review of DNOs' network modelling and analysis tools and capabilities may be required to support design engineers in applying new policies and processes relating to loss-inclusive network design*	Agreed and covered in response to recommendation one.
ENWL	Voltage Management on Low Voltage Busbars	Alignment with CLNR with regards to active voltage control. Keep watching brief on power factor control.
ENWL	CLASS	Aligns with NPg's voltage reduction programme.
ENWL	Low Voltage (LV) Network Automation	Meshed networks are rare on NPg networks but this is an interesting development and we are trialling similar on our LV Foresight project.
WPD	Voltage Optimisation 11kV Network	Aligns with NPg's voltage reduction project.
Berkshire Hathaway Company (Pacificorp)	CVR	The project had partial success on a technical basis, but was not successful over all. Even on handpicked circuits thought likely to provide a losses reduction, the losses reduction was marginal; in practice only around 10% of the modelled prediction of the reduction. Given this loss reduction it was not cost effective to make the investment necessary to gain the reduction.
Berkshire Hathaway Company (MidAmerican Energy)	VAr Support	This shows promise functionally, but given the capital intense nature of the method (238 VAr support devices were required for 3 HV feeders) it is not likely to be adopted in the UK until other methods have been exhausted.