Losses Strategy

May 2020, Version 2.2

Northern Powergrid approach to energy system losses

No system can be 100% efficient and electricity networks are no different. The losses on an electricity system are made up of technical losses (consists of fixed losses and variable load losses), non-technical losses (primarily related to unidentified, misallocated, and inaccurate energy flows, in which the end user is unknown or the amount of energy being consumed is uncertain; this includes theft from the network) and electrical energy consumed by network operations (for example the power consumption for heating and lighting at a substation). Northern Powergrid (NPg) 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 we recognise 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 to achieve Net Zero target involving the electrification of transport and heat has the potential to increase system losses due to increased network utilisation. Any such increase needs to be weighed against the carbon reduction benefit arising from this transition. The move towards a distribution system operator (DSO) role may offer market-based and smarter solutions-based opportunities to manage losses, and will be facilitated by better losses visibility and more potential for losses control, for example maximising the ability of zero-carbon generators to be dispatched. Such solutions themselves may involve local increases in losses but delivering an overall net carbon reduction benefit from the electricity system. Conversely, a smarter flexible energy system with large amounts of distributed generation offers the prospect to actively manage power flow locally to minimise the need to move power over long distances. Whole system thinking will be important so that overall benefits are maximised and costs are minimised across the energy system. Northern Powergrid believes that losses management is not only about reducing losses, but also includes taking into account the financial and carbon cost of losses to our customers with these being factored into any new and smarter technical or market-based solutions. In this fast changing environment, Northern Powergrid has adopted an approach of fully integrating this whole system understanding of losses within all 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 (SLC) 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 2.2 of this document we have also provided a progress update on these options; how we have adjusted our strategy based on learning from our own and other Distribution Network Operators) (DNOs) losses projects and changes to the external environment; and updates on delivering the actions.

The document covers both technical and non-technical losses.

It includes as appendices:

- a history of the updates and the reasons that drove them, and
- the proposed action plans 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 we continually review and update. In order to provide full information for stakeholders, we have 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 losses strategy is intended to be distinct from our losses discretionary reward submissions. They can be viewed on our losses webpage at https://www.northernpowergrid.com/losses

Other related information

The Code of Practice for the Methodology of Assessing Losses states our approach and provides guidance for the methodology of calculating losses and carbon emissions associated with the operation of the distribution system. This document can be accessed here.

For further information on our initiatives and activities to manage losses, please visit our losses webpage or email us at losses@northernpowergrid.com.

Contents

Northern Powergrid approach to energy system losses 2

Guidance for the reader 3

1 Summary....................6

2 Scope 10

3 Electrical losses 10

3.1 Technical losses....................11

3.2 Electrical energy consumed by network operations....................12

3.3 Calculation of electrical losses 12

3.4 Overall distribution of electrical losses....................13

3.5 Wider environment....................13

3.5.1 EU targets and directives....................14

3.5.2 BHE environmental policy 16

3.5.3 Historical performance....................17

3.6 Present policy on managing and reducing losses 17

3.6.1 Product specifications....................18

3.6.2 Design policy....................19

3.6.3 Network operations....................19

3.6.4 Promoting the efficient use of electricity....................20

3.7 Impact of future networks on losses 20

3.7.1 Increased parasitic losses 20

3.7.2 Embedded generation and low carbon transition....................21

3.7.3 Electrification of transport and heat 22

3.7.4 Impact of future time of use tariffs 22

3.8 Options for further loss reduction 22

3.8.1 Expand existing loss reduction techniques....................22

3.8.2 New technologies 26

3.8.3 Changes to network operations 32

3.8.4 Smart meters 34

3.8.5 Cost benefit analysis of practicable investment options 35

4 Non-technical losses and electricity theft 39

5 Recommendations....................41

6 Update process 46
Appendix 1 – Change Log 48
Appendix 2 - Actions to implement the losses strategy....52
Appendix 3 - Report on other DNOs' losses strategies 53
Appendix 4 - Report on other DNOs' innovation projects in relation to losses.55

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 activities. 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 (CBA) 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 flexibility solutions 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 UK government has pushed back the smart meters rollout deadline to 2024, which also impacts this projection.

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: Since 2015/16, the actual losses were lower than in the original forecast. This is thought to be due to a much reduced consumption from our customers then we originally forecast.

Year	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23
Energy lost	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 & low carbon technologies (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	***2,072,854***	***2,086,062***	***2,047,673***	***2,007,517***	***2,100,798***			

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 effect are:

- 2050 Net Zero target. The Committee on Climate Change (CCC) responded to a request from the governments of the UK, Wales and Scotland and recommended a new emissions target for the UK of net zero greenhouse gases by 2050. This resulted in the UK government to introduce legislation to implement this target, which has implications for our role as a DNO, our investment planning, and our valuation of a carbon price, in supporting such a target.

- 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.
- Electric vehicle targets. Due to the increased pressure on urban air pollution, the UK government has placed further emphasis on phasing out internal combustion engines, and is consulting on bringing forward the end to the sale of new petrol, diesel and hybrid cars and vans from 2040 to 2035, or earlier if a faster transition appears feasible[3]. We are now refreshing our forecasting, via our DFES[4], to meet these targets and to meet Net Zero.
- Smart meter delays. The smart meter programme has been delayed several times, which means that any benefits of the time of use (ToU) tariffs have 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[5].

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 there are a number of initiatives we have put in place to manage theft in conveyance, unregistered connections (untraded meter point administration numbers (MPANs)), settlement data inaccuracies, unmetered supplies (UMS) connections inventories and urgent metering services.

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.

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). We are also a full member of the United Kingdom Revenue Protection Association (UKRPA). The UKRPA is a voluntary

---

[3] https://www.gov.uk/government/consultations/consulting-on-ending-the-sale-of-new-petrol-diesel-and-hybrid-cars-and-vans

[4] https://odileeds.org/projects/northernpowergrid/dfes/

[5] 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)

trade association, established to provide a forum for the exchange of information, best practices, and discussion of matters of common interest related to Revenue Protection across the UK.

Electrical losses reduction as part of our wider carbon footprint reduction

We have been monitoring our carbon footprint since 2007. In 2018/19, we have successfully achieved a 16.7% reduction in carbon emissions compared to the previous year.[6] We are firmly on track to exceed our commitment to reduce our carbon footprint by 10% by 2023. Carbon reduction achieved by the end of the regulatory year 2018–19 has taken our overall reduction against our ED1 business plan baseline to 40%.

Alongside non-electrical measures such as installing telematics systems in our fleet vehicles, electrical loss reduction is part of this initiative. 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. 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 manage electrical losses.

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 low carbon technologies (LCTs), targeting flexible solutions 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 providing flexible solutions, agreements on how decisions might be implemented. For this reason, managing losses is 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.

More information on how we are planning to use smart meter data to develop specific solutions to manage losses is discussed in our LDR Tranche 3 submission which will be available on our losses webpage.

[6] Our carbon footprint is now published in our annual environment report: https://www.northernpowergrid.com/asset/0/document/5144.pdf

2 Scope

This document details our approach to manage losses. In general, electrical losses can be categorised and defined as below:

- Technical losses: Losses that occur naturally in power systems, associated with the passage of current through a resistance. This can be characterised as either:
  - Fixed losses: Losses that are incurred as a result of an asset being energised and are largely independent of network loading, contributing to roughly between a quarter and a third of the total technical losses on distribution networks.
  - Variable losses: Losses that are incurred directly as a result of load flowing through an asset, which are proportional to the load squared, contributing to roughly between two-thirds and three-quarters of the total power system technical losses.
- Non-technical losses[7]: Losses that are primarily related to unidentified, misallocated, and inaccurate energy flows, in which the end user is unknown or the amount of energy being consumed is uncertain[8]. These include theft and fraud in conveyance process and measurement errors.
- Electrical energy consumed by network operations: For example the power consumption for heating and lighting at a substation.

It discusses 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. We have, however, as part of our Enhanced Understanding of Network Losses project with Newcastle University, investigated data accuracy issues and its impact on network losses[9].

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.

The picture for losses going forward is mixed. However the future predicted changes in the nature of electrical demand, primarily through the use of LCTs are likely to lead to increased networks losses

[7] Internal Northern Powergrid policies related to Non-technical losses include: REG/008 – Policy in Respect of the Relevant Theft of Electricity, REG/008/001 – Code of Practice for the Investigation of Theft in Conveyance and REG/008/002 – Code of Practice for the Management of Unregistered Customers.

[8] CIRED WG CC-2015-2: Reduction of Technical and Non-Technical Losses in Distribution Networks'.

[9] 'Investigating the sensitivity of network loss estimation to data accuracy and fidelity issues'

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 (BAU) in future.

We will continue to develop and update the actions proposed in this document to reflect worldwide 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 Technical losses

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

- Fixed losses (also known as no load losses); or
- Variable losses (also known as load 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.[10] A more detailed assessment of the unmetered electricity consumption has been undertaken and will be impacted 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 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 or generation in terms of profiles and maximum values which vary with time of day and time of year. This relationship is derived and explained further in our Code of Practice for the Methodology of Assessing Losses[11].

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

[10] EATL "Energy Efficient Substation" S5195_2.

[11] Code of Practice for the Methodology of Assessing Losses, IMP/001/103 March 2019.

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[12] 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[13] CBA 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[14] 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.

3.5 Wider environment

Losses over the DNOs networks in the UK in 2018 is around 19 TWh, about 5.4% of the total UK electricity demand of 352 TWh, and accounted for about 71% of total UK electricity network losses[15]. This represents the largest component of the DNOs carbon footprint. In 2018-19, around 0.54

[12] 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.

[13] These CBA templates can be downloaded from our losses webpage https://www.northernpowergrid.com/losses and the guidance and working examples are presented in our Code of Practice for the Methodology of Assessing Losses.

[14] 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)

[15] Digest of UK Energy Statistics (DUKES) 2018 Chapter 5: Electricity

MTonnes of carbon dioxide equivalent (CO_{2e}) was emitted due to losses on the Northern Powergrid network, which is about 94% of the total carbon footprint[16].

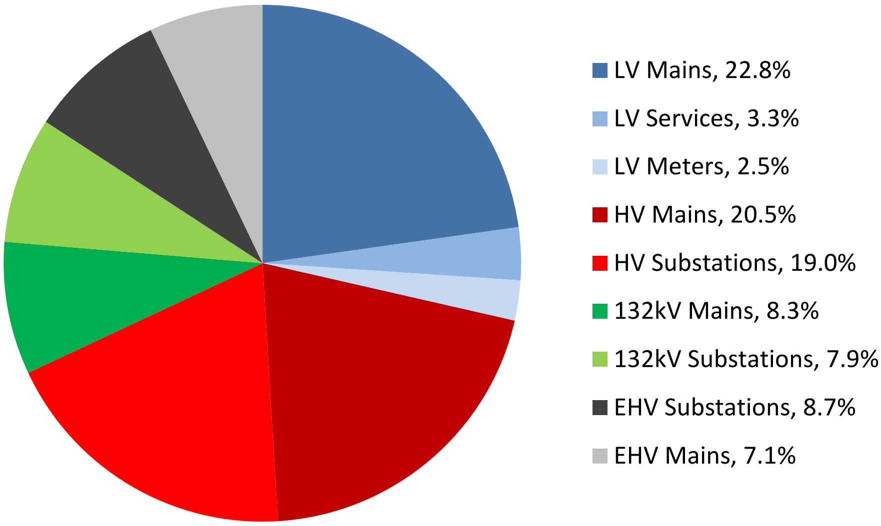

Figure 1: Typical overall distribution of percentage losses (adding up to 100%)

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[17], 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

2050 Net Zero target

To meet the UK's 2050 net zero target, which is considered as one of the most ambitious in the world, we are committed to work collaboratively with Ofgem and the whole industry to ensure that our strategies and investment planning meet the existing environmental targets and the commitments of the UK government. This includes our losses strategy. One of the challenges of meeting a Net Zero future is to factor in the cost of losses in our CBA. This will require a more sophisticated analysis in line with the new carbon targets and consideration of carbon intensity and pricing to be consistent with how we forecast our network during our investment planning and decisions. In our LDR Tranche 3 submission, we have carried out an analysis of variable cost of losses and carbon intensity on our network.

[16] Northern Powergrid 2018-19 Environment Report: https://www.northernpowergrid.com/asset/0/document/5144.pdf

[17] 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[18].

Tier 1 requirement started in 1 July 2015 and underwent a review in 2018, resulted in an amended version published in November 2019[19]. Tier 2 will start in 1 July 2021, with a review planned in 2024 to decide if there will be a Tier 3 requirement:

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

Our transformers can be split into four Ecodesign categories as shown in table 2:

Ecodesign category	Equivalent NPg category	Method of losses measurement	Expected impact on NPg
Three-phase medium power transformers rated power ≤ 3, 150 kVA	Ground-mounted distribution transformers (315kVA, 500kVA, 800kVA & 1000kVA)	Maximum load and no load loss level specified.	Tier 2 is under review (will probably be similar in terms of total losses as existing capitalised cost). An amorphous core transformer manufacturer estimated that to increase the efficiency of their Tier 1 transformer offering to an Amorphous core Tier 2 compliant transformer the price would increase by 50%.
Pole-mounted transformers 25 kVA ≤ rated power ≤ 400 kVA	Pole-mounted transformers (25 kVA to 315kVA)	Maximum load and no load loss level specified.	Tier 2 is similar in terms of total losses as existing capitalised cost.
Medium power transformers rated power > 3, 150 kVA	33kV CER primary transformers (i.e. 33/11kV)	Maximum load and no load loss level specified.	Tier 2 could perform slightly worse given Northern Powergrid estimated load loss factors (LLF) and utilisation rates. Existing stock has better iron losses, but worse copper losses than both Ecodesign tiers.

[18] The document published in May 2014 can be viewed at https://op.europa.eu/en/publication-detail/-/publication/9124a197-e17f-11e3-8cd4-01aa75ed71a1/language-en/format-xhtml

[19] The amended version published in 2019 can be viewed at https://op.europa.eu/en/publication-detail/-/publication/0009a44b-f735-11e9-8c1f-01aa75ed71a1/language-en/format-xhtml

Ecodesign category	Equivalent NPg category	Method of losses measurement	Expected impact on NPg
			Ecodesign minimum performance appears to be optimised for highly loaded transformers.[20]
Large power transformer rated power ≤ 0.025 MVA; 0.05 MVA ≤ rated power ≤ 200 MVA;	66kV CER Primary transformers (i.e. 66/11kV) & CMR system transformers	Chosen on calculation of minimum peak efficiency index (PEI).	Similar methodology to existing practices.

Table 2 : Transformer Ecodesign categories

Figure 2 shows how existing ground-mounted distribution transformers compare against the expected minimum requirements for the Ecodesign directive.

Since the first version of this strategy was published, we have installed 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 was small as manufacturers were able to meet the new requirements with improved designs using existing materials and manufacturing techniques. We are currently in the tendering process for Tier 2-compliant transformers.

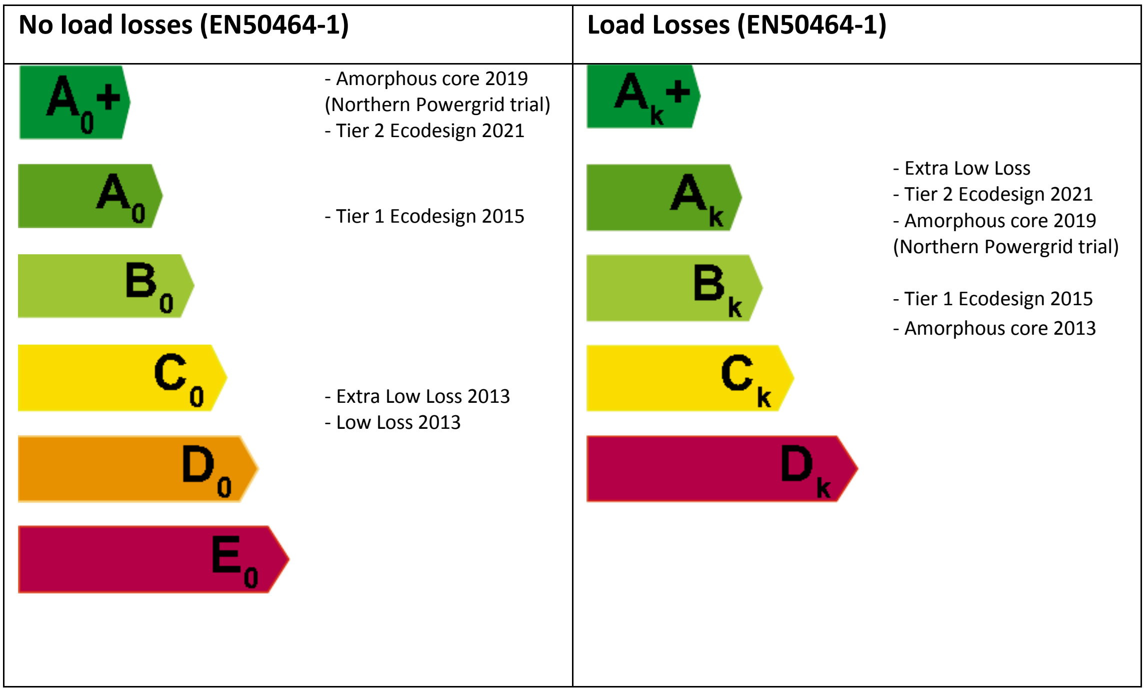

Figure 2: Existing ground-mounted distribution transformers

3.5.2 BHE environmental policy

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

[20] We will continue to investigate the impact of Tier 2 on our specification as we are not looking to reduce our level of losses performance (if possible). Due to our network topology and configuration and our security of supply requirement, our transformers are not running highly loaded under normal operating conditions.

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 our 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 in figure 3 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. Northern Powergrid, have similar losses as most of the other DNOs, with an 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 2005/06 and 2009/10 are examples of how metered data inaccuracies can skew the measured losses significantly.

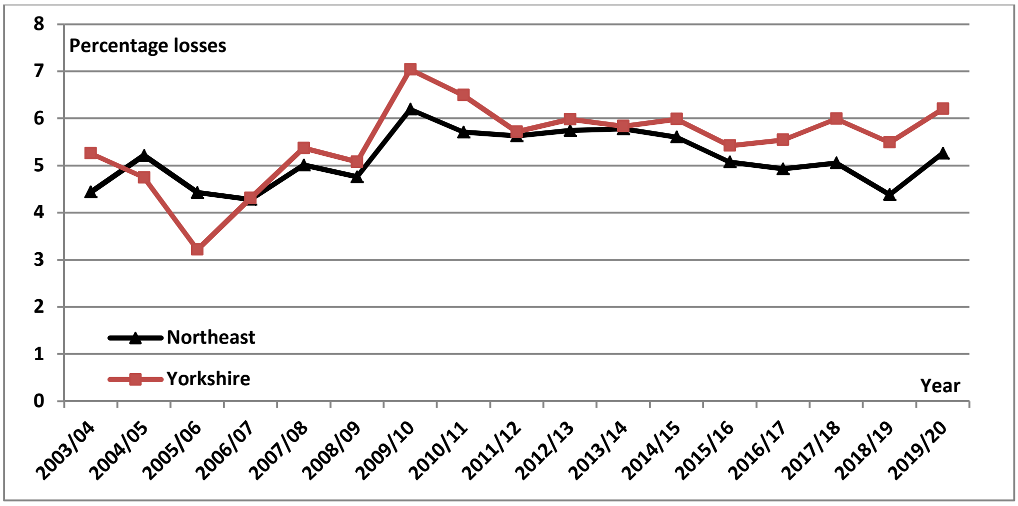

Figure 3: Comparison of Northeast and Yorkshire percentage losses from 2003/04 to 2019/20

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 (CBA). These CBAs 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 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 (2019) 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. Since 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 its 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[21].

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[22]. 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[23].

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

[21] IMP/001/911 – “Code of Practice for the Economic Development of the LV System”

[22] IMP/001/912– “Code of Practice for the Economic Development of the HV System

[23] IMP/001/913 – “Code of Practice for the Economic Development of the EHV System”

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[24] 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)[25].

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)

[24] IMP/001/ 010 – "Code of Practice for Standard Arrangements for Customer Connections"

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

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 below shows an estimate of smart meters parasitic (from maximum permitted losses stated in the Metering Instrument Directive) against existing meters.

From table 4, the parasitic losses from a typical household will increase from around 2 W to over 5 W (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[26].

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

3.7.2 Embedded generation and low carbon transition

An embedded generation connected to the network will lead to power flows which are different from historical flows. The change in network loading and the impact on losses will vary, depending on the size of the background network loading and the new connection, as well as the location and characteristics of the new connection.

We have learned that BESS could either reduce or increase network losses, depending on its scale and mode of operation. This is discussed further in our LDR Tranche 3 submission and full report for our case studies on the impact of BESS on losses can be obtained from our losses webpage.

We also understand that active network management (ANM) operation will increase existing network utilisation, thus increasing network losses. Holistically however, in helping to connect more low carbon generation, this operation will help to decrease the system-wide losses.

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

The uptake of low carbon technologies will significantly impact losses. Future connections of LCTs will increase losses depending upon the uptake level, the connection location and the balance between demand and generation.[27]

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. Our 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. We are investigating how these scenarios will be felt on a more granular level using our low carbon technology forecasting tool[28]. 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.

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

[27] A report on the ENA Working Group Project: Impact of Low Carbon Transition – Technical Losses

[28] More information on our innovation project ‘Improving Demand Forecasting (NIA_NPG_012)’ can be obtained from our innovation webpage https://www.northernpowergrid.com/innovation/projects/improving-demand-forecasting-nia-npg-012

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 (LLF) of 0.25 and is 3.9km long. CBA 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 beneficial 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.

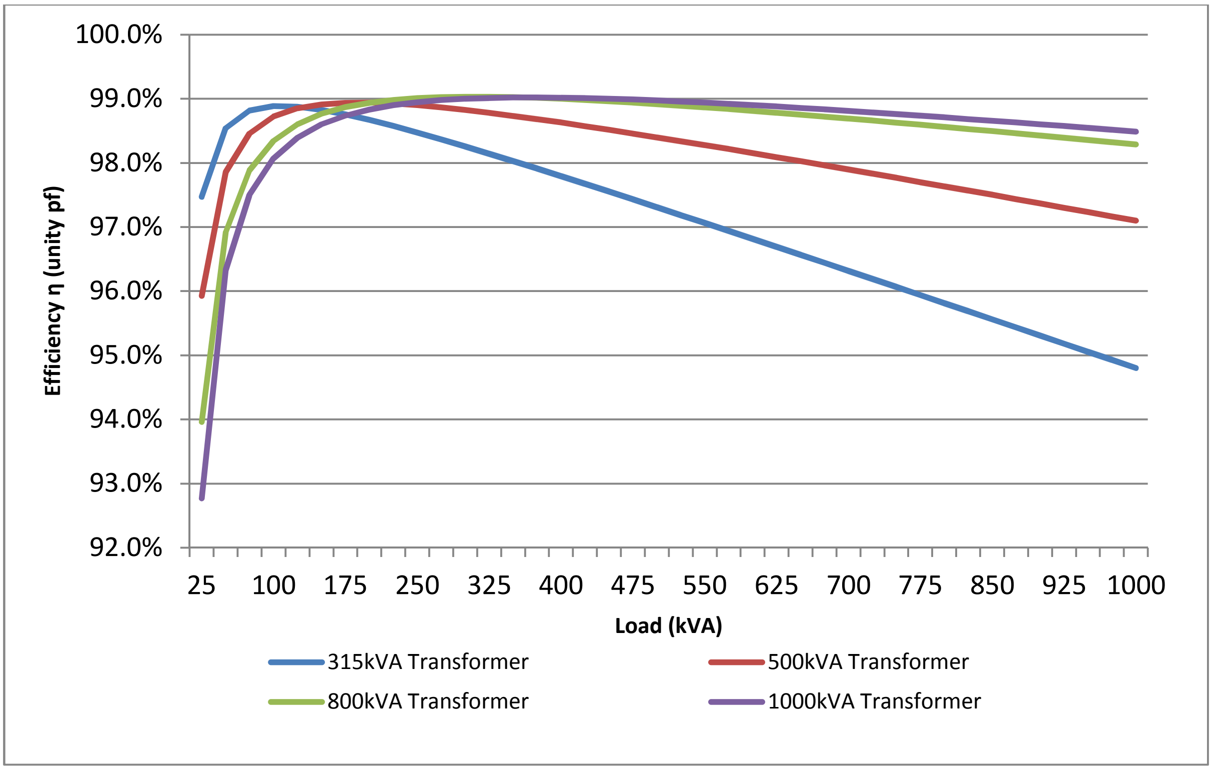

Figure 4: Approximate efficiencies against load for typical Northern Powergrid transformers

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.
- 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[29] to assess their benefits on distribution networks.

[29] 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 (WPD) 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.

As part of our Losses Discretionary Reward (LDR) commitments, we are installing five units of 1,000 kVA ground-mounted amorphous transformers on our network using standard working procedures. This trial helped to allay technical concerns around brittleness, size, weight, harmonics and noise in preparation for Ecodesign Tier 2 maximum loss levels which come into force in 2021. The replacement of older transformers with the new ground-mounted amorphous transformers has the potential to produce annual losses savings of up to 2 GWh.

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[30] (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.

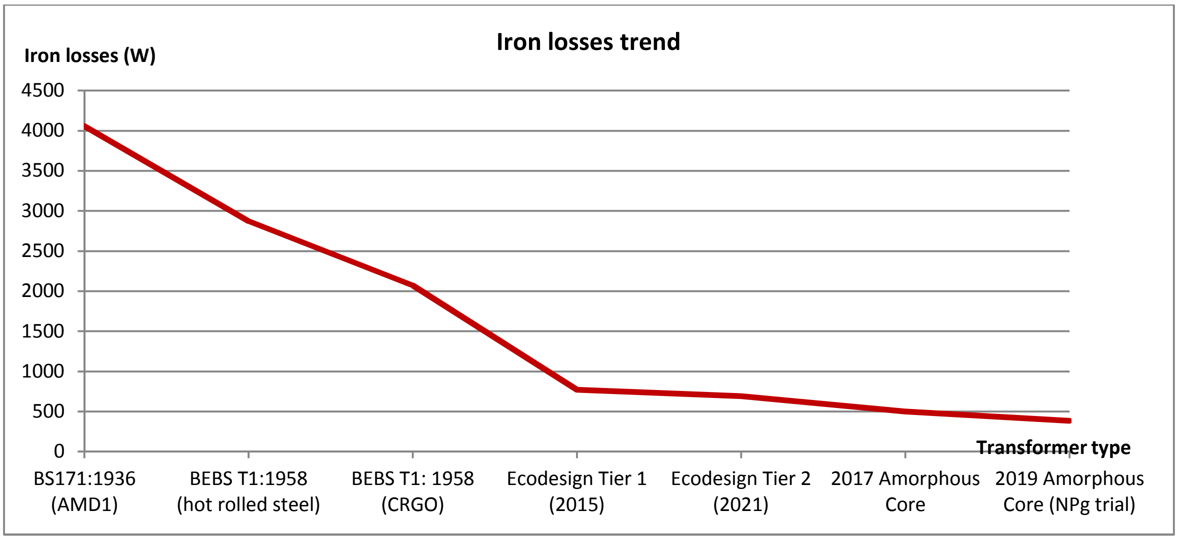

Figure 5: 1000kVA transformer iron losses trend from 1936 to 2019

[30] Heathcote [1998] – “J&P Transformer Book”.

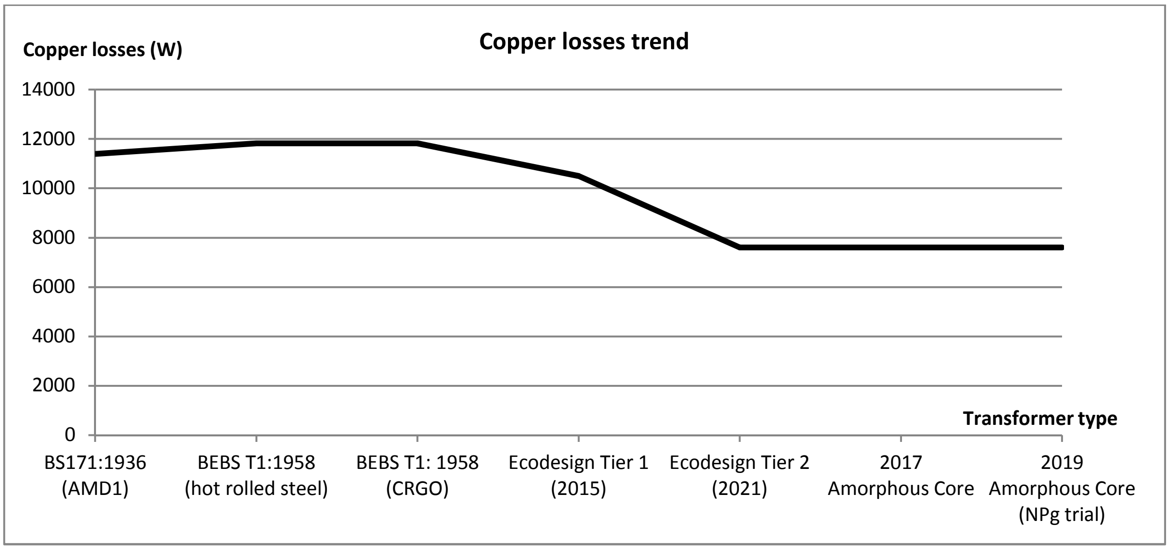

Figure 6: 1000kVA transformer copper losses trend from 1936 to 2019

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[31]. 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. Scottish Power Energy Networks (SPEN) is currently in the design and manufacturing stage of the Solid State Transformer (SST), a digitally-controlled power electronic transformer, as part of their ‘LV Engine’ Network Innovation

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

Competition (NIC) project. Western Power Distribution (WPD) is also using power electronics transformers in their EV charging initiatives.

Impacts of low loss transformers

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

There is also concern that due to lower iron losses in the transformer core that ferroresonance can occur more readily[32]. As part of our amorphous transformer trial, we are analysing the power quality and sound of these units.

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. Table 5 below shows the extent to which the size increases for 1000kVA ground-mounted transformers for different technology types. UK Power Networks (UKPN) has installed some three-phase amorphous core pole-mounted transformers to address some of these issues, as part of their LDR initiatives. Other DNOs, such as SPEN and WPD have already installed single-phase amorphous core pole-mounted transformers as part of their BAU.

1000kVA 11/.433kV transformer weight and dimensions							
Type	**Actual/ estimate**	**Mass (kg)**	**Increase in Mass from Standard %**	**Length (mm)**	**Width (mm)**	**Height (mm)**	**Increase in Volume %**
Pre-Ecodesign Tier 1	Actual	3135	-	1680	1170	1710	-
Ecodesign Tier 1	Actual	3440	9.7%	1970	1345	1660	31%
Ecodesign Tier 2 (laser etched high permeability core steel)	*Estimate*	*6080*	*94%*	*1935*	*1215*	*2075*	*45%*
Amorphous core (NPg trial)	Actual	4800	53%	2080	1616	1633	63%

Table 5 : 1000kVA 11/.433kV transformer actual and estimated weight and dimensions

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[33] makes recommendations to investigate several options for reducing losses, some of which are described below.

[32] R. A. Walling [2003] - “Ferroresonance in Low-Loss Distribution Transformers” PESGM 2003 - IEEE

[33] EATL “Energy Efficient Substation” S5195_2

Heat recovery from transformers at major substations to heat substation buildings

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[34].

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 transformers 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[35]. 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 a limited scope for us to heat public amenities from substations, this proves the concept that low level waste heat can be effectively 'recycled'. In our LDR Tranche 2 period, we have worked with Arup to carry out a feasibility study of retrofitting the waste heat recovery technology onto our existing transformers. The project concluded that although heat recovery from existing Northern Powergrid substations is technically achievable where local heat demands can be identified, it would not be commercially viable. Full report can be viewed on our losses webpage https://www.northernpowergrid.com/losses.

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

[34] Brush Transformer Test Certificate

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

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

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[36].

Microresilience – providing microgrid solutions

Our innovation project, Microresilience[37], is providing microgrid solutions that will increase resilience for low voltage (LV) customers whilst offering flexibility to support the wider HV network. Such flexibility involves distributed energy assets supporting phase balancing, voltage support, power quality improvement, losses reduction, power factor correction and islanded operation under planned (maintenance) and unplanned (fault) outages. This project offers novel solution architecture and functions of technology such as the two-terminal Power Electronic Devices (PED) and Microgrid Controller (MGC). The combination of an Energy Storage System (ESS), Distributed Energy Resources (DER) and PEDs will provide essential grid support functionality with co-ordination of devices, islanded status and data logging handled by a dedicated MGC. This is supported by the open-standard communications framework OpenFMB, for a Field Message Bus to ensure an effective delivery of this new technology on our network.

3.8.3 Changes to network operations

Voltage optimisation activities

We believe that losses cannot be managed in isolation and acknowledge that other actions that we do to manage the network holistically will have an impact towards losses. For example, our voltage optimisation activities help to unlock our network, allowing connection of low-carbon generations while enabling LCTs. Although we learned that smart solutions and low-carbon transition increase

[36] EA Technology - Andrew Bower et al (2013). S5195_2 - "Energy Efficient Substation".

[37] Delivering distribution system flexibility through Microresilience – CIRED 2020 Berlin Workshop

losses[38], an optimised network operation is to focus on a whole system approach to balance different priorities and systems to achieve the Net Zero target.

HV conservation voltage reduction and network re-configuration

Our HV conservation voltage reduction programme is approximately 62% complete, and is due for completion before the end of ED1. Rolling out this programme across the network will potentially achieve an estimated annual saving of £50m on customer bills via reduced energy consumption and reduced network losses. This will also provide more headroom for our network to connect more low-carbon generation.

We periodically re-configure our HV network and optimise open points to balance load and customer numbers as well as diverting current flow from small section conductors which improves losses performance. We have so far assessed over 1,000 HV feeders and have moved normal open points as required. In an extreme example, when an open point is moved from an interconnected primary substation to the mid-point, the current flow would be balanced, thus reducing losses. For a typical feeder pair to be optimised we estimate around 26 MWh/year would be saved or (£1,300/year).

EHV voltage optimisation studies

In our LDR Tranche 2 submission, we highlighted the conflict between reducing operating voltages for losses and energy reduction versus the need for providing system defence measures as stipulated by our Grid Code obligations, specifically OC6. Therefore, to assist with the HV conservation voltage reduction programme, to create EHV network headroom and to ensure OC6 compliance, we have been carrying out EHV voltage optimisation studies. The activity is 90% complete, and 8 sites have had their voltage reduced. We are also investigating sites suitable for dynamic voltage control, and have identified around 10% of our sites that are suitable for LDC operation. Adopting LDC operation would mean that there will be a net balance between losses and loading on customer side and looking at losses and loading on our network. We have also been coordinating with National Grid ESO and high profile customers, including Network Rail, to ensure that our voltage optimisation work does not impact their critical operations.

Boston Spa Energy Efficiency Trial (BEET)

Boston Spa Energy Efficiency Trial (BEET) is a Network Innovation Allowance (NIA) project that will use smart meter data in (near) real time to dynamically optimise the HV and LV network voltage. It is anticipated that this will decrease energy consumption for customers, and will therefore reducing losses, saving customers money and reduce carbon emissions. The savings for customers from energy efficiency are expected to far outweigh any capital and operational expenditure, given that the majority of the investment required is already covered by the ED1 smart grid enablers programme and the national smart meter rollout. The principle of conservation voltage reduction (CVR) is to optimise voltage to directly reduce energy consumption, which also serves as a short-

[38] A report on the ENA Working Group Project: Impact of Low Carbon Transition – Technical Losses

term measure to discharge our Grid Code obligation OC6. As a direct result of the smart meter rollout which will provide NPg with network voltage information, and the NPg smart grid enablers investment which will provide capability to run the network in a smart, flexible manner; we will soon be in a position to apply CVR in an innovative way – using all of this technology to optimise the network every half an hour.

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 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.

We have reviewed the Transformer Auto Stop Start (TASS) project by Scottish and Southern Electricity Networks (SSEN) through their innovation project LEAN which has achieved over 100 MWh total energy savings from the two trial sites to date. We see this as some valuable learning, albeit a potentially niche application, as we need to consider the interactions of such schemes with network automation, voltage optimisation and active network management schemes.

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. Although the roll-out deadline is pushed back to 2024, we are progressing changes and clarifications via the Smart Metering working group (SMWG) to access data and to correct errors in the data, for example the voltage synchronisation SECMP and voltage data format.

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. For instance, we are in discussions with Ofgem in relation to our data privacy plan to address the data aggregation issue. In our innovation funded Smart Network Design Methodology (SNDM) project[39], we explored the use of smart metering data using data analytics to analyse customer phase connectivity and to produce a design methodology through a process of Bayesian statistics to analyse thermal utilisation and voltage levels on LV networks.

[39] Smart Network Design Methodologies SNDM (NIA_NPG_020): https://www.northernpowergrid.com/innovation/projects/smart-network-design-methodologies

As part of the ENA Technical Losses Task Group (TLTG), we have commissioned WSP to carry out a Technical Losses Mechanism Study [40] to inform the development of a potential new losses incentive mechanism for ED2 which would adequately incentivise efficient management of both technical and non-technical losses in the context of the low-carbon transition. Deficiencies in the present metering arrangements were identified as barriers to the use of measured losses as an incentive. As actual losses are a small proportion (about 6% to 7%) of the total energy transferred, such errors in measurement can have a significant effect such that a measured incentive may reward or penalise these “errors” rather than losses. There is also the difficulty in establishing a target to reduce network losses as customer behaviours in influencing peak demand and duration is outside of DNO control. The project proposed a combined reputational incentive and CBA justified losses strategies within RIIO-ED2 business plans to ensure that activities which offer customer benefit are efficiently managed and incentivised.

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 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 losses 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.

[40] A project commissioned by the ENA TLTG to WSP: ‘CEP023 Technical Losses Mechanism Study – Development of a losses incentive mechanism: Phase 1 Final Report’.

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 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 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 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 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 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). Northern Powergrid is also a full member of the United Kingdom Revenue Protection Association (UKRPA). The UKRPA is a voluntary trade association, established to provide a forum for the exchange of information, best practices, and discussion of matters of common interest related to revenue protection across the UK.

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-offs may come from various sources including; general public, police, meter operator agents, revenue protection agents, our field operatives and the ETTOS. We will firstly establish if there is a registered electricity supplier using systems such as the Meter Point Registration System (MPRS) or the Electricity Central Online Enquiry Service (ECOES) to determine which party is responsible for the site investigation. If a registered electricity supplier is in place; in conjunction with Section 6 of the Electricity Act we liaise with the supplier and their meter operator (or revenue protection team) who follow up to ensure that the illegal connection is made safe (if required to do so) and further losses are prevented. Where there is no registered supplier, 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 have a legitimate supply but are using electricity which they are not paying for because their supply has not been registered. The units that 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 we are well placed to identify unregistered system users on our networks, we 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, we 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.

A dedicated office based support team under our shared services function identify unregistered customers, MPANs that do not have a registered supplier in the MPRS system. Information from our internal system(s) along with various external sources of data is used to establish whether we believe energy is being used at the property. Where this is the case, we initiate a series of letters to the property and request the occupier to contact an electricity supplier to agree a supply contract and confirm to us the electricity supplier they are contracting with. If we are provided with the electricity supplier details we will make contact with the supplier to support the customer as they often face difficulties as it is not in line with the normal industry process i.e. the supply should not have a meter without a registered supplier being in place.

Where the supply remains unregistered following a series of letters, our field operative staff will perform a theft in conveyance site visit as set out above.

Settlement data – improving inaccuracies

The settlement process hangs off the registration data that is maintained in MPRS by the electricity Suppliers. We undertake a number of desktop processes to identify data inaccuracies and liaise with the registered electricity supplier to request update of the data:

- De-energised records – records where the energy should not be used at the property. Where meter reads are being received to indicate that energy is used, we request the supplier to investigate the record and energise (reflecting that the supply is using energy) where necessary.
- Incomplete registrations – the supplier commences the registration process but does not complete it in full, which means that energy cannot be settled. We liaise with the supplier to request complete registration.
- General data inconsistencies – registration data items being incorrectly set, for example measurement class. We liaise with the supplier requesting to update the items.

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 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 and have added a downloadable fact sheet[41] from our 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 a DNO, we are aware that 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 operation team is already out at site.

5 Recommendations

This losses 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 do not make a retrograde step in performance.

[41] https://www.northernpowergrid.com/asset/0/document/572.pdf

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 table 6. 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 designs.	**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 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	**Initial exercise complete (2019)** Since 2015, much of the HV network has been assessed to optimise open points to balance load and customer

		mobilise a project to effect operational network configuration changes to the existing network where justified.	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.	**Complete (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 LV monitoring shows that our LV load has a power factor very close to unity. LV capacitors have been used by Electricity North West (ENWL) in their Smart Street project. We are not replicating their work. **New action (2022)** To capture learning from our innovation project, Microresilience, in delivering power factor correction.
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 (2022)** 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 the potential size of any problem. **New action (2022)** To capture learning from our innovation project, Microresilience, in providing active management of power quality

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 the worse imbalances and take corrective action.	**Analyse data from LV substation monitoring and smart meters (2022)** 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. We considered smart meter data to identify base loadings by the SNDM project. Rather than phase relocation, we are looking at phase imbalance work, e.g. triple concentric cables. **New action (2022)** To capture learning from our innovation project, Microresilience, in delivering phase balancing. **New action (2022)** To investigate static balancer as a potential solution.
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.	**Complete (2020)** Analysed in LDR through Enhanced Understanding of Network Losses project with Newcastle University. Output from the losses incentive work for RIIO-ED2 by the ENA Technical Losses Task Group.
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	**Started in ED1 (further initiatives in ED2)** We have started the pre-1958 distribution transformers, to assess triple concentric cables and other legacy plant and networks.

		will inform our investment plans for the ED2 period.	
Voltage rationalisation	Difficult	Building on UKPN's 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.	**Complete (2020)** No appetite to pursue this initiative due to the cost involved in the rationalisation programme.
New techniques			
Superconductors	Difficult	Monitor the development of low temperature superconductors and research projects in the next regulatory period. Pursue the most promising developments via innovation projects to understand their potential exploitation.	**Complete (2023-2031)** WPD's Superconducting Cables – Network 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 ecodesign minimum where economic. The X/R ratios have not yet led to any problems with protection or with ferroresonance.
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 fabric specifications such that the use of higher thermal insulation levels may be incorporated into the design	**Project on hold (2020)**

		policy where economically beneficial.	
Changes to network operations			
Voltage optimisation activities	Moderate	- HV conservation voltage reduction and network re-configuration. - EHV voltage optimisation studies. - Boston Spa Energy Efficiency Trial (BEET).	**To be completed in ED1** We have been carrying out voltage optimisation activities since 2013 and will continue these activities throughout ED1.
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. - SSEN LEAN project	**Complete (2020)** A potentially niche application. We need to consider the interactions of such schemes with network automation, voltage optimisation and active network management schemes. We have decided not to pursue to avoid duplication of the innovation work.

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	A new 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.
Version 2.2		
May 2020	General	Wording changes and update for consistency with other NPg strategy documents and data update to include 2019/2020. Added new innovation projects and initiatives throughout the document.
	Title of document: 'Losses Strategy	Title of document changed from 'Strategy for losses' to 'Losses Strategy'.
	Guidance for the reader	Further information added to guide readers to 'The Code of Practice for the Methodology of Assessing Losses' document, our losses webpage and email address.
	Summary	Bullet point on 2015 Net Zero target added under sub-section 'External Environment'.
	Summary	'Non-technical losses and electricity theft' sub-section updated.
	Summary	'Electrical losses reduction as part of our wider carbon footprint reduction' sub-section updated.
	Summary	'Smart meters' sub-section updated.
	Scope	Paragraphs in this section updated for consistent definition of electrical losses.
	Electrical losses	Text in this section updated for a consistent definition of electrical losses.
	Technical losses	The title of section 3.1 updated from 'Electrical energy losses' to 'Technical losses'.
	EU targets and directives	2050 Net Zero target paragraph added.
	EU targets and directives	Table 2 updated to reflect amendment in Ecodesign Directive (2009/125/EC).
	EU targets and directives	'EU network codes' sub-section removed, irrelevant to

		this document.
	Embedded generation and low carbon transition	The title of section 3.7.2 updated from 'Embedded generation' to 'Embedded generation and low carbon transition'.
	New technologies	Table 5 updated to clarify the actual and estimated data.
	New technologies	'Microresilience – providing microgrid solutions' sub-section added.
	Changes to network operations	'Voltage reduction at night' subs-section amended to 'voltage optimisation activities' and paragraphs updated to reflect existing and new innovation projects and initiatives.
	Smart meters	Paragraphs under this section updated.
	Non-technical losses and electricity theft	Paragraphs under this section updated.
	Recommendations	Table 6 updated to report on progress of strategies and actions.
	Appendix 2 - Actions to implement the losses strategy	Data updated to clarify actual and forecast data.
	Appendix 3 - Report on other DNOs' losses strategies	This section updated to reflect the updated strategies from other DNOs and relevance to NPg.
	Appendix 4 – Report on other DNOs' innovation projects in relation to losses	This section updated to report on progress of existing innovation strategies by other DNOs and relevance to NPg.

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
			Actual				*Forecast*			
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).	km 11kV cable	**317**	**249**	**213**	**240**	*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.	km LV cable	**370**	**280**	**284**	**324**	*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	**7**	**7**	**3**	**3**	*2*	*1*	*6*	*2*
		33kV ground-mounted transformers	**1**	**2**	**3**	**1**	*9*	*7*	*3*	*5*
Increasing transformer sizing	We will continue with our current distribution transformer oversizing policy.	HV pole-mounted transformers	**629**	**521**	**450**	**423**	*474*	*477*	*478*	*481*
		HV ground-mounted transformers	**403**	**361**	**251**	**277**	*417*	*417*	*417*	*417*

Appendix 3 - Report on other DNOs' 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 (2015)	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 (2015)	100mm^2 as standard conductor HV overhead	Our 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 losses cost benefit analysis.
SSEN	3.3 & 6.1 (2019)	6.6kV to 11kV upgrade is cost effective in certain circumstances	We are upgrading our Darlington network to 11kV.
SSEN	6.2 (2019)	Static Balancers on LV networks	Static balancers are used on our legacy networks. We will keep watching SSEN's progress. To investigate in 2022.
WPD	7.2.3 (2018)	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 CBA looking in the cost effectiveness of the early replacement or high loss on our older grid and primary and distribution transformers.
WPD	7.4.4 (2018)	HV phase balance correction using PV inverter technology at a customer solar generation site	Interesting development. We will keep a watching a brief and raise the issue with our distributed generation stakeholders

UKPN	2.4.3 (2019)	Voltage Rationalisation	No appetite to pursue this initiative due to the cost involved in the rationalisation programme.
UKPN	2.6.1 (2019)	Non-standard networks	Like UKPN we have some legacy triple concentric cables, and split phase transformers. We plan to holistically review these networks against modern networks to identify if any action to reduce losses is cost effective.
UKPN	2.1 (2019)	Contact Voltage Losses (CVL)	UKPN discovered CVL as a positive side-effect of the Mobile Asset Assessment Vehicle (MAAV) Innovation project that focussed on safety. We have analysed CVL via pole leakage in our LDR and we will trial MAAV in ED1.

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

Organisation	Section	Relevance to NPg
Sohn Associates Report [42]	*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 using the smart metering data and SCADA data to identify network locations with a poor power factor i.e. less than 0.9. Initial analysis from our LV monitoring shows that our LV load has a power factor very close to unity. LV capacitors have been used by Electricity North West (ENWL) in their Smart Street project. We are not replicating their work.
Sohn Associates Report	*Recommendation 3: 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-*	As part of our rollout of LV monitoring we 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

[42] 'Management of electricity distribution losses' report by Imperial College London and Sohn Associates

	balanced network. It may be appropriate to develop policies and working practices for avoiding excessive imbalance in future.	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 smart grid 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 carried out.*	Our voltage reduction programme at primary substations to reduce LV voltages, rollout of smart AVC units and voltage management policies align with this recommendation.
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*	We should continue to incorporate losses considerations in our production of network design policy on standard equipment ratings.

	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.	
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 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.*	We should assess the accelerated replacement of older poorly performing distribution transformers.
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*	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

	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.	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	Losses Investigation	This project investigated losses on HV and LV feeders through a field-work programme, establishing two methods to assess losses-power difference and I^2R approach. Learning from this project can inform our ED2 strategy.
WPD	Voltage Optimisation 11kV Network	Aligns with NPg's voltage optimisation project.
WPD	LV Templates	This project investigates the possibility of characterising substations into a number of 'templates' which could be used to describe the temporal load and voltage behaviour of substations nationwide. We referred to this project in our modelling for the Enhanced Understanding of Network Losses Project with Newcastle University

WPD	FALCON	This project investigated a range of smart-grid related loss reduction and network modelling/optimisation techniques, simulating various potential future consumption and distributed generation scenarios. Interesting to see how this is compared to our DFES model.
WPD	EQUILIBRIUM	The project considers three methods to improve voltage and power flows: Enhanced Voltage Assessment (EVA); System Voltage Optimisation (SVO) and a Flexible Power Link (FPL). Potential synergies with our voltage optimisation work and Microresilience (in terms of power electronics application for converters in FPL).
SSEN	SAVE	This project evaluates the potential for domestic customers to actively participate in improving the resilience of the network, which looks into energy efficiency, data, price signals and community energy coaching. Learning from this project could inform our stakeholder engagement activities in managing losses.
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.