NORTHERN POWERGRID

Achievements and preparations for the future

Losses Discretionary Reward

Tranche 3/March 2020

Hello and welcome

Losses are an unavoidable feature of operating an electricity network. Through our journey in ED1, we are now at the stage where our understanding of losses has improved and our expectations have shifted by undertaking additional actions to better understand and manage losses in the context of the overall system.

The future is both exciting and challenging. The transition to a more enhanced distribution system operator (DSO) service provision is already underway as we take on the challenges presented by the shift to Net Zero in providing a sustainable future while maintaining network security. Our approach to network development is to achieve economic and efficient operation of a distribution system that delivers greater utilisation and resilience.

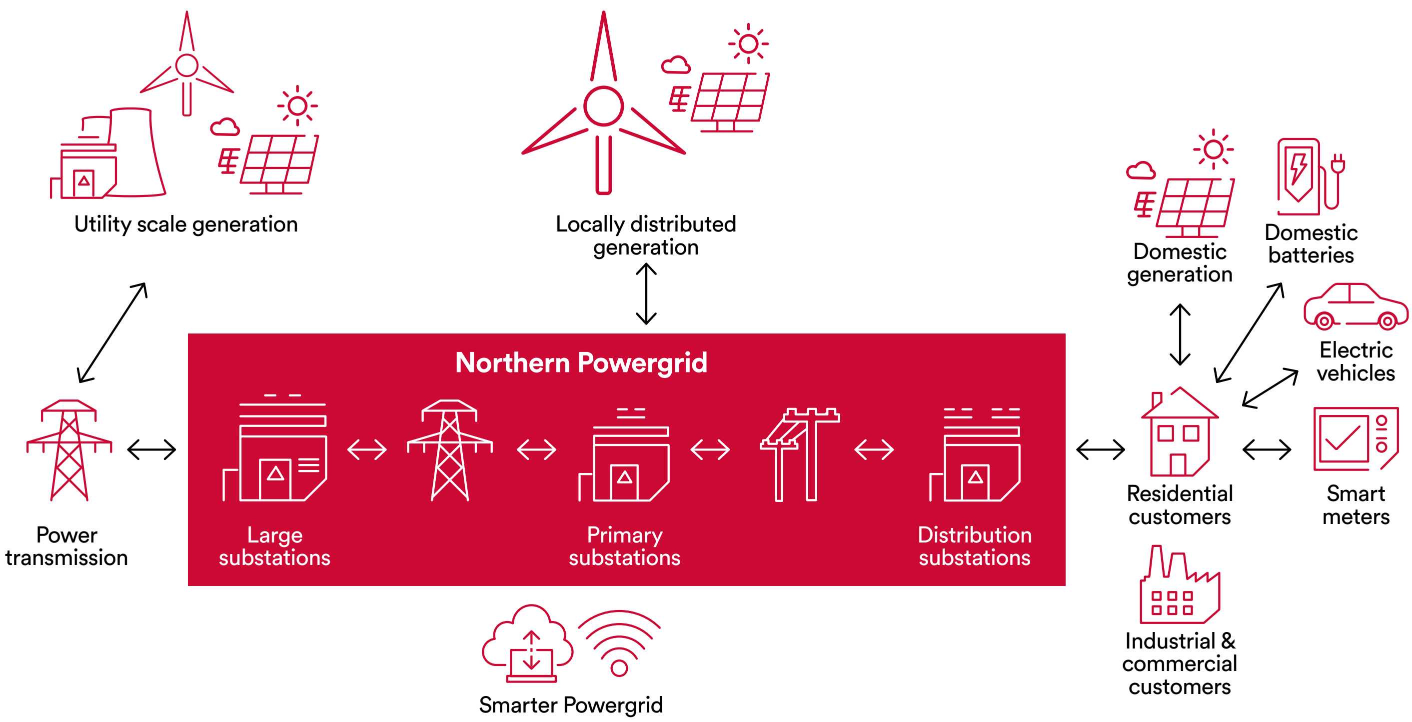
We can never eliminate losses, as it is a physical consequence of electricity distribution. We expect network losses to increase in the low-carbon future as we maximise network use to ensure that customers can perform the energy transactions they require. The losses management activities and achievements in this document are a strong basis for further improvements in effective losses management in the future in the context of Net Zero. We believe that we have implemented processes and explored opportunities that have the potential to significantly shift the expectation of what we could do to efficiently manage losses.

We have also taken on board the feedback from stakeholders during LDR Tranche 2 and have reflected this in our work plan. Expert stakeholder dialogue, coordination with other network operators on initiatives, sharing best practice and knowledge as well as building on each other's innovations are key to our strategy in the effective management of network losses.

Please feel free to visit our losses webpage for more details of our plans for managing losses at **www.northernpowergrid.com/losses**, or if you have any comments on the contents of this document please provide them in the first instance to **losses@northernpowergrid.com**.

Mark Drye
Director of Asset Management

Where we fit in the electricity industry



What's inside this document

Executive summary

This document outlines the work that we have done since our Tranche 1 and 2 LDR submissions and the additional actions that we will be carrying out throughout the remainder of ED1 and in preparation for ED2 to manage losses.

Throughout ED1, we have carried out a series of internal and external activities to improve our understanding of losses on our network and to identify optimal solutions in managing losses for our customers. Many of these activities have been collaborative with academics, consultancies and other network operators from across the world. This report details those activities, summarises the key learning and explains how we are delivering benefits for our customers.

Some of the highlights are: We have worked with local universities to perform theoretical assessments of present and future network losses through construction of network models and understanding errors in measurement of losses arising from network monitoring equipment and smart meters. Working with consultants, we have demonstrated how network losses will increase as we connect more low-carbon technology to reduce the overall system carbon footprint. Building on previous innovation projects, we have analysed the impact of energy storage on losses. We have transferred knowledge from overseas on conversation voltage reduction into our own initiatives to operational network changes that deliver real benefits to customers today. We have made changes to the equipment we use and how we design networks to reduce losses. We have developed comprehensive guidance on losses assessment for our engineers and are trialling the installation of super low-loss ground-mounted amorphous core transformers.

All this work has generated a lot of interesting results which have paved the way for more debate and discussions among our stakeholders. These results are all presented in detail through our case studies, both in the main body and appendices of this report.

Observations include that customer operation of energy storage can either increase or decrease losses, while voltage management on our network is about trading off the ability to connect more low-carbon technology, reducing customer energy consumption and producing a reduction in overall system losses.

We have engaged with a wide spectrum of stakeholder groups ranging from local communities to international DSOs. This has proved to be really useful because it provides a valuable input to inform our losses management actions through effective two-way dialogues. It also enhances our understanding through the sharing of knowledge and best practice, as well as giving us the opportunity to educate local communities and customers. We have learnt to target specific messages on losses for different customer groups: for example, wider customer awareness through our losses animation, discussion on energy efficiency with our more vulnerable customers and advice on power factor management with our larger energy users.

In the end, what this really means is that we allow network losses to increase when it is enabling a wider reduction in carbon emissions and then, when we do need to make network changes, we install solutions that reduce network losses. We believe that we are making changes to our network and its operation that achieve a Net Zero future for our customers.

Finally, in terms of next steps and ED2 implications, we will continue our successful ED1 initiatives as well as exploring other initiatives with our stakeholders as part of our losses strategies and plan development. This will cover a wide range of areas: design policy changes, asset specification solutions, accelerated asset replacement, consideration of new assets and smart systems enablement, enhanced stakeholder engagement and continued adoption of UK and international best practice. In the regulatory space, we are working with other DNOs and Ofgem on losses incentive arrangements for ED2 that best deliver the right outcomes for customers based on what we have learnt over ED1.

> **'We have engaged with a wide spectrum of stakeholder groups ranging from local communities to international DSOs.'**

Our approach

We set out in this section the work that we have done since our Tranche 1 and 2 submissions and the additional actions that we will be carrying out throughout the remainder of ED1 and in preparation for ED2 to manage losses.

This work is set out in the following four sections:
1. Understanding of losses.
2. Effective engagement and sharing of best practice with stakeholders on losses.
3. Processes to manage losses.
4. Innovative approaches to losses management and actions taken to incorporate these approaches into business as usual activities.

These sections describe what we have achieved to meet the commitments in previous losses discretionary reward submissions and outline what we are planning to do in the remaining years of ED1 and what our preparations are for ED2. We have also included some case studies in the main content and appendices of the report to add some context to what we are describing. As footnotes to the report, we have added links to relevant papers that we have written, references that we have cited and further clarifications or information from our main descriptions. Finally, we have added supplementary evidence in the appendices to support our statements, descriptions and demonstrations.

Our achievements, and the experience and knowledge that we have gained to better understand and manage losses have given us a greater insight into losses. The feedback that we obtained in our Tranche 2 submission has provided guidance on areas of improvement, especially on how we engage with our wide range of stakeholders and on collaborations with our fellow DNOs and other industry sectors. We have also addressed some of the questions that we raised and were keen to investigate in the last tranche, for example the impact of battery energy storage system (BESS) on losses, the impact of variable cost of electricity on losses and contact voltage losses (CVL). All these have helped us shape our future work plan.

Where we have included processes in this work plan that are also referenced in our losses strategies, we have made it clear how these processes shift (or are expected to shift) the expectation of what we, as a DNO, can do to reduce losses.

The work plan timeline we submitted as part of Tranche 2 has also been updated with our new commitments.

Objective	Highlights
To understand better the losses we experience on our network and the impact they have on our stakeholders	— Newcastle University project on "Enhanced Understanding of Network Losses[1]." — University of Sheffield Smart Data[2] project to understand impact on losses measurement using smart metering data with different time resolution and level of aggregation. — WSP study, via ENA, on losses impact of low-carbon technology (LCT) growth and use of smart reinforcement solutions[3]. — WSP study on impact of voltage and harmonic variations on domestic customer losses[4]. — Assessment of voltage reduction initiatives on overall system operation. — Assessment of network losses impact of energy storage operation for system balancing and domestic energy production.
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	— Voltage reduction programme across 62% or 347 primary substations so far, potentially achieving an estimated annual saving of £31m on customer bills. — Optimised open points on over 32 high voltage feeders, potentially saving up to £41,600 per year on customer bills.

[1] More information on the project can be obtained in the news section of our losses webpage: https://www.northernpowergrid.com/losses/news/northern-powergrid-joins-forces-with-newcastle-universtity-to-improve-power-network-losses
[2] 2017 CIRED publication 'Analyzing the ability of Smart Meter Data to Provide Accurate Information to the UK DNOs'. The publication can be viewed at http://cired.net/publications/cired2017/pdfs/CIRED2017_0654_final.pdf
[3] A study commissioned by the ENA Technical Losses Task Group (TLTG) to WSP: 'ENA working group Project: Impact of Low-carbon Transition – Technical Losses'
[4] A study commissioned by Northern Powergrid to WSP: 'Impact of voltage and harmonic variations on domestic losses'. The report can be viewed on our losses webpage: https://www.northernpowergrid.com/asset/1/document/4121.pdf

Objective	Highlights
To engage with our stakeholders on losses	— Created and then revised, based on stakeholder feedback, a losses website containing educational material and dissemination of specific losses project work[5]. — Produced educational animation on network losses. — Produced guidance on power factor for customers. — Consulted on our losses plans and inclusion in online community activity. — Updates on losses activity at stakeholder events and webinars. — Presentations on NPg losses projects at various CIRED conferences and local IET community events.
To share and learn from others on understanding and management of losses	— Sharing of best practice with other network operators via ENA Technical Losses working group. — Explored international best practice with our Berkshire Hathaway Energy sister companies and Norwegian DSO, Skagerak Nett. — Review of other DNO initiatives and incorporation of learning into our activity. — Discussions with manufacturers and consultants on losses initiatives.
To improve management of non-technical losses	— Led industry change request for management of customers not registered with a supplier. — Explored the use of smart meter tampering alerts with suppliers.
To use the data flows from smart meters and network monitoring as they become available to build knowledge about areas of our network where losses are and may become high	— Used smart metering data to change our loss load factors (LLFs) for distribution transformers and other assets. — Assessed network losses from low voltage monitoring deployed on innovation projects and as business as usual.
Develop our understanding of losses data sufficiently to explore the re-introduction of a financial incentive on losses performance or suitable alternative incentive arrangements for the RIIO-ED2 period	— WSP project on losses incentive mechanisms for ED2[6].
To explore innovative solutions for losses reduction	— Trial of amorphous core distribution transformers[7]. — Arup study into transformer heat recovery solutions at various NPg substations[8]. — Assessment of battery energy storage system (BESS) operation for management of network losses.
To incorporate losses learning into business as usual processes	— NPg team created to cover smart grid development, engineering policy development, network losses and use of smart data. — Updating of our code of practice for the methodology of assessing losses[9] in making decisions on asset selection and network design. — Various changes to network design guidance and equipment specifications. — Training of design engineers and embedding into Technical Staff Trainee/ Graduate development programme. — Environmental awareness for all staff on network losses.

[5] Northern Powergrid losses webpage: https://www.northernpowergrid.com/losses
[6] A project commissioned by the ENA TLTG to WSP: 'CEP023 Technical Losses Mechanism Study – Development of a losses incentive mechanism: Phase 1 Final Report'.
[7] More information about the trial can be obtained from our press release on our losses webpage: https://www.northernpowergrid.com/losses/news/back-to-news-northern-powergrid-begins-uk-first-trial-of-ground-mounted-energy-saving-transformers
[8] A project commissioned by Northern Powergrid to Arup. More information about the project and the report can be viewed on our losses webpage: https://www.northernpowergrid.com/losses/news/northern-powergrid-investigates-transformer-heat-recovery-viability
[9] IMP/001/103 – code of practice for the methodology of assessing losses can be obtained from our losses webpage https://www.northernpowergrid.com/losses

Objective	Highlights
To seek losses reduction through the selection of equipment and installation designs across the full range of our engineering activity	— Introduced oversized high voltage and low voltage cables. — Changed overhead line conductor for a low loss variant. — Maximum economic loading guide for new distribution transformers resulting in oversizing depending on load/generation type.
To bring forward the work programmes which provide losses reduction when justified by cost-benefit analysis	— Replacement of pre-1958 distribution transformers. — Deployment of over 600 low voltage monitors on high utilisation/loss networks and LCT growth hotspots. — Applying load drop compensation (LDC) using our smart automatic voltage controls (AVCs) at selected sites to provide further voltage and losses reduction.

1. Understanding of losses

Throughout ED1, we have been improving our understanding of losses on our network, through various internal and collaborative activities with other DNOs, academics and consultancies, to identify the optimal solutions for our customers.

We are using our own experts, experienced consultants and academics to critically review the work in this area and deliver the activities identified in previous Tranches. The outputs have allowed us to improve our understanding of losses and to prepare for ED2 and beyond.

Understanding of losses and measurement of losses: Since Tranche 2, our understanding of losses has been enhanced by our Enhanced Understanding of Network Losses project. We learned that in 20 years, our forecast load growth on our studied network will significantly increase network losses, up to four times from the level today if there are no interventions. However, with the domestic time of use tariff, EV smart charging and demand-side response (DSR), we can minimise the increase in losses to only 50% from the current level.

Losses measurement can be limited by the accuracy of data used in any analysis. We have observed that the sensor errors in the Northern Powergrid network consist of systematic errors (arising from the current transformers (CT)) and random errors (which combine the transducer, scaling, and quantization errors). These errors result in an underestimation of losses by around 2% on a typical urban network.

'The feedback that we obtained in our Tranche 2 submission has provided guidance on areas of improvement, especially on how we engage with our wide range of stakeholders and on collaborations with our fellow DNOs and other industry sectors.'

We have gained a better understanding of errors, data resolution, missing data, data uncertainty, and the correlation between demand values in power flow measurement from our Smart Data and Enhanced Understanding of Network Losses projects. By combining LV monitoring with smart meter data, we will have the ability to evaluate our losses with fewer approximations, which will ultimately result in better losses management.

Sources of losses: Our understanding on the impact of BESS on losses has improved through analysis of our own Rise Carr BESS and DS3[10] project. We have learned that BESS could either reduce or increase network losses, depending on its mode of operation. Understanding this means that we may be able to utilise services from BESS for a whole system operation. Although this could adversely impact network losses, its operation should not be discouraged, in order to achieve an overall carbon reduction. This situation is akin to the operation of active network management schemes which provide low cost flexible connections for low-carbon generation but increase local network losses.

A holistic approach to losses: The distribution network is part of the wider energy system that only exists to service the needs of our customers. Therefore, it would be wrong to consider the implications of a low loss distribution network in isolation. Actions undertaken by a network operator, for example to reduce voltage, may appear to reduce network losses but we do need to assess the impact on customer losses which is a function of the nature of customer load.

The actions of a transmission system operator impact the distribution network and vice versa. Therefore, we have tried to better understand the losses performance of existing and future customers and how this is influenced by the operation of distribution and transmission networks in the use of flexible services and system defence measures such as the Grid Code obligation OC6.

We have recognised our role in providing advice to customers on reactive power as well as engaging closely with local communities on energy efficiency measures, which all have benefits for customers and their energy bills.

Detail of actions

Enhanced Understanding of Network Losses

Status: In progress, due for completion May 2020

What we have achieved

Our Enhanced Understanding of Network Losses project with Newcastle University started in April 2018 and seeks to enable us to better understand, and make decisions pertaining to, the unavoidable losses which take place in our network. The project is broken into five work packages:

- **WP1:** Literature survey outlining the state-of-the-art in losses estimation techniques, the methods and tools for managing and reducing losses, and the key issues which need to be addressed by future research, including this project.
- **WP2:** Losses measurement data acquisition and analysis exercise. To identify the key drivers of losses, and the network and measurement parameters which dictate how accurately losses can be estimated.
- **WP3:** Building of a limited number of representative models and methods to provide learning which can benefit the majority of distribution networks in Great Britain.
- **WP4:** Analyse impact on network losses of future scenarios in which changing demand and new technologies are introduced into the network.
- **WP5:** Develop policy and regulatory measures to help incorporate losses into decision making, and particularly how losses should be viewed in a system with electricity where cost and carbon intensity vary with time and location.

We have disseminated initial learning at the 25th International Conference and Exhibition on Electricity Distribution (CIRED 2019) in Madrid, Spain[11]. The reports can be viewed at our updated losses webpage **www.northernpowergrid.com/losses**. Outputs from this project are described in case studies and appendix A of this report.

[10] Distributed Storage and Solar Study DS3 (NIA_NPG_011): https://www.northernpowergrid.com/innovation/projects/distributed-storage-solar-study-nia-npg-011

[11] CIRED 2019 publication: 'Enhancing the understanding of distribution network losses'. The publication can be viewed at https://www.cired-repository.org/bitstream/handle/20.500.12455/231/CIRED%202019%20-%20978.pdf?sequence=1&isAllowed=y

Case study 1:

The impact of our forecast load growth and use of customer flexibility on losses on our primary network.

Figure 1: Energy losses for each year from 2017–2050.

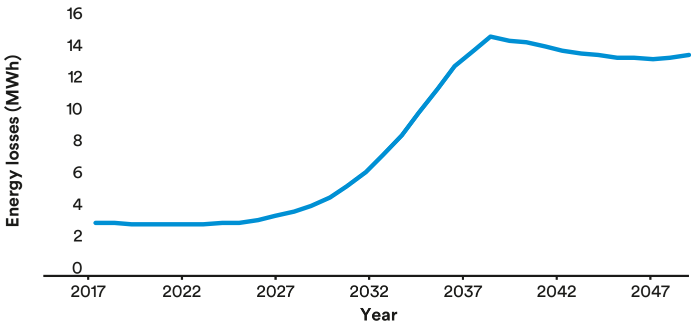
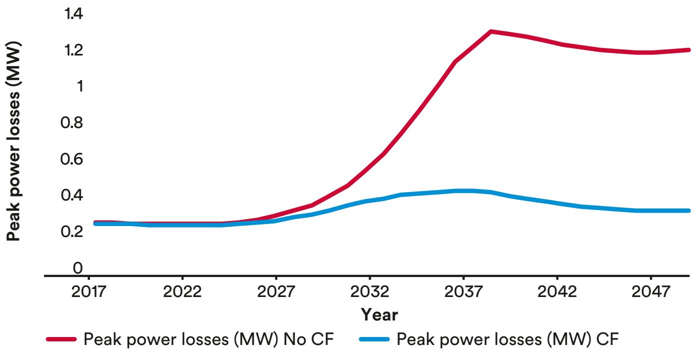


Figure 2: Power losses calculated at peak demand with and without customer flexibility (CF) for each year between 2017 and 2050.



Load growth:
We have looked at how our forecast load growth has impact on losses for our studied primary network. Demand data between 2017 and 2050 was obtained from the Element Energy Load Growth (EELG)[12] datasets which takes outputs from National Grid's 'Two degrees' scenario from their Future Energy Scenarios 2018 report (NGESO FES 2018) and interprets how they are distributed across NPg's substations. These data were used to forecast the energy losses utilising the modelled peak demand. The load profiles for 2017 were scaled in proportion with the peak demand increase for each load point, and the projected network losses are depicted in figure 1.

Customer flexibility (CF):
EELG Customer flexibility models the impact of domestic time of use tariff, EV smart charging and demand-side response (DSR) for industrial and commercial customers on future load growth. CF has the potential to substantially decrease overall network losses by reducing the peak demand. Data were available for the demand peak including CF; therefore, power losses at peak demand were calculated for each year and compared with the corresponding values without CF. As the demand peak grows, particularly between 2025 and 2035, the peak losses increase by around 400%, while with flexibility, the peak losses only increase by 50%. However, the overall impact of CF is likely to be less significant than this, since the demand profile will be flatter; therefore leading to higher losses during the non-peak periods (this corresponds to a higher load factor). Some of these losses could be offset by network reinforcement and asset replacement, which will result in a network with greater capacity and more efficient assets.

What we are planning to do
As the Newcastle University project draws to a close, we will further build the project learning into our Customer Led Distribution System (CLDS[13]) project: better understanding of local market operation, customer value propositions and impact on DSO transition. Internally, learning will be embedded into business as usual via the next iteration of our code of practice for the methodology of assessing losses and ED2 losses strategies.

Errors in power flow measurement

Status: Complete

What we have achieved
Extending the work from the University of Sheffield Smart Data project in Tranche 2, the work package 2 of the Enhanced Understanding of Network Losses Project focused on how accurately losses can be estimated. Specifically it looked at data resolution, missing data, data uncertainty, and the correlation between demand values. It was clearly shown that higher variability within the network demand leads to higher errors in loss estimation and specifically underestimation. As load variability is proportionally lower in high voltage (HV), because of the higher diversity arising from supplying a large number of customers, loss estimation errors will tend to be lower than at low voltage (LV). Loss estimation errors associated with measurements – including time resolution, measurement accuracy, and data unavailability – were all quantified using a set of Northern Powergrid (NPg) network data. In all cases, the impact of these phenomena on loss estimation errors was more severe at LV.

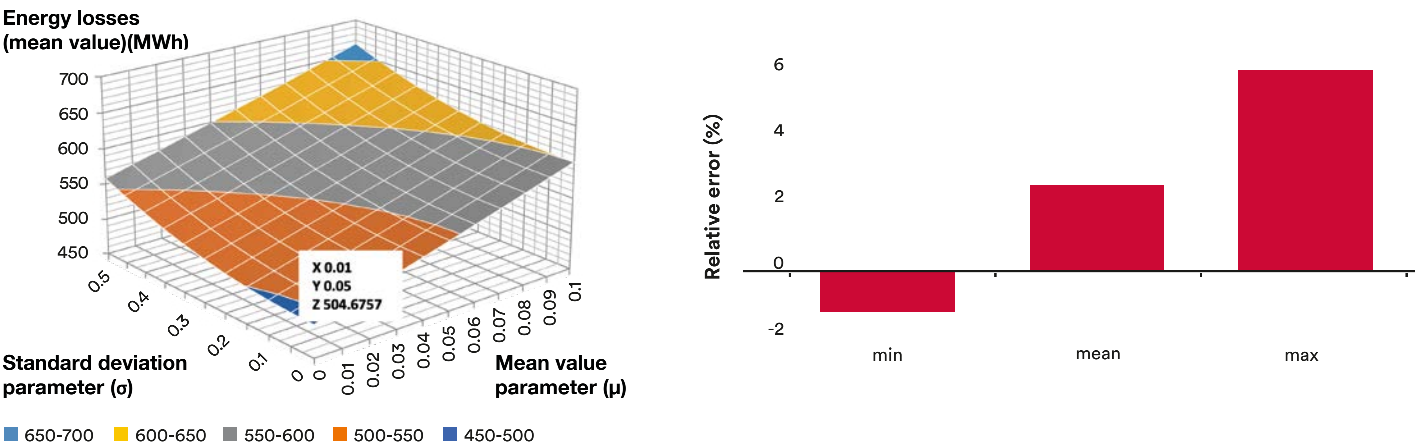
[12] National Grid's Future Energy Scenarios (NGESO FES 2018). More information on our innovation project 'Improving Demand Forecasting (NIA_NPG_012)' can be obtained from our innovation webpage https://www.northernpowergrid.com/innovation/projects/improving-demand-forecasting-nia-npg-012
[13] Customer-Led Distribution System (NIA_NPG_19): https://www.northernpowergrid.com/innovation/projects/customer-led-distribution-system-nia-npg-19

It was also found that correlation between demand groups will lead to an increase in the loss estimation overall, but the exact nature of this relationship will require further investigation.

Besides the learning derived from these observations, for a significant number of the studies undertaken, generalisable mathematical relationships were established between the various parameters considered as variables in the analyses, and loss estimation. These could be integrated with loss estimation models and other methods for calculating losses. The studies have also provided clear evidence around the importance of errors originating from measuring equipment and quantified their effect on network loss estimation for a variety of cases.

Case study 2:
Impact of measurement errors.

Figure 3: Surface plot for the studied primary network (left) and the corresponding relative error of measured losses at peak load compared to actual losses (right). The error in energy losses can be calculated for any combination of random and systematic errors.



The potential measurement errors encountered on real networks are a compound value encompassing the error from several discrete processes, namely:

— Current transformers (CTs) and voltage transformers (VTs) are used to transform the voltage and current on the real network to lower values which can be safely measured by a transducer. These devices have a ratio which is guaranteed to a certain accuracy depending on the accuracy class of the CT or VT. In the majority of installations, the CTs and VTs have accuracy class 1, which means the ratio is accurate to ±1%; a systematic error of up to 1% can be introduced. The accuracy of the CT is also affected by its power factor and burden, which can lead to a random error of up to ±1%.
— A transducer on the secondary coil of the CTs and VTs is used to measure the current or voltage and pass this data onto a relay. The relays used by Northern Powergrid remote terminal units (RTUs) which provide data to the supervisory control and data acquisition (SCADA) system have a current measurement error of 1-2%.
— The measurement from the CTs and VTs are then scaled up to represent the real quantity.
— This scaled analogue measurement is then converted to a 7-bit digital signal – this introduces a quantization error. Assuming the 7-bit signal is used to represent a value from 0-150% of the transformer rating, this will introduce an error of about 1.17%.

A reasonable approximation to the sensor errors in the Northern Powergrid network would be a systematic error of 1% – arising from the CT – and a random error of 4.2% – combining the transducer, scaling, and quantization errors. The surface plot in figure 3 provides the energy losses value for our studied primary network for any combinations of systematic and random errors. If these sensor errors were located on the xy plane of figure 3, the value for z is the derived energy losses, 504.6757 MWh (nearest point in figure 3 is 5% random and 1% systematic). Neglecting errors, the energy losses for the network is 493.89 MWh. Therefore, this corresponds to an underestimation of losses by around 10 MWh/year, or around 2%.

Analyse project data

Status: Complete

What we have achieved
The purpose of this action was to make best use of available data from our own and other DNO projects in order to improve our understanding of network losses. This describes how we have built upon the outputs from projects funded through innovation stimulus:

- The smart meter data set obtained from the Customer-Led Network Revolution (CLNR)[14] project is also used in the Enhanced Understanding of Network Losses project.
- Our monitoring data from the Distributed Storage and Solar Study DS3[15] project has been applied to understand the impact of BESS on network losses at LV.
- Our monitoring data for our BESS in Rise Carr substation has been applied to understand the impact of BESS on losses at our extra high voltage (EHV) network.
- LV representative model data derived from our LV network for the ENA LCT working group is applied in the Enhanced Understanding of Network Losses project.
- Element Energy Load Growth (EELG) datasets were used to forecast the energy losses in work package 1 (WP1) of our Enhanced Understanding of Network Losses project.
- The smart meter data set in CLNR was applied in our innovation project Smart Network Design Methodologies (SNDM)[16] which developed the Smart Data Analytics methodology and novel analysis techniques at LV. This project provides a new model platform to improve and upgrade our LV network modelling, which would allow the consideration of losses in the LV network. Our loss load factor (LLF)[17] calculations obtained from our smart meter data set in CLNR[18] have been referred to by UK Power Networks (UKPN) for their calculations of LLF in their losses assessment methodology[19].

Analyse low voltage board monitoring data

Status: Complete

What we have achieved
We are continuing to improve our understanding on losses from our ongoing LV monitoring roll-out programme. The findings described in our Tranche 2 report continue to remain valid and the emphasis since has been to align the use of statistical approaches to estimating demand with LV monitoring data and smart metering data. We believe that using a statistical method is the most cost-effective method in understanding and estimating our demand on LV networks which currently is only 1% monitored. We have at time of writing installed in excess of 480 units of LV monitoring and plan to have at least a further 800 units in place by end of ED1. The importance of a better understanding of demand profiles is that it will produce better losses estimation through the LLF methodology as described in our code of practice for the methodology of assessing losses. As an example, our LV monitoring data was used in our Enhanced Understanding of Network Losses project to validate the LV network modelling and losses assessment.

We are applying the existing statistical techniques (ACE 49[20] and CLNR) using modern programming and feedback from LV monitoring to tune and validate our demand estimation based on our knowledge of consumption. Combining this with smart meter data, we can obtain a baseline for demand forecasting to analyse LV network capacity, as well as to identify areas of network with high penetration of low-carbon technologies (LCTs) and network areas which are high in losses. The aim is to inform our decision making on the need for flexibility or network solutions to facilitate the connection of LCTs, taking losses into consideration. The knowledge that we gain from understanding our distribution substation loading provides a basis or a feedback loop to assess and analyse our upstream high voltage networks.

As mentioned earlier, we have now gained an understanding of errors, data resolution, missing data, data uncertainty, and the correlation between demand values in power flow measurement from our Smart Data and Enhanced Understanding of Network Losses projects. By combining LV monitoring with smart meter data, we will have the ability to evaluate our losses with fewer approximations. However, to make this a practical proposition requires the challenges of data availability, time synchronisation, computational power and cost effectiveness to be overcome.

[14] Customer-Led Network Revolution: http://www.networkrevolution.co.uk/
[15] Distributed Storage and Solar Study DS3 (NIA_NPG_011): https://www.northernpowergrid.com/innovation/projects/distributed-storage-solar-study-nia-npg-011
[16] Smart Network Design Methodologies SNDM (NIA_NPG_020): https://www.northernpowergrid.com/innovation/projects/smart-network-design-methodologies
[17] LLF is defined as the ratio between the average loss over a time period and the peak loss during that time period. More information on how LLF is used to calculate losses can be obtained from IMP/001/103-code of practice for the methodology of assessing losses.
[18] The CLNR data has been used to show the relationship between LLF and domestic customer numbers.
[19] To create this process, UKPN initially used data from NPg to create a relationship between the LLF value and number of downstream customers. This was done by creating a regression line using the LLF data from NPg and allowed for the calculation of an LLF value for any node on a feeder.
[20] ACE 49: The ACE Report 49 outlines a statistical method for the design of low voltage networks, in particular for the design of demands and for voltage regulations, taking account of diversity and unbalance between customers.

Case study 3:
Demand estimation from LV monitoring vs statistical method.

Figure 4: Half-hourly (HH) daily demand profile at a distribution substation from demand estimation and LV monitoring data.

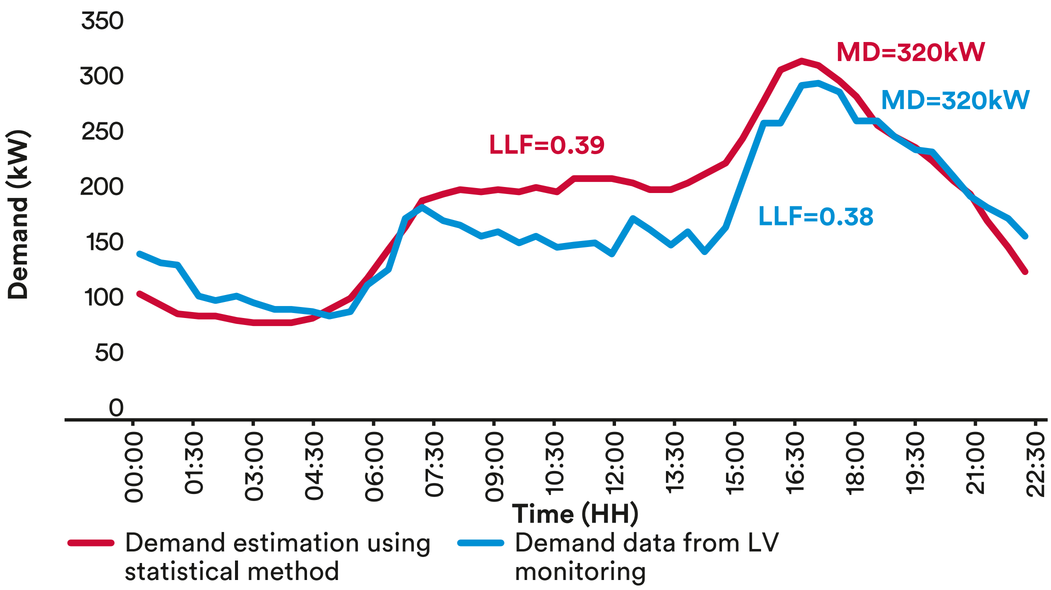


Figure 4 is an example of how the statistical method provides a good estimation of maximum demand (MD), only about 7% higher than the actual MD. The losses, on the other hand, are 19% higher compared to the actual value. The LLF value to calculate losses is almost the same for both. Note that the statistical method is half-hourly while the monitoring data is more granular (every 10 minutes). It is worth pointing out that high numbers of commercial load on the LV network will impact the demand estimation, and it is an ongoing work for us to analyse and investigate this further, by studying patterns and behaviours of different loading conditions, especially with better penetration of the LV monitoring on our LV network.

Impact of battery energy storage system (BESS) on losses

Status: Complete

What we have achieved
We have built on two of our innovation projects by carrying out two case studies to understand the impact of BESS on losses in our network: i) BESS from the DS3 project which are connected on our domestic LV network ii) BESS in Rise Carr which is connected directly onto Rise Carr 33/6.4kV primary substation. Both types of BESSs are of different sizes and were installed on different voltage levels of our network for different purposes, under different operating regimes. Since the BESS for our DS3 project are connected on domestic properties, we can assume that the monitoring data of these properties would be analogous to the smart meter-derived data.

We have learned that BESS could either reduce or increase network losses, depending on its scale and mode of operation. Understanding this would mean that we can utilise BESS to manage losses as well as factoring in the cost of losses into investment decisions for future BESS, for instance in the loss adjustment factor (LAF) charging. However, both case studies also demonstrated that the operation of the BESS is complex, and is outside of DNO control. The quality of data for both case studies has an impact on the level of accuracy of the analysis and quantification. More information on both case studies can be obtained in case study A1 and A2 in appendix A. Full reports for both case studies can be obtained from our losses webpage **www.northernpowergrid.com/losses**.

We will continue improving our understanding of the opportunity and impact of BESS on network losses, from these case studies, alongside WP4 and WP5 of our Enhanced Understanding of Network Losses project which we describe further in section v of appendix A.

Losses on the customer side of the meter and customer reactive power advice[21]

Status: Complete

What we have achieved
Following on from our Tranche 2 work on the impact of voltage and harmonic variations on domestic losses, we identified the need to engage with non-domestic customers regarding their reactive power consumption. We have produced an information guide, outlining the background and issues related to poor power factor and the impact this could have on their energy bills. We have provided advice on how to improve power factor, which, if adopted, could save customers money along with reducing network losses. This guidance can be obtained from our losses webpage **www.northernpowergrid.com/losses**. Following on from this we are identifying non-domestic customers with poor power factor and are engaging with them to provide reactive power (VAr) advice in our stakeholder engagement events.

Energy-saving advice and measures – The WSP report described above also concluded that focusing on improving the efficiency of UK domestic appliances will reduce the loading of the energy network, thus reducing losses. We have been actively working with communities, particularly vulnerable customers in fuel poverty, offering energy-saving advice and measures through our partners. It is important to recognise that engagement with communities not only discharges our social responsibility, but it also has the potential to reduce losses in our network. This is described further in the next section of this report – 'Effective engagement and sharing of best practice with stakeholders on losses'.

62%
Our HV voltage reduction programme is approximately 62% complete.

£50m
Estimated savings for customers, via reduced energy consumption.

Adapting network operation to load and losses characteristics

Status: In progress, due for completion 2022

What we have achieved
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).

In our Tranche 2 report, we highlighted the conflict between reducing operating voltages for loss 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, 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.

What we are planning to do
Completion of HV conservation voltage reduction and EHV voltage optimisation programmes aligned with the delivery of our smart grid enablers programme.

[21] A study commissioned by Northern Powergrid to WSP: 'Impact of voltage and harmonic variations on domestic losses'. The report can be viewed on our losses webpage: https://www.northernpowergrid.com/asset/1/document/4121.pdf

Exceptions to loss reduction actions

Status: Complete

What we have achieved
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 HV voltage conservation and integrated network optimisation of EHV voltage help to unlock our network, allowing connection of low-carbon generation while enabling LCTs. Although we learned that smart solutions and low-carbon transition increase losses[22], an optimised network operation is to focus on a whole system approach to balance different priorities and systems to achieve the Net Zero target.

We are implementing advanced voltage control techniques to our network via intelligent regulators and smart automatic voltage control (AVC). We understand that by deploying smart AVC, we are dynamically changing the voltage level of the network, which results in either a net increase or a decrease in network losses. However, the benefit of smart AVC in reducing the bottlenecks and increasing the flexibility of the network outweighs the losses impact of this action. We have also increased our understanding of transformer tap changer range limitation as part of the EHV voltage optimisation and LDC investigation work.

We also understand that active network management (ANM) operation will increase existing network utilisation, thus increasing network losses. There is the potential for ANM schemes to provide network optimisation to reduce losses. This mode of operation is currently not applied in our schemes. As our ANM deployment continues into ED2 we will explore the potential for losses optimisation in the operation of these schemes and any commercial implications of doing so.

On our enhanced electrical parameters in network models, we have reviewed the values and we continue to update models with values obtained as business as usual (BAU) model maintenance.

We have also used time series analysis to quantify network losses by using scripting, a powerful tool for power network simulation, which we identified as a functional requirement in our procurement specification for a new distribution system analysis tool as an enabler for the DSO transition. We will describe this further in the final section of this report on 'Innovative approaches to losses management and actions taken to incorporate these approaches into BAU'.

In our Pragmatic Security project[23] with Imperial College London and Newcastle University, we are finding non-network solutions for expected energy not supplied (EENS) in the HV network. Providing security and reliability from non-network assets will increase utilisation, reduce network resilience/redundancy, and this generally will increase losses.

'We understand that by deploying smart AVC, we are dynamically changing the voltage level of the network, which results in either a net increase or a decrease in network losses.'

[22] A study commissioned by the ENA Technical Losses Task Group (TLTG) to WSP: 'ENA working group Project: Impact of Low-carbon Transition – Technical Losses'
[23] Pragmatic Security project (NIA_NPG_029): https://www.smarternetworks.org/project/nia_npg_029

2. Effective engagement and sharing of best practice with stakeholders on losses

We are continuing to focus our stakeholder engagement on clear, open and honest communication. We have been sharing best practice with stakeholders, as well as engaging closely with our local communities. There is a strong synergy and alignment between social responsibilities and managing losses.

Utilising stakeholder engagement: We have built on and extended our existing stakeholder engagement approach to address losses. Losses are considered in the same way as innovation, the DSOs' transition, customer service and our social responsibilities. We have undertaken an extensive programme of stakeholder engagement around losses. This comprised a wide variety of stakeholders including local communities, academics, expert stakeholder panels and industry technical experts. We have developed an introductory animation to better communicate our losses programme. We have produced an analysis on the cost of losses which we built on one particular stakeholder's comment on how the cost of losses should take into account the variable electricity price during the day rather than an average price over the year. We will continue our extensive programme of stakeholder engagement to inform our losses management actions, educate local communities and customers on electrical losses and allow stakeholders to understand how those actions feed through to their bills. As with the rest of Northern Powergrid's stakeholder engagement activities, we ensure that dialogue is two-way, and with a commitment to close the loop on engagement with all feedback responded to in a timely manner.

Engaging with stakeholders to develop relevant partnerships: Partnership working has been crucial to the development of an effective and innovative losses programme and its delivery of positive outcomes. Collaboration with other network operators has featured highly in our losses work plan, such as sharing our understanding and learning on losses with the ENA Technical Losses Task Group (TLTG) and Open Networks project. This has been a key group to facilitate industry knowledge sharing and has fostered candid discussions between the respective losses experts from the different DNOs. We are, with our Powergrid Care Team, developing partnerships with various organisations to engage with communities in advocating energy efficiency initiatives. Finally, we are collaborating with our local universities to support their academic programme which can align with industrial needs in areas such as losses management in order to equip students with the right skill sets that are required by the industry.

Processes to share best practice: The outcomes from our projects have been published on our losses and innovation websites and communicated via stakeholder bulletins and focused bespoke engagement with key parties in order to ensure that maximum GB-scale value is extracted from the learning that is developed. This approach has allowed for communications to be targeted at an appropriate level for the audience and for it to be delivered cost effectively.

Detail of actions

Stakeholder-led consultation and dialogue with our range of stakeholders

Status: Ongoing

What we have achieved

General engagement – We ran a consultation on our losses plan as well as creating online communities for more targeted campaigns with regards to our losses management actions in our losses strategies and LDR. We learned that the response from interested stakeholders was limited in these approaches. In response, we looked at different methods, and have now chosen to re-build our losses webpage to be more informative as well as using social media for our campaigns. We use these digital routes for updating our stakeholders and general public with more information and latest news on our activities and actions to manage losses. We feel that this approach is more engaging, gives more impact and is more effective in capturing the interests of a wider range of stakeholders. For example, on our Amorphous Transformer (AMT) project, we carried out a joint news update with the transformer manufacturer, Wilson Power Solutions (WPS), and our service provider, Freedom. We believe that this successful collaboration is itself a result of an effective stakeholder engagement. We also targeted a wider range of stakeholders and audience using social media platforms, in addition to the usual trade media.

Visuals and animations – We created our 'Losses animation'[24] to educate our stakeholders on network losses, and provided simple explanations on the background of network losses, their impact and solutions. We had positive feedback via Scottish and Southern Electricity Networks (SSEN) on the usefulness of this approach to frame the issues[25]. Simple yet interactive animations like these are effective in educating and creating awareness on network losses.

[24] NPg Losses animation can be found at http://www.youtube.com/watch?v=M9v_2HDnMLI or on our losses webpage.
[25] This is mentioned in page 9 of the report 'Low Energy Automated Networks (LEAN) SDRC 9.4 Initial Learning from Trial installation and Integration'.

LCNI 2019 – As a member of the ENA Technical Losses Task Group (TLTG)[26], we and other DNOs have carried out a joint panel session which was chaired by WSP at the 2019 Low-carbon Network Innovation (LCNI) event in Glasgow. We carried out an interactive discussion with stakeholders from various backgrounds on our joint project with regards to the LCT impact and the regulatory approach on losses.

Energy-saving advice and measures – One of the conclusions of our report on the impact of domestic losses[27] states that focusing on improving the efficiency of UK domestic appliances will reduce the loading of the energy network. This avoids both the need for additional generation and electricity distribution, which ultimately will reduce losses. We have identified losses reduction opportunities within our existing effort to discharge our social obligation and responsibility, by working internally within our Powergrid Care Team and with our partners to engage with communities in advocating energy efficiency initiatives. Part of our Priority Service Register (PSR) package that we sent across our licence area (just over 900,000 customers) contains some advice on being energy efficient.

We have been working with a range of partners across the region where the outcome of those conversations can manifest itself in cost savings for our customers, arising from reduced consumption, and indirectly network loss reduction:

- **Infrastructure North:** We work in partnership with Northern Gas Network (NGN), Yorkshire Water (YW) and Northumbrian Water (NW) to help serve our customers in the north of England. Part of our initiative as a group is to advise customers on ways to use electricity, gas and water more efficiently to reduce energy bills whilst helping the environment (see appendix B).
- **Citizens Advice:** offering advice and support to those in fuel poverty in Leeds – partnering with offices in Bradford, Calderdale, Kirklees, Wakefield and Newcastle – partnering with offices across the North East.
- **Green Doctor:** offering energy-saving advice and measures in homes: North and West Yorkshire, North & South Tyneside, Hull & East Riding.
- **Ahead Partnership:** originally offering employability skills to pupils but evolved now to form a Youth Consumer Panel to assist with stakeholder engagement.
- **Energy Heroes:** energy-saving advice and measures for schools, pupils and communities.

Reactive Power (VAr) advice – We have been engaging and working with our non-domestic customers to help them to improve their power factor and have included this action into our ICE[28] initiative. We have published guidance on this on our losses webpage (see appendix B). Customers that improve their power factor can save money on energy bills, and reduce the carbon footprint associated with their electricity supply by reducing network losses. Improving power factor can also relieve voltage constraints on our network, which in turn allows connection of more low-carbon technologies. We also advised our customers on other measures available that could improve their power factor, such as installing newer machinery, or operating their site more efficiently. We recommended visiting the Carbon Trust website at **www.carbontrust.com** for more information about power factor correction and other measures available.

[26] ENA Technical Losses Task Group: http://www.energynetworks.org/electricity/engineering/technical-losses/
[27] A study commissioned by Northern Powergrid to WSP: 'Impact of voltage and harmonic variations on domestic losses'. The report can be viewed on our losses webpage: https://www.northernpowergrid.com/asset/1/document/4121.pdf
[28] Incentive on Connections Engagements (ICE): Introduced by Ofgem in RIIO-ED1 to drive electricity distribution network operators (DNOs) to understand and meet the needs of these types of larger customers.

2019 Stakeholder Summit – With over one hundred delegates attending from local authorities, environmental organisations, civic leaders and the energy industry, the summit was centred on the considerable challenge of energy, decarbonisation and climate change. The event consists of a mix of presentations and direct interactions with our stakeholders via exhibition of innovation and decarbonisation projects. We engaged with the delegates by discussing and educating them on the concept of network losses, its impact towards the environment, our role and obligation as a DNO on losses and our activities to manage losses, which include our Enhanced Understanding of Network Losses project with Newcastle University, Amorphous Transformer trial and VAr advice.

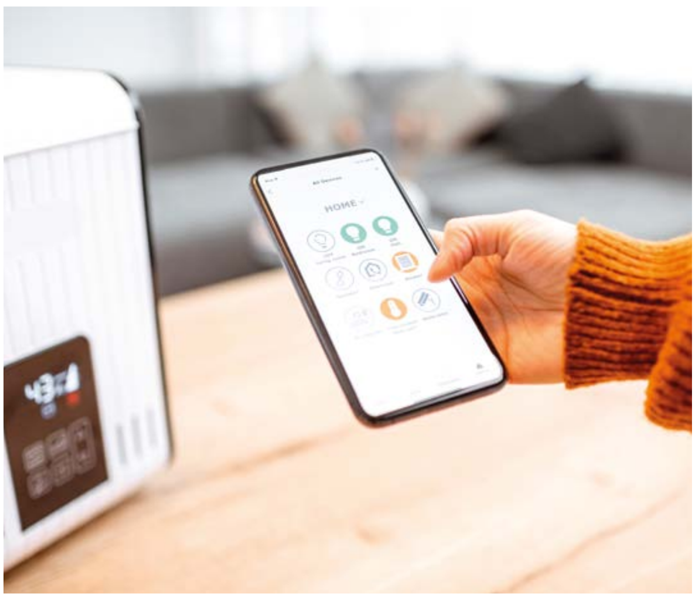
What we are planning to do
This is an ongoing process through the remainder of ED1, into ED2 and beyond. Learning that the stakeholder-led consultation has been a challenging experience in terms of gaining interest and responses, we will continue to engage via our updated losses webpage **northernpowergrid.com/losses**. Our targeted approach on this will be to continue utilising the mainstream social media and visualisation platforms. We will explore the possibility of having webinars or online interactive discussions to inform our losses management actions and strategies for ED2, for instance creating an animation on electricity theft and energy efficiencies and action buttons on our webpage. We will continue working with other DNOs under ENA TLTG to proactively engage with stakeholders. For example, ENA TLTG is planning to carry out another round of losses 'teach-in' session with Ofgem in the near future. We will also continue working and engaging with communities on energy efficiency measures and will increase our effort in educating them on the benefits of energy savings towards reducing network losses and decarbonisation, not just saving them in energy bills. We have demonstrated that through coordination and collaboration with our internal colleagues and external partners, we are not only discharging our social obligations, our activities also have
a positive impact on the environment by reducing losses. We will also learn best practice from SAVE[29] project by SSEN on how they evaluate 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.

In-depth dialogue with expert stakeholders

Status: Complete

What we have achieved
Variable cost of losses – We have built on one particular stakeholder's comment on how the cost of losses should take into account the variable electricity price during the day rather than an average price over the year. We analysed the impact of wholesale energy prices and carbon intensity on losses over the course of a year (from 01 Nov 2018 to 31 Oct 2019) on our network. We calculated the losses impact correction factors to be applied to the standard assumptions around the cost of energy and carbon footprint by comparing three annual values based around how the average is determined i) un-weighted average, ii) weighted average based on demand profile, iii) weighted average based on losses profile. The cost and carbon impact correction factors are then determined using this data. The result of this analysis is summarised in case study 4, with more information presented in appendix B of this document.

'We have built on one particular stakeholder's comment on how the cost of losses should take into account the variable electricity price during the day rather than an average price over the year.'



[29] Solent Achieving Value from Efficiency (SAVE): https://save-project.co.uk/

Case study 4:
Analysis of variable cost of losses on Northern Powergrid network.

Table 1: Energy cost analysis for Northern Powergrid network.

Method 1 – Simple average (no weighting)	
Non-weighted mean unit cost of energy (£/MWh)	**46.21**
Method 2 – Weighted average (demand profile)	
Total energy distributed (MWh)	14,678,193
Value of energy distributed (£k)	710,254
Weighted cost of energy (£/MWh)	**48.39**
Method 3 – Weighted average (losses profile)	
Total half-hourly losses (MWh)	1,900,000
Total cost of half-hourly losses (£k)	95,962
Weighted cost of losses (£/MWh)	**50.51**

Table 2: Carbon intensity analysis for Northern Powergrid network.

Method 1 – Simple average (no weighting)	
Non-weighted mean unit carbon intensity (gCO_2/kWh)	**219**
Method 2 – Weighted average (demand profile)	
Total energy distributed (MWh)	14,678,193
Volume of carbon associated with total energy distributed (tCO_2)	3,320,390
Weighted average carbon intensity (gCO_2/kWh)	**226**
Method 3 – Weighted average (losses profile)	
Total half-hourly losses (MWh)	1,900,000
Volume of carbon associated with total energy distributed (tCO_2)	449,971
Weighted average carbon intensity (gCO_2/kWh)	**237**

From table 1, we have calculated energy costs based on the weighted average cost of energy supplied at £48.39/MWh (Method 2). Energy costs could also be calculated using the weighted average cost of losses at £50.51/MWh (Method 3). Based on these values, a correction factor of 4.4% could be applied to adjust the energy cost based on the weighted average cost of energy supplied to take into account losses. Similarly from table 2, a correction factor of 4.7% can be applied to adjust the carbon intensity based on the weighted average carbon intensity of energy supplied at 226 gCO_2/kWh (Method 2), to take into account losses, which is 237 gCO_2/kWh (Method 3).

An important learning from our work is the recognition that the correction factor for the energy costs will become more important as the penetration of renewables increases in the future. This is because high cost and high carbon plants will become operational for fewer settlement periods. Marginal plants will increasingly become marginalised, which in turn will require revenues to be recouped for less energy provided. Besides, high penetration of zero-marginal and renewable energy sources will introduce more 'green losses' compared to 'carbon losses'. This would make the analysis more challenging and complex.

Engagement with IDNOs – We have raised our concerns with Ofgem and IDNOs via the ENA low-carbon technology group about the policy of IDNOs using small cross section low voltage mains cables on connections for new developments. In our view, this produces a distribution network that has higher losses and less capacity for the electrification of heat and transport and facilitation of the LCTs. On the other hand, for the same new connection, the local DNO would use higher capacity larger cross section cables. We can see that the market conditions and financial incentives drive IDNOs towards this type of shorter term decision-making on asset selection which is at odds with the wider pressure on electricity networks to facilitate the move to the Net Zero and whole-system thinking. We therefore welcome the consideration by BEIS Engineering Standards Review with regards to the adoption of minimum cable sizes.

CIRED 2019 – We have also engaged with academic and technical audiences at the 25th International Conference and Exhibition on Electricity Distribution (CIRED) 2019, where we presented our conference paper on 'Enhancing the Understanding of Distribution Network Losses' from the Enhanced Understanding of Network Losses project, covering our WP1 and WP2 on modelling future losses and data fidelity issues on losses. This high profile conference and exhibition event had a worldwide perspective and participation and it was a perfect platform for us to highlight our project while having a broad range and in depth engagement and interactions with the electricity distribution community.

Industrial Advisory Board (IAB) – We have started collaborating with the University of Bradford by becoming a member of their Industrial Advisory Board (IAB). We will support their academic programme which can align with industrial needs in areas such as losses management in order to equip students with skill sets required by the industry.

What we are planning to do
For our analysis on variable cost of losses, we are planning to discuss our analysis and the correct approach to the cost-benefit analysis (CBA) valuation through the ENA TLTG meeting and Ofgem ED2 working groups. We are also looking forward to working with the University of Bradford and exploring the possibility of embedding a decarbonisation theme in the programme, where losses will fit in.

Engagement with National Grid ESO (NGESO) on management of reactive power flow

Status: Ongoing

What we have achieved
Variable losses are a function of the current squared (I^2R). Reducing reactive power flow on our network significantly reduces losses. On the other hand, reactive power control plays an important role in maintaining a secure voltage profile, especially in a transmission network. Although we have no obligations to provide reactive power (VAr) support to NGESO, we acknowledge that our systems are interconnected and our network activities impact the VAr flow in the transmission network which creates a high voltage issue during low load periods. The system needs to control high voltage as we have seen an increasing need to absorb VArs in recent years, resulting in increased costs to voltage management overall. We have been engaging with them to address and manage this through the ENA Open Networks project. The Open Networks project is a collaboration that plays a major role in transforming the way that both local distribution networks and national transmission networks will operate and work for customers towards a holistic and coordinated approach to network management and solution as we transition to DSO roles.

What we are planning to do
Although losses are not the primary aim of this engagement, we realise that the outcome of this engagement might result in increased losses on our network and this is something that needs to be addressed. However, from a whole-system view, we are facilitating a holistic and coordinated approach in managing our network as we transition to DSO roles. We will continue to engage with NGESO and be part of the initiative of the ENA Open Networks project via its workstreams to develop a good practice for conflict resolution, management and co-optimisation (in our case DNO-NGESO), and aligning DSO and NGESO VAr flexibility services to manage the reactive power flow.

ENA Technical Losses Task Group (TLTG)

Status: Ongoing

We are a member of the ENA TLTG, with five other UK DNO groups and NGESO. ESB Networks has become the newest member. This group was created in March 2016, with the purpose and aims to improve understanding of technical losses, to develop best practice and sharing for losses strategies and activities and to review technical and regulatory requirements for a fair and effective losses incentive mechanism in ED2.

Collaborative activities
ENA TLTG is a platform for us to engage and collaborate with each other and other stakeholders on all aspects of losses. We have been contributing to the group in our initiatives. Some key activities carried out by the group since Tranche 1 and Tranche 2 are as follows:

— **Ofgem teach-in session (October 2017):** This presentation provided an introduction to losses, an overview of the current approach on losses and discussions on factors that will influence future regulatory approaches to losses.
— **LCNI presentation (December 2017):** This presentation summarised the work that the group commissioned WSP on 'The Impact of Low-carbon Transition on Technical Losses'.
— **'The Impact of Low-carbon Transition on Technical Losses' WSP (March 2018):** The aim of this study was to understand the impact of low-carbon and smart grid transition on technical network losses to inform losses strategies and the regulatory approach to losses. The key findings in this report concluded that the LCT uptake and how networks accommodate this will significantly impact losses and losses are complex, difficult to measure and vary based on regional topology.
— **LCNI panel discussion (October 2019):** The 'Deep Dive' session was an interactive discussion with the audience focusing on an overview of the project that the group commissioned WSP on the 'Technical Losses Mechanism Study', with key topics including the complexity of network losses, the impact of LCT and the regulatory approach on losses.
— **'Technical Losses Mechanism Study' WSP (September 2019):** Development of a losses incentive mechanism. The group recommended a reputational incentive option with a CBA approach for ED2. This work will be described further in the next section of this report.

We are continuing our contribution and engagement within the group. The group will maintain regular meetings to continue engagement, collaborations and sharing of best practice, particularly to prepare for ED2. The group will also continue to actively engage and work with Ofgem. The group is also working on an ENA recommendation document on losses. This is still at an early stage and the group has agreed on formulating a plan of delivery for the document in 2020.

3. Processes to manage losses

We identified good practice from other network operators, both international and in the UK, and used it to develop our internal processes for management of losses. That activity combined with our own research activity has informed a range of operational and investment initiatives implemented in our business during ED1 as well as being considered as part of our ED2 plan development. Although the national roll-out of smart meters have been pushed back, this has not stopped us from developing our understanding of how we may use this new source of information to design and operate a more efficient network.

Continuing to look at national and international best practice: In delivering actions that enable us to significantly develop our understanding, one source of learning is the international experience that others have in both the roll-out of advanced metering systems or more generally in the development of existing and future networks. We are also engaging with other utility sectors to share best practice in processes and methods to manage losses. Our engagements with these organisations provide a valuable knowledge resource for us to access for the benefits of our customers in the UK. As part of the Berkshire Hathaway Energy group of companies we have been working with our counterparts in North America on the sharing of best practice in the areas of network reliability, connection of distributed energy resources and smart grids. The management of losses is an important practical step we can take to support our group policy of delivering balanced outcomes for customers including decarbonisation of the grid.

In terms of our engagement with Skagerak Nett, Norwegian DSO, we have been exploring losses management and use of smart metering data. As decarbonisation is at a more advanced state in Norway, with further progress on adoption of EVs and heat networks, they have been able to offer an alternative perspective.

Business as usual implementation: Since the start of the LDR process we have rolled out low voltage monitoring at losses hotspots, started the replacement of pre-1958 distribution transformers, commenced a project for EHV voltage reduction, changed sizes of distribution transformers based on data from smart meters, and comprehensively rewritten our losses assessment guidance to aid decision making by our engineers, resulting in, for example, targeted investment on the rationalisation of network voltage. All of these activities were generated through either our own or other's research into network losses.

Preparing to use smart meter data: We have been actively involved with the technical specification of the smart meters and the overall system since its inception. Indeed, one of our smart grid development engineers is a nationally recognised leader for the DNO community on the meter specification, meter and system configuration and data privacy. So, we are well placed to understand what smart metering will provide for us. In our innovation funded SNDM[30] project, we explored the use of smart metering data in several different ways for network design which impacts losses management.

Preparing for ED2: We will continue our successful ED1 initiatives into ED2. We have identified further initiatives for implementation in ED2 and we are considering these with input from our stakeholders as our ED2 plan is developed. The desired outcomes from these initiatives are the overall economic investment, planning and strategies that will result in better losses performance of new assets and design solutions which help achieve Net Zero. Through the ENA TLTG, we have worked with WSP to assess international experience of losses incentives, external factors influencing network losses, measurement difficulties and the potential options for ED2.

Detail of actions

Sharing international best practice and understanding

Status: In progress, due for completion 2021

What we have achieved

In our Tranche 1 and 2 submissions, we had described our active engagement with our sister companies in the US and Canada that are part of the Berkshire Hathaway Energy Group. This dialogue allows us to leverage the international experience of five significant utility operators in areas such as conservation voltage reduction and reactive power support. Disappointingly, Ofgem viewed this as business as usual activity in their Tranche 2 feedback despite the resource burden that such activity entails so we will not expand further in this report other than to state that we will continue to engage with and seek value in areas of power system operation and management from the BHE group.

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

International loss incentive mechanisms – The ENA Technical Losses Task Group (ENA TLTG) commissioned WSP to come up with proposals for how losses incentives should be managed in RIIO-ED2. This work looked at international approaches to losses incentive mechanisms, where several international documents have been cited and discussions with international counterparts were carried out[31]. It was identified that not many countries require the suppliers to procure losses. Besides GB, these countries include Ireland, Spain, Portugal, Ireland and Belgium. For most countries, it is the responsibility of the network operator to procure losses, which generally indicates that it is an output measure incentive against a quantified target. This work however concluded that it is not clear if this approach is more advantageous compared to the supplier-led losses procurement arrangement that we currently have.

Skagerak Nett – We have been engaging with a distribution system operator (DSO) in Norway, Skagerak Nett, on processes and methods to manage losses. Although we have a different structure, economic regulation and incentives, we believe that both Northern Powergrid and Skagerak Nett apply the simple principles of good asset management in terms of selecting options with the 'lowest annualised whole life cost'. Thus, in general, our approach to losses would be aligned. The key points from our discussions are:

- Skagerak Nett procures losses, and is incentivised by their regulator, The Norwegian Water Resources and Energy Directorate (NVE) for efficient acquisition of energy for losses management. Their regional and local distribution networks are incentivised differently and their incentive mechanisms are mechanistic and complex, with future uncertainties presenting both challenges and opportunities for them.
- Skagerak Nett takes into account network losses as part of the assessment of their investment options, according to their 'Minimum 4' methodology, i.e. cost analysis based on a minimum of four sets of possible investment criteria.
- Skagerak Nett controls smart meters, and the uptake in their network is close to 100%. There is a central database for all the smart meter data, 'Elhub', an establishment which was initiated by their regulator, NVE. The data is bound by the GDPR. Suppliers can also access the data from the hub.

By engaging with Skagerak Nett, we are also taking this opportunity to get a useful insight into the future of electric vehicles (EVs), as Norway is leading the world in the uptake of EVs.

New Zealand Electricity Authority Guidelines on the calculation and use of loss factors for reconciliation purposes[32] – We have analysed this document to look at best practice and to improve our understanding on how the regulator in New Zealand provided guidance to their network operators in charging losses to their consumers. This document was published in June 2018 to provide guidance to both 'local network' distributors (similar to DNOs) and 'embedded network' distributors (similar to IDNOs) to calculate 'loss factors' to be reported annually to their Authority, which is not that dissimilar to the loss adjustment factors (LAFs), or also known as the Line Loss Factors for the GB networks. While this guidance is not mandatory for the distributors, the Authority published this to promote best practice and consistency in quantifying the cost of losses to consumers as part of their reconciliation[33] process. The document provides standard definition and classification of losses and other parameters related to the losses calculations. The methodology presented in this document is complex. It takes into consideration the impact of different types of generation on different sizes of the network as well as the embedded network. However, the methodology does allow flexibility in its application, depending on the network configuration, staff resources, sophistication level of software tool and data availability.

In GB networks, on the other hand, there is no common methodology for all DNOs to calculate the LAFs. Elexon approves DNOs' individual methodologies in accordance with the principles set out in the Balancing and Settlement Code Procedure (BSCP) 128. DNOs have their own losses strategies which have their own definition and classification of losses, although the common understanding is that losses consist of technical and non-technical losses. DNOs also have their own methodology of assessing losses to ensure compliance to the Standard Licence Condition (SLC) 49.

CIRED WG Report on losses[34] – We referred to this report when we updated our code of practice for the methodology of assessing losses.

[31] This includes i) Council of European Energy Regulators (CEER) report on losses, 2017 ii) Presentations from the "Workshop on incentives to reduce network losses in the Nordic countries, 2017" iii) Discussions with WSP Australia

[32] This document can be obtained from https://www.ea.govt.nz/dmsdocument/23580-guidelines-on-the-calculation-and-the-use-of-loss-factors-for-reconciliation-purposes

[33] Reconciliation in the New Zealand electricity market is the process of how electricity flowing in their power system is accurately allocated to buyers and sellers for invoicing, which is explained further at https://www.ea.govt.nz/operations/retail/reconciliation/

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

What we are planning to do
Following is what we are planning to do for our Tranche 3: On the next iteration of our code of practice for the methodology of assessing losses, we will continue to explore the methodology used in the New Zealand Guidelines mentioned above to improve our assessment on the impact of generation on losses. Currently we are applying the aggregated LLF method, having a set of assumed generation profiles based on our generation availability map[35]. We will also continue our engagement with Skagerak Nett as we are keen to learn how they are going to use the smart meter data, as almost all of their customers now have smart meters, and how they manage that data in respect of network design and operation. The learning from this will help us to inform our preparations to effectively use smart meter data. We could also see that going forward, there would be a benefit to collaborate on other areas, such as DSO transition, flexibility and future strategy around facilitation of LCTs, in particular EVs. We are planning a workshop with them at their headquarters in Porsgrunn, Norway, in March 2020 to exchange best practice, knowledge and experience in losses, present and future network planning and operation, smart meter benefits and innovation initiatives and challenges.

Sharing UK best practice and understanding

Status: Ongoing

What we have achieved
Knowledge sharing between UK network operators via ENA Technical Losses Task Group – The regular group meetings provide an ideal platform for all members to share best practice and progress on innovation projects and to identify potential areas for collaborative work. Some key areas of successful collaborations, learning and sharing of best practice are as follows:

- **Amorphous transformers (AMT):** We agreed to focus on installing ground-mounted AMTs, with UKPN to focus on pole-mounted AMTs. SPEN shared the specification where they had installed pole-mounted AMT as part of BAU. The learning from this will be shared amongst the group members and the wider industry.
- **Losses assessment methodology and CBA:** We and other DNOs share best practice on the approach to assess losses for policy and design decisions. In general, all DNOs apply the concept of loss load factor (LLF) to estimate losses with the NPg methodology being at the more comprehensive end of the available guidance.
- **Mobile asset assessment vehicle (MAAV) and contact voltage losses (CVL):** UKPN (and Power Survey) have shared their knowledge and experience based upon their trial work. They agreed to lend us their MAAV for a short trial on our network, which we plan to carry out in Q2 2020. We also built on the work by Princeton University Report on CVL[36] by analysing the CVL on pole leakage, which we will discuss further in the next section.
- **Transformer waste heat recovery:** We built on UKPN's Bankside Project with the same consultancy (Arup) to look into the roll-out of this technology into BAU by retrospective design of the system onto our existing transformers. We will discuss our project further in the next section of this report.

Reviewing initiatives, strategies and projects from DNOs and other parties – We regularly review the outputs from innovation projects, losses strategies and learning from our fellow DNOs and implement ideas as necessary. For instance, we have adopted the pro-active replacement of pre-BEBs T1:1958 ground-mounted distribution transformers after we came up with the same conclusion as our fellow DNOs following our own cost-benefit analysis.

We have reviewed SSEN's Transformer Auto Stop Start (TASS) project through their innovation project LEAN[37] 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. We are looking at their SAVE project to learn more about their methodology and approach, which will provide valuable input into our engagement with communities on energy-saving advice and measures.

We have also taken on board the recommendations from Sohn Associates reports[38] where most of them are aligned with our existing strategy, including the waste heat recovery feasibility study.

Other reports that we reviewed as part of our initiative to understand and manage losses include UKPN 'Managing Losses: International Best Practice', UKPN 'Smart meters and Losses: Best Practice Review' and the Princeton University report on CVL.

Amorphous Transformer (AMT) trial – From our Eco-design directive (Tier 2) discussions with other DNOs on the ENA Transformer Assessment Panel (TAP), there was some reluctance to adopt very low loss amorphous core transformers on certain technical grounds. We therefore collaborated with Wilson Power Solutions (AMT manufacturer) and Freedom (our service provider) to install 5 units of 1,000 kVA ground-mounted AMTs on our network using standard working procedures. We also collaborated with UKPN on this as described earlier. This trial helped to allay technical concerns around brittleness, size, weight, harmonics and noise in preparation for Eco-design Tier 2 maximum loss levels which come into force in 2021. The replacement of older transformers with the new ground-mounted AMTs has the potential to produce annual losses savings of up to 2 GWh. Thermal imaging result for the AMT on one of our sites is presented in appendix C. The lower temperature of the AMT indicates that its losses are lower compared to the old transformer.

[35] Northern Powergrid generation availability map: https://www.northernpowergrid.com/generation-availability-map
[36] 'Analysis of Contact-Voltage Losses in Low-Voltage Electricity Distribution Systems of the U.K.', by Princeton University. The report can be downloaded from UKPN Losses webpage at https://www.ukpowernetworks.co.uk/losses/static/pdfs/analysis-of-contact-voltage-losses.f7e1d56.pdf
[37] Low Energy Automated Networks (LEAN) project can be viewed at https://www.ssen.co.uk/LEAN/
[38] There are two Sohn Associates reports: i) Management of electricity distribution network losses ii) Electrical Distribution Systems Losses Non-Technical Overview (a paper prepared for Ofgem by Sohn Associates Limited)

Other industry sectors – we are engaging with our fellow utility companies, Yorkshire Water (YW) and Northern Gas Networks (NGN), when we consider processes and methods to manage losses, including both technical and non-technical losses.

What we are planning to do – Tranche 3
We will continue to share best UK practice and understanding individually or as a member of the ENA TLTG. We will consider any key learning from other DNO activities and wider expert stakeholders to inform our losses strategies for ED2. We are also continuing our pro-active replacement of pre-BEBs T1:1958 ground-mounted distribution transformers in synergy with other investment drivers. For our AMT trial, we will feedback our experience to the ENA transformer panel. This learning has the potential to shift expectations by helping to remove potential technical barriers for very low loss transformers and by using this trial as a positive case study for other DNOs, commercial and industrial users. We are committed to continue our engagement with YW and NGN, learning best practice from these sectors to inform our losses strategies. Our AMT trial will inform us on whether to include the technology in future transformers' specifications and how to install the assets from an operational perspective, while building understanding of the AMTs' environmental noise impact and power quality factors. The outcomes will be shared as a UK case study for DNOs together with commercial and industrial users.

We intend to continue our engagement with YW and NGN to develop deeper understanding of losses management and to share best practice. This will inform our losses strategies by improving our approaches and processes in managing losses. We will carry out regular meetings every few months to follow up with discussions or any potential collaborations that we will develop as our engagement continues to progress. We believe that any collaborations and innovations towards decarbonisation of joint utilities is a good opportunity to be involved with. One potential area to be explored is comparing CO_2 and cost impact of losses (or leakage/shrinkage) on customers, and how these are factored in on any investment decisions to be made. We are also keen to explore the opportunity of a cross-vector, whole system and collaborative approach that integrates heat, gas, water and electricity for de-carbonisation of the energy system, while benefitting customers.

Management of non-technical losses

Status: Complete

What we have achieved
Following the implementation of a formal industry change to introduce more rigour and clearer guidance in managing customers who are not registered with a supplier, we have invested in technology and resource to tackle this issue. We also mobilise field operative staff to physically act on information received and carry out premise inspections, by working in conjunction with key back office support staff such as our call centres and a dedicated team operating within our Registration Services function.

As part of our Smart Metering Programme, we have explored the use of tamper alerts from smart meters as a means of improving the management of non-technical losses. The alerts being received from the initial deployments of smart meters are not reliable and our discussions with suppliers indicate that they are experiencing similar problems with the volume of false positives from the four types of potential tamper alert. At this stage we do not believe that the tamper alerts are a suitable input for business process that would drive DNO action.

OBJECTIVE – How we are preparing to effectively use smart meter data to develop specific actions to manage losses. Processes that we have in place now, following Tranches 1 and 2 submissions.

The national smart meter roll-out and the associated move to half-hourly market settlement processes will introduce more accurate metering point data such that losses may be more readily evaluated. This will be supplemented by the network monitoring we are rolling out as part of our smart grid enabling investment programme. Although the smart meter 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 learned that small metering accuracy values appear as a large tolerance on losses. The smart meters' energy consumption will increase compared to normal domestic meters due to the requirement of additional wide area network communications for them to provide essential information to us. If this energy consumption is not recorded by the meter, this will also result in inaccuracy issues. Although having smart meters can provide greater visibility of downstream power flows, aggregation of data as part of the requirement of the Data Protection Act could limit our understanding of where losses occur. We are in discussions with Ofgem in relation to our data privacy plan to address the data aggregation issue.

In our innovation funded SNDM project, we explored the use of smart metering data in several different ways:

1. Using data analytics[39] in order to manipulate and disaggregate the smart meter data. The project proved that aggregation levels of two or greater are sufficient to anonymise customer consumption half-hourly data.
2. Although we were unsuccessful in being able to demonstrate a method to identify LV customer phase connectivity using voltage correlation techniques, we believe that the method will be re-examined in the future, with a large amount of phase imbalance and high roll-out of SMETS2 smart meters on our LV networks. A benefit of this approach is the identification of networks with high losses due to the unequal phase loading.
3. The project produced a design methodology building on existing ACE 49 and CLNR based after diversity maximum demand (ADMD) approaches for analysing thermal utilisation and voltage levels on LV networks. Rather than accessing raw smart metering data, the method uses smart meter consumption data to statistically model customer demand. Through a process of Bayesian statistics, these can be updated with smart meter data for specific LV networks as this data becomes available to the DNO. The methodology allows the models to be continually refreshed and updated as more recent smart meter data becomes available. Although this method needs further development and testing, it could form the basis of a losses modelling tool.

We have discussed elsewhere in this report that a reduction in network losses and customer energy consumption can be realised through the use of conservation voltage reduction and other forms of voltage management. Building on this, we are working on an innovation project to use our smart grid enabling infrastructure in combination with smart metering data to drive further optimisation in our network operating voltage. This project will create and prove an algorithm that utilises real time smart meter voltage data to dynamically control the upstream voltage.

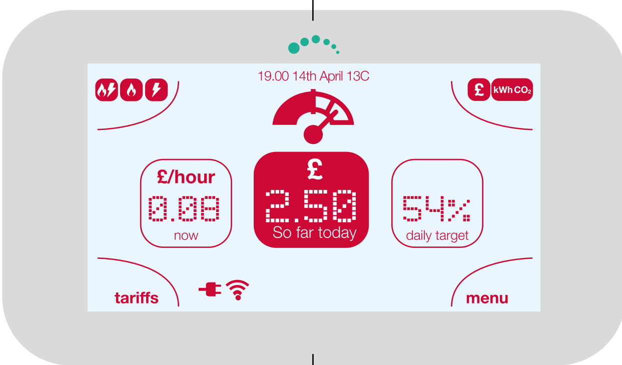
Learning from SPEN and other DNOs on utilising smart meter data to manage theft, we will explore the application of smart meter data to effectively manage non-technical losses. We will also take the opportunity to learn from Skagerak Nett on how they use or plan to use the smart meter data to manage losses as the uptake of smart meters in their network is close to 100%.

Focus on smart meter tasks

Smart meter data comparison with low voltage monitoring data (see Analyse low voltage board monitoring data)
Status: Complete
(to be reviewed when more smart meter data becomes available)

Tamper alerts management processes (see Management of non-technical losses)
Status: Complete

Smart meter-derived loss load factors (LLFs) (see Analyse project data)
Status: Complete



University of Sheffield Smart Data project (see Errors in power flow measurement)
Status: Complete

Smart Network Design Methodologies (SNDM) (see Processes to manage losses)
Status: Complete

Newcastle University Enhanced Understanding of Network Losses (see Enhanced Understanding of Network Losses)
Status: Complete

[39] Smart Network Design Methodologies – Smart Meter Data Analytics' at https://www.northernpowergrid.com/asset/0/document/4803.pdf

Preparing for ED2

OBJECTIVE – Consideration of the actions that we have taken from Tranches 1, 2 and 3 that will help feed into RIIO-ED2 on losses.

We will continue our successful ED1 initiatives into ED2 and have also identified other initiatives for ED2 that we will explore further with our stakeholders as part of our losses strategies and plan development. Some of these new initiatives are described below:

- **Design policy initiatives:** We will ensure that our design policy initiatives are 'losses-inclusive' while facilitating the attainment of Net Zero.
  - **Consideration of 3-phase service connection:** We will identify opportunities for 3-phase where the predicted whole lifetime costs are lower, taking into account losses and our forecast load growth.
  - **Oversizing the standard power and distribution transformers size:** We will also consider further oversizing our standard transformers size as part of our assessment, considering the whole lifetime cost to include losses and the ambient temperature at which they are specified taking into account climate change.
  - **Smart meter data:** We will ensure that the smart meter data will inform our design policy initiative and assist with losses management.
- **Asset specification solutions:** We will identify specifications that prove to be cost-effective throughout the lifetime of the assets or solutions, again considering scenarios to achieve Net Zero.
  - **Amorphous transformers (AMTs):** We will consider installing AMTs as part of BAU from the learning of our ground-mounted AMT trial and other DNO trials of pole mounted units.
  - **HV overhead line conductor resizing and conversion of split phase into 3-phase construction:** We will consider this where economic, as this facilitates a more balanced HV network and voltage compliance, which in effect will minimise network losses.
  - **On-load tap changer (OLTC) as standard configuration on ground-mounted distribution transformers:** We will consider OLTC where we think it is practicable and economic. OLTC voltage control will optimise the power flow of the LV network in response to the dynamic loading condition as a result of high penetration of LCTs. This will effectively minimise network losses.
- **Accelerated asset replacement initiatives:** We will expedite the replacement of assets below to improve our network and to minimise losses.
  - **Replacement of triple-concentric LV cables:** We will replace these cables to mitigate the risk of excessive phase imbalance due to asset design, which has an impact on network losses.
  - **Pre-1958 distribution transformers:** We will ensure that these are replaced because their iron or no-load losses are very high.
  - **LV small-section conductors:** We will also ensure that LV small-section conductors are replaced, where economic, to reduce bottlenecks on our LV network and to minimise network losses.
- **New assets:** We will ensure that any new assets that we consider facilitate the requirement of a future network.
  - **Enhanced network monitoring:** Our enhanced network monitoring will provide better visibility of our network, taking into account more parameters as well as having prediction capability to allow pro-active and holistic actions to manage the network.
- **Systems:** We will continue to enable smart systems onto our network and infrastructure so that they are future-ready.
  - **Modern communication:** Our communication infrastructure will be fit for purpose, up-to-date with new technologies to facilitate our transition to DSO, allowing better data acquisition for network analysis, planning and control, which includes quantification of losses.
  - **Voltage optimisation:** We are implementing smart voltage control on our network to respond to the dynamic loading conditions due to high penetration of LCTs. This will optimise the power flow on the network, which will effectively minimise network losses.
  - **New distribution system analysis tool:** In parallel with our effort to modernise IT infrastructure, we will build up from our work in ED1 on time series analysis of our simulation tool using scripting method. We will apply time series analysis for our new system analysis tool in ED2 as we recognise that analysing losses using a snapshot load profile via LLF method will no longer be suitable as the network is getting more complex with higher uptake of LCTs.
- **Engaging with our stakeholders:** We will develop an effective engagement strategy using various platforms to listen to our stakeholders on their views on how best for us to manage losses in ED2.
- **Adopting UK and international best practice:** We will also continue to engage with our sister companies under BHE and the international DSO, Skagerak Nett, on sharing best practice in managing losses. We will continue to use the ENA TLTG platform to share best practice, knowledge and experience amongst DNO members and other industry sectors to further enhance our preparation of losses management in ED2.
- **Embedding losses into our cost-benefit analysis (CBA):** We will ensure we continue to take into account losses in our cost-benefit analysis to come up with economic lifetime costs of investment decisions or design solutions. We will adopt the most up-to-date and Ofgem-approved CBA tool as part of the ED2 planning and develop good practice guidance on the use of this tool via the ENA TLTG.
- **Building up the good learning outputs from innovation projects in ED1:** We will assess the innovation projects that we and other fellow DNOs carried out in ED1 and will identify and build up the good learning outputs from these innovation projects that will inform our RIIO-ED2 losses management.

OBJECTIVE – Consideration for RIIO-ED2 when understanding and managing losses. Learning from the LDR in RIIO-ED1 to create proposals for how losses incentives should be managed in RIIO-ED2.

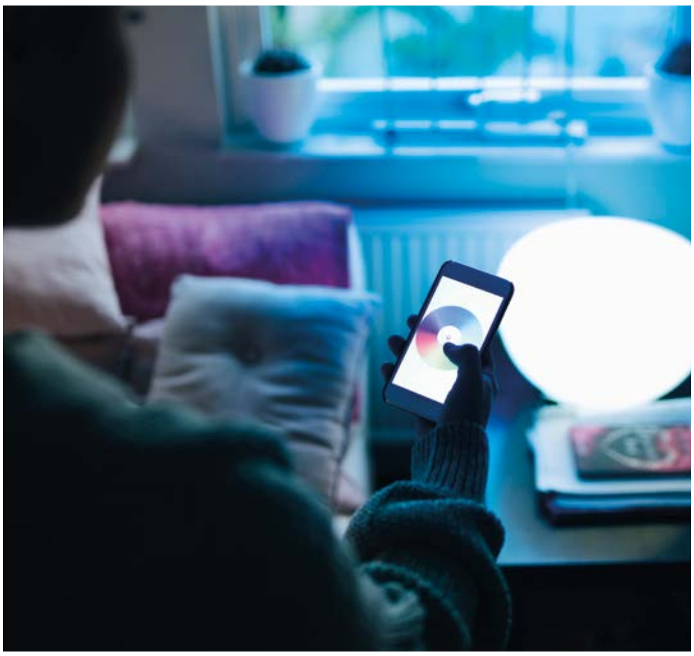
We have, through the ENA TLTG, created proposals for how losses incentives should be managed in ED2. The group has commissioned WSP to carry out a 'Technical Losses Mechanism Study' to inform the development of a potential new losses incentive mechanism for ED2 which would adequately incentivise efficient management of both technical and non-technical losses in the context of the low-carbon transition. This work has now been completed and is being shared in detail with Ofgem through the development of the ED2 price control methodology.

During RIIO-ED1, Standard Licence Condition (SLC) 49 ensures DNOs maintain losses as low as reasonably practicable, and in compliance with their losses strategies. In RIIO-ED2, distribution networks will be a key enabler to Net Zero with greater levels of utilisation and flexibility to accommodate the electrification of heat, transport and decentralisation of generation, in parallel with decreasing consumption of fossil energy sources (including gas, diesel and petrol). Network losses will therefore increase materially with utilisation. Hence, absolute losses reduction is counter to Net Zero. Furthermore, the carbon intensity of network losses is proportional to the carbon intensity of the energy generation mix (decreasing year-on-year with renewable energy trends). The effect of losses on DNO and customer carbon footprint is reducing, relative to previous levels.

The guiding principles for the ED2 regulatory approach are:
i) Incentivise economic and efficient management of losses
ii) Balance between today's and tomorrow's customers
iii) Harmonious with other incentives and revenue streams
iv) Efficient to operate and practical to implement.

The 'Technical Losses Mechanism Study' performed a review of losses incentive schemes in use worldwide to identify learning that could inform a new mechanism. A range of possible incentive mechanisms was devised and then evaluated against criteria that were in line with the guiding principles. 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.

'The effect of losses on DNO and customer carbon footprint is reducing, relative to previous levels.'



4. Innovative approaches to losses management and actions taken to incorporate these approaches into business as usual activities

Improved understanding, and ultimately reduction in losses, is one aspect of our innovation strategy. We have delivered losses-focused projects and built on other innovation project outputs as a leveraged way of delivering further losses activities. Particular attention has been paid to taking action to develop a culture of conscious losses management in the business through colleague training, development of engineering guidance and changes to design policy that impact day-to-day activities.

An important consideration in innovation is the transfer of learning into business as usual practices. This is as imperative in the area of losses as it is with other categories of innovation. For losses, we have delivered actions to encourage this transition such as ensuring that losses are taken into account in our investment appraisal processes as set out in our code of practice for the methodology of assessing losses. Promoting and explaining internal decisions made as part of design policy or individual investment decisions to factor in losses will continue to be important for us.

Innovative approaches to manage losses: We have built upon the success of UKPN's Bankside Project with Arup by also working with Arup to carry out a feasibility study of retrofitting the waste heat recovery technology onto our existing transformers. We learned that although the technology is technically achievable, under the current market condition, it is not commercially viable.

We have built on the findings by UKPN on contact voltage losses (CVL) by examining CVL in the perspective of pole leakage current in our HV network. We learned that the losses impact due to pole leakage current is small and thus considered negligible. The primary concern for the pole leakage detection is safety.

We have developed a scripting capability in our software modelling tool, IPSA, to enable us to carry out time series analysis of losses of our network. This innovative approach improves our losses quantification and allows us to easily analyse the impact of any changes in the network that we modelled towards losses. We also increased our understanding on how BESS impacts network losses from our Rise Carr BESS and DS3 project, leveraging output from previous innovation projects.

Incorporating these approaches into BAU activities: We have implemented into business as usual an assessment of the social cost of losses in the options assessments in our investment appraisal documentation. We have provided guidance for this as part of our code of practice for the methodology of assessing losses.

This ensures that proposals made by engineers are transparent and appropriately documented while taking losses into consideration. To facilitate this, tools and associated training for losses assessment have been rolled out to design engineers. We recognise that it is not only process or system changes that are required, there is an issue of a cultural change to be addressed and we have recognised this in the training we have delivered to our engineers. In this report, we have also provided an example, case study D3 in appendix D, to demonstrate how consideration of network losses can significantly influence our investment decision to select an option which has the highest capital cost, but provides the highest value option to the business when losses are capitalised in a net present value (NPV) analysis.

Details of action

Waste heat recovery

Status: Complete

We have built upon the success of UKPN's Bankside Project with Arup to recover heat from transformers, as well as learnings on the re-use of low grade heat being undertaken in industries and academic institutions. We have also worked with Arup to carry out a feasibility study of retrofitting the waste heat recovery technology onto our existing transformers (see appendix D).

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. Enhanced profitability and scheme viability is possible through the development of a novel-engineered heating system and a heat purchase agreement with sufficiently high tariffs. However, under current market conditions, ensuring the attractiveness of such a scheme would be challenging. Full report can be viewed on our losses webpage **https://www.northernpowergrid.com/losses**.

Contact voltage losses (CVL)

Status: In progress and due for completion 2020

What we have achieved

We acknowledged the findings by UKPN on CVL and we are collaborating with them in trialling the mobile asset assessment vehicle (MAAV) to survey two big cities within our licences, Newcastle and Leeds, in 2020 for defects in our LV underground network while improving our understanding of losses due to leakage current. Although we appreciate that safety is the primary concern in the roll-out of MAAV, after reviewing the report on CVL produced by Princeton University, we also learned that further work is needed to validate the assumptions and calculations used in the report, whether or not different network topologies have any impact on the assessment. For example, the difference between meshed and radial LV network, different cable types, construction and configuration (separate neutral earth SNE and combined neutral earth CNE) would affect the detection of the contact voltage and the flow of the leakage current for the losses calculations. However, we are particularly interested to see if CVL can be easily detected on defects in CONSAC cable-type network in our north-east licence area.

We have examined CVL from the perspective of pole leakage current in our HV network, learning from the Princeton University report and following our previous work with EATL[40]. This is explained further as case study D1 in appendix D.

We concluded that the losses impact due to pole leakage current is small (less than 0.01% of total annual losses of our network), and thus can be considered negligible. The primary concern for the pole leakage detection is safety.

What we are planning to do
We will carry out the MAAV trial in 2020. The findings from this would inform our next steps, such as whether or not to pro-actively look for defects in our LV network to mitigate the risk of these defects becoming a fault.

Time series analysis by using scripting method to quantify network losses

Status: Complete

What we have achieved
We have carried out time series analysis in software modelling tool IPSA to quantify network losses by using scripting method. This powerful tool can accurately calculate variable losses for any assets in the network or for the network as a whole, by carrying out loadflow half-hourly for any set duration of time using half-hourly loading data available from our Plant Information (PI) system. This will allow us to assess the impact of losses for any set of conditions in the network. The flexibility and capability that this method can offer will allow us to analyse the impact of any changes in the modelled network on losses, which will inform our design optioneering and decisions. For instance, we can analyse the impact of changing transformer sizes, network configuration or voltage setpoints on network losses more easily, which would otherwise involve a lengthy process as currently outlined in our code of practice for the methodology of assessing losses. Case study D2 in appendix D provides an example of time series analysis of losses at Hartmoor 66kV network by using the scripting method.

Adoption through changes to processes, systems and culture

Status: Complete

What we have achieved
Losses application guide – To support our designer engineers in assessing losses on smart solutions, we produced an application guide aimed at the more complex design schemes so that losses are appropriately valued. This guide was embedded into our recently updated code of practice for the methodology of assessing losses. Case study D3 in appendix D provides an example on our optioneering process when losses were taken into consideration for reinforcement necessary to address the fault level issues at Darlington 132/6kV substation by applying our losses application guide. This example provides a valuable evidence on how consideration of network losses can significantly influence our investment decision to select an option which has the highest capital cost, but provides the highest value option to the business when losses are capitalised in a net present value (NPV) analysis.

Internal environmental newsletter – NPg Safety, Health and Environment (SHE) directorate produce a quarterly internal newsletter, to provide an update on activities and latest news related to SHE. We have published our article in the Q4 2019 issue entitled ‘Working to Reduce Network Losses’ which underlines our commitment and initiatives to manage losses.

In-house training

Status: Ongoing

What we have achieved
We have disseminated our code of practice for the methodology of assessing losses and guidance update to our design engineers, training them on how to incorporate losses into their designs. The training involved an explanation of the cost-benefit analysis tool, what loss load factors (LLF) are and why they are used and some examples using Northern Powergrid loadflow software. We have also formally trained our engineers, as part of their training scheme.

What we are planning to do
As well as continuing to reinforce losses management training to our design engineers, we will also continue to train our graduate engineers, technical staff trainee and our foundation degree engineers.

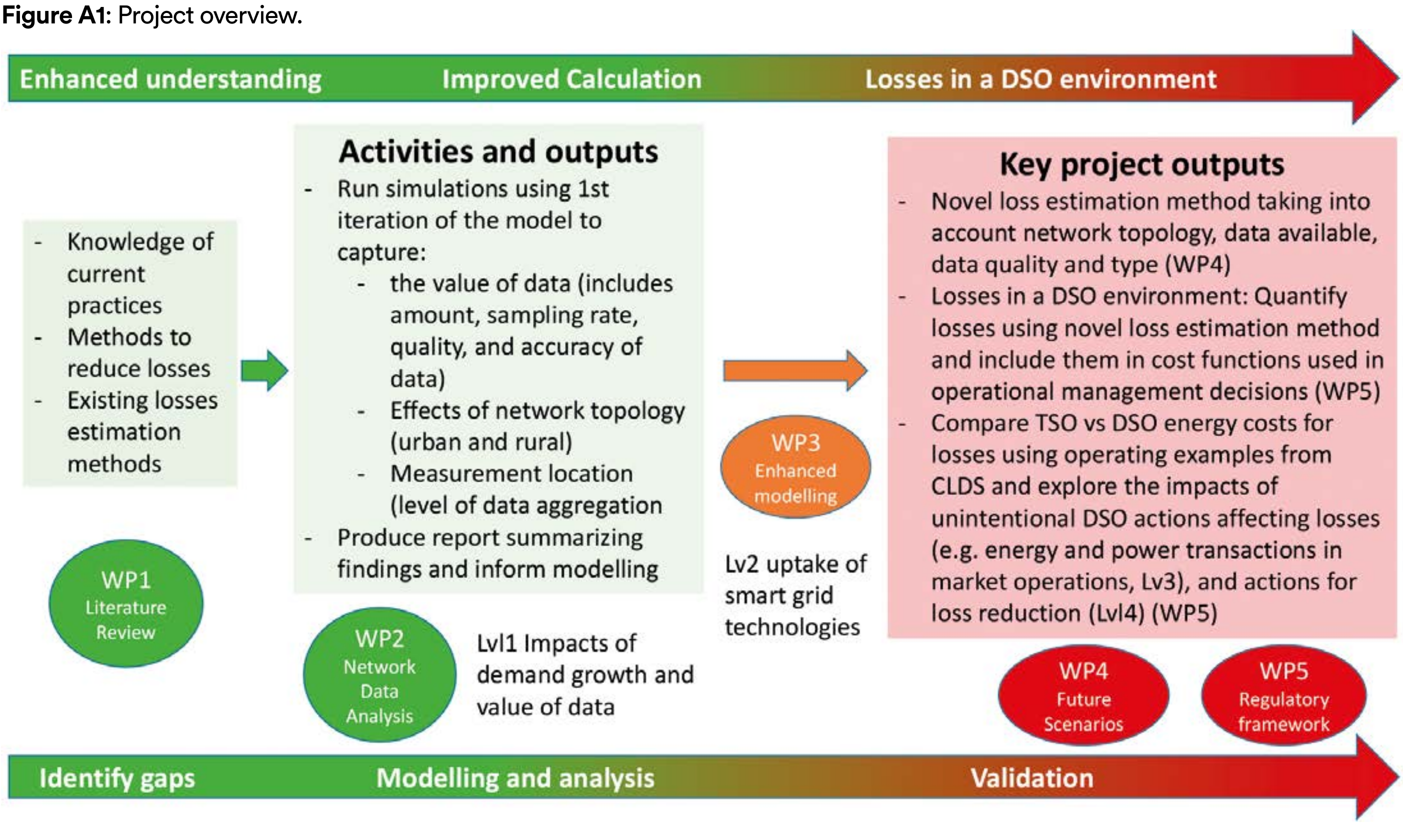
[40] EATL STP reports related to pole leakage include 1) ‘Leakage current measurements on eleven unused wood poles’ 2) ‘In-situ Megger Testing of Wood Poles on De-energised High Voltage Overhead Lines’ 3)’Field Trials of Prototype Pole Leakage Detectors’ 4) ‘”Call-out” Leakage Current Measurements on Suspect 11kV Poles’ 5) ‘Leakage Current Measurements On Poles With Defective Insulators’

5. Appendices

Appendix A:
Understanding of losses

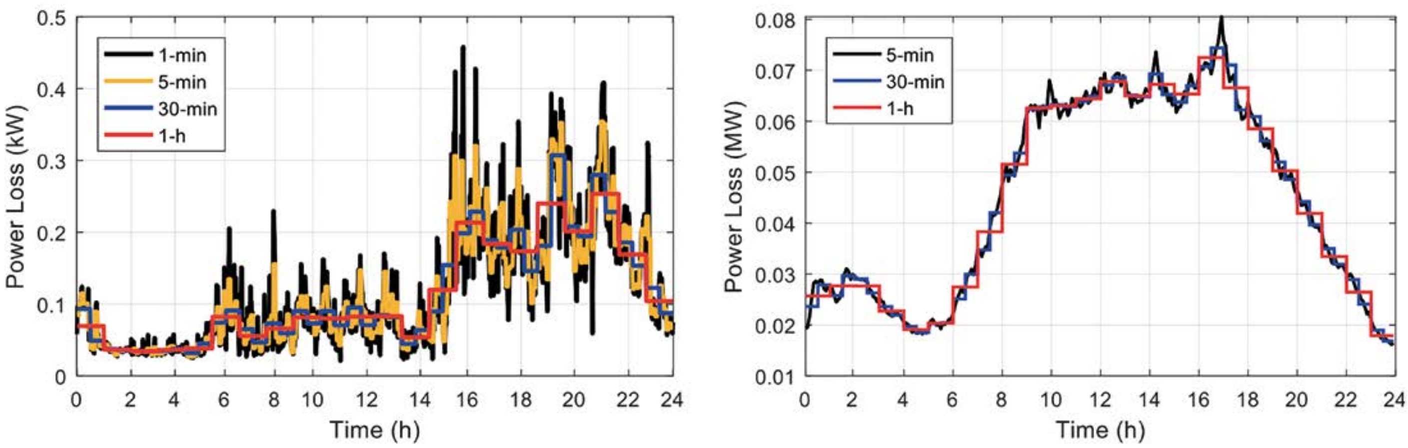
i) Enhanced Understanding of Network Losses project – overview

Figure A1: Project overview.



ii) Enhanced Understanding of Network Losses project – impact of data resolution

Figure A2: Variation of power losses during a day in an LV (left) and HV (right) network at different data resolutions.



The project studied the effect of loading sampling rate on loss evaluation using 1-min, 5-min, 30-min, and 1-h time steps. Two networks – an HV rural and an LV urban – were considered in the analysis, and the results indicated that the most significant factor that impacts losses (in terms of time resolution) is the variability of the feeder loading, which is related to the load diversity. The error in energy losses was approximately 0.1% and 3% in HV and LV, respectively; load diversity is much higher in HV because of the number of customers supplied at this voltage level compared to LV. Increasing the sampling rate leads to greater underestimation of energy losses because of the resulting smoother profile.

iii) Case study A1: Impact of domestic BESS on losses

We used the data collected as part of the Distributed Storage and Solar Study (DS3) project to understand the impact domestic photovoltaic (PV) generation and battery energy storage system (BESS) have on network losses for the low voltage (LV) network. The analysis, which was outside the scope of the DS3 project, estimated losses for the scenarios of (a) no PV – no BESS, (b) with PV – no BESS and (c) with PV and BESS. For scenario (c) two different BESS operating modes were examined, that of threshold charging (BESS charges/discharges based on excess generation/demand) and maximum impact (BESS charge/discharge at their maximum rate at set times). Average losses were calculated for single phase service as well as LV mains cables using half-hour data. The analysis of various levels of generation showed that the relationship between network losses and PV generation resembles a parabola. Low levels of generation combined with high levels of consumption, at times experienced in the winter, have the potential to reduce losses. However as generation levels increase and/or consumption reduces, i.e. in the summer, losses increase.

On the mains cable, aggregated consumption exceeded generation, hence PVs reduced losses overall. On the service cable this only happened during periods of low generation levels hence it was observed that on average PV increased losses.

The impact of BESS on the other hand varies depending on season, size and operating mode. When operating in threshold charging mode, BESS have a positive impact on losses (i.e. reduce losses) on both service and mains cables as they absorb excess generation and supply evening demand. However the impact of the maximum impact mode is somewhat different. Although it also has a positive impact on losses, particularly on mains cables, its impact was less than that of the threshold charging mode as forcing the BESS to charge/discharge regardless of generation and demand caused additional power flows, particularly at periods of low generation or demand (charging the BESS in the winter and discharging it in the summer) or extended periods of generation (discharging the BESS in the summer).

Full report can be viewed on our losses webpage **https://www.northernpowergrid.com/losses**.

Figure A3: Average annual losses per single phase service cables per customer.

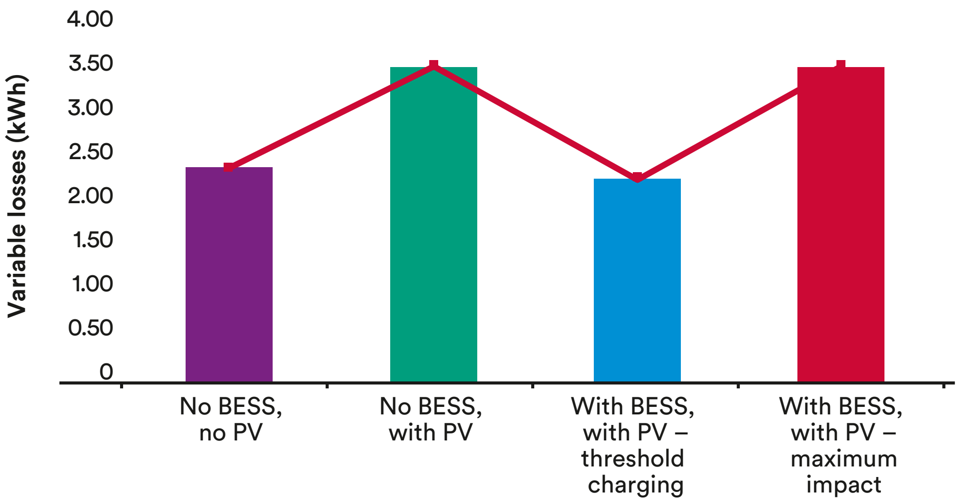
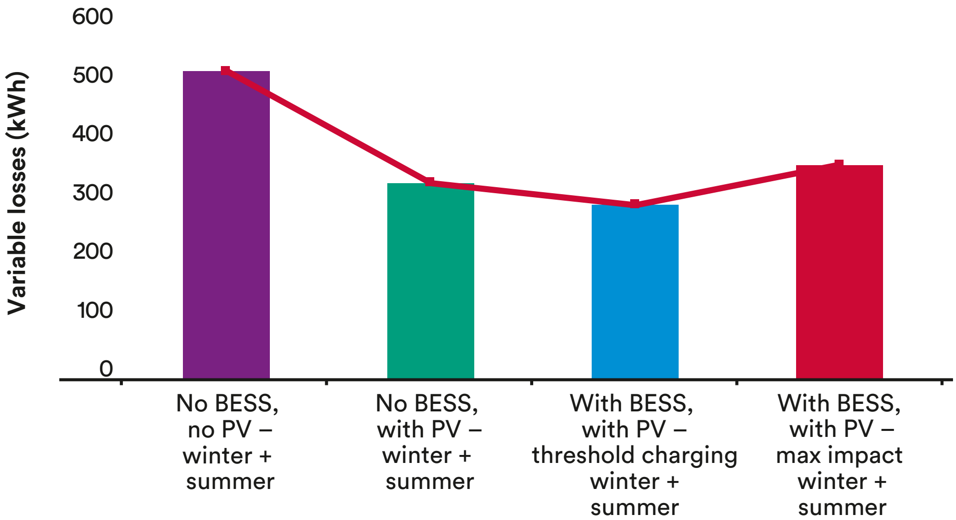


Figure A4: Total LV feeder cable losses per year.



iv) Case study A2: Impact of BESS in Rise Carr on network losses

We analysed the impact of Rise Carr battery energy storage system (BESS) on network losses, and used this analysis to estimate the wider impact of BESS on network losses. Variable losses are calculated for the 33 kV Darlington North – Rise Carr double circuit and the two 33/6.4 kV transformers at Rise Carr for the scenarios of i) no BESS, and ii) BESS. Losses are also calculated for the Rise Carr BESS based on the difference between energy in and energy out of the BESS, and the network losses impact of BESS operation under Firm Frequency Response (FFR) and Triad regimes are reviewed. All analysis is undertaken using half-hourly data and some generalised assumptions, on the basis that this will be sufficient to determine the materiality of the losses impact.

The losses refer to losses on the Darlington North 33 kV – Rise Carr 33 kV circuits and the two 33/6.4 kV Rise Carr transformers. Losses analysis on the Darlington North – Rise Carr double circuit (inc. T1 and T2) is for the 326 days of BESS operation. The losses increased by 677 kWh, which is an increase in losses on this section of the network in real terms of 0.0014 percentage points; which equates to a 0.8% increase in losses when compared to the losses scenario 'without BESS'.

Figure A5: Darlington North – Analysis of Rise Carr losses for the 326 days of battery operation. Total = 677 kWh; a 0.8% increase in the losses on this section of the network.

	Without BESS	With BESS	BESS impact
Rise Carr EHV losses (kWh)	82,753	83,430	677
As % of Rise Carr consumption* without battery	0.1745	0.1759	0.0014
As % of circuit losses without battery	100.00	100.82	0.82

* Total consumption of Rise Carr (without BESS) over duration of analysis is 47.4 GWh

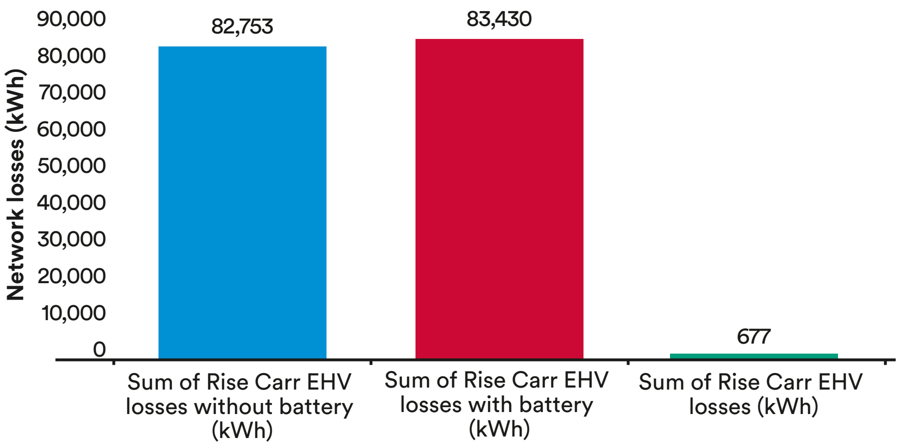
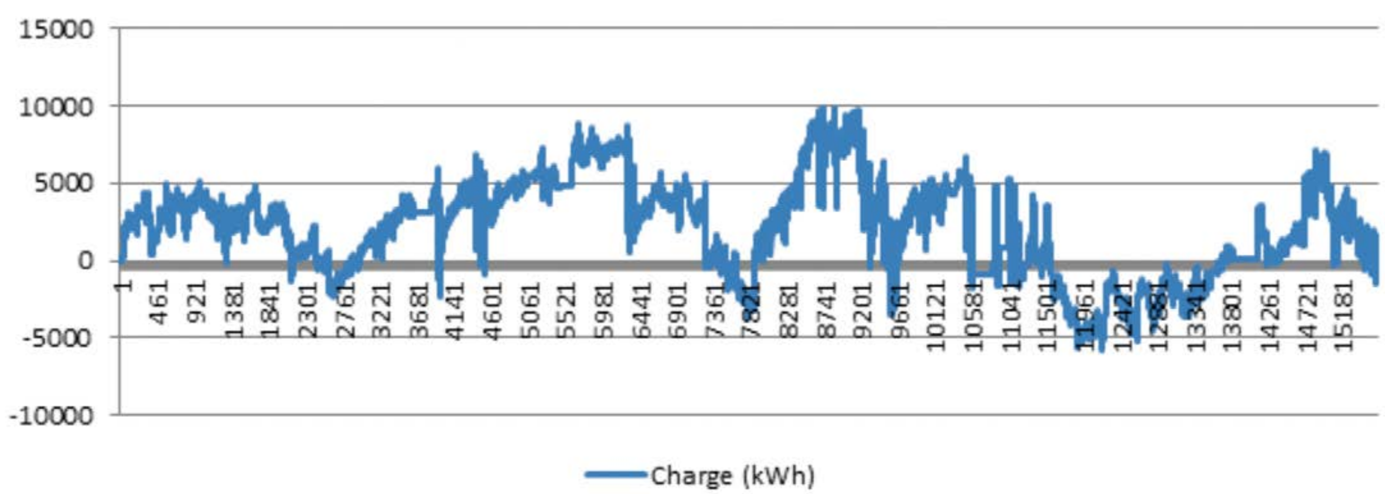


Figure A6: Calculated BESS charge status (kWh) based on cleansed data assuming round trip efficiency of 72.7%. Purpose of this figure is to show that within the expectation of charge status between 0 kWh and 5,000 kWh, the calculated value (ranges from -6,000 kWh to +10,000 kWh) is broadly aligned to the expectation, and gives confidence in the round trip efficiency value of c73%.



BESS site losses – Over the period 29 Aug 2017–24 Aug 2019, the losses for the BESS Rise Carr system (i.e. not the distribution network) can be assessed based on the total energy in and the total energy out (measured on the HV side of Transformer 3). Noting that the demand data is cleansed by the removal of settlement periods with bad data; therefore there will be some errors in the energy flows. On average, however, across the 326 days worth of half hours (15,635 HH), this error should reduce to zero.

For the windows E, F1, F2 and G, for the BESS site (including the transformer and inverter/rectifier):
1) Total Energy In = 1,134 MWh
2) Total Energy Out = 824 MWh
3) Efficiency = 100*(In – Out)/In = 100*(1134-824)/1134 = 72.7 (i.e. 27.3% losses)
4) BESS Losses = 27.3% * Total Energy In = In-Out = 309 MWh.

This calculation highlights that the network losses are small in magnitude compared to the losses at the battery site; 2.1 kWh per day vs. 947.9 kWh per day (a ratio of 1:451). Figure A6 provides more context around the validity of this calculation and the round trip efficiency of c73%.

Full report can be viewed on our losses webpage **https://www.northernpowergrid.com/losses**.

v) Enhanced Understanding of Network Losses project – impact of new and existing LCTs on losses

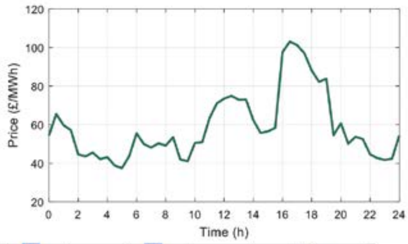
This methodology is applied on the representative feeders derived from the clustering process that we built in this project. This offers the significant advantage of being able to make decisions for any of the cluster feeders based on the results of the representative feeder of each cluster. Of course, this methodology can be applied directly to any feeder in order to evaluate a specific asset connection (or operation). Finally, this study considers different characteristic days of the year (e.g. winter weekdays, winter weekends, summer weekdays, etc.) in order to provide representative results for the whole year.

Figure A7: Investigation of the optimal operation of a battery energy storage system to maximize its Arbitrage Benefit. Price profile (top). Optimal schedule of the battery energy storage system (bottom).

— Considering impact of ESS operation on losses.
— Assume an ESS performing arbitrage with the following price profile.

ESS (1 MW / 2 MWh) at bus 8
Objective Function:

$$\max \sum_t (P_{dch}(t) - P_{ch}(t)) \cdot p(t)$$



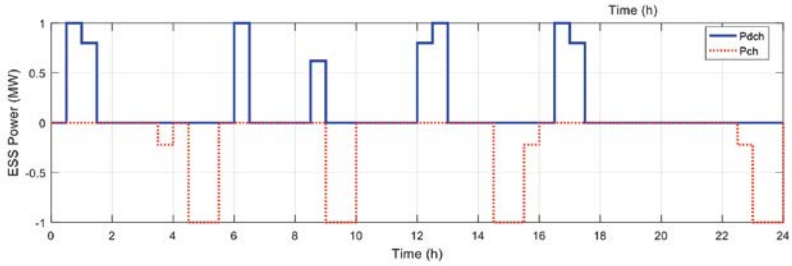
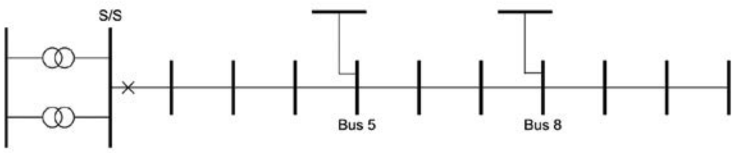


Figure A8: Impact of the battery energy storage system operation (in order to maximise its profit) on losses for two different sizes and three different network locations. Representative feeder of cluster 1 (top). Results (bottom).



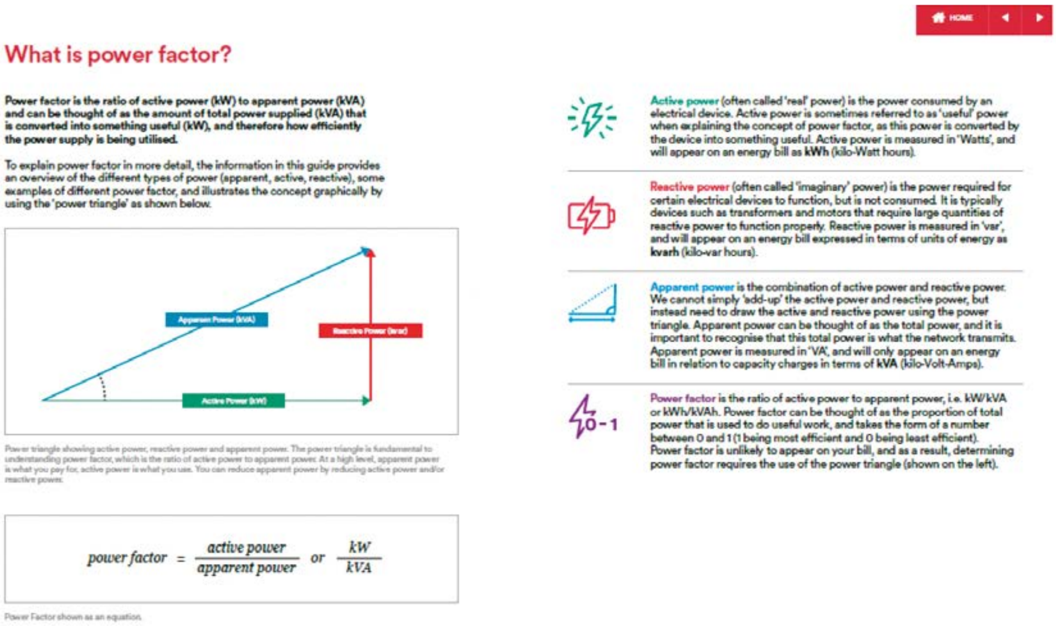
Case	Losses (kWh)	Arbitrage Benefit (£/day)	Loss Increase (%)
No ESS	178.5	–	–
Bus 5, 0.25MW / 0.5MWh	181.9	27	1.90
Bus 5, 0.5MW / 1MWh	190.4	54	6.67
Bus 5, 1MW / 2MWh	223.2	108	25.04
Bus 8, 0.25MW / 0.5MWh	184.3	27	3.25
Bus 8, 0.5MW / 1MWh	199.1	54	11.54
Bus 8, 1MW / 2MWh	256.6	108	43.75

Appendix B:

Effective engagement and sharing of best practice with stakeholders on losses

i) Energy-saving advice and measures

Figure B1: A snapshot of ‘a guide to power factor’ for our customers. This guidance can be obtained from our losses webpage **https://www.northernpowergrid.com/losses**.



HOME

What is power factor?

Power factor is the ratio of active power (kW) to apparent power (kVA) and can be thought of as the amount of total power supplied (kVA) that is converted into something useful (kW), and therefore how efficiently the power supply is being utilised.

To explain power factor in more detail, the information in this guide provides an overview of the different types of power (apparent, active, reactive), some examples of different power factor, and illustrates the concept graphically by using the ‘power triangle’ as shown below.

Power triangle showing active power, reactive power and apparent power. The power triangle is fundamental to understanding power factor, which is the ratio of active power to apparent power. At a high level, apparent power is what you pay for, active power is what you use. You can reduce apparent power by reducing active power and/or reactive power.

$$power\ factor = \frac{active\ power}{apparent\ power} \quad or \quad \frac{kW}{kVA}$$

Power Factor shown as an equation.

Active power (often called ‘real’ power) is the power consumed by an electrical device. Active power is sometimes referred to as ‘useful’ power when explaining the concept of power factor, as this power is converted by the device into something useful. Active power is measured in ‘Watts’, and will appear on an energy bill as **kWh** (kilo-Watt hours).

Reactive power (often called ‘imaginary’ power) is the power required for certain electrical devices to function, but is not consumed. It is typically devices such as transformers and motors that require large quantities of reactive power to function properly. Reactive power is measured in ‘var’, and will appear on an energy bill expressed in terms of units of energy as **kvarh** (kilo-var hours).

Apparent power is the combination of active power and reactive power. We cannot simply ‘add-up’ the active power and reactive power, but instead need to draw the active and reactive power using the power triangle. Apparent power can be thought of as the total power, and it is important to recognise that this total power is what the network transmits. Apparent power is measured in ‘VA’, and will only appear on an energy bill in relation to capacity charges in terms of **kVA** (kilo-Volt-Amps).

Power factor is the ratio of active power to apparent power, i.e. kW/kVA or kWh/kVAh. Power factor can be thought of as the proportion of total power that is used to do useful work, and takes the form of a number between 0 and 1 (1 being most efficient and 0 being least efficient). Power factor is unlikely to appear on your bill, and as a result, determining power factor requires the use of the power triangle (shown on the left).

ii) Energy cost analysis for Northern Powergrid network

Figure B2: Total losses impact for each month Oct 2018 – Nov 2019. Cost of carbon assumes £50/MWh (i.e. the social cost) using actual volume of carbon emitted using HH MWh losses and carbon intensity, cost of energy calculated based on HH MWh losses and wholesale energy costs. The losses impact is heavily skewed by the winter months; whereby marginal plant is typically high cost and high carbon.

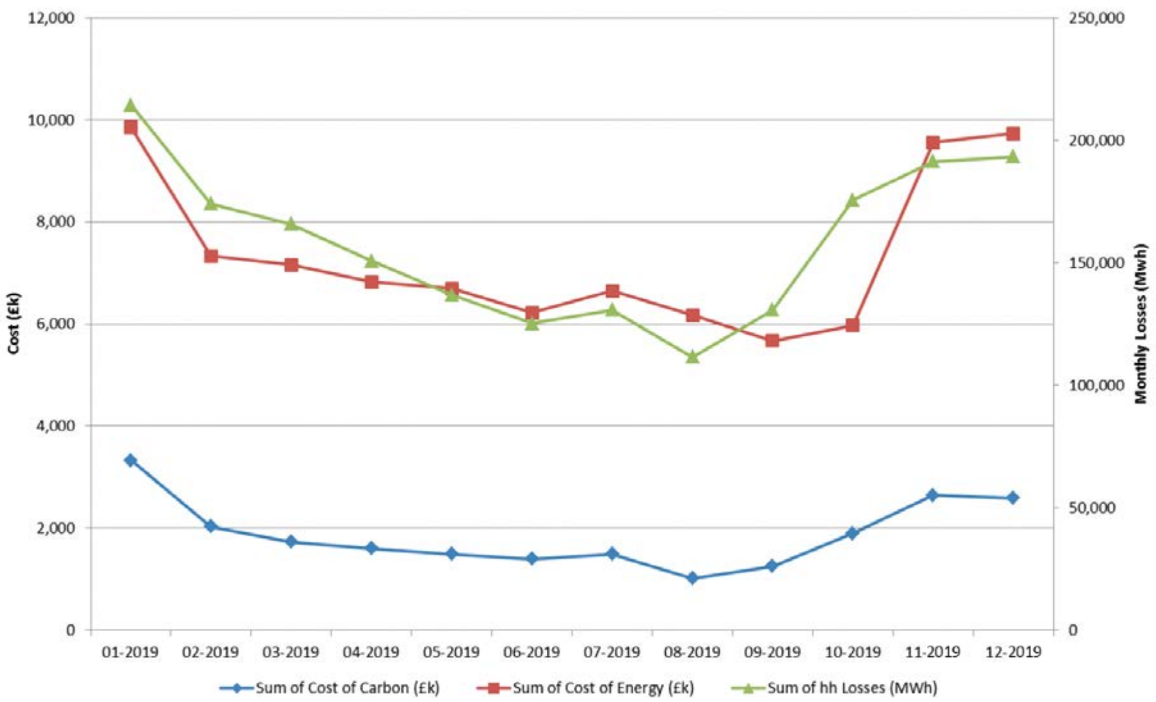


Figure B3: Average monthly (bars) and annual (dotted line) energy cost for methods 1, 2, 3. Winter months average above £60/MWh, whereas summer months average around £40/MWh for all methods. The annual (average) unit cost of energy for methods 1, 2 and 3 are £46.21, £48.39, £50.051 respectively (as per table 1 in the main report).

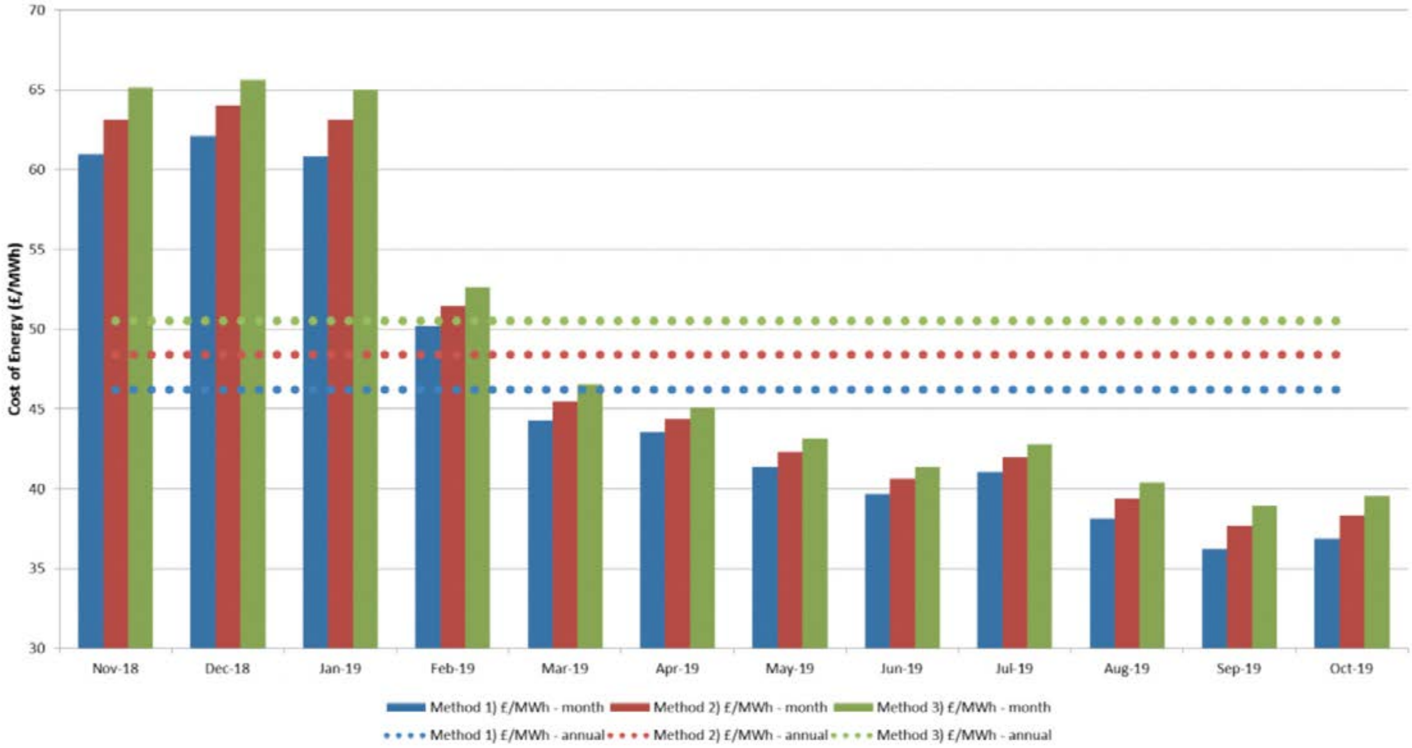


Figure B4: Average monthly (solid line) and annual (dotted line) energy cost correction factors for transitioning from methods '1 to 2' (blue line), '1 to 3' (red line), and '2 to 3' (green line). The annual numbers are equivalent to the annual correction factors, and in order of listing, these factors are 4.7%, 9.3% and 4.4%.

iii) Carbon intensity analysis for Northern Powergrid network

Figure B5: Average monthly (bars) and annual (dotted line) carbon intensity for methods 1, 2, 3. Winter months average above 250 gCO_2/kWh, whereas summer months average around 250 gCO_2/kWh for all methods. The annual (average) carbon intensity (gCO_2/kWh) for methods 1, 2 and 3 are 219, 226, 237 respectively (as per table 2 of the main report).

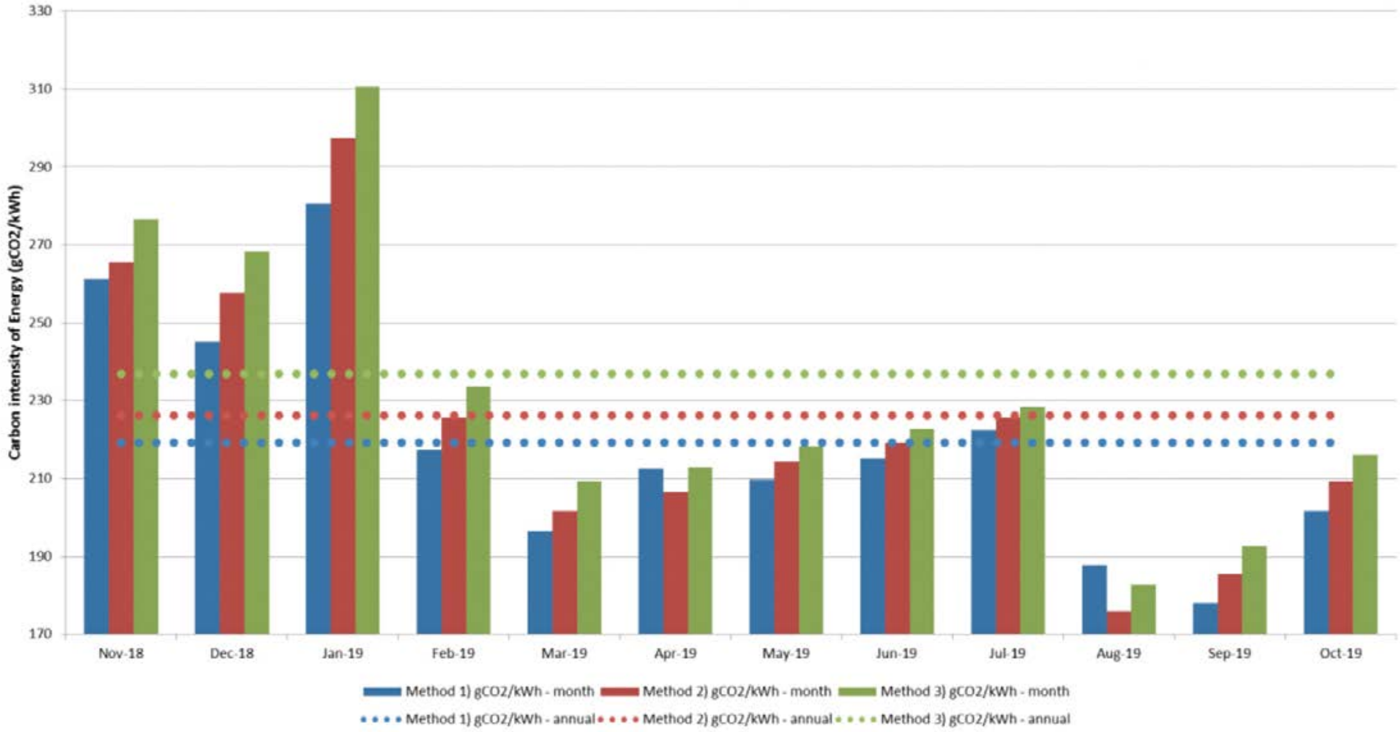


Figure B6: Average monthly (solid line) and annual (dotted line) carbon intensity correction factors for transitioning from methods '1 to 2' (blue line), '1 to 3' (red line), and '2 to 3' (green line). The annual numbers are equivalent to the annual correction factors, and in order of listing, these factors are 3.2%, 8.0% and 4.7%.

Table B1: Summary of collaborative work that we have with our stakeholders

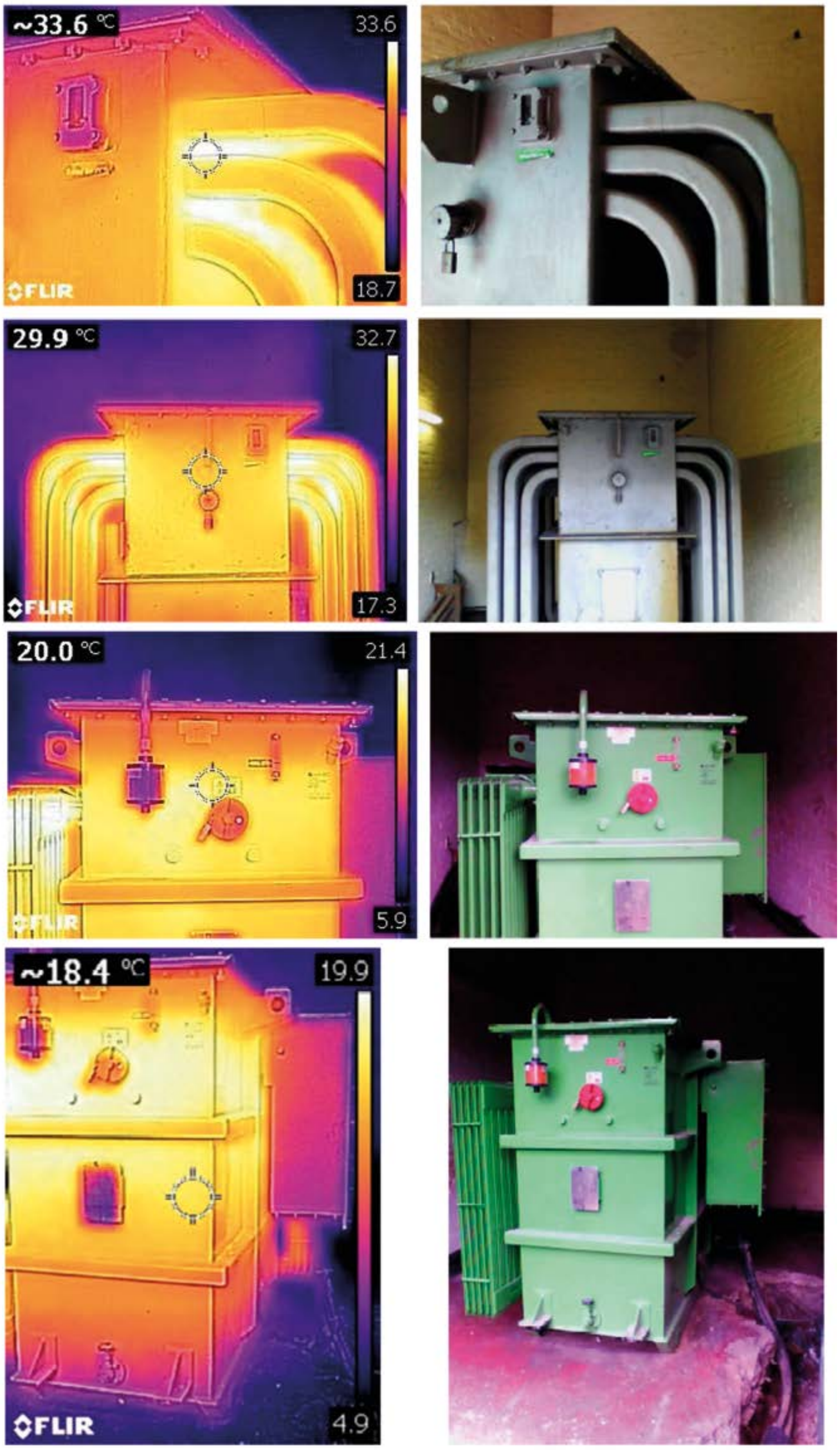
Collaborations with	Collaborative activities	Measures to continue collaborations
ENA TLTG (ENA working group)	— Teach-in session with Ofgem on losses. — Commissioned WSP to study the impact of LCT on losses. — Commissioned WSP to develop a losses incentive mechanism for ED2. — Presented at LCNI 2017 and 2019. — Shared best practice, identified areas for collaborations: BAU, trials results, develop common policies. — Produced group initiatives tracker for losses strategies and LDR.	— Continue to work on the Engineering Recommendation document. — Regular meetings – sharing best practice, preparing for ED2. — Active engagement with Ofgem for ED2. — ENA webpage update. — Amorphous transformer (AMT): NPg to share outcome of ground-mounted trial as a case study – informing future specifications, operational aspects of installation, environmental noise impact and power quality factors.
Other ENA working groups	— ENA LCT working group. — ENA Open Networks. — ENA Transformer Assessment Panel (TAP).	— Continue to engage with different ENA working groups to generate ideas, share information and knowledge.
UKPN (DNO)	— Reviewed contact voltage losses (CVL) from Princeton report, built on the work from this report to investigate pole leakage CVL. — Joint meeting with UKPN and Power Survey on CVL and mobile asset assessment vehicle (MAAV) trial. — AMT trial.	— We are planning to trial MAAV, which is to be provided by UKPN, in Q2 2020. — We will discuss our pole leakage CVL in the ENA TLTG meeting.
Wilson Power Solutions (AMT manufacturer)	— AMT trial. — Joint news update on AMT trial via social and trade media platforms.	— To share outcome of trial as a case study – informing future specifications, operational aspects of installation, environmental noise impact and power quality factors.
Freedom (service provider)	— AMT trial – operational aspects. — Joint news update on AMT trial via social and trade media platforms.	— To share outcome of trial as a case study – informing future specifications, operational aspects of installation.
Non-domestic customers	— Customer VAr advice.	— Continue working with customers. — Track progress and feedback in the ICE initiative.
Social responsibility partners and local communities	— Energy efficiency initiatives.	— Continue working with our partners to discharge our social responsibility which has a positive impact of reducing losses.
YW and NGN (other utilities)	— Sharing best practice to manage losses.	— Regular meetings to follow up with discussions or any potential collaborations. — Inform losses strategies for ED2.
Skagerak Nett (international DSO)	— Sharing best practice to manage losses.	— Regular meetings to follow up with discussions or any potential collaborations. — Inform losses strategies for ED2.
Academic partners	— Sheffield University: Smart Data project. — Newcastle University: Enhanced Losses. — University of Bradford: Industrial Advisory Board (IAB).	— Continue direct involvement in losses-related projects. — Continue to learn about any losses impacts from other projects with academia. — Continue to involve academic partners in research on losses. — IAB: Explore opportunity for syllabus on network losses.
Consultancies	— WSP, TNEI, Element Energy, EA Technology.	— Continue working with consultancies on losses work and any projects that have impact on losses.
Delegates for stakeholder summit	— Stakeholder engagement to inform and educate stakeholders on network losses.	— To continue to inform and educate stakeholders on network losses and their importance in Net Zero targets.
Energy suppliers	— Smart meter tamper alerts.	— Continue collaboration, review position from tamper alerts data analysis as penetration of smart meter grows.
YW, NW and NGN	— Infrastructure North.	— To continue collaborations in this platform to promote energy efficiency and waste reduction.

Appendix C:
Processes to manage losses

i) Amorphous transformer (AMT) trial – thermal imaging result from one of the sites

Thermal images of the original transformer (grey) were taken that showed the tank temperatures in different areas. These have been repeated on the new amorphous core transformer (green) for comparison, as temperature could be seen as an immediate and simple way to gauge the efficiency of the transformer, i.e. the lower temperature in the amorphous transformer indicates that it is more efficient than the old transformer.

Figure C1: Thermal images comparison between 1000 kVA 20kV old CRGO transformer (grey) and the new amorphous transformer (green).

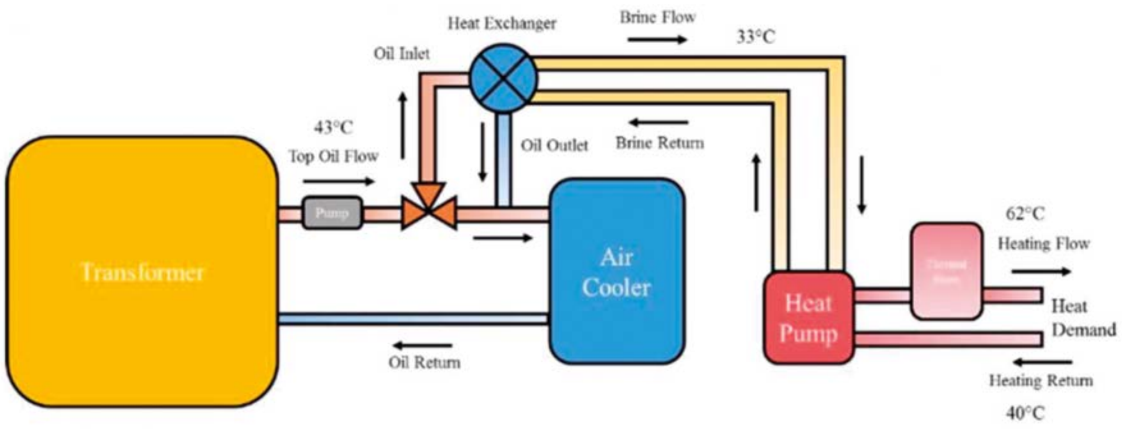


Appendix D:

Innovative approaches to losses management and actions taken to incorporate these approaches into business as usual activities

i) Waste heat recovery project

Figure D1: Schematic for heat recovery for major substation transformer converted to Oil Forced Water Forced (OFWF). The component from left to right: Transformer, pump, heat exchanger, air cooler, heat pump and thermal store.



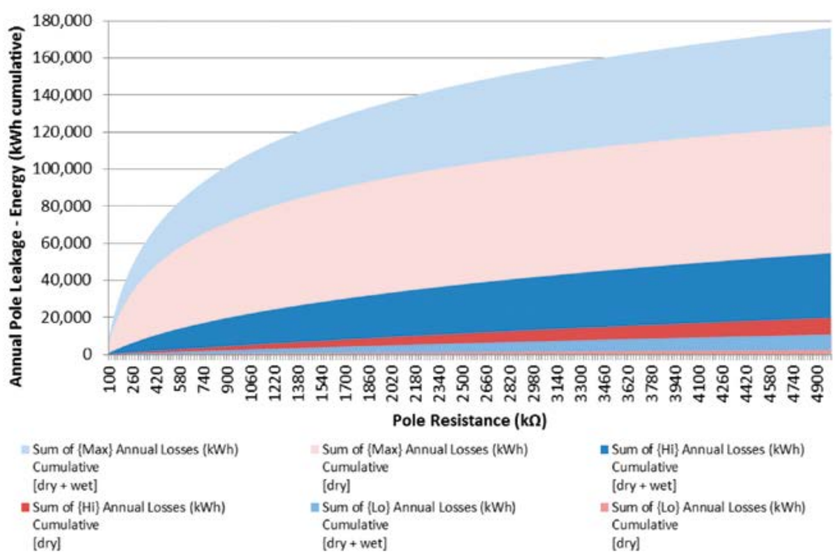
A mapping and shortlisting process was completed based on agreed selection criteria and methods to identify potential candidates for the cost-benefit assessment. These included the loading data of the transformers to estimate the heat loss, as well as proximity to heat networks or local heat loads to utilise each substation's waste heat.

After the refinement of the shortlisting and loss estimation process, sites were selected for techno-economic appraisal, based on their ideal location to supply heat to adjacent sites (heat load) and also satisfying all other selection criteria.

Full report can be viewed on our losses webpage **https://www.northernpowergrid.com/losses**.

ii) Case study D1: CVL from leakage current on HV poles

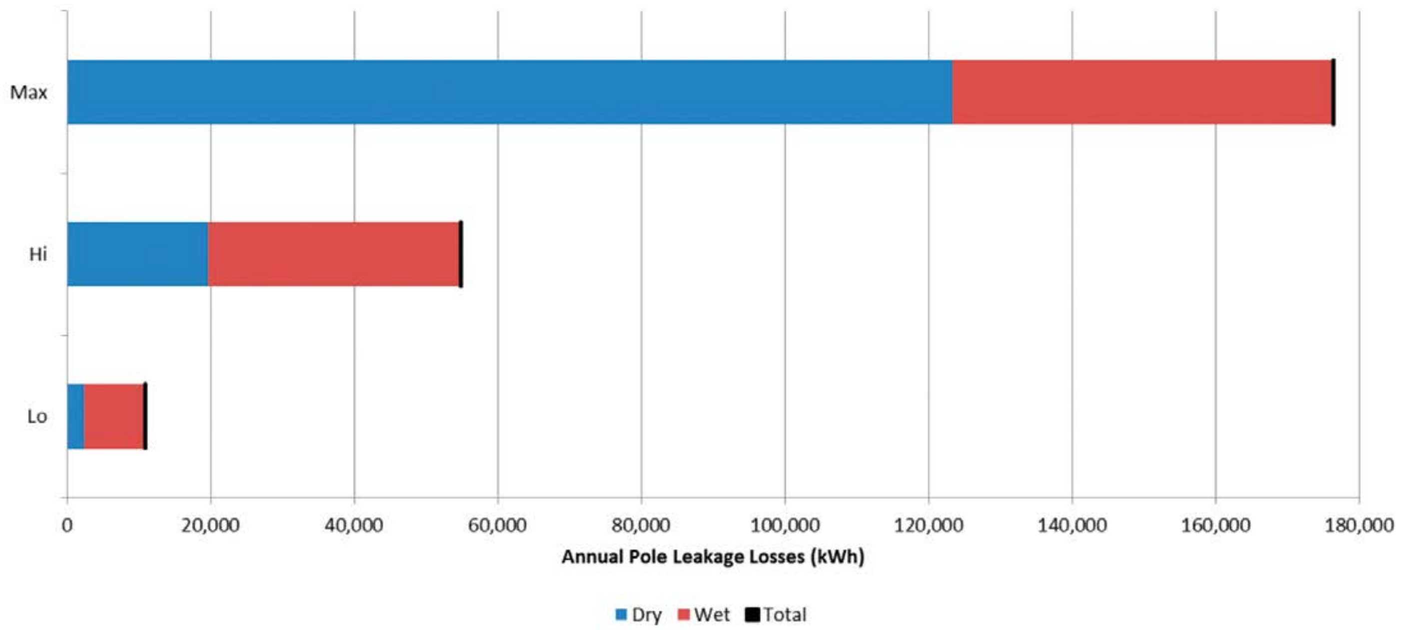
Figure D2: Lower bound {lo}, upper bound {hi} and maximum {max} annual pole leakage energy losses (cumulative kWh) for i) dry conditions, and ii) dry + wet conditions, across the full range of pole resistance values. The max case study losses are disproportionately skewed by the lower pole resistance values. For example; 20% occurs beneath 200 kΩ, and 50% occurs beneath 860 kΩ and 60% beneath 1 MΩ. The total pole losses are therefore highly sensitive to the pole resistance assumptions below 1 MΩ.



Pole losses were estimated for unearthed HV wooden poles using high level assumptions regarding i) pole insulator failures (600), ii) ground resistance (c7Ω), ii) pole resistance (values ranging from 100 kΩ to 5 MΩ), iii) insulator resistances (ranging from 0 Ω to 63 MΩ), and iv) dry and wet variations of insulator resistance. The three cases studied were i) a lower bound, ii) an upper bound (both assuming the insulator has finite resistance), and iii) a maximum (assuming the insulator has completely failed and provides zero resistance). The upper and lower bound form a reasonable losses estimate based on observed leakage currents from historical field tests, whilst the maximum forms a theoretical maximum losses estimate on the assumption that damaged insulators have all completely failed.

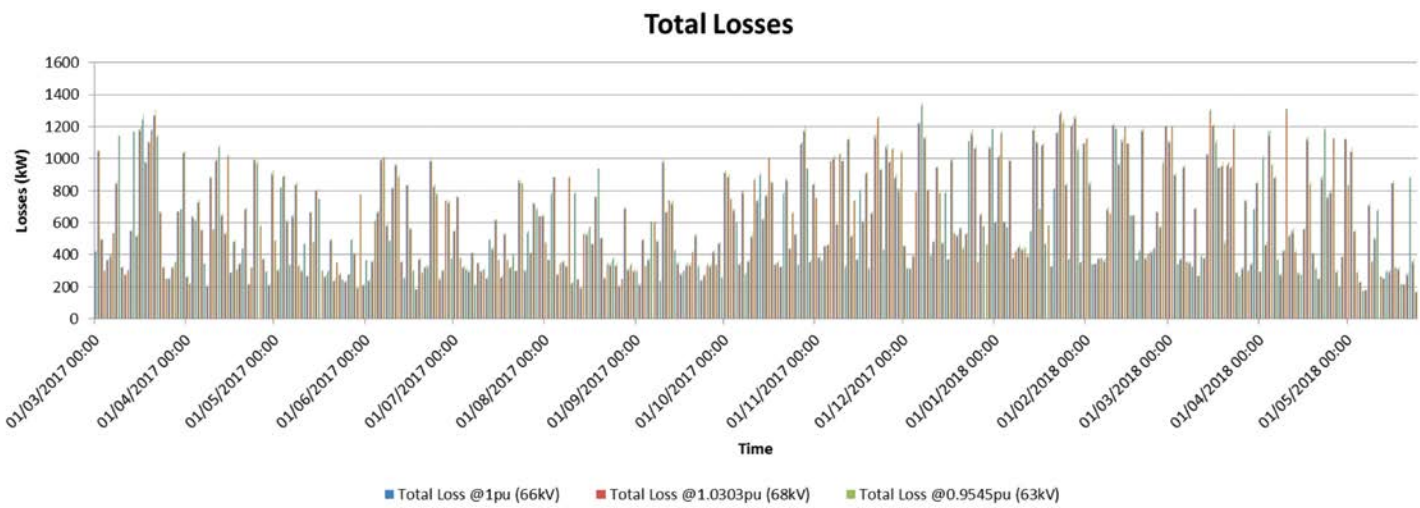
The total annual losses for the lower bound, upper bound and maximum case studies are 11 MWh, 55 MWh and 176 kWh respectively. Using a typical wholesale cost of energy of £50/MWh, this equates to an annual losses impact of c£0.5k, c£2.8k, and £8.8k respectively. Comparing to the total annual NPg losses of 1.9 TWh (£95m), even the maximum case forms less than 0.01% of total annual losses. It is therefore concluded that pole leakage losses are negligible compared to other forms of losses on the network, and shall therefore not be included in the losses strategies. Similarly, the losses associated with pole leakage would not have a material impact with regard to insulator replacement programmes, and can also be omitted from any cost-benefit analysis undertaken as part of insulator replacement programmes.

Figure D3: Summary of lower bound {lo}, upper bound {hi} and maximum {max} annual pole leakage energy losses (cumulative kWh) for i) dry conditions, and ii) dry + wet conditions, stacked to show totals. The annual kWh values for dry, wet and total (respectively) are as follows: | Max; 123,380, 52,877, 176,257 | Hi; 19,651, 35,011, 54,662 | Lo; 2,306, 8,422, 10,728 |.



iii) Case study D2: Time series analysis of losses at Hartmoor 66kV using the scripting method

Figure D4: Time series analysis of losses at Hartmoor 66kV network for different voltage setpoints.



Quantifying losses on the EHV network with a standard IPSA software model, for any set duration, on individual parts of the network would have to be performed manually and would be labour intensive. An IPSA script can greatly simplify this by automating several repetitive steps required. With the use of Python script, we have identified that this will greatly reduce execution time and increase productivity. Multiple load flow for each time-stamp, on any set duration, could be carried out efficiently in a couple of minutes.

The Hartmoor 66kV network comprises both loads and generations. Seven primary substations are fed from the Hartmoor supply point. The generations are connected at 66kV, 20kV and 11kV network which equates to 160.5MVA in total. In this losses quantification exercise, Python script performed 21,551 load flow calculations (Time period between 1 March 2017 – 24 May 2018) for each scenario when calculating network losses for lines and transformer. We applied load scaling on different scenarios (80% Load, 90% Load, 100% Load, 110% and 120% load) to analyse the impact of increased or decreased demand on the 66kV network. We also assessed the impact of voltage setpoint changes at the supply point (63kV, 66kV and 68kV at 100% load and generation) to see how voltage set point affects losses.

Key observations

1. Losses profile does not match with that of the load profile due to the bidirectional power flows as a result of both load and generation.
2. Significant power flow was found to be flowing upstream at times of minimum demand. The losses identified on the network were as a result of both load and generation.
3. Distributed generation (DG) can increase or reduce the losses depending upon the location of the generation. Hence, optimum location for DG needs to be taken into consideration during generation connection design.
4. The same script can also be used for future studies, for example voltage studies (voltage excursion outside the statutory limits) and network utilisation (loading of lines and transformers).

iv) Case study D3: Taking losses into consideration for reinforcement necessary to address the fault level issues at Darlington 132/6kV substation

Reinforcement at Darlington 132/6kV substation is required to fully mitigate fault level issues, as well as to address the long-standing condition issues that cause operational difficulties at this site. This will take into account the following risk considerations: safety, customer service, environmental, financial, regulatory integrity and operational excellence.

The Darlington 6kV system (supplied from Darlington 132/6kV and Rise Carr 33/6kV substations) has been operating under operational restrictions to mitigate the fault level issue temporarily.

Ten options to address these issues were initially investigated in our optioneering process. A total of five of those ten options were considered potentially viable, as summarised in table D1:

Table D1: An assessment of the options for the reinforcement to address the fault level issues at Darlington 132/6kV substation.

Options	Issues
1. Do nothing	— Would require indefinite operational restrictions at the Darlington 132/6kV substation. — Presents ongoing risk to safety due to deteriorating assets and quality of supply due to operational restrictions. — Presents no viable long-term option to remove risk and maintain/improve risk (relative to current levels). — Not a preferred solution.
2. Install new higher rated 6kV switchboard at Darlington 132/6kV substation.	— Addresses fault level and some equipment condition issues. — Presents no viable long-term option to remove risk and maintain/improve risk (relative to current levels). — Does not facilitate upgrade to 11kV.
3. Supply the 6kV network connected to the Darlington 132/6kV substation from the existing Darlington 33/11kV substation via two new 11/6kV transformers.	— Initial investment required for technically viable solution is in the same region with option 2 and 4, in 2020/21. — Does facilitate upgrade to 11kV, but note that additional capital will also be required for future network upgrades to 11kV.
4. Supply the Darlington 6kV network from the existing Darlington Central 33/11kV substation via two new 11kV feeders and two new 11/6kV transformers.	— Lowest capital cost technically viable option compared to option 2 or 3. — Does facilitate upgrade to 11kV, but note that additional capital will also be required for future network upgrades to 11kV.
5. Upgrade Darlington & Rise Carr 6kV networks to 11kV via reinforcements and equipment reconfiguration.	— Highest capital cost option considered (about 4 times the capital cost of option 2 or 3 or 4). However, it has the lowest NPV when considering like for like cost comparison including losses. — Total magnitude of risks reduced is greatest compared to alternative options, as Darlington 132/6kV substation entirely recovered. — Reduces losses in the 6kV network significantly immediately after implementation. — Highest value option to business when losses are capitalised in an NPV analysis.

An additional important consideration is a comparison between the losses incurred on a 6kV system with the losses incurred at 11kV. Although these losses do not directly impact Northern Powergrid as a business, electrical losses represent a significant cost to generators and consumers of electricity, and we have a strategy to reduce losses where this is possible and economically feasible.

A comparison of the losses on the Darlington/Rise Carr 6kV network shows that the I^2R losses incurred on the 6kV network are approximately 2.1 MW at full load, and at 11kV these would be reduced to approximately 0.6 MW.

Taking in to account the long-term strategy of uprating the 6kV network to 11kV it is prudent to assess whether this would be the optimum opportunity to do it by looking at the cost of doing the works now (Option 5) versus the cost of applying an alternative solution now and then upgrading the network to 11kV at a later date.

Using the Northern Powergrid losses CBA template for design solution and applying the process as set out in IMP/001/103 – code of practice for the methodology of assessing losses, the cost savings that would result from upgrading the 6kV network to 11kV, along with the associated EHV reconfiguration of the network, which would also result in marginally lower losses, would equate to approximately £128,000 per year.

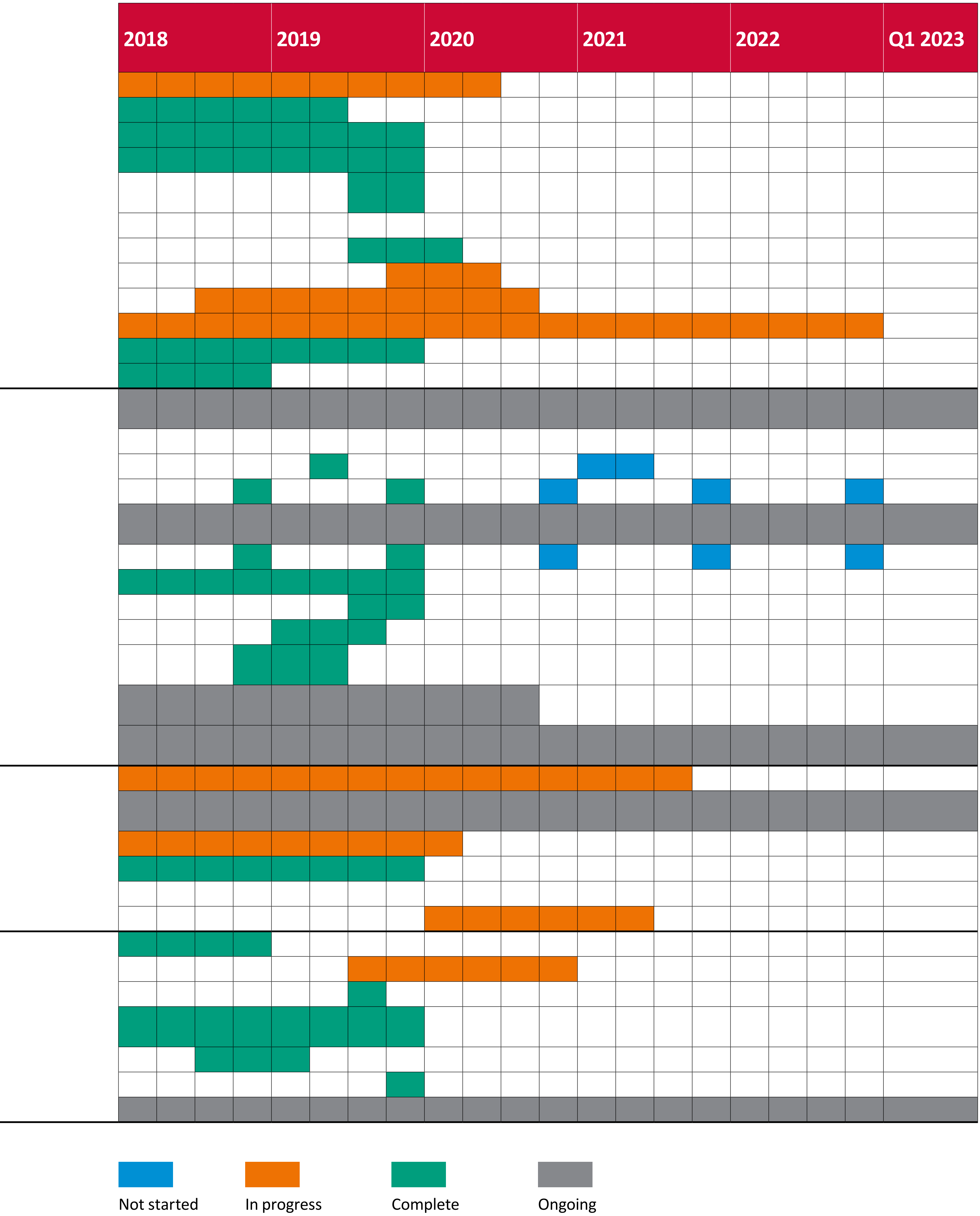
Continuing to use the cost comparison tool, an assessment of the NPV for the option to upgrade to 11kV is included below, alongside the NPV for the least cost alternative (option 4) which includes both the cost of losses and the cost of a future projected upgrade from 6kV to 11kV. By adjusting the future year of expenditure for the 6kV to 11kV upgrade, it is then possible to determine a preferred option.

It is considered that the business may view a five to ten year deferment to upgrading the 6kV network acceptable, provided it may be financially justified by the reduced cost of capital. However, a longer deferment is not considered to be optimal, due to the age of assets on the 6kV network, and the ongoing additional cost of procuring dual rated 6/11kV equipment during any equipment failures to facilitate the 11kV upgrade. This assessment demonstrates that if it is expected that the Darlington/Rise Carr 6kV network is to be upgraded at any point in the next 15 years, then it is more cost efficient to perform the upgrade to 11kV now, rather than perform network modifications to address the fault level and equipment condition issues now, and then upgrade the network to 11kV at any point in the next 15 years. This is when compared to the least cost alternative technically acceptable option which would be capable of resolving the fault level issues.

Proposed work plan

Section	Objective	2016				2017			
Understanding of losses	Enhanced understanding of network losses			In progress	In progress	In progress	In progress	In progress	In progress
	Errors in power flow measurement			Complete	Complete	Complete	Complete	Complete	Complete
	Analyse project data			Complete	Complete	Complete	Complete	Complete	Complete
	Analyse low voltage board monitoring data			Complete	Complete	Complete	Complete	Complete	Complete
	Impact of Rise Carr and DS3 battery energy storage systems (BESSs) on losses								
	Losses on the customer side of the meter			Complete	Complete	Complete	Complete	Complete	Complete
	Reactive power (VAr) advice								
	EHV LDC investigation								
	EHV voltage optimisation programme								
	HV conservation voltage reduction	In progress	In progress	In progress	In progress	In progress	In progress	In progress	In progress
	Exceptions to loss reduction actions			Complete	Complete	Complete	Complete	Complete	Complete
	Enhanced electrical parameter in models								
Effective engagement and sharing of best practice	Stakeholder-led consultation and dialogue with our range of stakeholders	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing
	Losses education animation							Complete	Complete
	Losses webpage development							Complete	
	Low-carbon Network Innovation (LCNI)								Complete
	Energy-saving advice and measures for communities and vulnerable customers	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing
	NPg stakeholder summit								
	In-depth dialogue with expert stakeholders							Complete	Complete
	Variable cost of electricity on losses								
	Engagement with IDNOs								
	Conference and Exhibition on Electricity Distribution (CIRED)								
	Engagement with National Grid ESO on management of reactive power flow	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing
	Membership of the ENA Technical Losses Task Group (ENA TLTG)	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing
Processes to manage losses	Sharing international best practice and understanding	In progress	In progress	In progress	In progress	In progress	In progress	In progress	In progress
	Sharing UK best practice and understanding (e.g. via ENA TLTG)			Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing
	Amorphous Transformer (AMT) trial								
	Management of non-technical losses	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete
	New progressive Investment Team	Complete							
	ED2 plan development and ED2 losses strategies								
Innovative approaches and implementation into BAU	Waste Heat Recovery Project								
	Contact voltage losses (CVL) investigations & trial								
	Time series analysis of losses using scripting method								
	Adoption through changes to processes, systems and culture				Complete	Complete	Complete	Complete	Complete
	Losses application guide								
	Internal environmental newsletter								
	In-house training					Ongoing	Ongoing	Ongoing	Ongoing

Not started   In progress   Complete   Ongoing


2018
2019
2020
2021
2022
Q1 2023
Not started
In progress
Complete
Ongoing