National Grid Strategy Paper

National Grid’s Strategy Paper to address

Transmission Licence Special Condition 2K:

Electricity Transmission Losses

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Title	Date	Authored	Modifications
National Grid Transmission Losses Strategy	30/11/2013	Owen Wilkes National Grid	Initial Publication
National Grid Transmission Losses Strategy 2014 review	29/09/2014	Owen Wilkes National Grid	• **Executive Summary:** Modified to account for October 2014 updates, and April 2013-April 2014 Transmission Losses Report references • **Introduction:** Modified to account for October 2014 updates, including reference to the addition of April 2013-April 2014 Transmission Losses Report • **Section 2 :** No Change • **Section 3:** Transformer European Legislation update, addition of ACSR conductor information. • **Section 4:** Introductory Text update, enabling works description update, Annual Losses update moved to the Transmission Losses Report • **Section 5:** Cable, Overhead Line and Transformer replacements (plus losses) added for previous Relevant Year. • **Section 6:** HVDC converter text updated • **All:** Reference to National Grid's Transmission Losses Annual Report (published separately)

Executive Summary

This paper presents National Grid Electricity Transmission's strategy for the consideration and mitigation of transmission losses over the RIIO-T1 Price Control period. This second edition (published October 2014) is prepared in accordance with Special Condition 2K of the electricity Transmission Licence, providing a review and update of the strategy to support the submission of the 2013/2014 transmission losses annual report (published separately).

Throughout the design and development of the transmission network, National Grid's Whole Life Value framework is utilised to support the selection of a preferred option to meet the investment need. This framework assists selection of the appropriate investment, backed by economically justified decisions based on a broad range of investment criteria that include transmission losses.

This updated strategy paper describes this approach, its employment in investment decision making, and updates transmission developments (and loss estimates) delivered in the 2013/14 financial year. Where the Whole Life Value framework identifies that the cost of transmission losses are material to an investment decision and that sufficient certainty of future year-round transmission flows make the analysis worthwhile, then further detailed transmission loss assessments will be undertaken that quantify year-round transmission losses.

Detailed year-round loss assessments are likely to impact investment decisions for, amongst others, incremental wider works and overhead line reconductoring schemes. For the former, detail of the key transmission reinforcements, the method of associated transmission loss estimation and results expected under the 2013 Electricity Ten Year Statement (ETYS) Gone Green base case are outlined. As an updated ETYS publication will not be provided until November 2014, wider works results are unchanged in this revision and will be reviewed via the 2014/15 strategy update (and subsequent transmission losses annual report). Proposals to revise the method of wider works loss calculation for future revisions of this strategy (i.e. 2015 onwards) are discussed. Transmission loss estimates for key enabling works developments are also defined. Where transmission losses increase for recommended investments, this demonstrates that transmission losses are one in a number of factors considered by National Grid when selecting the most economic and efficient transmission solutions.

Recent overhead line reconductoring, transmission cable replacement, and grid transformer replacement examples are provided as an indication of the likely impacts on transmission losses of similar replacements in the RIIO-T1 period. In the case of both overhead line and cable schemes, transmission losses are considered on a case-by-case basis, whereas material and manufacturing improvements indicate that a transmission loss reduction can be expected from replacing 'old' for 'new' transformers. Published data from National Grid indicates that future system-wide transmission losses are likely to increase as a result of developments that include the connection of more generation to the periphery of the network. As of this revision, this forecast will be compared to annual metered data via the National Grid's transmission losses annual report.

The methods by which National Grid account for transmission losses in equipment specifications and procurement processes are outlined for cables, overhead lines and transformers. For transformer tenders, associated losses are often a significant or deciding factor in the choice of a winning bid. National Grid has deployed extra high conductivity (EHC) alloy in all non – load related overhead line conductor replacements. All Aluminium Alloy Conductor (AAAC) has been utilised to counteract an increase in transmission losses. For load related replacements, overhead line conductors such as GAP, ACCC (Aluminium Conductor Carbon Core) and ACCR (Aluminium Conductor Composite Reinforced) have been developed to provide significant increases in transmission capacity. The increase in transmission loss (cost) resulting from increased transmission capacity must be considered alongside the capital saving of avoiding new lines build to meet system requirements.

The trade-off between capital investment and transmission loss costs are clear throughout this strategy paper. This will continue to be the case with future technology developments where the capital cost of increased capacity on existing (e.g. series compensation) or new (e.g. HVDC links) assets must be considered alongside their impacts on transmission losses.

Glossary of Terms

BS	British Standard
EHC	Extra High Conductivity
AAAC	All Aluminium Alloy Conductor
ACCC	Aluminium Conductor Carbon Core
ACCR	Aluminium Conductor Composite Reinforced
GAP	GZTACSR conductor (Gap Type super heat resistant Aluminium alloy Conductor Steel Reinforced)
HVDC	High Voltage Direct Current
HV/LV	High Voltage/Low Voltage
WLV	Whole Life Value
JRG	Joint Regulators Group
CBA	Cost Benefit Analysis
NPV	Net Present Value
NGET	National Grid Electricity Transmission
OHL	Overhead Line
XLPE	Cross-Linked Polyethylene
ETYS	Electricity Ten Year Statement
NDP	Network Development Policy
SOR	Strategic Optioneering Report
GIL	Gas Insulated Line
ELSI	Electricity Scenario Illustrator
NETSO	National Electricity Transmission System Operator
E&W	England and Wales
TRALC	Transformer Loading Code
RMS	Root Mean Squared
SGT	Super Grid Transformer
IEEE	Institute of Electrical and Electronic Engineers
VSC	Voltage Source Converter
CSC	Current Source Converter
LCC	Line Commutated Converter
IEC	International Electrotechnical Commission
MI PPL	Mass Impregnated Polypropylene Paper Laminated
SSR	Sub-synchronous Resonance
TCSC	Thyristor Controlled Series Capacitor
FSC	Fixed Series Capacitor
SRMC	Short Run Marginal Cost

1 Introduction

National Grid Electricity Transmission (NGET) has a number of duties as part of its statutory and Transmission Licence obligations to report on transmission losses. Special Condition 2K includes, but is not limited to, the requirement for National Grid to publish an annual transmission losses report. It will report (in accordance with provisions of this licence condition) for the previous relevant year on or before 31 October 2014, and for each subsequent year, unless the Authority directs otherwise.

A further requirement of Special Condition 2K as a precursor to annual reporting was the publication of a strategy that set out how National Grid intended to take account of the level of transmission losses on its transmission network, in respect of National Grid's duty under section 9 (2) of The Act to develop and maintain an efficient, co-ordinated and economic system of electricity transmission. This paper in its latest version contributes to both requirements of Special Condition 2K, providing a refreshed version of National Grid's transmission losses strategy (originally published 1 December 2013), plus an update on losses assessments against this strategy to support the separate 2013/14 transmission losses annual report.

Transmission network losses result from the transport of power between power producers and Grid Supply Points through transmission infrastructure equipment such as power transformers, overhead lines, cables and switchgear. Losses consist of two key components:

- Fixed losses (or no-load losses) result where transmission assets are energised and are therefore independent of loading.
- Variable losses (or load losses) are proportional to the square of the current loading of the transmission asset being considered.

Heating losses (I^2R) due to the resistance of the conductor in overhead lines or copper in the HV and LV windings of the transformers are examples of variable losses. The magnetising ('iron') losses in a transformer's core are an example of fixed losses.

This paper outlines National Grid's strategy for taking account of transmission losses when making investment decisions. This strategy also acknowledges that transmission losses are only one of the economic factors which need to be taken into account when making transmission network development investment decisions.

Methods of accounting for losses via National Grid's investment processes are described; considerations of losses in our specifications and procurement processes are outlined and estimates of the impacts of key load and non-load developments on transmission losses are both provided via the strategy and updated via this revision. An indication of how emerging new technologies will affect transmission losses are also provided, accounting for any adverse effects. This is delivered through the following key sections which are referenced to the detailed requirements of Special Condition 2K;

Section 2 – The consideration of transmission losses through investment planning.

Section 3 – Accounting for transmission losses in equipment specifications and procurement processes.

Section 4 – The key load related developments on the National Grid electricity transmission network and the estimated impacts on transmission losses.

Section 5 – A summary of National Grid's non-load related asset replacement programmes and the estimated impacts on transmission losses.

Section 6 – Consideration of the impact of new technologies on transmission losses.

2 Methodology for consideration of transmission losses during the optioneering phase of investment planning

Licence Condition: 2K.3.(a):
A description of the methodology used by the licensee to take Transmission Losses into account when planning load related reinforcements to the licensee's Transmission System.

Licence Condition: 2K.3.(b):
A description of the licensee's methodology to take Transmission Losses into account when the licensee is planning non-load related asset replacement programmes on the licensee's Transmission System.

This section outlines National Grid's methodology for considering transmission losses in investment decisions for both load related and non-load related transmission network developments.

The optioneering phase of investment planning involves establishing a need case, identifying the range of options that address that need and developing them in sufficient detail to allow a preferred option to be chosen for further, detailed development. The optioneering phase is carried out by a cross functional investment team which includes specialists and representatives from a number of functions including finance, engineering, commercial, construction and legal within National Grid's electricity transmission business.

2.1 Whole Life Value framework

When a number of competing options have been identified and sufficiently developed, National Grid's Whole Life Value (WLV) framework is used in investment decisions to support the selection of a preferred option where appropriate.

This framework is used to achieve a consistent WLV appraisal when evaluating alternative investment and policy decisions. The policy applies across the whole asset life cycle from initial definition and design selections through to final decommissioning and disposal. This approach ensures that option selection decisions are based on a broad range of investment criteria, which include the needs of all key stakeholders.

The framework is in place to facilitate the consideration of WLV with all issues, so that mitigations are understood, valuable conversations are captured and that key decision drivers are recorded.

The themes which make up the WLV framework are described in the table below and can be explored when option selection decisions are being made;

Whole Life Value Theme	Description
Safety by design	Identification and assessment of the health and safety factors encountered through the whole life cycle
Asset ownership	Factors considered with living with the asset through the whole life cycle
Versatility	Future use to support new requirements and how the asset will be used and re-used
Direct capex	Capital expenditure
Direct opex	Operational expenditure
Performance	The effects on the safety, reliability, efficiency and performance of the transmission network
Sustainability	Potential impacts on the environment and any known environmental

	considerations
Practicability	Ability to perform activities throughout the asset life cycle
System access	Factors which address the accessibility to the network

To determine a WLV score, an appraisal of the investment options is conducted for each of the themes using the criteria shown in the table below. The appraisal criteria identify issues in a number of key areas including; issues with perceived reliability (failure rates), capability (ratings) and efficiency (transmission losses). Each appraisal will be conducted using the same criteria.

A	B	C	D	E
Good proactive enhancement Avoidance of negative impacts Extensive benefits Permanent enhancements Direct benefits	Slightly proactive Minor negative impacts, but good mitigation enhances the situation Local or short-term enhancements Indirect benefits	Some impacts, but they are neutralised by mitigation	Slight negative impacts, or negatives that are wholly neutralised by mitigation Local or short-term negatives Minor indirect impacts	Significant negative impacts, especially ones that cannot be mitigated Extensive detriment Permanently irreversible Direct and major indirect impacts

National Grid therefore account for transmission losses in investment decisions as a measure of efficiency in the WLV Framework. Efficiency (and therefore transmission losses) are factored into the consideration of an investment option's performance (as defined in the WLV framework) - one of a number of key criteria that are considered in the appraisal of competing transmission development options.

2.2 Criteria for more detailed losses assessment

Where the WLV framework identifies that there are options with high capex or opex costs but low transmission losses being compared with options with low capex or opex costs but high transmission losses, then a more detailed assessment of losses costs may be required to support the choice of the preferred option.

A more detailed losses assessment involves a quantification of the cost of year-round losses over the medium term. This analysis is consistent with the recent paper by the Joint Regulators Group (JRG) "Discounting for CBAs involving private investment, but public benefit"[1]. The cost of transmission investment options is annuitized at the post-tax weighted average cost of capital. This is then added to the losses costs in each year and the totals are discounted at the Treasury's social time preference rate.

A more detailed losses assessment represents a significant piece of analysis, and therefore is only carried out when:

[1] ''Discounting for CBAs involving private investment, but public benefit'', Joint Regulators Group, 25 July 2012. http://www.ofwat.gov.uk/aboutofwat/stakeholders/jrg/pap_tec201207jrgdiscount.pdf

- An initial assessment concludes that the quantification of the cost of losses could realistically impact the option decision made by the investment team – i.e. where the capital cost of two options for investment are comparable on capital cost.
- There is sufficient certainty in the future energy flows to allow a realistic quantification of the cost of losses to be performed. In some circumstances, year-round power flows cannot be forecast with sufficient accuracy in the medium term, and a quantification of losses costs would therefore not provide further benefit to the WLV framework assessment.

There are certain types of investment for which a more detailed losses assessment is more likely to impact the option decision made by the investment team. These include:

- **Incremental wider works** – these schemes tend to have a significant impact on power flows and therefore the cost of transmission losses becomes important. The Network Development Policy (as described in Part B of Special Condition 6J of the transmission licence) is used to determine the appropriate options and timings for these schemes, and the associated analysis presently includes losses costs. Whilst this losses assessment method is described in Appendix A, it will be superseded by an alternative method for future revisions of this strategy (i.e. 2015 onwards), as National Grid continues to evolve and refine the assessment of transmission losses.
- **Overhead line conductor asset replacement schemes** – these schemes often involve a choice of replacement conductor systems. The incremental cost of the larger, lower loss conductor system may not be as high as the associated savings in transmission losses in the medium term.

3 Accounting for transmission losses in equipment specifications and procurement processes

Licence Condition: 2K.3.(c):

A description of how the licensee determines the optimal specifications in relation to Transmission Losses arising from the operation of new equipment in its asset procurement processes.

The following section of this strategy document outlines how transmission losses are considered through National Grid's equipment specifications and procurement processes.

National Grid recognises the need to consider the impact of transmission losses in the procurement of new transmission equipment in conjunction with other key economic factors (outlined in section 2) that will influence the final optimised purchase decision. A reduction of transmission losses through asset design typically results in increased material costs. This economic trade-off must therefore be considered when determining asset specifications and policies. Transmission losses of new equipment are determined by three key factors; the specification, procurement and operation of new equipment. The first two factors are considered in this section of the strategy document.

High voltage, low current transmission is utilised in Great Britain to reduce variable losses (I^2R or load losses) and improve electrical efficiency in comparison to medium and low voltage alternatives. For instance, upgrading circuits on the electricity transmission network from 275kV to 400kV are estimated to reduce electrical transmission losses from 20% to 40% for the equivalent power transfer. However this loss reduction would need to be considered against the increased capital cost of the up-rating of these circuits over the lifetime of the investment.

National Grid's specification and procurement methodology takes into account Whole Life Value and commercial tender evaluation. The WLV (outlined in section 2) takes into account both quantitative and qualitative data and information and whilst previously utilised for asset policy decision – making, this method is now adopted to provide a consistent approach for the evaluation of transmission investment options. Commercial tender evaluation considers what the market can deliver, evaluating the lowest cost option against a technical criteria. This ensures that optimal investment decisions are driven by the specification, evaluation and procurement processes, to ensure value for our customers and wider stakeholders.

The losses resulting from substation switchgear are not considered in this strategy document as the electrical losses are low compared to the other categories of transmission equipment such as cables, overhead lines and power transformers. Each of these remaining main plant groups are discussed in the remainder of this section.

3.1 Transformers

3.1.1 Transformer losses

The key electrical loss components (variable and fixed losses) have been introduced in section 1. In a transformer, fixed losses (no-load or iron losses) primarily result from losses in the magnetic steel core of the transformer as it is alternately magnetised and demagnetised by the 50Hz alternating voltage. These losses will be present whenever the transformer is connected to the network, and are independent of the loading on the transformer. The variable loss (load or copper loss) results from the electrical resistance of the windings and the currents induced inside the transformer when it is carrying load current. These losses are proportional to the square of the load current. Section 5 of this strategy paper outlines how these losses (fixed and variable) are combined to calculate a total MWh loss figure for recent asset replacement schemes.

The losses in a transformer can be reduced through the use of more material, but this must be balanced against the resulting capital cost increase in order to produce an optimal design;

- Fixed losses can be reduced through use of a low-loss magnetic steel transformer core and by reducing the magnetic field strength, but this low-loss material is more costly.
- Variable losses can be reduced by either increasing the conductor cross section or by reducing the number of turns (the length of the copper), thereby reducing resistance. Reducing the number of turns increases the magnetic field, requiring the use of a larger transformer core and therefore increases fixed losses.

The design must therefore be optimised for a particular ratio of variable (load losses) to fixed (no-load losses) whilst considering material (i.e. capital) costs. Only high conductivity copper is used in large transformers so the conductor material is already optimised for losses, but in general, lower losses require additional or more expensive material. The additional material in a low loss transformer can cause problems for transport and this may limit the loss reductions that are practically achievable.

The fixed loss and variable loss at full load current are guaranteed by the manufacturer in the tender and subsequently measured on each unit during the factory tests.

3.1.2 Transformer specification for optimum losses

To provide consistency with the terms outlined by National Grid to external parties in outlining transformer specifications, the terms 'fixed loss' and 'no-load loss' are used in this section (3.1.2) interchangeably. The terms 'variable loss' and 'load loss' are also used interchangeably in this section.

To allow the transformer manufacturer to optimise the balance between electrical loss and capital cost in their transformer design for tender evaluation, National Grid uses CIGRE, IEC and EU recognised industry best practice and provides values to be ascribed to the load (variable) and no-load (fixed) losses in terms of £ per kW of loss. The £ per kW whole life cost value is established from the Net Present Value (NPV) of the cost of electricity over the lifetime of the transformer, multiplied by the proportion of the time the transformer will be connected to the system to provide the no-load loss capitalisation figure. The NPV value is multiplied by the mean square of the anticipated loading to provide the load loss capitalisation figure.

The loss capitalisation figures incorporated into the latest enquiries to National Grid are:

No-load (fixed) loss capitalisation figure (All transformers)	£6214/kW
Load loss (variable) capitalisation figure for Transformers supplying distribution voltages (Grid Transformers)	£1260/kW
Load loss (variable) capitalisation figure for Inter bus transformers and series reactors	£580/kW

Work performed by T&D Europe in benchmarking loss capitalisation figures used by utilities in enquiries to their members indicated that NGET's loss capitalisation values are around the median of values used in Europe.

These loss capitalisation figures are modified only when considered necessary, and are non-site-specific. This allows manufacturers to offer a single transformer design without regularly being subjected to engineering costs for multiple redesigns as a result of changes in the loss evaluation figure. At the tender stage, the manufacturer is required to provide a guarantee of the maximum load and no-load losses that will be measured on test. These losses are evaluated using the formula:

$$\begin{aligned}\textit{Evaluated Cost of Losses}(\pounds) = {} & (\text{No load loss capitalisation figure } (\pounds/\text{kW}) \times \text{No load loss (kW)}) \\ & + (\text{load loss capitalisation figure } (\pounds/\text{kW}) \times \text{load loss at full load (kW)})\end{aligned}$$

The evaluated cost of losses is added to the bid cost (together with other evaluated costs submitted as part of the evaluation process) to arrive at a total cost. This cost is used to compare different bids, and the most economically advantageous bid will be accepted if the technical criteria are fulfilled. In practice losses can vary between bids by approximately 20%, and so this is often a significant or even deciding factor in the choice of the winning bid.

3.1.3 Future prospects for reducing transformer losses

The specific loss of core steel has reduced significantly in the last 40 years, driven by improvements in steel alloys, processing and increasing loss capitalisation values. The loss capitalisation value used by NGET is now predominantly driving the lowest loss commonly available grade steel to be used. This material has losses of around 85W/kg and is 0.23mm thick. It is possible that market pressure will stimulate development and production of steels with losses up to 10% lower than this in the next few years.

Variable (load) losses are greatly influenced by the capitalisation value, and would therefore decrease if higher capitalisation values were used. Exceptions to this statement are the largest transformers (1100MVA interbus transformers and Quad Boosters) that are constrained by allowable transport weights. National Grid believes that employment of the loss capitalisation method using the existing capitalisation values provide the best value for consumers.

3.1.4 European legislation

A regulation under the Ecodesign Directive on the efficiency of power transformers was adopted by the European Commission in May 2014. NGET has provided some input to the drafting of this regulation, which for transmission transformers, sets a tough, but achievable, baseline for transformer efficiency. This efficiency regulation is based on the ‘peak efficiency index’, which is the apparent efficiency of the transformer based on loss values measured in the factory when it is operating at its most efficient load. The most efficient load occurs when the variable (load) and fixed (no-load) losses are equal - for a typical transmission transformer this is designed to be at a load of between 30 and 45% of rating.

The efficiency values which are relevant to NGET (for transformers of >100MVA) are 99.737% (2015) and 99.770% (2020). The 2020 figure will be used as a minimum requirement in future transformer purchase events. It is not anticipated that suppliers will have particular difficulties meeting this requirement and many transformers will have higher efficiencies based on the present loss evaluation values.

3.2 AC overhead lines – conductors

National Grid owns over 7,000 route km of high voltage overhead line transmission circuits in England and Wales. High Voltage AC Overhead Lines (OHL) are employed to efficiently transport bulk power over long distances. The main transmission voltages are 275kV, in general circling major cities and 400kV, acting as power corridors linking remote generation to distribution sites. Differing electrical conductor types are used, depending on the amount of required power transfer and the operational voltage level employed.

Variable losses (load losses or I^2R losses) in conductors account for most of the overall electrical transmission losses. These losses increase with the amount of current flowing, and also vary depending on the associated power flow and the length of circuit, as further detailed below.

The physical dimensions and design materials will affect the resistive characteristics of the conductor system. Factors such as the purity of aluminium conductor material, cross sectional area, insulation medium will control the resistive and reactive loss associated with a circuit.

The length of the conductor determines the total resistance of a transmission line route; this will increase linearly with circuit length. The thermal or ohmic losses are the most significant element. This heat loss varies depending on the product of circuit resistance and the square of the circuit current; I^2R – these are the circuit’s variable losses. Therefore circuit loading significantly increases thermal loss, which is dissipated in the form of heat. For example - three circuits loaded to 2000A will produce less losses by a factor of 50% when compared to two circuits loaded to 3000A each (assuming equal circuit impedance).

Since a significant proportion of the system losses are related to thermal loss, the options to lower losses requires a fundamental lowering of either current flow or resistance, or both (due the I^2R relationship). There are a number of different technologies that have the potential to help in the cumulative reduction of these factors. However, all of the technologies introduce additional network issues, which need to be considered in conjunction with the overall loss reduction. For most of the technical options, it is not economically justifiable to replace assets if the only driver is the reduction of transmission losses. Replacement is generally only considered in cases where there is a driver such as deterioration of asset conditions or a load related requirement to increase capacity.

Specifying conductor replacement involves the replacement of old or low rated conductors with larger diameter conductors, which is principally driven by an increase in transmission capacity, but also reduces line resistance and associated losses. For the same material, a smaller diameter conductor will have a high resistance and hence, greater losses. There is a down side to reconductoring from a system loss perspective, since increased utilisation of the line will increase current flow and increase losses much more than any resistance change would reduce losses.

3.2.1 Non-load related asset replacements

Over the last twenty five years National Grid's OHL non-load related conductor replacement schemes have employed All Aluminium Alloy Conductor (AAAC), which was developed in the late 1980's. This is outlined in the table below. The BS50189 standard for this conductor states a DC resistance of 54.4µΩ for the 500mm^2 Rubus conductor. In order to counteract a general increase in system losses, National Grid specify a lower DC resistance of 53.13µΩ. Any further DC resistance reduction would impact on the mechanical strength of the alloy.

The AAAC alloy was developed solely to reduce transmission losses and is designated as an extra high conductivity (EHC) alloy conductor. This is the conductor type of choice for all non- load related schemes as it is relatively inexpensive, robust, easy to install and maintain.

3.2.2 Load related asset replacements

Where a significant increase in capacity is required (load related schemes) high temperature, low sag conductor systems such as GAP and the composite core conductors, ACCC (Aluminium Conductor Carbon Core) and ACCR (Aluminium Conductor Composite Reinforced) have been developed. These conductors have the capability to double the capacity of existing circuits; however this doubling also increases losses accordingly.

National Grid's preferred choice for the load related schemes is to deploy GAP as it is relatively inexpensive on a per unit basis when compared to ACCC & ACCR. However there are other considerations in respect of installation, operation and maintenance that need to be taken into account.

Conductor x 2	Type	Diameter (mm)	DC Resistance (micro-ohms @20deg C)	Post Fault Rating (MVA)	% Increase in Rating over Rubus
Rubus	AAAC	31.5	53.13	2240	-
Mathew	GAP (Trap)	31.6	47.8	3100	38%
London	ACCC (Trap)	31.5	38.3	3630	62%
Zebra	ACSR	28.62	67.4	3420	53%
Curlew	ACCR	31.7	53.4	3120	39%

Whilst the next generation of conductors (outlined above) can double the capacity of the existing network, the associated increase in losses is offset by the capital saving of not having to build new lines, to meet the growth in demand. Consequentially, this also aligns with National Grids desire to reduce its carbon footprint.

National Grid has been assessing the performance of both the ACCC & ACCR technologies via two trial deployments on the transmission network at 400kV. ACCR conductor is now available for general use; however its high unit cost may presently restrict wide scale deployment. ACCC conductor requires a design change to improve the mechanical strength in order to meet the National Grid's specification. However, the overall installation cost is reduced, as the conductors are easier and quicker to install, and appear not to suffer from the operational problems associated with GAP.

The main benefit of these emerging technologies is the increase in capacity. For example, the ACCR Curlew conductor has almost the same characteristics as the Rubus AAAC conductor in terms of weight, diameter and electrical resistance (53.13 and 53.4 microhms for Rubus and Curlew respectively). However, performance in demand capability increases from 2210MVA to 3630MVA for a proportionally smaller increase in losses through employment of the Curlew conductor.

3.3 AC cables

High voltage cables are generally used where underground transmission is required. Cables have lower current ratings than overhead lines for similar sized conductors. Both the insulation and installation of a cable will negatively impact the current rating of the cable;

- Unlike for overhead line circuits, air does not form part of the insulation in cable circuits, hence the conductor must be completely insulated.
- Cables are generally not installed in open air.

The losses generated by a cable system are carefully calculated, as losses produce heat. As the maximum operating temperature of the cable limits the maximum current rating of a cable system, these thermal losses form part of the calculation to establish a cable's rating.

There are no specifications requiring reduction losses from cable systems, however incentive to reduce cable systems losses (for example by increasing cross sectional area of the conductors or using copper rather than aluminium as a conductor) exist to allow the cable system to carry the required current rating and decrease the capital cost of the cable system.

The losses of a cable system generally split into a number of different sources, which are described through the rest of this section. Lifetime cable losses costs are typically less than 10% of the capital cost of the cable systems.

3.3.1 Resistive losses of the conductor

The DC resistance of the cable can be reduced by increasing the cross sectional area of the conductor or choosing a lower resistivity material (e.g. copper as opposed to aluminium). This will reduce the variable (I^2R) losses, but this will have capital cost impact.

For AC cables, the resistance to be considered is the AC resistance and must consider the skin and proximity effects. Both skin and proximity effects can be minimised by using Milliken conductors. In recent years, additional improvements in AC resistance have been obtained by using oxidised conductors that provide additional reductions in the skin and proximity effects. Given that a typical DC resistance at 90°C of a 2500mm² copper conductor is 9.18µΩ/m and the AC resistance is 10.25µΩ/m it can be seen, by comparison with the DC resistance values in the table of section 3.2.2, that the overall resistances (and therefore losses) of cable conductors are generally considerably lower than those for overhead lines outlined in section 3.2.2.

As outlined for most technologies discussed in this strategy document, the resistive loss of the conductor is generally the major contributor to losses generated in a cable. Whilst the loss is independent of the cable system voltage, it increases with load current. Analysis outlined in section 5.2 of this strategy takes these losses into account.

3.3.2 Dielectric losses

The dielectric loss is the heat generated by the insulation material when subjected to a time varying electric field. The electric field within the cable insulation increases with cable voltage, and hence the magnitude of the losses will increase. For older oil filled cables operating above 400kV, the losses were significant. However, newer XLPE cables generate less heat loss for the same magnetic field and therefore the dielectric losses are generally not as prominent at typical operating voltages of 400kV.

Dielectric losses are always present when a cable is energised and are independent of the load. These are fixed losses. When the cable is operating at full load, the dielectric loss only forms approximately 10% of the overall losses of a 400kV XLPE cable system. However at lower loads, the dielectric loss can be a significant proportion of the losses. Analysis outlined in section 5.2 of this strategy (to indicate the potential impact on transmission losses of cable replacements) does not account for dielectric losses, and therefore only provides an estimate of transmission losses.

3.3.3 Sheath losses

High voltage cables have a metal sheath to keep the cable water tight. The current in the cable conductor will generate a magnetic field in the sheath that will in turn generate currents in the sheath. These sheath currents will create additional heat losses. For high power cable systems typically used by National Grid, cable sheaths are connected together and earthed to minimise the sheath losses to eddy currents.

These eddy currents are dependent on the spacing of the cables, the material of the sheath and the dimensions of the sheath. Sheath losses are approximately 15% of the overall losses of a typical National Grid 400kV XLPE cable system at full load. Cable system designs that do not mitigate sheath losses will adversely impact its current rating and hence will not be economic. Sheath losses, like conductor losses, vary with the load on the cable.

3.3.4 Cooling losses

For tunnel installations, forced ventilation (via ventilation fans) is required to cool the cables, whilst some older circuits use water cooling (via pumps). In both cases, energy is expended in actively cooling cables, and therefore cooling losses do not directly result from the cable system, but are still required to support the cable system’s current rating. Typically cooling systems are avoided, as not only do they introduce additional losses, but also introduce additional maintenance costs and adversely impact on the reliability of the circuit. Hence active cooling is only chosen where natural cooling cannot be achieved. The cooling losses will increase as the load on the cable increases.

3.3.5 Losses in long cable circuits

Power transmission cables have a relatively high value of capacitance to earth per metre, which increases with cable length. This will lead to a charging current in the cable that will generate additional losses. Additionally, for longer circuits, higher capacitance to earth values will reduce the overall active power that the cable can transmit, and reactive compensation will be required at regular intervals to reduce the overall capacitance of the cable circuit. The addition of reactive compensation it's self will also generate losses. These factors will be considered when selecting the optimal transmission solution (cable, overhead line, HVDC) over the lifetime of the equipment.

3.3.6 Comparison of cost of losses to capital cost

A study of cable system costs has been undertaken in an independent report endorsed by the Institution of Engineering & Technology called "The Electricity Transmission Costing Study"[2]. This showed that the lifetime cost of losses were generally less than 10% of the capital cost of the cable systems, except for very long circuits (>75 km).

A 400kV AC underground cable (direct-buried) 15 km route, medium capacity (6380MVA) case study in the above report (pg.50) outlines a lifetime cost of £289.6m and a cost of losses of £25.9m. If a method to reduce losses by 10% is used (for example using cables with larger cross sectional areas), this would reduce the cost of losses by £2.59m. A 10% reduction in losses, assuming they are I^2R losses, could result in a 4.8% increase in power transfer and equate to a £14.1m increase in value of the cable system.

It can be seen from this example that a reduction in losses will generally increase the current rating of the cable and decrease the capital cost of the cable system. The saving in capital costs is greater than the saving in the cost of losses, and therefore a reduction in losses is already incentivised by the requirement of the cable system to meet the required current ratings.

3.3.7 Future prospects for losses of AC cable circuits

In general, National Grid's requirements are for cable systems with higher current ratings. This will act as a driver to reduce losses to enable higher current ratings (as outlined by the example in 3.3.6). For example, the increase requirement of current ratings may lead to the introduction of larger cross sectional cables than the 2500mm² currently used. As these have a lower resistance, they will produce lower losses per MW of active power transmitted. However this increase in power transfer requirement may also lead to a corresponding increase in utilisation of cable systems, these will tend to increase the variable losses of a cable system.

3.3.8 Conclusions on cable system losses

A variety of cable systems exist where a number of different parameters such as voltage, materials, and design can be chosen. These cables can be installed in a number of different installation arrangements such as ducts, troughs, tunnels, buried, laid direct in the ground, or installed subsea. There are a number of sources of loss associated with a cable system, but for cables of less than 75km in length, the lifetime losses are typically less than 10% of the capital cost of the cable system. While the requirement to reduce losses is not explicitly stated in any specification, the requirement to maximise current ratings and minimise capital costs of a cable system require that the losses are reduced to the optimum level.

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[2] ''Electricity Transmission Costing Study: An Independent Report Endorsed by the Institution of Engineering Technology'', Parsons Brinckerhoff, 31 January 2012. http://www.theiet.org/factfiles/transmission-report.cfm

4 The key load related developments on the National Grid electricity transmission network and the estimated impacts on transmission losses

Licence Condition: 2K.3.(d):

A summary of key developments to the licensee's Transmission System and estimates of the impacts those developments will have on Transmission Losses on the licensee's Transmission System.

This section of the strategy paper outlines the key load related developments on the National Grid owned electricity transmission network over the RIIO-T1 Price Control period, with associated estimates of their impacts on total system transmission losses. Recommended reinforcements are quoted up to 2025 to account for any spend that may occur within the RIIO-T1 period for outputs delivered outside of this period.

The majority of developments outlined in this section are the major reinforcements that affect bulk flows across the transmission network and consequently are those that have the most significant impact on losses. As per the initial publication of this strategy, these developments are consistent with those described in the 2013 Electricity Ten Year Statement (ETYS), under the 2013 Gone Green baseline scenario. No further update is provided for these major system reinforcements and their associated loss figures in this first revision, reflecting that no further ETYS publication (i.e. ETYS 2014 – due November 2014) had been released since National Grid's last reporting obligation on transmission losses on 1st December 2013. An exception is the proposed development of Hinkley - Seabank new 400kV circuit, where further transmission loss assessments have been undertaken in 2014. Whilst such assessments demonstrated a reduction in transmission losses by reinforcing the local transmission network (more conductors of lower current loading reduces I^2R losses), the incremental benefit of transmission loss reduction between reinforcement options was deemed immaterial in comparison to the capital cost of options. This exemplifies National Grid's strategy - to undertake detailed assessment of transmission losses where they may be material to the investment decision. This case is further discussed in National Grid's transmission losses annual report for 2014.

National Grid would recommend that future revisions of the strategy and accompanying annual transmission losses reports are delivered after the annual ETYS submission (November each year) to allow up to date system developments to be included in this strategy. These solutions were identified through application of the Network Development Policy and its associated loss calculation (described in Appendix A), as per the methodology outlined in section 2. The loss calculation outlined in Appendix A will be superseded by an alternative method for future revisions of this strategy (i.e. 2015 onwards), as National Grid continues to evolve and refine the assessment of transmission losses for load related schemes. Whilst the losses calculation method for load related reinforcements will be modified, National Grid's strategy for the consideration of the resulting estimated transmission losses remains unchanged – they shall continue to be one consideration in the Whole Life Value framework. This section of the transmission losses strategy will be updated to reflect the revised methodology and updated losses figures in future revisions.

A number of reinforcements outlined under 2013 ETYS scenarios and sensitivities other than the Gone Green base case are not outlined in this strategy paper – please refer to the published 2013 ETYS for consideration of recommended reinforcements under these scenarios.

This section also outlines key enabling works reinforcements planned in the RIIO-T1 Price Control period. As the use of the NDP methodology is not appropriate for calculating transmission losses for these investments, reference is instead made to the method of transmission loss calculation utilised in National Grid's Strategic Optioneering Reports (SOR). Where transmission losses are deemed material and further detailed loss assessments are undertaken for key system developments, then such updated figures will supersede those quoted via ETYS or SOR losses calculation methods.

4.1 Key transmission network developments and associated losses

Each development outlined in this section is accompanied by an estimate of its impact on total transmission losses on National Grid's transmission network - in sections 4.1.1 - 4.1.6, the impact of losses are reported for key incremental wider works schemes, whilst section 4.1.7 refers to losses associated with key enabling works schemes.

Please note that for sections 4.1.1 to 4.1.6, percentage loss figures outlined in the tables below are not directly comparable. The loss impact of each individual development has been assessed by considering the background pre- and post-investment. However, as developments are incrementally staged, the background against which losses are assessed continually evolves with each incremental investment. Whilst this provides an accurate reflection of transmission network development, it does not provide a consistent base for direct comparison of losses figures established at different stages of transmission network reinforcement.

4.1.1 Scotland – SHE Transmission to NGET

Name of reinforcement	Description	ETYS 2013 Gone Green base case date	Impact on net losses (annual MWh) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
Eastern HVDC One	A new ~2GW submarine HVDC cable route from Peterhead to Hawthorne Pit with associated AC network reinforcement works on both ends. The three onshore TOs will continue to work together during 2014 to determine the most economic and efficient design solution for the Eastern HVDC link.	**2020**	**+46758**	**+0.59%**

4.1.2 Scotland – SP Transmission to NGET

Name of reinforcement	Description	ETYS 2013 Gone Green base case date	Impact on net losses (annual MWh) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
B6 NGET series and shunt compensation	Series compensation to be installed in the Harker – Hutton, Eccles – Stella West and Strathaven – Harker routes. Strathaven – Smeaton route uprated to 400kV and the cables at Torness uprated. Reduces the impedance of the Anglo--Scottish circuits improving the loading capability of the circuits.	**2014**	**+27776**	**+0.55%**
Western HVDC Link	A new 2.45 GW (short term rating) submarine HVDC cable route from Deeside to Hunterston with associated AC network reinforcement works on both ends.	**2016**	**+187608**	**+3.15%**
Eastern HVDC Two	A new ~2GW submarine HVDC cable route between Torness and North East England with associated AC network reinforcement works on both ends.	**2024**	**-11055**	**-0.12%**

4.1.3 North England

Name of reinforcement	Description	ETYS 2013 Gone Green base case date	Impact on net losses (annual MWh) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
Penwortham Quad Boosters	Install a pair of 2750MVA Quadrature Boosters (QBs) on the double circuits which run from Penwortham to Padiham and Daines at the Penwortham 400kV substation. They will improve the capability to control the north to south power flows on the circuits connecting the North Midlands and the West Midlands, and hence improve the transport of excess generation from the north to demand centres in the south.	**2014**	**+1864**	**+0.04%**
Kirkby and Rainhill substation upgrade	Replace circuit breakers and equipment at Rainhill so that Kirkby and Rainhill can be changed to a two-way split configuration. This will divert more power to flow into the Kirkby – Rainhill – Fiddlers Ferry route from the Kirkby – Lister Drive – Birkenhead route; as a result, loading on the Kirkby to Lister Drive circuits will be better shared. Improved utilisation of the existing 275kV Mersey ring will significantly increase the capability of the network to handle north to south power flows.	**2016**	**+41485**	**+0.72%**
Yorkshire lines re-conductor (Norton – Osbaldwick hotwiring and re-conductor & Lackenby–Norton re-conductor)	Re-conductor sections of the Lackenby – Norton 400kV circuit with higher-rated conductor and up rate the cross-site cable at Lackenby 400kV substation to a similar or higher rating. Re-conductor a small section and hotwire the remainder of the existing 400kV double circuits which run from Norton to Osbaldwick. This will help ensure the circuits will provide sufficient thermal capacity to transport the excess generation from Scotland to southern demand.	**2020**	**+45398**	**+0.56%**
Penwortham – Padiham & Penwortham – Carrington re-conductor & Kirkby – Penwortham upgrade (Mersey Ring stage 1a)	Up rate the 275kV double circuit overhead lines from Kirkby to Penwortham to operate at 400kV and carry out associated work (including construction of Kirkby 400kV substation and a new Washway Farm 400/132kV substation with two 400/132kV 240MVA SGTs). Uprate the limiting sections of the Penwortham - Carrington and Penwortham Padiham double circuit to improve overall transmission capability. This will improve the capability of the network to handle the heavy north to south power flows from the large amount of expected generation connection in Scotland.	**2020**	**+43204**	**+0.53%**
Lister Drive Quad Booster Installation	Replace the existing series reactor at Lister Drive with a Quad Booster (QB). The Quad Booster will enable flexibility to control power flows through the circuit south of Lister Drive.	**2020**	**-33787**	**-0.37%**

4.1.4 East England

Name of reinforcement	Description	ETYS 2013 Gone Green base case date	Impact on net losses (annual MWh) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
Bramford – Twinstead Tee	Re-conductor the existing Pelham – Braintree – Rayleigh Main circuit, and construct a new transmission route from Bramford to the Twinstead tee-point, creating double circuits which run between Bramford – Pelham and Bramford – Braintree – Rayleigh Main. These works will result in two transmission routes for power to flow south from the East Anglia area and hence increase the capability of the network to export excess generation from the area significantly.	**2022**	**+16806**	**+0.21%**
Rayleigh – Coryton South – Tilbury re-conductor	Re-conductor the existing Rayleigh Main – Coryton South – Tilbury circuits with higher-rated conductor. This will help ensure the circuits will provide sufficient thermal capacity to transport the excess generation from the East Anglia area to the south east demand, as an increasing amount of future wind and nuclear generation is expected to connect in the area.	**2014**	**+22309**	**+0.26%**
East Anglia MSC	Install a 225MVAr MSC to provide voltage support to the East Anglia area. The MSC will help ensure voltage compliance for local faults where power is diverted through a longer transmission route.	**2026**	**+13195**	**+0.12%**

4.1.5 South England

Name of reinforcement	Description	ETYS 2013 Gone Green base case date	Impact on net losses (annual MWh) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
Wymondley turn-in	Modify the existing circuit which runs from Pelham to Sundon; turn in the circuit at Wymondley to create two separate circuits which run from Pelham to Wymondley and Wymondley to Sundon. This will improve the balance of the power flows on the North London circuits, and increase the capability of the network to import power into London from the north transmission routes.	**2018**	**-2249**	**-0.04%**
Barking – Lakeside Tee new double circuits	Construct a new 400kV transmission route from Barking to the Lakeside tee-point on the existing transmission route from Tilbury - Littlebrook. This will divert some power flows from the heavily loaded North London circuits to the south east transmission route to supply London demand; as a result the networks capability to import power into London will improve.	**2014**	**-2734**	**-0.05%**
Hackney – Tottenham – Waltham Cross up-rate	Uprate and reconductor the Hackney – Tottenham – Brimsdown – Waltham Cross 275kV transmission route with higher-rated conductor to operate at 400kV, and reconductor the Pelham - Rye House double circuits with higher-rated conductor. Carry out associated work including construction of a new Waltham Cross 400kV substation, modification to Tottenham substation and installation of two new transformers	**2022**	**+12166**	**+0.12%**

	at the Brimsdown substation. This work will facilitate future East Anglia, Thames Estuary generation.			
Wymondley Quad Boosters	Install a pair of 2750MVA Quadrature Boosters (QBs) on the Wymondley to Pelham double circuits at the Wymondley 400kV substation. The pair of QBs will improve the capability to control the power flows on the North London circuits, and significantly improve the capability of the network to import power into London from the north transmission routes.	**2019**	**+259**	**+0.01%**

4.1.6 West England and Wales

Name of reinforcement	Description	ETYS 2013 Gone Green base case date	Impact on net losses (annual MWh) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
Wylfa – Pentir second transmission route	Construct a second 400kV transmission route from Wylfa to Pentir, with associated work including the modification to the Wylfa 400kV substation and extension of Pentir 400kV substation. This extra transmission route will allow the connection of generation at Wylfa beyond the infeed loss risk criterion (currently 1320MW and changing to 1800MW from April 2014). The capability of the network to export power from Wylfa into the main transmission system will be improved significantly.	**2023**	**-7371**	**-0.08%**
Pentir – Trawsfynydd second circuit	A second circuit is created by using one side of a route currently occupied by an SP-MANWEB 132kV circuit. A large single core per phase cable section is required across Glaslyn where no overhead line currently exists. A single 400/132kV transformer is teed off the new circuit to provide a connection to SP-MANWEB at Four Crosses to replace its circuit.	**2020**	**+2867**	**+0.04%**
Trawsfynydd – Treuddyn Tee re-conductor	Reconductoring the ZK route double circuit to GAP forms the first part of a suite of anticipatory investments in North Wales, designed to deliver increased transmission capacity in readiness for the first stages nuclear and wind farm generation connecting in North Wales. It is planned in 2014 as a result of asset condition drivers.	**2014**	**+3711**	**+0.07%**
Bredbury – South Manchester re-conductor	The work includes replacement of Bredbury substation cables and Bredbury to South Manchester transmission cable with two parallel single core per phase XLPE 2500mm^2. The busbars, circuit breakers and cable tower termination shall also be replaced. The reinforcement, enhances the Midlands to South power flows and ultimately, supporting the networks ability to transfer more power from the north to the south.	**2021**	**+102157**	**+1.14%**
Cellarhead – Drakelow re-conductor	Re-conductor the existing double circuits which run from Cellarhead to Drakelow with higher-rated conductor. Together with other West Midlands reinforcements, this will further increase the thermal capability from Midlands to South, supporting the networks ability to transfer more power from north to south.	**2022**	**+236242**	**+2.36%**
Pentir – Trawsfynydd	The existing cable sections of the Pentir – Trawsfynydd 1 are	**2021**	**+3037**	**+0.03%**

1 single core per phase	replaced by large single core per phase cable sections.			
Pentir – Trawsfynydd 2 single core per phase	The cable sections across both existing circuit and new circuit connecting Pentir to Trawsfynydd including the long sections across the Glaslyn estuary are paralleled with additional large single core per phase. The OHL will be the limiting component after this reinforcement is constructed.	**2021**	**+13374**	**+0.13%**
Running Carrington 400kV substation solid and Daines 400kV rationalisation	Having both Carrington and Daines 400kV substations split limits the boundary transfer and overloads one of the Carrington to South Manchester circuit due to poor load sharing. This is solved by running Carrington 400kV substation solid and tee-in circuits coming into Daines 400kV substation subsequent decommissioning. The scope of the project also involves extension of the Carrington 400kV that will accommodate new generation connection in the future. This reinforcement shall improve the power transfer from north to south and relaxes the thermal stress on west region boundary circuits.	**2019**	**-76483**	**-0.96%**

4.1.7 Key enabling works schemes

The above incremental wider work reinforcements do not account for some key enabling reinforcement works planned on National Grid's electricity transmission network in the RIIO-T1 period. A summary of these key reinforcements are outlined below. In some cases (e.g. Bramford – Twinstead new overhead lines, Wylfa – Pentir second transmission route) key enabling works have also been identified as incremental wider works requirements under the Network Development Policy (NDP) in sections 4.1.1 - 4.1.6 and therefore associated transmission loss calculations are not repeated in this section.

In the case of enabling works, the transmission reinforcement must be developed prior to the connection of the customer who triggers its requirement. If a customer is connected to the transmission network without its required enabling works, unrealistically high loading of local circuits and associated transmission losses would be witnessed. To establish the impact on transmission losses associated with an individual reinforcement, the transmission system must be assessed before and after its implementation. However, to avoid unrealistic loadings and losses, the assessment of the transmission network without the reinforcement would also need to be void of the associated connectee. The transmission network conditions will therefore be inconsistent in the 'before and after' assessments of transmission losses impact for the investment, meaning that the NDP method of loss calculation on a per-development basis is not appropriate for the key enabling works outlined in the rest of this section (4.1.7). In future revisions of this strategy, an updated losses calculation method for key transmission network reinforcements established under the Network Development Policy may allow greater alignment with the losses calculation method for enabling works developments outlined below.

To report the estimated lifetime transmission losses impact of enabling works investments, reference is instead made to the transmission loss calculation methodology outlined in National Grid's Strategic Optioneering Reports (SORs).

This method calculates the cost of losses based on an assumed 40 year asset life, with an applied Net Present Value (NPV) discount rate of 3.5% per annum. An average utilisation of 34% of all circuits has been assumed – a figure based on system analysis. This considers the load on each circuit forming part of National Grid's transmission network over the course of a year, taking into account variation in generation and demand conditions.

To provide consistency in transmission losses reporting, the lifetime transmission loss figures quoted in this section align with those quoted in SORs, except where more detailed loss assessments have been undertaken. SOR transmission losses costs are calculated on a single-technology basis. Whilst it is acknowledged that some transmission network solutions are developing, or will develop, to include more than one technology (for example – the Hinkley – Seabank connection is likely to include 8km of cable), such considerations have not been accounted for in the SOR transmission losses figures. The resulting impact on losses is a small proportion of the overall lifetime investment cost and will be accounted for through further project development. Detailed losses assessments are undertaken as part of the Whole Life Value assessment where they are deemed material to the investment decision. In the case of London Power Cable Tunnels project, although an SOR is not required, the same transmission loss calculation method has been followed to provide an estimate of lifetime transmission losses on a consistent basis.

Further background information on the projects outlined in this section (4.1.7) is publically available at the National Grid 'Projects in Your Area' website;

http://www2.nationalgrid.com/uk/in-your-area/projects/

<table>
<tr><th>Name of reinforcement</th><th>Description</th><th>Expected Completion Date</th><th>Impact on transmission losses</th></tr>
<tr><td>Hinkley-Seabank New 400kV overhead lines</td><td>In the South West, EDF Energy has been granted a Development Consent Order for a new nuclear power station at Hinkley Point. A number of other projects, including offshore wind, are also proposed. Additional transmission capacity in the South West is required to ensure that these new connections are safe and reliable, and National Grid believe the best way to provide this is to remove the existing 132kV overhead electricity line owned by Western Power Distribution and build a new 400kV volt connection between Bridgwater and Seabank.

National Grid are proposing to remove 65 km (40 miles) of existing 132kV overhead line between Bridgwater and Seabank substations and put up 46.6 km (29 miles) of 400kV overhead line. Over eight km (five miles) of the new connection would be placed underground.</td><td>2019</td><td>Constructing a new overhead line between Bridgewater and Seabank will result in estimated transmission losses of £49.5m over the lifetime of the project**.

The costs of losses for the range of options considered, including the preferred option above, is:

£20.9m-£251.3m.</td></tr>
<tr><td>Mid- Wales substation connection</td><td>National Grid has an agreement with SP Manweb to provide a new transmission connection in Mid Wales. Changes to the transmission system are needed due to the proposed connection of new onshore wind farms to SP Manweb's distribution system. For this connection, National Grid will be building a new 400/132kV hub substation in Mid Wales. This substation will connect to the Main Interconnected System via the Legacy-Ironbridge-Shrewsbury and the Legacy-Ironbridge 400kV circuits. The new double circuit will comprise 40km of overhead line and 13km of cable.</td><td>2019</td><td>Constructing a 400kV transmission connection from Mid-Wales into the existing Legacy-Ironbridge-Shrewsbury and Legacy-Ironbridge circuits will result in estimated transmission losses costs of £46m over the lifetime of the project.

The costs of losses for the range of options considered, including the preferred option above, is:

£16m-£157m</td></tr>
<tr><td>London Power Cable Tunnels</td><td>In order to meet increasing electricity demand and help London access the renewable energy of the future, National Grid are constructing 32km of tunnels between 20m and 60m deep below the road network. The tunnels will carry high voltage (400kV) electricity cables and connect existing substations at the following locations:

• Hackney
• St John's Wood
• Willesden
• Wimbledon</td><td>2016*</td><td>Installing the following 400kV cables results in the corresponding estimated lifetime transmission losses costs;
<table><tr><th>Cable circuit</th><th>Lifetime loss cost</th></tr><tr><td>Hackney - Highbury</td><td>£4m</td></tr><tr><td>Highbury - St. Johns Wood</td><td>£3m</td></tr></table></td></tr>
</table>

			St.Johns Wood – Kensal Green	£3m
			Kensal Green – Wimbledon	£7m
			Kensal Green – Wilsden	£2m

* Cable install will complete through 2014 to 2016. The circuits will commission through 2016 to 2017.

** Detailed Hinkley-Seabank losses assessments identified clear benefit to reinforcement of the existing transmission system, but the incremental benefit of transmission loss reduction between reinforcement options is immaterial. See National Grid's transmission losses annual report for 2014.

Transmission losses are considered within National Grid's options appraisal process where they are one of the factors included amongst environmental, socio-economic and economic assessments. In meeting its statutory obligations the preferred option is that which best balances these duties and in some cases that can mean the option with the least transmission losses may not be preferred. For example an underground cable will generally have lower transmission losses than the equivalent overhead line, but would also have a greater capital cost and impact on ecology and archaeology. As such, an overhead line is often preferred. This reflects National Grid's Whole Life Value framework approach; making economic investment decisions which appropriately consider transmission losses.

Only one cost figure has been reported per cable for the London Power Cable tunnels. Due to their installation in central London, an overhead line alternative is not realistic and the cable lengths required for installation (3-12km) mean that HVDC is not an economic solution. As Gas Insulated Line (GIL) will not be sufficiently developed to provide the capability in the required project timescales, there is no realistic alternative to cable installation in this case.

4.1.8 Concluding remarks

It is acknowledged that for the reasons outlined in Appendix A, the Electricity Scenarios Illustrator (ELSI) analysis can only provide an estimate of transmission losses for the incremental wider works outlined in sections 4.1.1 - 4.1.6. Whilst ELSI shall be continued to be employed for wider works transmission reinforcement analysis by the National Electricity Transmission System Operator (NETSO), its losses calculation method will be superseded by a more robust assessment that will be established by National Grid for use in future transmission loss assessment activities. Whilst this calculation method is evolving, National Grid's approach to the consideration of load related transmission losses as part of a Whole Life Value assessment remains unchanged.

Whilst a different approach to transmission loss calculation (to that employed for wider works) has been undertaken for key enabling works projects for the reasons outlined in section 4.1.7, this alternative approach remains consistent with the method of transmission loss calculation published in National Grid's Strategic Optioneering Reports.

The significant majority of proposed incremental wider works transmission developments outlined above for the 2013 ETYS Gone Green base case have demonstrated a reduction in transmission losses as a result of analysis undertaken using the ELSI model. This reduction ranges from 259MWh per annum (installation of Wymondley Quad Boosters) to 236,242MWh per annum (Cellarhead-Drakelow 400kV reconductoring).

There are, however, a number of developments outlined that have the potential to increase transmission losses on the transmission network (Eastern HVDC Two, Lister Drive Quad Booster installation, Wymondley turn-in, Barking – Lakeside Tee new double circuits, Wylfa-Pentir 2 circuit, running Carrington 400kV substations solid and de-commissioning Daines 400kV). In each of these minority cases, the detailed ELSI analysis shows that transfer increases and transmission loss reductions are achieved on the transmission boundaries for which the reinforcement is required. However, this loss reduction is outweighed by the negative transmission loss impact when aggregated against all transmission system boundaries that results from ELSI's re-assessment of the optimal economic transmission dispatch once the reinforcement is installed. It is the net transmission system loss figure that is used to reflect the impact of network developments in the tables in sections

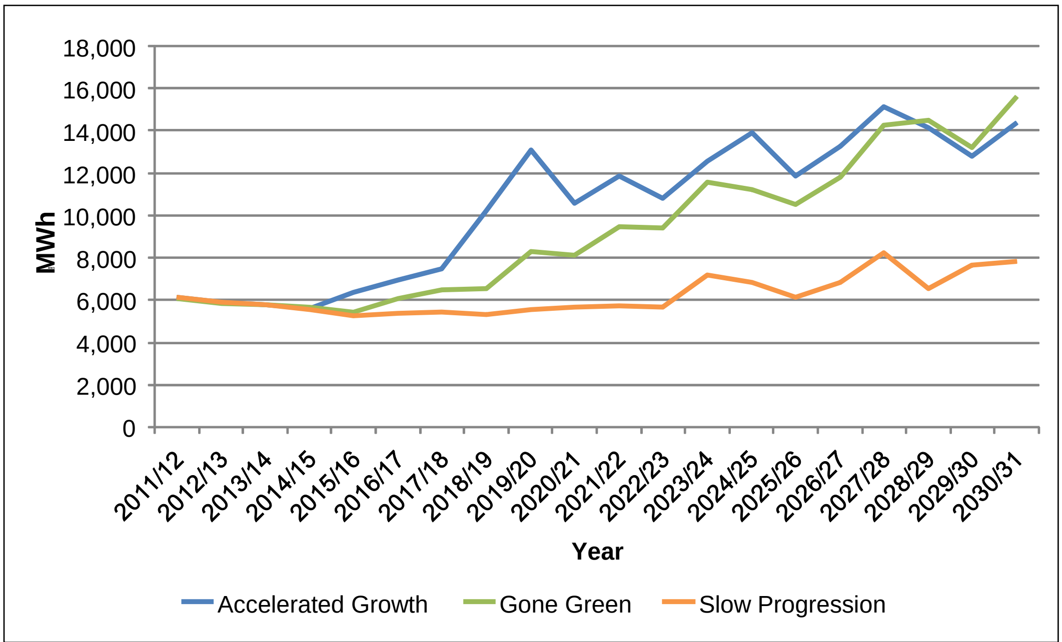
4.1.1-4.1.6, as this is consistent with the depth of assessment required from ELSI for other contributory elements to establish the least regret investment decisions during NDP assessments. A review of load-related losses calculations will be undertaken and a more robust assessment method will be outlined in further revisions of this strategy.

The reinforcements that increase net transmission losses in sections 4.1.1 - 4.1.6 are still deemed the most economic, despite consideration of the associated increased net transmission loss cost. This assertion is also reflected in the enabling works projects outlined in section 4.1.7, where preferred investment solutions based on lifetime cost assessment are not necessarily those with the least transmission loss costs.

These examples further support National Grid's methodology outlined in Section 2, which will ensure that economically justifiable decisions on the appropriate investment are based on a broad range of investment criteria, which will include the consideration of transmission losses. Where transmission loss costs are material to the investment decision, a more detailed transmission loss assessment shall be undertaken. Section 2 of this strategy paper has highlighted incremental wider works as one such potential area where detailed loss calculation assessments may be required.

4.2 Overall impact of all investments on transmission losses

The figure below shows National Grid's forecast transmission losses for the whole GB network for the RIIO-T1 period and beyond to 2031[3]. It is noted that since this figure was published, National Grid (and the NETSO's Network Development Policy (NDP) work in particular –see Section 4.1) have focussed on, amongst additional new scenarios, the Gone Green and slow progression scenarios (including appropriate sensitivities). This strategy document has particularly focussed on the Gone Green scenario.



Over recent years National Grid has reported that losses across the transmission network have been reducing (see Figure above). For the year 2012/13, the total loss volume was 5.64TWh (4.93TWh attributable to National Grid and 0.71TWh to Scottish Transmission Owners), a decrease on the previous year's level of 6.12TWh, and also a lower volume than the 2009/10 level of 6.14TWh[4].

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[3] "RIIO-T1 Outputs" publication, National Grid Electricity Transmission, March 2012.
[4] "Network Operations – Energy Requirements Transmission Losses Report", National Grid, Reporting Period 1 April 2012 to 31 March 2013.[5] Table 4.15.1, "Asset Quantities – Total Annual Additions and Disposals", National Grid RIIO-T1 Submission, National Grid, March 2012.

The 2013 ETYS outlines the NETSO's expectation of transmission loss increase over the RIIO-T1 Price Control period (and beyond to 2023) as a result of all network investments. This position is mirrored by NGET's projection of future transmission losses outlined in the graph above.

In general, there are a number of factors which influence net transmission network losses. These include; variations in zonal generation patterns, the level of Scottish exports to E&W system, changes in interconnector exports, the level of part loaded plant, the degree of geographic dispersal of plant and demand growth. In this case, it is the change in the geographical distribution of generation across the transmission network that is anticipated to have the greatest impact on future losses. In particular, with more generation connected on the periphery of the transmission network, power has further to travel to demand centres, and existing local circuits will experience heavier loading. Both of these factors will culminate in higher losses (I^2R). The expected continued change in generation distribution is in part driven by, but not limited to, the connection of low-carbon technologies.

If reinforcements that would alleviate transmission losses are not deemed cost-effective when undertaking WLV assessment, then this anticipated increase in transmission losses is forecast to remain (recognising that transmission losses are only one consideration of investment decisions).

As of this second edition of the transmission losses strategy, updates against these historic and forecast future positions are provided via National Grid's transmission losses annual report.

5 A summary of National Grid's non-load related asset replacement programmes and the estimated impacts on transmission losses

Licence Condition: 2K.3.(e):

A summary of the licensee's asset replacement programmes and estimates of the impacts those programmes will have on Transmission Losses on licensee's Transmission System.

This section of the strategy paper summarises the relevant asset replacement programmes on the National Grid-owned electricity transmission system over the RIIO-T1 Price Control period and provides associated estimates of their impacts on transmission network losses. Non-load related developments are the subject of focus, as a summary of the key load related developments (that encompass load related replacement where appropriate) have been outlined in section 4.

For consistency, the asset replacement programmes detailed in this section reflect those outlined by National Grid's RIIO-T1 business plan submissions with outputs for delivery within the years 2013-2021 inclusive. Cables, overhead lines (outlined in section 2 of this strategy as a focus area for detailed analysis) and transformers prominently feature in this section because of their direct impact on transmission losses and the significant number of replacements planned in the RIIO-T1 period. The impact of other replacement programmes, such as those for busbars and circuit breakers, are deemed to have minimal impact on transmission losses and are therefore not discussed in this section. The loss calculation methods for individual cable, overhead line and transformer replacements are outlined, and for recent replacement examples (including those in the previous Relevant Year), expected impacts on losses are provided. These examples serve to inform of the potential loss increase or reductions from National Grid's proposed RIIO-T1 asset replacement schemes, where such generalisations are appropriate, and will be refreshed as further asset replacements are completed during the RIIO-T1 period. The most recent updates are outlined below, and are also discussed in National Grid's annual transmission loss report, published separately in coordination with this strategy update.

The loss calculation methods employed in this section are to be used consistently with the strategy outlined in section 2 - the calculation and comparison of transmission losses where their impact is deemed material.

The following sub-sections outline the methodology and calculations for estimating the impact on transmission losses for transformer, cable and overhead line replacements.

5.1 RIIO-T1 transformer replacement projects and estimated losses

National Grid's base case submission for RIIO-T1[5] proposed a non-load transformer asset replacement programme consisting of 136 transformers being removed from the network, with 133 new transformers being brought on as replacements. The difference in these figures is driven by network changes such as site rationalisation, where transformers removed from the transmission network do not require replacement.

To indicate the scope of loss improvement that could be realised for these replacement schemes, the indicative impact on losses are outlined for recent transformer replacement examples. As outlined in section 3.1.2, in practice losses can vary between manufacturer transformer bids by approximately 20%, which is often a significant or deciding factor in National Grid's choice of winning bid.

The methodology for assessment of transformer losses is different to that of other equipment types detailed in this strategy document – transformer loss assessment requires consideration of both

[5] Table 4.15.1, "Asset Quantities – Total Annual Additions and Disposals", National Grid RIIO-T1 Submission, National Grid, March 2012.

variable (load or copper) and fixed (no-load or iron) losses. An explanation of these terms is outlined in section 3.1.1 of this strategy paper. For consistency with the established calculation methods outlined below, the terms ‘fixed loss’ and ‘no-load loss’ are used interchangeably throughout the rest of this section (5.1). The terms ‘variable loss’ and ‘load loss’ are also used interchangeably. The following equation has been utilised to estimate the impact on transformer losses (quoted as an annual MWh figure) for 6 recent transformer replacement schemes, and is akin to that outlined in section 3.1.2 for establishment of the evaluated cost of losses.

Impact of replacement (annual losses in MWh)

$$= \frac{\left(\frac{(LoadLoss_{Old} - Load\ Loss_{New})}{\Delta} + (No\ LoadLoss_{Old} - No\ Load\ Loss_{New})\right) \times \frac{50}{52} \times 8760h}{1000}$$

Where;

‘old’	**=**	**Transformer characteristics prior to replacement**
‘new’	**=**	**Transformer characteristics following replacement**
Δ	**=**	**Loading adjustment factor (4.94 for grid transformers, and 10.7 for interbus transformers).**

Load (variable) loss and no-load (fixed) loss figures used in the above calculation are measured at nominal tap and are in kW to provide a losses impact figure in MWh.

The comparison of load losses and no-load losses in the above equation was carried out for recently completed transformer replacement using historic figures from the National Grid TRALC2 (Transformer Loading Code) database. This database contains test certificate information for transformers connected to, or recently connected to the electricity transmission network.

Consistent with the methodology detailed in section 3.1.2, an adjustment factor (Δ) is applied to represent the RMS average loading of the transformer, in order to account for year-round operating conditions. It has been highlighted in section 2 of this strategy that consideration of year-round conditions is a requirement for detailed loss calculations. For both interbus and grid transformers this factor is calculated using the equation below;

$$\Delta = \frac{1}{(RMS\ average\ transformer\ loading)^2}$$

Adjustment factors of 10.7 and 4.94 are applied using the above equation to represent an RMS average transformer loading of 30.6% and 45% for interbus and grid supply transformers respectively – from section 3.1.4, it is known that between 30% and 45% loading the transformer is at its most efficient loading.

A ’50 in 52’ factor is applied to account for an annual two week maintenance outage period. To convert the calculation from a MW value (converted from kW by the use of a 1000 factor) to a MWh equivalent, the equation includes a multiplication by the number of hours in a year, to ultimately provide an annual MWh change in losses as a result of the asset replacement.

The table below outlines a range of 6 recent transformer replacements, to which the above methodology has been applied, to provide an estimate of transmission loss impact resulting from each replacement. Further additions and modifications to this table will be made as more replacement schemes are delivered throughout the RIIO-T1 period. For this revision, an additional two like-for-like replacement transformers at Lovedean (SGT1) and Beddington (SGT3B) substations are outlined for the previous Relevant Year (2013/14). Transformer installations also recently completed Willington

East, Walpole and New Cross are not outlined, as are either not like for like replacements (Willington East – interbus transformer replaced with demand transformer) or are new transformers (Walpole and New Cross – new transformer that are not replacing existing). This leaves no basis for comparison of losses improvements resulting from transformer replacement/

				PREVIOUS TRANSFORMER		NEW TRANSFORMER			
Replacement scheme	**Replaced in *Relevant Year*?**	**Voltage (kV)**	**Rating (MVA)**	**No-load losses (kW)**	**Load losses (kW)**	**No-load losses (kW)**	**Load losses (kW)**	**Reduction in losses (annual MWh)**	**Percentage change (from old)**
Rochdale SGT 5	N	400/275	1100	92	1746	71	1564.78	318	15%
Stanah SGT 2	N	400/132	240	117	700	54	602.60	697	32%
Margam SGT1	Y	275/66	180*	88	674	54	569.14	460	24%
Poppleton SGT2A	Y	275/33	120	56	491	37	482.40	175	13%
Lovedean SGT1	Y	400/132	240	130	1028	53	556	1448	51%
Beddington SGT3B	Y	275/132	240	106	968	40	599	1184	46%

* Previous transformer losses based on 120MVA original transformer.

The above table provides data for 6 transformer types that cover a range of key transformation voltages and transformer ratings presently used on the England and Wales electricity transmission network. This range includes both interbus and grid supply transformers, but excludes single phase transformers used for the connection of traction load.

All transformers assessed under this methodology demonstrate a reduction in transformer losses as a result of each recent replacement scheme. The range of improvement estimates varies by transformer voltage and rating, but loss reductions are in the range of 13-51% across all examples. The most recent examples included in this latest revision of this strategy (Lovedean and Beddington) increase the upper range of loss savings identified for transformer replacements (previously quoted as 32% in the initial publication of the strategy).

The table demonstrates that a greater proportion of this reduction in loss is attributable to the no-load (fixed) losses – this reflects the improvement in core loss over the last 40 years as a result of improvements in alloys and processing, as outlined in section 3.1.3. This section (3.1.3) also suggests that core loss improvement has resulted from increased loss capitalisation value, and that further improvements in load (variable) losses could be achieved by increases in the load related loss capitalisation value.

As the range of transformers outlined above has been selected to be representative of (voltage transformation, MVA rating) recent replacement schemes, and also includes those replaced in the previous relevant Year, it is therefore likely that similar levels of improvement will be achieved, on average through the replacement of transformers of a similar age during the RIIO-T1 period.

In 2013/14 the total transmission network annual loss figure was estimated to be 5.31TWh. Of this figure, 4.45TWh was attributable to National Grid's England and Wales electricity transmission network (accounting for approximately 1.57% of total energy supplied). For the Lovedean SGT1 replacement, which had the largest improvement in transformer losses, the MWh loss improvement as a result of replacement accounts for 0.033%(1448MWh/4.45TWh x 100%) of England and Wales' total TWh transmission losses for 2013/14.

5.2 RIIO-T1 cable replacement projects and estimated losses

National Grid's base case submission for RIIO-T1[6] proposed a cable replacement programme consisting of 94 circuit km of cable being removed from the transmission network, and being replaced with 100 circuit km of new cable. Some disparity exists between the quantity of cable removed and that replacing it because replacement cables may not always be laid along the same cable route as the original cable.

To indicate the scope of loss improvement that could be realised for the RIIO-T1 replacement schemes, the indicative impact on losses (quoted as a percentage change in loss with respect to the originally installed cable) are provided for recent cable replacements.

The methodology for calculating the change in losses for cable replacements assumes that the pattern of year-round current loading will be unchanged before and after replacement, and therefore assesses losses by comparing the resistive element of the original asset and its replacement. Year-round loading conditions are still accounted for by assuming the current flow is unchanged as a result of the replacement at any point in the year and therefore remains consistent with the requirements for detailed loss assessment outlined in section 2 of this strategy. As the current flow may differ as a result of replacement, and other aspects of transmission loss are considered negligible (dielectric losses, sheath losses and cooling losses – see section 3.3), this method can only provide an estimate of the impact on transmission losses. Whilst the limitations of this calculation are recognised, because the focus of this strategy is the reporting estimates of active power (I^2R) losses, this is deemed acceptable.

In some non-load related replacement schemes, like-for-like cable replacement is either not feasible or not suitable; changes in cable manufacture and technology since the initial cable installation may drive a suitable alternative to be selected, or cable replacement based on asset health assessments may be aligned (where possible) with an identified load related driver, meaning that a cable of greater transmission capacity is installed.

The table below outlines 2 examples of recent cable replacement schemes; the first replaced a single cable per phase system on the Stalybridge - Thorpe Marsh 400kV circuit (Woodhead Tunnel) with another single cable per phase system. The second replaced a single cable per phase system on the Ross-on-Wye 400kV circuit (Rassau – Walham) with a two cable per phase system - these cables are assessed as one two cables per phase system in the table below. Further additions and modifications to this table will be made as more replacement schemes are delivered throughout the RIIO-T1 period. For this second edition (October 2014), there are no further cable scheme delivery updates from the previous Relevant Year.

Cable replacement project	Replaced in previous Relevant Year?	Cable length (km)	Cable type (before)	Cable rating before (Winter /Summer) (MVA)	Cable type (after)	Cable rating after (Winter /Summer) (MVA)	Resistance before (ohm)	Resistance after (ohm)	Decrease in losses (%)
Woodhead Tunnel (Stalybridge – Thorpe Marsh)	Y	4.98	Single core $1600mm^2$ oil filled	1040/1040	Single core $2500mm^2$ XLPE	1920/1690	0.080	0.054	32.0%
Ross-on-Wye (Rassau – Walham)	N	2.54	Single core 3 sq in. oil filled	1105/987	Single Core $2500mm^2$ XLPE	3000/2800	0.033	0.014	57.2%

[6] "Table 4.15.1 Asset Quantities – Total Annual Additions and Disposals" National Grid RIIO-T1 Submission, National Grid, March 2012.

The cable ratings stated above are provided for both winter and summer. All cable replacements assessed under this methodology demonstrate a reduction in transmission losses as a result of the cable replacement. However, the range of loss improvement estimates will be impacted by both pre- and post-replacement cable types (and resistive elements), and therefore this range is likely to continue to vary on a per-cable basis.

As the number of cables per phase on the Rassau – Walham circuit has increased from 1 to 2 the decrease in transmission losses is two-fold: each individual cable in the new circuit has a lower resistance than the original cable system, while the parallel configuration of these new cables leads to a further halving of the new combined cable system's resistance. It is for these reasons that the reduction in transmission losses is so significant.

The wide range of transmission loss reductions shown here indicate that, as cable types and laying conditions for existing cables and their planned replacements under RIIO-T1 will vary, it is likely that loss reductions will also vary considerably for these future replacement schemes.

Therefore, where transmission losses are deemed to be an influencing factor in option selection for investments, the impact of losses will be considered on an individual cable replacement basis, taking into account the characteristics of existing cable and its likely replacement. As section 3.3 of this strategy outlines, any detailed analysis of cable replacement options should also consider that any loss improvement that can be gained will not only reduce the capital cost of losses for the cable system, but also improve its power transfer capability, thus increasing its value.

5.3 RIIO-T1 overhead line replacement projects and estimated losses

National Grid's base submission for RIIO-T1[7] proposed an overhead line replacement programme consisting of 1005 circuit km of non-load related overhead line replacement.

To indicate the scope of loss improvement that could be realised for these RIIO-T1 replacement schemes, the indicative impact on losses (quoted as a percentage change in loss with respect to the originally installed conductor) are provided for recent overhead line replacements based on the largest contributing factor to overhead line losses- the resistive loss element (see section 3.2 for further information on elements of overhead line loss).

The methodology used is equivalent to that outlined for the assessment of cables – it assumes that the year-round current loading will be unchanged before and after replacement, and therefore assesses losses by comparing the resistive element of the original conductor and its replacement on the basis that the replacement is of the same length as the original. Year-round loading conditions are still accounted for by assuming the current flow is unchanged as a result of the replacement at any point in the year and therefore remains consistent with the requirements for detailed loss assessment outlined in section 2 of this strategy. As the current flow may differ as a result of replacement, this method can only provide an estimate of the impact on transmission losses.

The strategy outlined in section 2 states that for overhead line conductor asset replacement schemes, the impact of transmission losses are more likely to require detailed assessment than other investments. This is because transmission loss cost reductions could be comparable or greater than the incremental capital cost of investment in the medium term when considering replacement with a larger, lower-loss conductor. As outlined in section 3.2, National Grid does not always replace overhead line sections on a like-for-like basis for non-load related purposes. This may be because technology and manufacturing advances mean that the original conductor type is no longer produced (and therefore a suitable alternative is required), larger conductors are installed to reduce losses, or, similar to cables, the overhead line section replacement based on asset health assessments may be aligned (where possible) with an identified load related driver, meaning that a conductor of greater transmission capacity is installed.

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[7] "Table 4.15.1 Asset Quantities – Total Annual Additions and Disposals" National Grid RIIO-T1 Submission, National Grid, March 2012.

The table below outlines 6 examples of recent replacement schemes;

Overhead line replacement project	Replaced in previous Relevant Year?	Conductor length (km)	Conductor type (before)	Conductor type (after)	Resistance before (ohm)	Resistance after (ohm)	Decrease in losses (%)
Lackenby - Todd Point 275 kV	N	6.0	4 x 400mm^2 (Zebra)	2 x 260mm^2 (GAP)	0.21	0.15	28.571%
Creyke Beck - Thornton 2 400kV	Y	29.81	4 x 400mm^2 (Zebra)	3 x 700mm^2 (Araucaria)	0.52	0.42	19.231%
Hartmoor – Hawthorne Pit 275kV	Y	17.28	2x sections & 4x sections 400mm^2 (Zebra)	Twin Sorbus 2x570mm^2	0.59	0.44	25.424%
Hartlepool – Tod Point 275kV	Y	18.43	2x & 4x 400mm^2 (Zebra)	2x620mm2 Matthew GZTACSR	0.52	0.56	-7.69%
Lackenby – Norton 400kV	Y	2.447	2x570 mm2 (Sorbus),	2x620mm2 Matthew GZTACSR	0.655	0.658	0.005%
Pentir – Trawsfynydd	Y	51.408 (2.35 replaced)	2x700mm2 (Araucaria)	Twin Sorbus 2x570mm^2	1.0139	1.0139	0%

The overhead line replacements assessed under this methodology for the most part demonstrate a reduction in transmission losses as a result of the recent replacement schemes. This reduction in losses is expected in these cases as the conductor has been replaced with an alternative, lower resistance conductor. This change in conductor is however representative of typical non-load replacement works – for the reasons outlined above, the conductor type of a replacement may change despite the absence of a load related requirement.

The range of loss improvements from these examples (-7.69% to 28.6%) suggests that loss improvement will be dependent on the type of existing and replacement conductor. Therefore, where transmission losses are deemed to be an influencing factor in investment decisions, replacements undertaken during RIIO-T1 are considered on a case-by-case basis.

6 Consideration of the impact of new technologies on transmission losses

Licence Condition: 2K.3.(f):
A description of the potential application of new and alternative technologies to the license's Transmission System during the Price Control Period and the impact these technologies may have in relation to Transmission Losses.

NGET is committed to remaining informed of the latest technological developments in the field of electricity transmission and will incorporate their use, where appropriate, in ensuring security of supply is maintained economically and efficiently. As described elsewhere in this document, NGET consider transmission losses when purchasing new equipment, but other factors will also influence the final optimised purchase decision. During the RIIO-T1 period National Grid expect to see the application of new and alternative technologies to the transmission system. For example, HVDC transmission and series compensation will be utilised to increase the transmission capacity on the UK transmission network, and NGET is also jointly sponsoring a research and development project looking at upgrading 275kV routes to 400kV operation using existing 275kV tower bodies and foundations. This section considers the impact of these technologies on transmission losses.

6.1 HVDC transmission

A significant increase in transmission capacity is needed between Scotland and England due to the connection of a significant amount of onshore wind generation in central Scotland. Over long distances, DC transmission losses (including conversion Losses) are lower than AC losses at higher voltages.

A typical application for the preference of HVDC connections over AC circuits are where long cable circuits are required - for example the Western HVDC Link, which provides 2.2GW capacity at 600kV, via a 385km undersea cable connection[8]. Transmission of power at DC overcomes the effect of capacitive charging current, which reduces the effective rating of cables in AC applications and makes the use of AC circuits increasingly impractical for long distances. In DC applications, there is no technical limit on cable length.

6.1.1 HVDC converters

The major sources of losses in HVDC converter stations are; the valves, converter transformers, ac filters, other reactive compensation plant, DC smoothing reactors and auxiliaries / station service losses. Typical converter losses are 0.7 – 0.8% of the transmitted power.

During the development of tender specifications for HVDC converters and their evaluation criteria, losses are amongst the factors considered. The tender document or technical specification details any special requirements or considerations that shall be applicable. To comply with these requirements, the tenderer shall be expected to perform and submit a loss calculation with his tender return to demonstrate that lifetime losses have been taken in to consideration and have been optimized for the design being offered. National Grid's technical specification TS 2.31 'High Voltage Direct Current (HVDC) Converters' requires the losses to be calculated in accordance with BS EN 61803 'Determination of losses in high-voltage direct current (HVDC) converter stations'. A monetary value of losses in £/kW to be used for capitalisation purposes is stated in the tender specification.

Consideration of the losses forms part of the overall decision taken during the tender evaluation process when comparing submissions from multiple tenderers and ensures a solution is selected which balances, cost, safety, functionality, performance, deliverability, risk and losses. The approach outlined above was applied in procurement of the Western HVDC Link.

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[8] "Western HVDC Link Preparing our energy network for the future", National Grid & SP Transmission, January 2011.
http://spng.opendebate.co.uk/files/_CD_WHVDC_Consulation_Document_reduced.pdf

6.1.2 HVDC VSC converters

It seems likely that within the RIIO-T1 Price Control period, HVDC systems using voltage sourced converter (VSC) technology will find application on the GB transmission system. Compared with conventional line commutated converter (LCC) HVDC, VSC offers a number of advantages and is likely to be the favourable solution for a number of future applications. VSC valves use self-commutating switching devices which, in contrast to LCC, are not dependent on a strong ac system for their correct operation. VSC is therefore suitable for weak and even passive systems. It requires little or no provision of ac harmonic filters and reactive compensation plant. Consequently, a VSC converter station can be accommodated within a smaller footprint than its LCC equivalent. The direction of power flow is reversed without changing the dc voltage polarity, the limitation on the rate of change of power being that imposed by the ac system in most cases.

Early designs of VSC converter exhibited greater losses than their LCC equivalents. Much development has taken place in recent years with reduction of losses a key aim. For the present generation of VSC converters, the losses have been reduced to around 1% of the transmitted power or less.

IEC SC22F has developed International Standards for determination of VSC valves losses. IEC 62751 'Determination of power losses in voltage sourced converter (VSC) valves for high voltage direct current (HVDC) systems – Part 1: General requirements' and 'Part 2: Modular Multi-level converters' were published in August 2014.

6.1.3 HVDC cables

HVDC Cable losses are largely resistive in nature and, unlike AC cables, tend not to suffer from sheath losses and generally do not require special bonding arrangements. This allows their use in very long length submarine projects.

Due to the high power transfers required for the Western HVDC subsea link, MI PPL cable has been selected as it is the only cable currently available that can meet this requirement. As the resistivity of copper (and aluminium) increases with temperature, the move to higher temperature cable insulations (from MI at 50 ^{o}C to XLPE at 70 ^{o}C or 90 ^{o}C and MI PPL at 80 ^{o}C) will see an increase in losses. This is more important for DC circuits operated with a high load factor, than for AC circuits which generally only operate at 100 % rating for a small proportion of their lives. Losses can be reduced by using larger sized conductors in the cables. However at transmission power levels where currents at or around 2000 A are often required, cable sections are likely to necessitate conductor sizes at the top end of constructability, leaving little margin for increasing conductor size to reduce losses.

Losses are indirectly specified in Specification 3.5.15 "Mass Impregnated Cables up to 800 kV" by referencing IEC 60228 in the conductor part of the specification.

The Western HVDC Link Invitation to Tender included a cost per megawatt value for losses (both converter and cables) and required suppliers to take this into account optimising their overall solutions accordingly.

6.2 Series compensation

Series compensation equipment is considered for use when existing OHL circuits have reached their natural loading point and require additional reactive compensation to increase the amount of active power that can transmitted. This makes efficient use of existing assets, and in some cases can be used as an alternative to building additional transmission circuits. Whilst improving existing asset capability and removing the need to build new OHL routes, the down side is that transmission losses are increased on the existing circuits as the active power load is increased.

The first application of series compensation on the GB transmission system is already planned for commissioning in 2014/15. This has been jointly designed by National Grid and Scottish Power to increase the power transfer capability across the Anglo-Scottish boundary by carefully choosing locations within the National Grid and Scottish Power transmission systems to install series compensation equipment.

The use of series compensation comes with technical challenges, by introducing complex power system protection arrangements and potential interactions (Sub-Synchronous Resonance - SSR) with power plants, which require to be carefully managed throughout the life of the series compensation equipment. Two issues (from a losses perspective) arising as a result of using series compensation are;

1. The heating losses in overhead lines are proportional to the square of the current passing through the circuit, (i.e. $I^2 \times R$), so, by increasing the current through the circuit, this will also increase the losses through that circuit.

2. The series compensation equipment itself will have some losses depending on the choice of technology employed. Losses such as thyristor valve conduction losses, turn-on / turn-off losses, snubber circuit losses, thyristor controlled reactor losses, cooling system losses and harmonic filter (where required) losses for Thyristor Controlled Series Capacitor (TCSC) designs may exist. Circulating current losses in SSR filters for Fixed Series Capacitor (FSC) designs may also exist.

   Both of these designs (TCSC and FSC) may be employed to provide solutions to mitigate and manage potential SSR interactions with power plants. If SSR is not a risk then it may be possible to use a simple FSC instead of a TCSC or FSC+SSR Filter design. The simple FSC would have considerably lower losses associated with it compared to the other solutions but may not be readily suitable within the GB transmission system due to its highly integrated and meshed nature. Each potential application of series compensation has to be considered on a case-by-case basis to determine the most appropriate solution.

When considering the most appropriate solution to utilise, the economics of the series compensation designs which manifest these losses have to be carefully balanced against the capital and lifetime costs of alternatives such as building, owning and maintaining additional power circuits to achieve the same overall power flows.

From a technology perspective, the series compensation solutions offered by different suppliers through tendered exercises are evaluated in the procurement process, as previously outlined, including loss evaluation. The loss evaluation is specified within the National Grid Technical Specification to be in accordance with IEEE Std 1534-2009. This approach has been applied in the procurement of the Anglo-Scottish Series Compensation at Hutton substation.

6.3 Upgrading from 275kV to 400kV composite cross-arms Network Innovation Allowance study

In conjunction with the University of Manchester, EPL Composite Solutions and SSE, National Grid has undertaken a research and development project to develop and trial the application of new materials to replace existing 275kV overhead line conductor insulation and supporting arms with a composite insulated supporting arm capable of 400kV operation. The new arrangement will allow the option of upgrading of existing 275kV overhead line routes to 400kV operation, to increase system capacity without the requirement to build new OHL routes. If successful, this innovation has the additional benefit to reduce circuit transmission losses by 20% to 40% depending on circuit loading, for routes which can justify this investment. The research and development project is now complete, but awaiting a suitable scheme for consideration as a development option.

Appendix A: The Electricity Scenarios Illustrator (ELSI) model

A.1 Overview

The Network Development Policy (NDP) was introduced by National Grid in 2012 as a means of comparing multiple options for accommodating forecast increased flows across major system boundaries. Under the policy, cost benefit analysis is carried out for each reinforcement option (including the option not to reinforce) under a number of industry defined scenarios. The option that is determined to have the least regret is recommended. This cost benefit analysis uses the Electricity Scenarios Illustrator tool (ELSI), which accounts for the costs of transmission losses in its calculations in determining the least regret investment.

The load related incremental wider works developments outlined in this strategy paper reflect the transmission network solutions proposed by the England and Wales Transmission Owner and selected by the National Electricity Transmission System Operator (NETSO) in the 2013 Electricity Ten Year Statement (ETYS), under the 2013 Gone Green baseline scenario. Therefore the 2013 ETYS the ELSI tool has been utilised to provide transmission loss estimates for key future transmission solutions and associated cost figures. This approach provides consistency with other documentation published by National Grid Plc on wider works developments. It is also consistent with the assessment of transmission losses on a Whole Life Value basis, as section 2 of this strategy recommends for detailed loss calculations for incremental wider works.

Section 4 only outlines significant developments on the transmission network over the 8-year Price Control period under the 2013 Gone Green base scenario and does not form a definitive investment plan – for a more detailed outline of recommended future reinforcements and further description on the Network Development Policy, please refer to the 2013 ETYS.

A.2 The model

The Electricity Scenario Illustrator (ELSI) is an excel model, created by National Grid, that is driven by visual basic code. Its primary aim is to dispatch generation to meet representative levels of demand throughout a year of system operation. ELSI is publically available on NGET's website at this link.

More information on the Electricity Scenario Illustrator can be found at the following link;

Electricity Scenarios Illustrator Further Information,

ELSI is used to model the energy market assuming that it is perfectly competitive; i.e. there is ideal information for all parties, sufficient competition so that suppliers contract with the cheapest generation first, and that there are no barriers to entry or exit from the market. It is a simple representation of the Great Britain electricity market that was initially devised as part of the RIIO Price Control review process to demonstrate to network users the consequences of National Grid's transmission investment plans. It has since been utilised under the NDP for establishment of the 'least worst regret' wider transmission works reinforcements, which in turn inform the annual ETYS submission from the NETSO. ELSI does not model a network of nodes connected by circuits, but instead models boundaries which are mathematical summation of any number of zones.

ELSI uses two steps to model the electricity market. The first is to look purely at the short run marginal cost (SRMC) of each zonal fuel type and dispatch available generation from the cheapest, through the more expensive types, until the total level of GB demand is met (the unconstrained dispatch – assuming that transmission network boundaries have infinite capacity). The second step is to take the unconstrained dispatch of generation and look at the resulting transfers across the boundaries. ELSI will compare these transfers with the actual capability of the boundary and re-dispatch generation where necessary in order to relieve any instances where boundary flow exceeds capability (i.e. where a constraint has occurred). ELSI will do this in the most economic and cost effective way by using the SRMC of each fuel type. This re-dispatch of generation is referred to as the constrained dispatch of generation. The cost associated with moving away from the most economic dispatch of generation (unconstrained dispatch), to one which ensures the transmission network remains within its limits (constrained dispatch) is known as the constraint cost and is calculated using the bid and offer prices of each fuel type.

The yearly demand in ELSI is represented by 26 sample dates which are taken from historic data. Within the 26 samples, ELSI models 6 winter days, 12 spring/autumn days, 6 summer days and the system minimum and system peak. Each day is split into 4 sample periods which represent the daily peak, plateau, pickup/drop-off and the night trough. These 104 sample periods (26 sample dates x 4 sample periods) are selected to ensure that both the yearly and daily demand variations are represented.

ELSI can be run on different scenarios, but the information outlined in this section is with reference to the Gone Green base scenario developed by National Grid. This provides compatibility with National Grid's transmission owner RIIO-T1 base submission, and the ETYS.

A.3 Using ELSI to calculate transmission losses

The ELSI model runs analysis for 104 sample periods of demand (with appropriate generation backgrounds) to approximate system conditions for year-round operation of the GB transmission system. The calculation of transmission losses forms only one aspect of the considerations undertaken for the establishment of the most suitable wider transmission works investments via NDP, but is the focal point of the considerations for this strategy document. ELSI uses the method outlined in Appendix A.2 to establish the constrained dispatch of generation and bases loss calculations on the resulting constrained transmission boundary flows, using the following equation;

$$BoundaryLosses(TWh) = \frac{(\frac{ConstrainedFlow}{100})^2 \times kmWT \times R\%/km}{\frac{CCTWT}{CapWT}}$$

Where;

km WT	**=**	**Boundary length in km**
CCT WT	**=**	**Number of circuits on a boundary**
Cap WT	**=**	**Capacity weight of each boundary**
R%/km	**=**	**% Resistance per km of the transmission lines used for losses. (Fixed at 0.003% on a 100MVA base for ELSI runs)**

The boundary reinforcements introduced into ELSI contribute to the boundary capability by impacting on the constrained flow. As the constrained flow is proportional to the current, the boundary losses are proportional to the square of the constrained flows (determined by the ELSI constrained dispatch). The losses across a particular boundary are also proportional to the boundary length (km WT), and the resistance per km (R%/km) of the transmission lines. Boundary resistance is taken to be inversely proportional to the number of circuits per boundary (CCT WT). The Capacity Weight factor (CAP WT) accounts for the efficient redistribution of power flow as a result of increased transmission reinforcement, thus proportionally reducing the losses calculated for a boundary with increased capability.

The losses associated with each individual transmission boundary are then summated to calculate the total system losses via to following formula;

$$TotalLosses(TWh) = \left(\sum BoundaryLosses\ per\ boundary\right) + Load\ \mathrm{Re}lated\ Losses + Fixed\ Losses$$

Where;

Load related losses = (National demand)^2 * calibration factor

Fixed losses ≈ 280MW.

To assess the losses impact of an individual transmission system development (as opposed to losses associated with a particular boundary – outlined above), the ELSI model can be run with and without the proposed system development and therefore a 'delta' in transmission losses (and associated cost, based on system marginal price) can be established for the introduction of an individual transmission system development.

This approach has been taken for each of the key transmission developments outlined in section 4.1, to establish an estimate for their individual impact on net transmission system losses.

Appendix B: