SP Energy Networks

Transmission Losses Strategy for RIIO-T1

Updated April 2019

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1. INTRODUCTION

Losses are an inevitable consequence of transferring energy across electricity networks. They represent the difference between all the energy that is injected into a system from generation and the energy that is taken out of the same system by demand. In the case of SP Transmission (SPT), the energy being transferred across our transmission system between Scottish Hydro-Electric Transmission (SHE Transmission) to the north and National Grid Electricity Transmission (NGET) to the south also contributes to our transmission losses.

The Electricity Act 1989, Section 9(2), requires all electricity transmission licensees to develop and maintain an efficient, co-ordinated and economical system of electricity transmission. In addition, our transmission licence Special Condition 2K requires SPT to develop and maintain a strategy for managing transmission losses and to report on how we have acted accordingly to make sure losses are as low as reasonably practicable.

In response to feedback from consumers and stakeholders since our RIIO T1 losses strategy was published SPT is providing this update. This document gives more detail on the impact on losses due to the development and modernisation of the transmission network and how transmission losses are being mitigated where possible through the application of new technology during the RIIO T1 price control that runs until March 2021. As required by transmission licence Special Condition 2K, this strategy describes:

- How we take losses into account when planning load related reinforcements and non-load related asset replacement on our transmission system;
- How we determine optimal specifications in our asset procurement processes;
- Key developments on our transmission system and estimates of their impact on losses;
- Our asset replacement programme and estimates of the impact on losses; and
- The potential application of new and innovative technologes and the impact of these on transmission losses.

To conclude we describe our approach to reporting and stakeholder engagement.

2. CAUSES AND IMPACTS OF LOSSES

Transmission losses are largely due to the heating of various components of the power system and can be categorised as follows:

- **Fixed Losses**: This refers to electrical power being lost when equipment such as transformers, overhead lines and power cables are energised even if there is no power flowing through them. This component of technical losses mainly depends on the electromagnetic and dielectric characteristics of the energised equipment and the applied voltage, sometimes referred to as ‘iron losses’ or ‘no-load losses’. Considering that the operating voltage of transmission equipment needs to remain within statutory limits, the commonly used approach to manage these losses is to improve the electromagnetic and dielectric characteristics of equipment.
- **Variable Losses**: This refers to electrical power being lost in the current carrying conductors of transmission equipment. This type of power loss is proportional to the square of the current, or power flow, passing through the conductor and its electrical resistance (often referred to as I^2R losses), sometimes referred to as ‘copper losses’ or ‘load losses’. Therefore, efforts to mitigate

variable losses are mainly focused on reducing power transfers or reducing the resistance in the power transport path.

- **Substation Auxiliaries**: This refers to electrical energy being used by the auxiliary facilities in transmission substations. Cooling, air and hydraulic systems, protection, control and monitoring are all essential services, as is environmental management for sensitive equipment. Power is also required for the safety and comfort of those working in and around substations, e.g. heating, air conditioning and lighting. These energy uses are essential for safe and reliable operation of the system although some actions can be taken to improve energy efficiency.

Apparent losses can also arise due to energy theft and errors in unmetered supplies but these are more applicable to distribution networks and are not considered relevant for the management of losses on the SPT network.

Losses are closely related to the overall power transfer capability of the transmission network, which is often due to the thermal limits of circuits or transformers, i.e. the heating effect of losses. For a given flow of power, losses can be reduced by a decrease in series resistance, as in the conductors on overhead lines, or an increase in shunt resistance, as in the no-load losses of transformers. This has two important side-effects:

- The time constant associated with the DC component of fault currents is increased, leading to more onerous circuit breaker duties. This is particularly significant at many SPT grid supply points, where the fault current is dominated by the characteristics of the grid supply transformers. Here, a reduction in transformer losses increases the DC fault current component time constant to values in excess of the standard value, necessitating the use of higher-rated circuit breakers than normal. The issue is exacerbated by increased volumes of embedded generation, which also contribute to increased fault levels. However, our view is that the deliberate use of transformers with high load losses to counter this problem is not justifiable.

- A second impact of reduced system losses is the reduction in damping that is available to higher-frequency phenomena such as harmonics or switching transients. The implication is that harmonic resonances are more pronounced and that oscillating transients take longer to decay. These effects can impose additional costs on consumers, e.g. the need for harmonic filters or generation constraints due to reduced stability margins.

Increased harmonic levels themselves lead to increased losses, e.g. in MSCDNs or due to losses caused by harmonic currents flowing in circuits and equipment. Similarly, phase imbalance results in higher losses than if voltages and currents are perfectly symmetrical across all three phases. Changes in load characteristics, e.g. due to the increasing use of power electronic equipment, has an impact on system harmonics and other aspects of power quality. We continue to keep our modelling techniques under review and also rely increasingly on direct measurements to manage power quality on our network.

Transmission losses can be managed within both the investment planning and operational time frames. However, in our role as a Transmission Owner (TO) we have limited scope to influence transmission losses in operational time frames. National Grid Electricity System Operator (NGESO) has the responsibility to operate and direct the flow of energy over the GB electricity transmission system, taking into account underlying constraints while optimising the performance of the whole system. Therefore, our initiatives toward managing transmission losses are mainly focused on optimising the consequential environmental impacts of our investment decisions.

Effective electricity losses management is required to protect customers from unnecessary costs and to limit the greenhouse gas emissions associated with power generation. However, it should be noted that further integration of renewable energy resources over coming years will reduce the carbon content of the power system, including losses, helping to reduce carbon emissions from GB as a whole.

3. TAKING ACCOUNT OF LOSSES IN INVESTMENT PLANNING

Our investment planning decisions are driven by customer needs and our licence obligations including the requirements of the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS). There is a wide range of factors that determine the design of both load related reinforcements and non-load related asset replacement. These include the practicalities of construction and deliverability, overall environmental impact of each development, as well as the impact on system performance, capability and operability. The impact on losses is considered but in most cases it will not be a determining factor in the overall design. In instances where the impact on losses will affect the decision being made more detailed analysis is performed.

The losses associated with a proposed reinforcement can be estimated in power system studies by comparing the results from simulations with and without the reinforcement. As per industry codes, our investment planning studies are based on generation and demand backgrounds provided by NGESO that reflect the Future Energy Scenarios (FES). Studies are performed to assess the impact of proposed reinforcements against these backgrounds, with losses being one of the results that can be extracted from the studies.

Losses associated with asset replacement can be estimated by examining historical data to determine the power flows in that asset then calculating how losses may be different following replacement. This approach can provide only indicative results because the differences in resistance and other parameters between the old and new asset will affect the power flows. Furthermore, asset replacement often involves upgrades or improvements that affect the behaviour of the wider system, or they are partly to accommodate anticipated changes in usage patterns, so historical power flow measurements may not be representative of future use.

4. OPTIMAL SPECIFICATION OF NEW EQUIPMENT

This section explains our approach to the specification and procurement of various types of new equipment and how this includes consideration of transmission losses.

4.1. Transformers

When procuring transformers, we consider an estimate of the total cost of ownership in order to determine the most economic purchase. This evaluation recognises both the purchase price of the transformer and the transformer losses, by capitalising the cost of these losses over the expected life-time of the transformer[1].

Modern transformers have considerably lower losses when compared to transformers that have been in service for many decades. For example, a typical 90 MVA, 132/33 kV transformer installed in the 1970s had no-load losses of 50 kW and an equivalent short-circuit resistance of 0.08 Ω. An equivalent 2019 transformer has no-load losses of 20 kW and a short-circuit resistance of 0.05 Ω. The no-load losses are reasonably constant while the transformer is energised so the old transformer would consume 438 MWh each year compared with 175.2 MWh for the new transformer. Assuming a typical loading pattern, load

[1] Appendix A-20 of Specification for Transmission System Double Wound Transformers (TRAN-03-022, Issue No. 7) and Specification for Transmission Autotransformers (TRAN-03-024, Issue No.5).

losses might add another 125 MWh for the old transformer and around 80 MWh for the new transformer. Assuming a cost of £60/MWh, a new transformer of this type delivers an annual saving of around £18k in avoided losses.

4.2. Overhead lines

On overhead lines, modern conductors offer a number of improvements over older types including a small reduction in losses. A typical example is the replacement of twin Zebra (400 mm^2 Aluminium Conductor Steel Reinforced (ACSR)) conductor bundles with twin Totara (425 mm^2 All Aluminium Alloy Conductor (AAAC)). The old "Standard Conductivity" Zebra conductor has a resistance of 67.4 μΩ/m while the new "Extra High Conductivity" Totara conductor has a resistance of 62.5 μΩ/m. This reduces losses by 7.3% when loaded on a like for like basis.

However, asset replacement on overhead lines also illustrates how increasing power flows across the SPT network may lead to higher losses. One approach to increasing network capacity is for overhead line routes to be upgraded with new conductor technology that can be run at much higher temperatures. This allows the same tower routes to carry much higher amounts of power, and thereby accommodate the growth in renewable generation, and while the higher temperature means higher losses, the need to build new or rebuild existing overhead line towers is avoided.

Losses are also affected by the upgrading of circuits to operate at higher voltage, e.g. from 275 kV to 400 kV. For the same power flow, operation at a higher voltage will mean lower current and so lower losses. However, the nature of the interconnected network is such that the higher capacity circuit is likely to carry more power than the circuit it replaced. Significant upgrades often mean fundamental changes to the network toplogy so it is not practical to calculate before and after values for losses on individual circuits. In the present context, upgrades to the network like this are primarily driven by the required increase in power transfers due to the connection of new renewable generation.

4.3. Shunt reactors

Similar to transformers, when procuring shunt reactors, we establish the total cost of ownership in order to determine the most economic purchase. This evaluation recognises both the purchase price of the reactor, as well as reactor losses, by capitalising the cost of these losses over the expected life-time of the asset. We have installed a number of new shunt reactors during the RIIO-T1 period. At most sites, when space constraints permit, we have decided to use air-cored reactors, which do not have an iron core and therefore do not exhibit the associated iron losses. Our older 33 kV, 60 MVAr shunt reactors were installed in the mid-1960s and typically have losses of 240 kW when energised. Modern air-cored shunt reactors of a similar rating have losses around 160 kW. Note that shunt reactors are brought into service only when required, such as during light-load system conditions to limit excessively high voltages. Although system conditions require increasing use of reactive compensation, the duration for which shunt reactor losses are present on the system is typically less than a transformer, which is normally energised all of the time.

4.4. Shunt capacitors

SPT has installed mechanically switched capacitors with damping networks (MSCDNs) at Windyhill, Longannet, Elvanfoot, Moffat and Cockenzie with a combined rating of 1275 MVAr. These devices are switched in and out as required operationally for voltage control or to support the system after a fault. In most cases, the MSCDNs will not be in service for extended periods of time, which helps to minimise power losses from these devices.

The losses in an MSCDN broadly arise from two sources: fundamental frequency (50 Hz) losses and losses due to the presence of harmonic voltages on the network. Under ideal conditions, the losses associated with a MSCDN are not very high, but the 50 Hz losses could rise to over 100 kW per installation due to changes in system frequency or due to component tolerances. Harmonic voltages can lead to significant losses in the damping resistors of MSCDNs. It is difficult to quantify the harmonic losses as harmonic voltages on the network vary considerably. In fact, switching the MSCDN in or out of service will itself have an impact on the harmonic voltage levels. Under worst-case conditions, the losses in the damping resistor could rise to several hundred kW, although the associated reduction in harmonic distortion on the network is beneficial and reduces the impact of distortion on other equipment and customers.

The design of MSCDNs has been standardised to the point where an evaluation of losses at tender stage does not have an impact on the choice of supplier. The variation between suppliers is minimal, depending only on small component-level variations.

4.5. Series compensation

The installation during the RIIO-T1 period of four series capacitors on the Anglo-Scottish interconnector circuits provides an illustration of our approach to new types of equipment. Tenders were evaluated on a whole-life cost basis and losses were included in this calculation. Tenderers were required to submit a detailed loss calculation report, considering a range of operating conditions and the impact of component tolerances. For tender evaluation, the losses at 50% load and nominal component values were used, as this was considered a realistic operating point for comparison on an intact network.

We opted for fixed series capacitors with passive bypass filters for sub-synchronous resonance mitigation. The losses in these installations are more susceptible to changes in system frequency and variations in component tolerances than competing technologies such as thyristor controlled series capacitors. However, under normal operating conditions, the losses were assessed as being lower than those of alternative options.

The final tender evaluation involved careful consideration of the sub-synchronous resonance risks, balanced against cost, a high availability requirement, losses and environmental impacts such as noise emission. The losses of the winning bid were assessed as approximately 70 kW per installation lower than the nearest competitor. These losses led to a difference in whole-life cost in the order of £100k per series compensation installation.

Note that when the series capacitors are not required for network operation, i.e. at time of lower power transfer, they are switched out (by closing a bypass circuit breaker). Although this is primarily an additional sub-synchronous resonance mitigation measure, it also eliminates losses from the series compensation equipment during such periods. An estimate of this out-of-service time was included in the calculation of the cost of losses.

It is important to understand that the series capacitors do not have a direct impact on the losses associated with the circuits in which they are installed. Although series compensation has the effect of reducing the overall circuit impedance, the resistance of the conductors remains unaffected. Series compensation actually allows higher transfers on the existing interconnector circuits, which will in turn lead to higher losses in these circuits. However, this has to be considered against the benefits of an increase of 1100 MW in the capability of the Anglo-Scottish interconnectors, which leads to increased utilisation of renewable generation and a considerable reduction in constraint costs associated with these circuits.

4.6. Western Link HVDC interconnector

One of our major projects in the RIIO-T1 period was the construction of the Western Link HVDC interconnector, which connects Hunterston in the SPT area to Flintshire Bridge in the National Grid transmission area and has a rated capacity of 2250 MW. When operating at rated current, the total losses of the link are in the order of 45 MW, which is significantly lower than the losses of an equivalent AC circuit of the same capacity and length. This includes losses in both converters and in the DC cable, but does not include losses in the harmonic filters or reactive compensation that have been installed at Hunterston as part of this project. It is difficult to predict the total losses as these will depend on the operating point of the link, as decided by the System Operator.

The Western Link is designed to minimise losses over and above the loss reduction that can be achieved by using HVDC technology instead of an AC interconnector. A good example is if the HVDC station control system detects that a shunt reactor and a harmonic filter (that is not required for harmonic performance) are switched in at the same time, it will switch out both devices to reduce losses. Although the reactive power control system will primarily control harmonics and system voltage, it will manage losses if there is an opportunity to do so.

5. THE IMPACT OF KEY DEVELOPMENTS AND ASSET REPLACEMENT

The key reinforcements and asset replacements across the SPT network in the RIIO-T1 period are described in other reports available on our website. Major developments include the Western Link, series compensation, and the installation of shunt reactors and capacitors, as described above. The impact of developments in each year is reviewed in our annual transmission losses reports published every October.

6. NEW TECHNOLOGIES AND INNOVATION

Our strategy is to remain informed of the latest technological developments in the field of electricity transmission and their impact in respect of transmission losses. New technologies may have a beneficial effect and help to reduce transmission losses but it is also possible that new technologies deployed to deliver benefits in other areas may actually result in higher losses. As described above, our approach is to assess the costs and benefits of each investment, examining losses in detail where they may be critical to the decision, then to procure equipment based on an assessment of whole lifetime costs, including losses.

Our major driver is to facilitate carbon reduction and other environmental improvements. Of particular relevance to our transmission system, there are currently technical limitations on the proportion of renewable energy that can be allowed to contribute to the energy mix at any given time. We are determined to play a full part in overcoming these by seeking to introduce new and innovative technology within our network that will support ever greater penetration of renewable energy on the whole energy system; examples of this in the RIIO-T1 period include Western Link and series compensation.

7. REPORTING AND STAKEHOLDER ENGAGEMENT

Special Condition 2K requires that we publish an annual report on transmission losses that includes:

- The level of transmission losses on our system;
- A progress report on implementation of this strategy; and
- Any changes or revisions made to the strategy.

It is difficult to accurately measure losses on the transmission network because it involves combining a large number of separate measurements of power flow at all points of input/output, and all of these separate measurements are prone to inaccuracies. As per an agreed methodology, to provide a consistent and coordinated approach to the measurement of transmission losses for each TO, NGESO calculates the

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losses across the whole GB system using settlement metering data from Elexon, which gives the power flow at each generator connection and grid supply point. The total is then apportioned to each transmission area based on SCADA measurements on the boundary circuits, with corrections applied as deemed necessary. SPT and other the TOs are therefore reliant on the data provided by NGESO to fulfil their obligations under SpC 2K.4.

The annual losses report is one means by which we engage with stakeholders, which provides an opportunity to inform our decisions, while encouraging the sharing of knowledge to help shape an industry-wide understanding of best practice for managing electricity losses in the context of a low carbon system. It is important that we position losses in the context of the environmental objectives and benefits that our business is at the heart of delivering for all customers. We consider that a whole systems approach that reduces carbon emissions is the most appropriate objective and that local initiatives to reduce losses as measured in isolation may not have the desired benefit overall. We remain engaged with our stakeholders to discuss common issues with respect to managing electricity losses.

We are committed to considering all reasonable measures which can be applied to reduce losses on the transmission system and adopting those measures which provide benefit for customers. As we continue to connect more renewable generation in Scotland we are working toward getting the most out of our existing assets and increasing the capacity of our network to accommodate this generation. At the same time, we are also aiming to improve the overall performance of our network. This includes careful consideration of losses and minimising these as far as possible in a way that balances capital investment, operational cost and environmental impact. We will continue to analyse and report losses to demonstrate how our decisions are helping to reduce losses where that is economic and efficient and consistent with wider environmental and stakeholder objectives.