SP Energy Networks

October 2019

Transmission Losses Report 2019

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1. INTRODUCTION

Special condition 2K of the SP Transmission plc (SPT) transmission licence requires SPT to publish an annual transmission losses report detailing the present level of transmission losses and progress on our strategy to minimise transmission losses. In April of this year we updated the Transmission Losses Strategy that describes our approach in the RIIO-T1 period to March 2021. Our strategy for the RIIO-T2 period is described in our T2 business plan, which is available on our website.

Based on metered data provided by National Grid Electricity System Operator (ESO) the total losses on the SPT network, i.e. the difference between energy flowing into and out of our network, for the period between 1 April 2017 and 31 March 2018 were 720 GWh[1], representing an operational cost of approximately £43.2 million[2]. Energy loss on the SPT network, as a percentage of the total energy transmitted, was 2.13% for the year. This is similar to the values seen in previous years, as summarised in Table 1.

Table 1. Summary of losses reported in previous years

	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Losses (TWh)	0.67	0.49	0.53	0.55	0.44	0.49	0.42	0.395	0.639	0.532
Losses (%)	1.81	1.46	1.54	1.47	1.30	1.29	1.17	1.13	2.12	1.52

Last year we noted that these values were being reviewed with the ESO. That review has concluded that the values reported previously, and as shown above, are correct according to the methodology applied by the ESO since 2005. While the methodology remains valid and suitable for producing the values reported here, it must be recognised that there are inherent errors in the metering data used to calculate transmission losses and revisions to that data, or the use of different methods in error correction, may produce different different results.

The following sections of this report discuss a number of factors that have an impact on losses and how they might change in future. It also outlines progress made towards improving the losses-related performance of our network and the impact of new technologies.

2. KEY FACTORS THAT INFLUENCE SPT TRANSMISSION LOSSES

2.1. Increased network power flows

Increased renewable generation connections in Scotland lead to increased power flows on our network and therefore to higher losses. The closure of other power stations, like Longannet in March 2016, also has an impact but the increase in power transfers due to new renewables is the largest contributor to the expected increase in transmission network losses.

Losses are proportional to circuit resistance, but also proportional to the square of the current flowing in those circuits. In other words, halving the resistance of a circuit will halve the losses in that circuit, but doubling the current will increase the losses by a factor of four. That means that if it has been possible to

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[1] The level of Transmission Losses from the licensee’s Transmission System, measured as the difference between the units of electricity metered on entry to the licensee’s Transmission System and the units of electricity metered on leaving that system as per licence special condition 2K.4 (a).

[2] In assessing the financial value of losses we have assumed £60/MWh, which is the value generally used in our cost benefit analyses.

halve the resistance in a circuit by using lower-loss conductors and/or increasing the number of conductors in the bundle, a 40% increase in current neutralises the benefit of the reduced circuit resistance.

Against a background of increased power transfers, achieving a reduction in total network losses would not be economic or efficient. However, we are working to reduce the losses associated with each unit of energy transmitted across the SPT network by considering losses and wider environmental impacts carefully when evaluating options for transmission reinforcements or asset replacement. For example, the cost benefit analysis we perform takes account of what can be achieved with options like low-loss transformers. This feeds into decisions on network development prompted by asset condition, customer connections or other reasons. In general, the cost of avoided losses alone is unlikely to justify the replacement or upgrading of a circuit or transformer.

2.2. Changes in distribution networks

The amount of generation connecting directly to the distribution network, rather than to the transmission system, continues to grow. This embedded generation can have the effect of offsetting demand, reducing the current through grid supply transformers and associated circuits and therefore reducing losses. At some grid supply points, however, the volume of embedded generation is significant and leads to a power flow from the grid supply point to the transmission network, potentially up to the available capacity limit. In some circumstances this might actually result in higher transmission system losses than without the embedded generation. The overall impact of embedded generation on transmission losses is therefore difficult to judge.

In recent years there has been a substantial reduction in reactive power demand at grid supply points, due to changes in demand and generation at distribution level, and this is expected to continue. The relationship between real power (MW) and reactive power (Mvar) can be described in terms of power factor, with a value of 1 indicating zero Mvar and lower values indicating greater amounts of reactive power. An improvement in power factor (for example from 0.95 to 0.98) leads to a small reduction in current and therefore a small reduction in losses[3], mainly in transmission feeders and grid supply point transformers.

In combination with embedded generation, the pattern of load on the network determines the time profile of power that is carried on the transmission network. Given that losses are proportional to the square of the current, a ‘peaky’ profile will result in more losses overall than a ‘flat’ profile that delivers the same amount of energy. Thus, changes in load, or embedded generation, that result in higher peaks in power transfer even if total energy transfer remains the same, will result in higher losses. The overall load profile shape is outside the control of SPT but is another factor that influences losses on our network.

3. THE IMPACT OF ASSET REPLACEMENT

3.1. 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

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[3] Assuming constant active power, this change in power factor leads to a load current reduction of about 3%. Losses are proportional to the square of the current. For example, a transformer with a load loss of 50 kW at 0.95 power factor, will have losses of 47 kW if the power factor of the load is improved to 0.98; a reduction of 6%.

the transformer losses, by capitalising the cost of these losses over the expected life-time of the transformer[4].

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 new 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 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.

3.2. 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, a reduction of 7.3%.

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 increase in power transfers due to the connection of new renewable generation.

3.3. 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 in recent years. At most sites 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 existing 33 kV, 60 MVAr shunt reactors were installed in the mid-1960s and typically have losses of 240 kW when energised. Modern shunt reactors of a similar rating have losses in the order of 160 kW. Note that shunt reactors are brought into service only when required, such as during light-load system

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[4] 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).

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. NEW TECHNOLOGIES

4.1. Series compensation

We recently installed four series capacitors on the Anglo-Scottish interconnector circuits. Tenders for this equipment 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 contributions 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 forms of generation and a considerable reduction in constraint costs associated with these circuits.

4.2. Shunt capacitors

In recent years we have 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 have an impact on the harmonic voltage levels. Under worst-case conditions, the losses in the damping resistor could rise to several hundred kW.

Note that 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.

4.3. Western Link HVDC interconnector

The Western Link HVDC interconnector 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 the SVC that have been installed at Hunterston as part of this project. It is difficult to predict the total losses of the link, e.g. over a year of operation, as these will depend on the operating point of the link, the operating point of the SVC and the number of harmonic filters and/or reactors switched in.

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.

Between April 2018 and March 2019, approximately 2.56 TWh of energy was transferred across the Western Link. This comprised of 2.55 TWh from Hunterston to Flintshire Bridge (north to south), and a much smaller 5.51 GWh in the opposite direction (south to north). Total losses in the primary plant amounted to approximately 76.7 GWh, where:

- 55.5 GWh was during north to south power transfer, equivalent to 2.17% of energy transferred
- 0.21 GWh was during south to north power transfer, equivalent to 3.87% of energy transferred
- 21.0 GWh was when power transfer was at or near zero

Focusing on the losses during north to south power transfer, the total splits approximately as follows:

- 18.5 GWh, 33%, in the primary plant of the Hunterston Converter Station
- 21.5 GWh, 39%, in the DC cables
- 15.5 GWh, 28%, in the primary plant of the Flintshire Bridge Converter Station

The Hunterston Converter Station also consumed approximately 7.78 GWh across the whole year for its auxiliary systems, supplied at 11 kV from the local distribution network. The Flintshire Bridge Converter Station, owned and operated by National Grid, will have consumed a similar amount for its auxiliary systems.

In 2018-19 the Western Link was still undergoing commissioning and subject to various periods of testing and being out of service. The energy transfers and losses observed in this year should not be considered indicative of future expected values. However, the values observed in this year do demonstrate total losses of approximately 3% when the link is transferring power, with slightly more than a third of those losses being incurred on the DC cables, approximately a third at the sending end converter station, and the remainder at the receiving end converter station. We will continue to monitor performance of Western Link and report on its performance in future losses reports.

5. SUBSTATION AUXILIARY SUPPLIES

The power supplies to our substations (for protection and control equipment, battery chargers, cooling systems, lighting, heating, etc.) are usually derived from secondary windings on 33 kV neutral earthing transformers. These supplies are not metered and substation demand, which is a transmission loss, is therefore not accounted for separately. Most equipment at substations is essential and could not be switched off. However, it may be that lighting and room heating for example, could be better controlled. We aim to identify where efficiencies can be made through energy saving measures and will implement these where it is cost effective to do so.

In 2018 we completed a project with Edinburgh Napier University and Logic Energy that involved the installation of energy metering at a number of transmission substations. Data was collected on power consumed, primarily for heating and lighting, and used to calibrate energy use models that were then used to assess the potential impact of energy-saving measures such as:

- Improved insulation in the walls, roof and floor of substation buildings
- Draught proofing to reduce heat loss, while maintaining adequate ventilation
- Replacement of doors or blocking out windows to improve insulation
- Lowering of heating set points, taking account of the risks of condensation build-up
- Replacement of lighting with LED equivalents
- Occupancy detection control of lighting

Based on initial cost estimates, the most cost effective option in most cases is to improve draught proofing, followed by improved roof insulation. In specific instances the lighting improvements may also be an economic option. The outcomes from this project have informed our plans for substation renovation in the RIIO-T2 period.

6. OTHER IMPACTS

As described above, for a given flow of power, the reduction of losses implies a reduction in series resistance of equipment or an increase in shunt resistances, such as the no-load losses of transformers. This has two important side-effects:

1. 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 or in line with our sustainability strategy. We will therefore continue to

strive to minimise transformer losses and are employing and investigating other methods to manage system fault levels.

2. 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. Increased harmonic levels themselves lead to increased losses, e.g. in MSCDNs as explained above or due to losses caused by harmonic currents flowing in circuits and equipment. In the longer term, changes in load characteristics (e.g. due to the increasing use of power electronic equipment) will also have an impact on system harmonics. We continue to keep our harmonic modelling techniques under review and also rely increasingly on direct measurements to manage harmonic levels on our network.

7. CONCLUSION

We are committed to reducing losses on our network wherever and however it is economic and efficient to do so. 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, monitor and record losses to demonstrate how our decisions are helping to reduce losses and thereby serving our customers better.