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Guidance on TNUoS modelling for HVDC circuits

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Contents

Disclaimer

In the event of any inconsistencies between this guidance note and the CUSC, then the latest CUSC will take precedence.

The latest CUSC can be downloaded from the National Grid Electricity System Operator website.

Background

For a transmission connected generator, its Transmission Network Use of System (TNUoS) tariffs consists of the following elements:

- **Local tariffs:** including onshore/offshore local substation tariffs and onshore/offshore local circuit tariffs. Local tariffs are designed to reflect the local infrastructure works needed to connect the generator into the wider transmission network.

- **Wider tariffs:** including the locational wider tariffs (rates that vary by zone, to send investment signals), and the non-locational wider tariffs (a flat rate across all zones to ensure accurate revenue recovery and compliance with relevant regulation)

TNUoS tariffs (including local and wider) are calculated by using the DCLF- ICRP (Direct Current Load Flow - Investment Cost Related Pricing) transport and tariff model. The transport model consists of all onshore transmission circuits which connect all onshore transmission substations, to form a simplified 'node-and-branch' version of the transmission network. The transport model calculates the marginal costs of providing additional network capacity at a location, by adding an additional 1MW of generation at each substation, and calculating the incremental cost incurred in the entire transmission network. The locational cost is measured in 'Megawatt-Kilometres' or 'MW*km' (for 1MW of capacity at a "node"), and is then converted into tariffs by using the expansion constant (in £/MWkm).

In order to calculate the MWkm costs, the transport model uses DC load flow (DCLF) to work out the MW loading on each of the circuit. The DCLF is an established methodology in transmission network simulations, and is based on a set of detailed assumptions; one of them being the network works under AC (Alternating Current) frequency (50Hz in the GB).

For a HVDC circuit, its MW loading may not be determined by DCLF alone. Therefore, the CUSC has set out special rules for the modelling of HVDC circuits by the DCLF, in order to determine non-ambiguous TNUoS tariffs.

The purpose of this guidance note is to clarify the approach and assumptions we use when modelling a three-terminal HVDC circuit in the TNUoS calculation.

Types of HVDC circuits

There are three types of HVDC circuits in the DCLF-ICRP model, categorised by different ways of modelling methodologies.

Two-terminal "parallel" HVDC circuits

CUSC 14.15.12 specifies the approach to set the impedance for HVDC circuits in the TNUoS model –
"*For HVDC circuits, the impedance will be calculated to provide flows based on a ratio of the capacity provided by the HVDC link relative to the capacities on all major transmission system boundaries that it parallels.* "

The "HVDC circuits" in the above paragraph refers to the HVDC circuits that run parallel with the wider AC transmission circuits. This type of HVDC circuits are built to provide additional network capacities for transmission system boundaries. CUSC 14.15.12 is applicable to this type of HVDC circuits.

We will use the term "parallel" to describe this type, as they provide wider network capacities for those boundaries they parallel. They are also referred to as "embedded HVDC" in some engineering documents. According to CIGRE (The International Council on Large Electric Systems), an embedded HVDC is defined as a DC link with at least two ends connected to a single synchronous AC network.

These "parallel" HVDC circuits are identified as "HVDC" in the DCLF-ICRP model.

To Western
Isles

Figure 1 The Western "bootstrap" HVDC   Figure 2 The Western Isles HVDC (planned)

Two-terminal "radial" HVDC circuits

The "parallel" HVDC circuit in

Figure 1 above has both ends connected to a single synchronous AC network (the GB network). In contrast, the planned Western Isles HVDC link (Figure 2) is a radial circuit connecting two separate HVAC grids (the GB grid and the Western Isles grid), with no AC circuits or transmission network boundaries running in parallel.

In the DCLF-ICRP model, the radial HVDC circuit is modelled as if it is a "cable" or "overhead line" (with its specific "unit cost", called the expansion factor). Any excessive generation on the Western Isles will flow 100% via the HVDC link to the GB network, with no other parallel paths. Therefore, altering its impedance does not change TNUoS tariffs.

Following the implementation of CMP320 (Island MITS Radial Link Security Factor), if the link is part of the "wider" network (i.e. not considered a 'local circuit'), its expansion factor in the DCLF-ICRP model will be adjusted to reflect the fact that there is no parallel path (and thus no redundant circuits for additional system security).

Three-terminal "hybrid" HVDC circuits

In Figure 3, the Caithness-Moray link (already built) is a "parallel" HVDC circuit which increases capacities across wider boundaries in North Scotland. The planned third terminal to Shetland is a radial link connecting to a separate HVAC network. Overall, this three-terminal HVDC circuit is a "hybrid" type in TNUoS modelling.

A three-terminal HVDC link is highly flexible at controlling the flows to each of its three ends. The TNUoS transport and tariff model, however, is aimed at deriving predictable and stable tariffs. Therefore, certain rules will be needed to specify how the MW flows on a three-terminal HVDC link are distributed.

Figure 4 shows the substations at each of the three terminals and the switching station in the middle, named Noss Head. The assumption we used when forecasting the TNUoS tariffs is also illustrated. The excessive generation from Shetland flows across the Kergord – Noss Head circuit, and then split evenly across Noss Head – Spittal and Noss Head – Blackhillock circuits. Without better information, the assumption of 50:50 split has been used in TNUoS 5-year view.

The 50% of energy flowing from Noss Head to Spittal will offset the predominant system flow (North to South), and thus reduce the loading on Spittal-Noss Head cable. The remaining 50% on the Noss Head-Blackhillock cable will increase its loading.
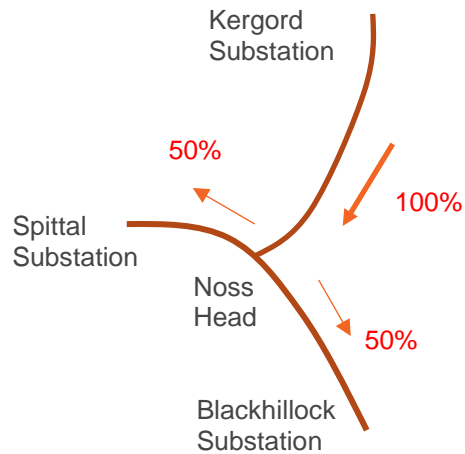

Figure 3   The Caithness-Moray-Shetland HVDC

Figure 4   The assumed flow distribution

Modelling a three-terminal HVDC link in the DCLF-ICRP model

Our approach is to separate the "radial" element of the HVDC link from its "wider" element to avoid any double counting of the cable lengths or MW flows. To do this, we have derived an equivalent model of the HVDC link as show in Figure 5.
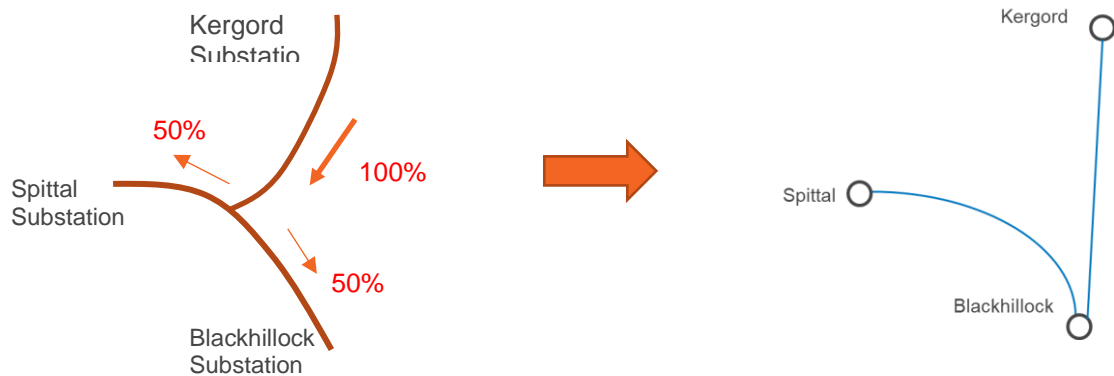

Figure 5   The equivalent model

In the equivalent model, the Spittal – Blackhillock link is a normal "parallel" HVDC, while the Kergord – Blackhillock circuit is a virtual circuit representing the marginal cost to transfer Shetland generation from Kergord to Blackhillock.

The length of this virtual circuit, running from Kergord to Blackhillock, is calculated by comparing the marginal cost at Kergord with the marginal cost at Blackhillock. The marginal cost difference is then translated into circuit length of the Kergord – Blackhillock "radial" link.

The marginal cost at Kergord, is the total of additional MWkm incurred on the entire network, caused by adding an extra 1MW at Kergord.
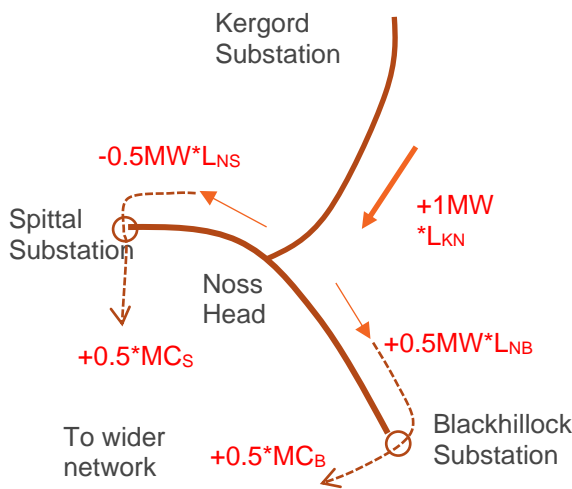
Figure 6 Impact on the network by the additional 1MW at Kergord

Figure 6 illustrates the marginal cost at Kergord, where MC_K , MC_s and MC_B are the marginal cost at Kergord, Spittal and Blackhillock respectively, and l_{KN}, l_{NS} and l_{NB} are the equivalent lengths of Kergord-Noss Head, Noss Head – Spittal and Noss Head – Blackhillock cables respectively.

On circuits where the additional flow offsets the predominant flow (the Noss Head – Spittal circuit in Figure 6) the incremental MWkm is negative.

Using equation to summarise Figure 6 we get the marginal cost at Kergord expressed below

$$MC_K = l_{KN} - (0.5 * l_{NS}) + (0.5 * l_{NB}) + (0.5 * MC_s) + (0.5 * MC_B)$$

By comparing the marginal cost at Kergord and the one at Blackhillock the equivalent length of Kergord – Blackhillock "virtual" circuit as in

Figure 7 can be calculated as below

$$
\begin{aligned}
l_{KB} &= MC_K - MC_B \\
&= l_{KN} - 0.5l_{NS} + 0.5l_{NB} + 0.5MC_s + 0.5MC_B - MC_B \\
&= l_{KN} - 0.5l_{NS} + 0.5l_{NB} + 0.5MC_s - 0.5MC_B
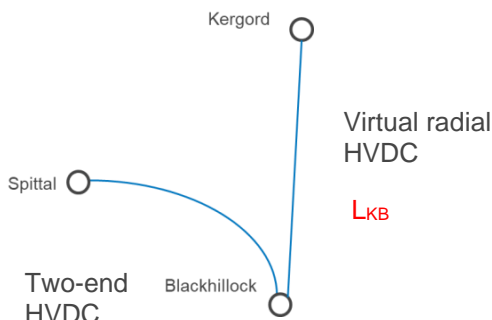\end{aligned}
$$

Figure 7 the equivalent model

The equivalent model in

Figure 7 is built in the DCLF-ICRP model, to represent the Shetland – Caithness – Moray three-terminal HVDC circuit.

Contact us

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