Proposed Treatment of HVDC Systems Under P229

High Voltage Direct Current (HVDC) transmission assets are not currently a feature of the Transmission System[1], but it is anticipated that this could change over the next few years (particularly in the offshore context). When the use of HVDC under P229 was raised, the P229 Modification Group asked ELEXON to develop a possible approach to include provision for HVDC within the BSC.

In developing this proposed approach, our main intention has been to allow P229 to support the two types of HVDC asset that were considered in the Task 10 modelling:

- HVDC circuits connecting one point on the AC Transmission System to another (e.g. an HVDC circuit from Scotland to England); and
- HVDC circuits connecting individual users (e.g. offshore wind farms) to the AC Transmission System.

However, we believe that the approach is sufficiently general to support more complex HVDC networks (e.g. an offshore HVDC network connecting multiple offshore wind farms to multiple points on the AC Transmission System).

Summary of Recommendations

The Modification Group is invited to agree the following recommendations:

- Recommendation 1 – HVDC circuits should be excluded from the Load Flow Model (because the nature of the power flows on DC systems makes it impractical for the TLFA to calculate them).
- Recommendation 2 – For the purposes of the Load Flow Model, any flow between the AC system and an HVDC circuit should be treated as an additional power flow (a 'DC Nodal power flow') at the Node on the AC system that represents the connection point.
- Recommendation 3 – Losses on HVDC circuits will be socialised through the TLMO mechanism (except where the HVDC circuit is serving specific, clearly identifiable users – see Recommendation 4).
- Recommendation 4 – If an HVDC circuit is specific to one or more users (e.g. a circuit connecting one or more offshore wind farms to shore), then the losses on that HVDC circuit will be incorporated into the Nodal TLF values for that user or users, and hence into the appropriate Zonal TLF. Note that this adjustment of Nodal TLF values will have to be done outside the Load Flow Model proper, using data on the actual measured HVDC losses in each Sample Settlement Period.
- Recommendation 5 – When averaging Nodal TLF values to derive a Zonal TLF, DC Nodal power flows will be taken into account if they represent genuine demand or generation connected to the HVDC system, but not if they are internal to the Transmission System.
- Recommendation 6 – In order to implement Recommendations 2 and 4, settlement metering should be installed at each point of connection between the AC Transmission System and the HVDC Transmission System.
- Recommendation 7 – The P229 solution does not need to include drafting for an 'HVDC sandwich' i.e. two separate parts of the AC Transmission Systems joined only by HVDC circuits.

The remainder of this note explains the thinking behind these seven recommendations.

[1] There are HVDC connections to France and Northern Ireland, but these are not part of the GB Transmission System. The treatment of losses on these Interconnectors is therefore outside the scope of P229.

Recommendation 1 – Exclude HVDC Circuits from the Load Flow Model

We understand (from discussion with Siemens PTI and National Grid) that HVDC flows are different in nature to AC flows:

- The flow on an AC circuit depends on the generation and demand at different points on the system, and on the characteristics of the network itself. This means that the TLFA can calculate the flows of energy caused by a given set of nodal injections, and hence calculate TLF values that reflect the impact on total losses of additional demand or generation at any point on the system.
- In contrast, the flow on a DC circuit is determined by an operational decision. For example, somebody sets the flow to be 975MW. This could be due to system operation reasons or due to trading requirements or due to combination of these. This level of flow can be reset very frequently and even the resetting automated, but still, in principle, the flow is fixed and maintained fixed (until reset).

For this reason, we do not believe that it will be possible to include HVDC assets in the Load Flow Model.

Recommendation 2 – DC Nodal Power Flows

The question of how to treat HVDC circuits was considered in modelling Task 10, which included two HVDC connections from Scotland to England. The HVDC circuits themselves weren't included in the Load Flow Modelling, but the flows between the HVDC system and the AC Transmission System were. Each HVDC circuit therefore appeared in the Load Flow Model as additional demand in Scotland, and additional generation in England.

We propose to take the same approach in the enduring P229 solution i.e. additional Nodal power flows will be introduced into the Load Flow Model at each point where the AC Transmission System connects to an HVDC Transmission asset.

For example, suppose that Nodes A and B on the AC Transmission System are joined by an HVDC circuit, which (in a particular Sample Settlement Period) transmitted 800 MWh from A to B (with losses of 10 MW). The Load Flow Model for that Settlement Period will have 800 MWh of demand added at Node A, and 790 MWh of generation added at Node B.

This approach to handling HVDC assets means that two different types of Nodal power flow will need to be input into the Load Flow Model:

- Flows between users (i.e. BM Units, GSPs or Interconnectors) and the AC Transmission System. These are the Nodal power flows that were recognised in previous Modification Proposals (e.g. P203), and for the purpose of this note will be referred to as '**AC Nodal power flows**'.
- Flows between the HVDC and AC parts of the Transmission System. These have not been allowed for in previous Modification Proposals, and for the purposes of this note will be referred to as '**DC Nodal power flows**'.

Recommendation 3 – Losses on HVDC Circuits

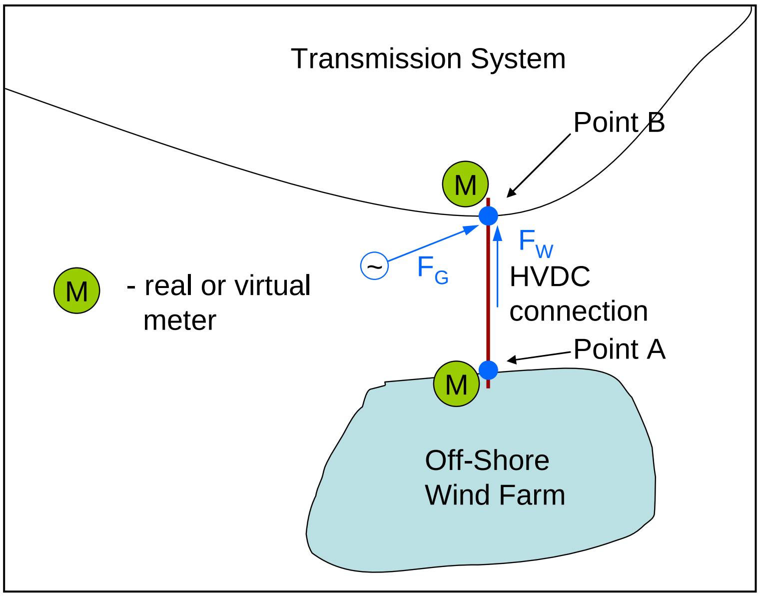
The implication of the approach outlined above is that (unless the circuit is serving specific identifiable users *as per* Recommendation 4) losses on HVDC circuits will not be reflected in TLF values, and will therefore be socialised through the TLMO calculation.

The reason for this is that we have no way of attributing the losses on the HVDC circuit to particular Nodes or users. Where losses are incurred on an AC circuit, we can identify (through Load Flow Modelling) the impact on those losses of additional demand or generation at any point on the system, and therefore (P229 argues) the losses can be attributed to Zones in a cost-reflective manner.

Where losses are incurred on a DC circuit, we cannot identify the impact that individual Nodes on the system had on those losses. It is therefore proposed that these losses are not reflected in the calculated TLF values (and are therefore apportioned through the TLMO mechanism, like fixed losses).

Recommendation 4 – HVDC Circuits Specific to Particular Users

As described above, recommendation 3 is based on the premise that, in general, flows (and therefore losses) on HVDC circuits cannot be attributed to specific users. However, there will be some HVDC networks where the topology of the network is such that flows are attributable to one or more specific users. For example, if an HVDC circuit connects a single offshore platform to shore, then all the flows on that point-to-point connection must be caused by the BM Unit (or BM Units) attached to that platform.



The diagram (to the right) illustrates this type of configuration. An HVDC circuit connects an offshore wind farm (at point A) to the AC Transmission System (at point B). Point A is not included in the Load Flow Model (see recommendation 1), but Point B is. The Nodal power flows for Point B include both:

- AC Nodal power flows from any onshore BM Units connected to that Node. For illustrative purposes, the diagram assumes there is an onshore generator with power flow F_G onto the AC Transmission System; and
- DC Nodal power flows from the HVDC circuit. The diagram shows this as F_W i.e. the flow of power generated by the offshore wind farm (less the losses on the HVDC connection).

Using these values, the Load Flow Model will calculate a Nodal TLF for point B that represents the impact of F_G and F_W on the total losses on the AC system. However, this TLF value does not reflect the additional losses on the HVDC circuit. It is therefore proposed that the TLFA should calculate an adjustment to the TLF that reflects the additional losses caused by F_W on the HVDC circuit. Note that this adjusted TLF applies only to the DC Nodal power flow F_W; the original TLF value continues to apply to the AC Nodal power flow (F_G).

The required adjustment to the TLF value is given by:

$$\text{TLF adjustment (to allow for HVDC losses)} = 2 \times \text{Measured Losses on HVDC Circuit} / F_w$$

Annex 1 to this note provides an explanation of this equation. Note that the factor of 2 is required because this is an un-scaled TLF (representing marginal losses, not average losses).

The overall Nodal TLF for the offshore wind farm is therefore[2]:

$NTLF^{TW}_{newB} = NTLF_B + (2 \times \text{Measured Losses on HVDC Circuit} / F_w)$

where $NTLF_B$ is the unadjusted TLF for Node B, and $NTLF^{TW}_{newB}$ is the adjusted TLF that applies only to the flow F_W.

Recommendation 5 – Treatment of DC Nodal Power Flows in Averaging Process

P229 proposes that settlement should be based on Zonal rather than Nodal TLF values. It therefore includes an averaging process that determines a Zonal TLF for each Zone and Sample Settlement Period:

$$TLF_{Zj} = \Sigma_N (TLF_{Nj} * QM_{Nj}) / \Sigma_N QM_{Nj}$$

where for that Settlement Period, and for each Node in that Zone (determined by the TLFA on the basis of the initial network mapping statement):

TLF_{Nj} *is the value of Nodal TLF; and*

QM_{Nj} *is the absolute value of the Nodal power flow;*

and where Σ_N *is summation by Node in a Zone.*

The Modification Group has previously discussed the rationale for this volume-weighted averaging at some length (in response to the PTI observation that the Zonal TLF values will tend to under-recover losses compared to the Nodal TLF values). The conclusion reached was that averaging methodology should seek to minimise the errors in losses allocated to each Node by the settlement process.

The implication of using this criterion is that DC Nodal power flows should be taken into account in the Zonal averaging if and only if those flows are themselves included in the settlement process:

- A flow on an HVDC circuit that joins two points on the AC Transmission System (but has no demand or generation connected to it) is not included in settlement, and should therefore not be included in the zonal averaging. To illustrate this idea, consider a hypothetical Zone that only contains two Nodes: one with BM Units connected to it, and one with an HVDC circuit connected to it. All the energy attributed to that Zone in the settlement process would be connected to the first node, and it is therefore appropriate that the TLF for that Zone should be the TLF of the first Node, not a weighted average of the two TLF values.
- A flow on an HVDC circuit that represents energy generated (or consumed) by users of the HVDC Transmission System will be included in settlement, and should therefore also be included in the zonal averaging process. An example of this is the HVDC connection to shore discussed in Recommendation 4 above. The flow F_W from the HVDC circuit represents generation from the wind farm, which will be included in settlement, and which should therefore be included in the zonal averaging with an appropriate TLF value $NTLF^{TW}_{newB}$ (as discussed in Recommendation 4 above).

Recommendation 6 – Metering at Points of Connection Between AC and DC

In order to implement recommendations 2 and 4 above, we need to know the flow of energy (in each Sample Settlement Period) at each point of connection between the AC and HVDC portions of the Transmission System. Broadly speaking, there would seem to be two options for achieving this:

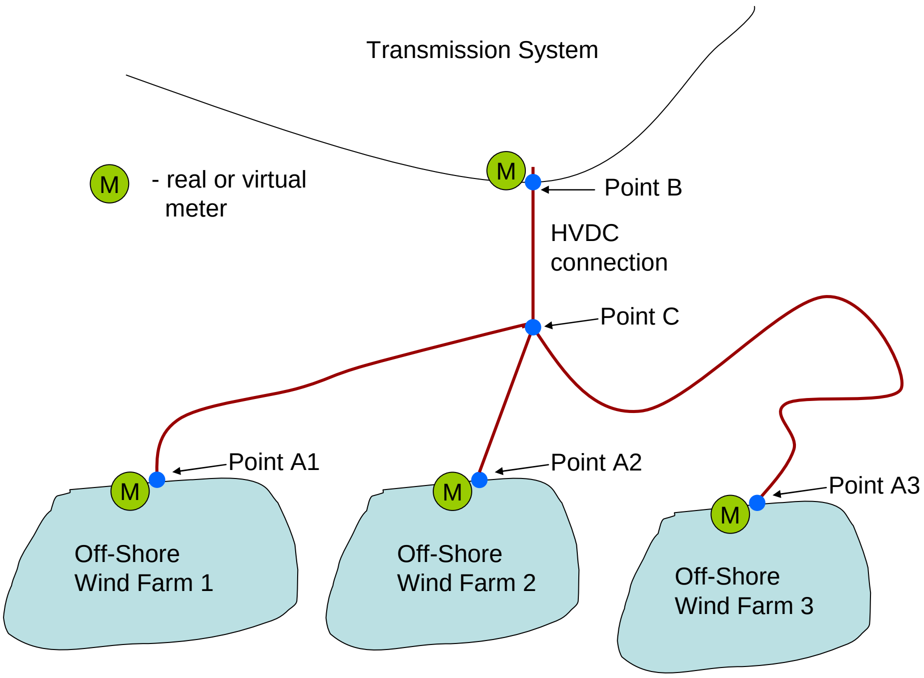
[2] The '+' sign in this equation is intended to represent an increase in the volume of losses attributed to the Node. How this is achieved arithmetically (i.e. whether the adjustment is added to or subtracted from the TLFB value) depends on the sign conventions used for TLF values. Annex 1 discusses this further.

- Option 1 - Install settlement metering at each point of connection, so that CDCA can read the meters and calculate the power flows in each Sample Settlement Period. Note that this metering would be required only for use in calculating TLF values; the data would not be used in settlement itself (as internal Transmission System flows are not relevant to settlement); or
- Option 2 - Use other sources of data (e.g. operational metering, or data from the HVDC control system) to estimate the flows in each Sample Settlement Period.

Our initial thought (subject to the views of the Modification Group and the Transmission Company) is that option 1 probably represents a more transparent and appropriate method of calculating TLF values.

Recommendation 7 – Treatment of a DC Sandwich

As offshore HVDC networks become more complex, situations may eventually arise in which an HVDC circuit connects two otherwise unconnected portions of the AC Transmission System. The following diagram illustrates this:



If the circuits connecting points A1, A2 and A3 to point C are AC, then they should be included in the Load Flow Model. However, they are separated from the rest of the AC Transmission System by the HVDC connection from Point C to point B.

We believe that, in principle, this issue is similar to the 'DNO sandwich' issue that the Group has already discussed. The 'HVDC sandwich' (like the DNO sandwich) can be addressed by the TLFA 'joining up' the two parts of the AC Transmission System in the Load Flow Model.

However, as this situation is (as far as we're aware) totally hypothetical, we don't necessarily propose to include it in the solution. Instead (unless the Modification Group specifically want us to include it in the legal drafting) we can simply note that, were such a scheme ever to be proposed, the BSC could be changed to handle it in a similar way to a DNO sandwich.

A Mathematical 'Trick' for Simplifying the Calculation of Zonal TLFs

In order to make clear the rationale for the proposed approach, the previous sections of this document described the calculation of two types of TLF values:

- For AC Nodal power flows QM^{AC}_{Nj}, we use normal TLF values TLF_{Nj} from the Load Flow Model. These TLF values represent losses on the AC system only;
- For DC Nodal power flows QM^{DC}_{Nj} (arising from generation or demand on the DC system) we adjust the TLF value from the Load Flow Model to allow for losses on the HVDC network. The adjusted TLF is equal to[3]:

  $$\text{Adjusted TLF} = TLF_{Nj} - 2 * Losses^{DC}_{Nj} / QM^{DC}_{Nj}$$

  where $Losses^{DC}_{Nj}$ is the amount of generation or demand on the DC system that is lost as losses on the DC network before reaching the AC Transmission System.

However, because we're actually only interested in Zonal TLF values, we don't have to calculate the Adjusted TLF values explicitly. The equation for volume weighted averaging of Nodal TLF values (as used in previous losses Mods) is as follows:

$$TLF_{Zj} = \Sigma_N\, TLF_{Nj} * QM^{AC}_{Nj} \;/\; \Sigma_N\, QM^{AC}_{Nj}$$

If we now extend this equation to include DC Nodal power flows (and their adjusted TLF values) we get:

$$TLF_{Zj} = \Sigma_N \{TLF_{Nj} * QM^{AC}_{Nj} + (TLF_{Nj} - 2 * Losses^{DC}_{Nj} / QM^{DC}_{Nj}) * QM^{DC}_{Nj}\} \;/\; \Sigma_N (QM^{AC}_{Nj} + QM^{DC}_{Nj})$$

This simplifies to:

$$TLF_{Zj} = \Sigma_N \{TLF_{Nj} * (QM^{AC}_{Nj} + QM^{DC}_{Nj}) - 2 * Losses^{DC}_{Nj}\} \;/\; \Sigma_N (QM^{AC}_{Nj} + QM^{DC}_{Nj})$$

Or, if we use QM_{Nj} to mean the sum of QM^{AC}_{Nj} and QM^{DC}_{Nj}:

$$TLF_{Zj} = \Sigma_N (TLF_{Nj} * QM_{Nj} - 2 * Losses^{DC}_{Nj}) \;/\; \Sigma_N\, QM_{Nj}$$

Expressing the formula in this way removes the need for explicit calculation of adjusted TLF values (but is mathematically equivalent to calculating them).

Summary of Proposed Changes to Legal Text

We are still working on legal text for P229. However, we anticipate that the following provisions will be required to implement the above recommendations:

- Sections K and L will be amended to introduce a new obligation to meter HVDC Connections i.e. points where HVDC transmission assets connect to the AC Transmission System;
- Section R will be amended to recognise HVDC Connections as a new form of Volume Allocation Unit;
- In Section T, the definitions of Load Flow Model and Network Data will be changed to clarify that they relate only to the AC portion of the Transmission System;

[3] At this point I have switched from the TLFA sign convention (in which a positive TLF means that generation increases losses) to the settlement sign convention (in which a positive TLF means that generation decreases losses), and hence the sign in the equation has changed from a plus to a minus.

- In Section T, the definition of the Network Mapping Statement will be amended to include details of the Node at which each HVDC Connection joins the AC Transmission System;
- In Section T, the process of deriving TLF values will be amended to recognise that the TLFA must calculate (and use in the Load Flow Model) DC nodal power flows in addition to AC nodal power flows
- In Section T, the equation for calculating Zonal TLF values will be amended as follows:

$$TLF_{Zj} = \Sigma_N (TLF_{Nj} * QM_{Nj} - 2 * Losses^{DC}_{Nj}) \ / \ \Sigma_N QM_{Nj}$$

where:

- TLF_{Nj} is the Nodal TLF calculated for Node N by the Load Flow Model (representing variable losses on the AC Transmission System);
- QM_{Nj} is the sum of all relevant power flows at the Node (i.e. AC Nodal power flows plus those DC Nodal power flows that represent generation or demand on the DC system)
- $Losses^{DC}_{Nj}$ is the volume of generation or demand on the DC system lost on the DC system before reaching Node N on the AC Transmission System

Annex 1 – Derivation of Adjustments to TLF Values

This Annex provides further details on the method for adjusting a Nodal TLF value to include losses on HVDC networks.

A Note on Sign Conventions

The sign convention used in this Annex is that losses and generation are both positive quantities, and TLF values represent the rate of change of losses with additional generation at a Node. A positive TLF value therefore indicates that additional generation at a Node increases the losses on the system. This is the natural sign convention for load flow modelling, but is the opposite to the one used in settlement.

The approach taken in previous attempts to implement Zonal losses has been for the TLFA to use the 'natural' sign convention within its Load Flow Model, but to convert to the 'settlement' sign convention when reporting TLF values to settlement.

For P229 we will need to give careful attention to these issues in the legal text, in order to ensure that the correct adjustments are made to TLF values to represent HVDC losses.

Explanation of Equation for TLF_W

Consider the diagram of an offshore wind farm in the main body of the document (Recommendation 4), and define the following quantities:

$NTLF_B$ - "un-reconciled" nodal TLF at node B – i.e. it is not scaled; it is obtained from the current calculations method directly

$SYSL$ - total "un-reconciled" system variable losses; note that these losses are calculated independently of calculating TLFs, we calculate them after TLFs for reporting reasons (i.e. having them are not needed for calculation of TLFs).

F_G - nodal flow at Point B due to the small generator (so, part of the total net nodal flow at Point B).

F_W - nodal flow at Point B due to the wind farm (so, part of the total net nodal flow at Point B); note that the nodal flow due to the wind farm at Point A would be larger than F_W for the losses on HVDC connection (between Point A and Point B) – i.e. part of that nodal flow at Point A is lost on the HVDC connection before "arriving" at Point B

Note that with respect to the system modelling F_G has a more usual meaning as an "injection" or "nodal flow". F_W appears in this modelling as an "injection" or "nodal flow" since we do not actually model the HVDC connection, F_W represents the effect of this connection (that would be the flow on the connection, arriving to that node, Point B, that we now model as nodal flow, the same value "arriving" to that node, point B).

$SYSL_G$ - part of $SYSL$ attributable to the small generator at Point B (all "un-reconciled"); this is calculated as $SYSL_G = NTLF_B \times F_G$

$SYSL_W^{AC}$ - part of $SYSL$ attributable to the nodal flow at Point B due to the wind farm (all "un-reconciled"); this is calculated as $SYSL_W^{AC} = NTLF_B \times F_W$; index AC is used to denote that these "un-reconciled" losses take place in the entire AC transmission system (due to the nodal flow F_W at Point B)

$SYSL_W^{DC}$ - losses on the HVDC connection; they would be either measured or estimated/calculated; **these losses are comparable to "reconciled" losses**; therefore, in the DC modelling approach (i.e. linearised AC approach) to calculating TLFs, in order to compare/utilise these losses with $SYSL_W^{AC}$ losses they have to be multiplied by 2; so, $2 \times SYSL_W^{DC}$ are comparable to "un-reconciled", and thus to $SYSL_W^{AC}$.

$SYSL_W^{TOT}$ - total “un-reconciled” losses attributable to the wind farm; they are composed of

$SYSL_W^{TOT} = SYSL_W^{AC} + 2 \times SYSL_W^{DC}$

$NTLF_{newB}^{TW}$ -“total” nodal TLF at Point B exclusively for the wind farm that returns $SYSL_W^{TOT}$ when applied to F_W, i.e. $NTLF_{newB}^{TW} \times F_W = SYSL_W^{TOT}$; the indexing “newB” indicate “decoupling” from $NTLF_B$ - normally a nodal TLF is applicable equally to the net nodal flow and any constituent nodal flow at that node; therefore it would be suitable introduce (even if in a “hidden” way) a new node, Point “newB”; this is not exactly as node Point A, but for our purpose the effect is the same – the reason is that we do not use wind farm’s nodal flow at Point A, but the wind farm’s nodal flow at Point B

$NTLF_{newB}^{TW}$ is determined as follows:

$$SYSL_W^{TOT} = SYSL_W^{AC} + 2 \times SYSL_W^{DC}$$
$$NTLF_{newB}^{TW} \times F_W = NTLF_B \times F_W + 2 \times SYSL_W^{DC}$$
$$NTLF_{newB}^{TW} = NTLF_B + \frac{2 \times SYSL_W^{DC}}{F_W}$$

Conditions for the above are that we will need to know constituent nodal flows at Point B and the losses on HVDC connection.

