



Guidance on calculating and compensating for power transformer and cable (or line) losses - standard methods

Foreword

This guidance sets out basic standard methods for calculating electrical loss compensation factors for power transformers and cables (or lines) that need to be applied to Half Hourly Metering Systems (HHMS) used for Settlements purposes. This is in the event the measurement transformers for a HHMS cannot be located at the Defined Metering Point (DMP), as set out in the relevant metering [Code of Practice](#) (CoP). Due to this non-compliance with the requirements of the CoP the Registrant of the HHMS needs to apply for a Metering Dispensation and it may be necessary to compensate the HHMS for electrical losses in any power transformers and/or cables (or lines) between the Actual Metering Point (AMP) and the DMP.

Purpose

The purpose of this guidance is to assist Registrants/Meter Operators Agents (MOAs) in calculating these compensation factors and to provide assurance to the BSC Panel and industry participants that, where compensation is to be applied to a new HHMS¹ under a Metering Dispensation, suitable compensation factors for electrical losses in any power transformer and/or cable (or line), between the AMP and the DMP, are applied to that HHMS before the Metering System Effective From Date.

The Electrical Loss Validation Agent (ELVA) will validate the compensation factors provided for any new Metering System as part of the Metering Dispensation application process ([BSCP32](#)²).

In addition, as part of the Technical Assurance of Metering (TAM) technique as set out in [Section L](#)³ (7) of the Balancing and Settlement Code (BSC) and [BSCP27](#)⁴, the Technical Assurance Agent (TAA) will continue to request values of any compensation⁵ applied (including evidence to support the applied values) to any HHMS (i.e. existing or new) from the Registrant or its MOA.

BSC Requirements

[Section K](#)⁶ of the BSC requires Active Energy, and where relevant, Reactive Energy flowing across Boundary Points⁷ to the Total System⁸, and flowing between Systems⁹ at Systems Connection Points¹⁰ (SCPs), to be measured and recorded by compliant Metering Equipment.

¹ From the implementation date of CP1485.

² 'Metering Dispensations'

³ 'Metering'

⁴ 'Technical assurance of Half Hourly Metering Systems for Settlements purposes'

⁵ Including any compensation for measurement transformer errors.

⁶ 'Classification and Registration of Metering Systems and BM Units'

Section L of the BSC requires Metering Equipment to comply with the relevant CoP at the time the Metering Equipment is first registered as a Metering System for Settlement purposes.

The metering [CoPs](#) set out the DMPs at which overall accuracy of the Metering System is to be maintained. Where measurement cannot take place at the DMP for a particular circuit then a Metering Dispensation needs to be applied for and approved.

Where the AMP and the DMP do not coincide CoPs 1, 2, 3 and 5 require compensation for any electrical losses in any power transformer and/or cable (or line) between the AMP and the DMP to be considered and, if necessary, applied to the Settlement Meter(s) or via the Data Collector's system. This may need to be done to ensure that overall accuracy is maintained within the limits set out in the relevant CoP at the DMP (e.g. for CoP1¹¹ the overall accuracy limits at the DMP for Active Energy are $\pm 0.5\%$ for 120% to 10% rated current at Unity Power Factor).

A standard method for deriving compensation factors for power transformer losses

In order to calculate the electrical losses in a power transformer it will be necessary to obtain relevant information about the power transformer, including the power transformer test sheet.

Power transformers are typically tested to determine the electrical losses associated with them when operating under no-load conditions and full load conditions. Electrical losses at other loads will need to be derived from these figures.

The two tests used to determine the Active Power (watt) losses (and sometimes the Reactive Power (var) losses) associated with a power transformer are:

- the open circuit test; and
- the short circuit test.

Open circuit test

In the open circuit test the no-load (iron) watt losses are determined by applying the rated voltage to one of the power transformer's windings¹² and measuring the winding current (known as the no-load, exciting or excitation current) and power (watts). This is done with the other winding open circuited (i.e. with no load connected).

Short circuit test

In the short circuit test the full load (copper) watt losses of the power transformer are determined by shorting one of the power transformer's windings¹³ (through an ammeter - a device for measuring

⁷ Section X Annex X-1 define a Boundary Point as a point at which any Plant or Apparatus not forming part of the Total System is connected to the Total System.

⁸ Section X Annex X-1 defines the Total System as the Transmission System, each Offshore Transmission System User Assets and each Distribution System.

⁹ Section X Annex X-1 defines System as the Transmission System, a Distribution System or Offshore Transmission System User Assets.

¹⁰ Section X Annex X-1 defines Systems Connection Point as a point of connection (whether consisting of one or more circuits) between two or more Systems excluding: (a) a point of connection between Distribution Systems in the same GSP Group; and (b) a point of connection between Offshore Transmission System User Assets and the Transmission System.

¹¹ 'Code of Practice for the metering of circuits with a rated capacity exceeding 100MVA for Settlement purposes'

¹² The test voltage can be applied to either the higher voltage winding or the lower winding to do this test.

¹³ Either the higher voltage winding or the lower voltage winding can be shorted to do this test and a small voltage applied to the other winding.

current) and applying a small voltage to the other winding which is gradually increased until the rated full load current flows in the shorted winding. The current that flows in the other winding as a result is measured and the power (watts) being supplied to the other winding is also measured. Since full load current is circulating in the shorted winding, the windings have the same power loss as on full load.

Calculating power transformer electrical losses

The results from the power transformer test sheet can also be used to calculate losses that aren't directly provided (e.g. no load (iron) and full load (copper) var losses). Also, the losses that occur at different load conditions other than no-load or full load can be calculated by appropriate scaling factors.

Some Meters can be programmed with the relevant parameters from the transformer test sheet and automatically calculate and add or subtract the losses to/from the measured quantities (known as dynamic compensation) seen by the Meter (i.e. taking into account the correct measurement transformer ratios¹⁴). Different Meter types will have different methods of calculating and applying loss compensation so the Meter manufacturer's documentation should be consulted.

The power transformer test sheet will usually provide the following information:

- rated apparent power of the power transformer (VA_{test});
- rated primary voltage of the power transformer (kV);
- rated secondary voltage (kV);
- no-load (iron) watt losses ($NLWFe_{test}$) – the Active Power consumed by the transformer's core at rated voltage with no load current (during the open circuit test)
- full load (copper) watt losses ($FLVCu_{test}$) - the Active Power consumed by the transformer's windings at full load current for rated VA (during the short circuit test);
- % excitation current - the ratio of the no-load test current (at rated voltage) to the full load test current; and
- % impedance - the ratio of the full load test voltage (at rated current) to the rated voltage.

If the no-load (iron) var losses and full load (copper) var losses are not provided these can be calculated using some of the information provided above, as follows:

$$\bullet \quad NLVFe_{test} = \sqrt{\left(VA_{test} * \frac{\%Excitation}{100} \right)^2 - (NLWFe_{test})^2}$$

$NLVFe_{test}$ is the no-load vars lost in the power transformer's iron core under test conditions.

$$\bullet \quad FLVCu_{test} = \sqrt{\left(VA_{test} * \frac{\%Impedance}{100} \right)^2 - (FLVCu_{test})^2}$$

$FLVCu_{test}$ is the full load vars lost in the power transformer's copper windings under test conditions.

To determine the losses at actual operating voltages¹⁵ and currents the test losses must be scaled by the actual voltage or current:

$$\begin{aligned} \bullet \quad NLWFe_{actual} &= NLWFe_{test} * \left(\frac{V_{actual}}{V_{test}} \right)^2 \\ \bullet \quad FLVCu_{actual} &= FLVCu_{test} * \left(\frac{I_{actual}}{I_{test}} \right)^2 \\ \bullet \quad NLVFe_{actual} &= NLVFe_{test} * \left(\frac{V_{actual}}{V_{test}} \right)^4 \end{aligned}$$

¹⁴ The Meter may also need to be compensated to account for any measurement transformer ratio and phase angle errors.

¹⁵ Special care must be taken when calculating magnetic core losses if the voltage level on the primary winding changes, for example, due to a tap change. A tap change will alter the maximum flux level in the power transformer iron core and this will alter the eddy current and hysteresis losses. If the tap position doesn't normally change the nominal tap can be assumed.

- $FLVCu_{actual} = FLVCu_{test} * \left(\frac{I_{actual}}{I_{test}}\right)^2$

If the actual voltages and current are the secondary voltages and currents from the measurement transformers, as seen by the Meter, then these readings need to be scaled by the current transformer ratio (CTR) or the voltage transformer ratio (VTR), as appropriate, to give the primary circuit¹⁶ values:

- $NLWFe_{actual} = NLWFe_{test} * \left(\frac{V_{secondary} * VTR}{V_{test}}\right)^2$
- $FLWCu_{actual} = FLWCu_{test} * \left(\frac{I_{secondary} * CTR}{I_{test}}\right)^2$
- $NLVFe_{actual} = NLVFe_{test} * \left(\frac{V_{secondary} * VTR}{V_{test}}\right)^4$
- $FLVCu_{actual} = FLVCu_{test} * \left(\frac{I_{secondary} * CTR}{I_{test}}\right)^2$

Care should be taken when performing loss calculations where equipment other than the power transformer lies between the DMP and the AMP, for example, power factor correction equipment, other 'parasitic' loads (e.g. lighting or heating in a substation for instance) and lengths of cable or line.

¹⁶ i.e. the current flowing in the conductors which make up the primary winding of the current transformer and voltage of the conductors connected to the primary winding of the voltage transformer.

A standard method for deriving compensation factors for cable (or line) losses

Cables and lines are not 100% efficient at transferring power. Energy (Active and Reactive Energy) is lost (or generated in the case of Reactive Energy due to capacitance) transmitting power over the length of the cable or line due to the following factors:

- the (series) resistance (R) of the cable or line;
- the (series) inductive reactance (X_L) of the cable or line;
- the (shunt or parallel) capacitive reactance (X_C) of the cable or line; and
- the (shunt or parallel) leakage resistance¹⁷ ($r_{leakage}$) of the cable or line.

For short cables or lines the main factors to consider when estimating the losses are the series resistance¹⁸ (which contribute to the watt losses) and series inductive reactance (which contribute to the var losses).

Remember that the resistance of the conductors changes with temperature so the typical operating temperature of the conductor must be taken into account when performing loss calculations.

With longer lengths of cable or line the effects of capacitive reactance and leakage resistance need to be considered. These calculations are more complex and are not covered in this guidance.

The manufacturer of the cable or line will provide the tested electrical parameters of the cable or line, e.g.:

- resistance (r) per unit length (Ω/m) per conductor (at a given temperature)
- reactance (x) per unit length (Ω/m) per conductor

If the impedance (z) per unit length (Ω/m) of conductor is given in complex (notation) form, e.g. $r + jx$, then r and x can be taken from this.

Knowing the total length (l) of the conductors that form the cable or line, the total series resistance (R) and total series inductive reactance (X_L) of each conductor can be calculated by multiplying the per unit length figure (r or x) by the length (l):

$$R = r * l$$

$$X_L = x * l$$

The total resistance (R) of the each conductor contributes to Active Power losses (P) and the inductive reactance (X_L) contributes to the Reactive Power losses (Q).

Since the power lost due to resistance is:

$$P = I^2 * R$$

and the power lost due to inductive reactance is:

$$Q = I^2 * X_L$$

Then, for a 3 phase system, the losses for each phase are calculated separately according to the current flowing in each phase (a, b and c):

¹⁷ This refers to the dielectric losses in insulated cables and on higher voltage lines the losses due to current leaking into the surrounding air (coronal discharge). Dielectrics also suffer from hysteresis losses.

¹⁸ It may also be necessary to consider losses in cable screens but these are generally much lower than losses associated with the conductors themselves.

$$P_a = I_a^2 * R_a$$

$$P_b = I_b^2 * R_b$$

$$P_c = I_c^2 * R_c$$

and

$$Q_a = I_a^2 * X_{La}$$

$$Q_b = I_b^2 * X_{Lb}$$

$$Q_c = I_c^2 * X_{Lc}$$

The total Active Power loss is:

$$P_{total} = P_a + P_b + P_c = (I_a^2 * R_a) + (I_b^2 * R_b) + (I_c^2 * R_c)$$

and the total Reactive Power loss is

$$Q_{total} = Q_a + Q_b + Q_c = (I_a^2 * X_{La}) + (I_b^2 * X_{Lb}) + (I_c^2 * X_{Lc})$$

If the resistance (and the inductive reactance) is the same for each conductor then the equations can be simplified to:

$$P_{total} = (I_a^2 + I_b^2 + I_c^2) * R$$

and

$$Q_{total} = (I_a^2 + I_b^2 + I_c^2) * X_L$$

In the case where the currents in each conductor are very similar (i.e. a balanced load), the average of the square of the three currents could be used:

$$P_{total} = \left(\frac{I_a^2 + I_b^2 + I_c^2}{3} \right) * R = I_{average}^2 * R$$

and

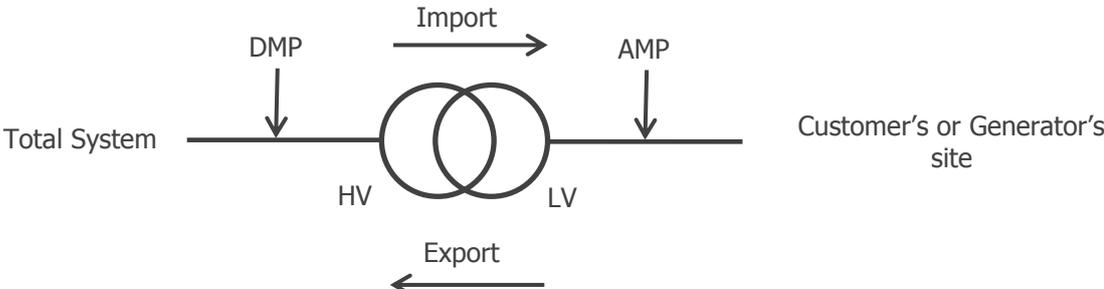
$$Q_{total} = \left(\frac{I_a^2 + I_b^2 + I_c^2}{3} \right) * X = I_{average}^2 * X_L$$

Some Meters can be programmed with the relevant parameters from the cable manufacturer's sheet and automatically calculate and add or subtract the losses to/from the measured quantities (known as dynamic compensation) seen by the Meter (i.e. taking into account the correct measurement transformer ratios¹⁴). Different Meter types will have different methods of calculating and applying loss compensation so the Meter manufacturer's documentation should be consulted.

Applying loss compensation factors for power transformer losses and/or cable (or line) losses

Care should also be taken when applying loss compensation factors such that the losses are correctly added or subtracted from the measured quantities depending on the location of the measurement transformer (AMP) relative to the DMP and the direction of flow of energy through the measurement transformers.

e.g. if the DMP is on the higher voltage side of the power transformer and the measurement transformers are located on the lower voltage side of the power transformer, and an Import is defined as a flow of Active (and Reactive) Energy away from the lower voltage side towards a Customer's site, then the power transformer loss compensation factor(s) for Active Energy will be added to the Active Import (AI) Energy measured quantity in order to refer the Meter register readings back to the higher voltage side for Active Import (AI) Energy. In the same DMP/AMP scenario, in the case of an Export from a Generating Plant towards the lower voltage side of the power transformer then the power transformer loss compensation factor(s) for Active Energy will be subtracted from the Active Export (AE) Energy measured quantity in order to refer the Meter register readings to the higher voltage side for Active Export (AE) Energy.



The same principles apply where cable (or line) losses apply alone or in addition to power transformer losses.

