Proposed Frequency Conversion Factor Wording for C57.12.90

WG Loss Tolerance & Measurement

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Add to Annex A - Bibliography:

[B6] Ramsis S. Girgis, Barry Beaster, Ed G. teNyenhuis, "*Proposed Standards for Frequency Conversion Factors of Transformer Performance Parameters*", IEEE Transactions on Power Delivery, Pages 1262 – 1267, Vol. 18, No. 4, October 2003

New Section:

Annex B

(Normative)

Frequency Conversion of Measured Performance Parameters

While it is most preferred to perform all tests at the rated frequency, in the event it cannot be done at the rated frequency, then upon mutual agreement with the customer at the tender stage or prior to a contract, conversion factors given below shall be used to convert the measured values from the frequency used for measurement to the required rated frequency. The purpose of the frequency conversion factors is to have uniformity amongst the manufacturers when such cases arise. The below conversion factors are mainly intended for 50Hz to 60Hz conversion, however similar 60Hz to 50Hz conversion is also described. The 60Hz to 50Hz conversion factors are essentially the reciprocal of the 50Hz to 60Hz values.

B1. No Load Loss & Exciting Current

The following conversion factors shall be used to convert the values of measured no load loss and exciting current at the design flux density from the frequency used for measurement to the required rated frequency. Voltage should be applied such that the resulting core flux density is equal to the flux density at the rated frequency of the transformer. For example, in the case of the test performed at 50 Hz on a 60 Hz transformer, the applied voltage should be 5/6 of the voltage corresponding to the 60 Hz operation.

No Load Loss Conversion Factors (50 to 60 Hz):

Single Phase: $B \le 1.4T = 1.32$

$B > 1.4T = -0.05\times(B-1.4) + 1.32$

Three Phase: $B \le 1.4T = 1.33$

$B > 1.4T = -0.05\times(B-1.4) + 1.33$

Where B = flux density [T]

Similarly, the 60 to 50Hz frequency conversion of no load loss shall be the reciprocal of the above mentioned 50 to 60 Hz values.

Since the value of these conversion factors is an average value for all core materials, this would add 1% uncertainty to the accuracy of the measurement

The exciting current conversion factor is 1.00, thus the measured value at 50Hz of the exciting does not need to be converted.

Example:

Design Flux Density = 1.7 T
Voltage at 60Hz = 13.8 kV
Voltage applied at 50Hz = 13.8 × 5/6 = 11.5 kV
Correction Factor = -0.05×(1.7-1.4) + 1.33 = 1.315 (Three phase power transformer)
Measured No Load Loss at 50Hz = 22.8 kW
Corrected No Load Loss at 60Hz = 22.8 × 1.315 = 30 kW

Measured Exciting Current at 50 Hz = 2.3 A
Exciting Current at 60Hz = 2.3 A

B2. Load Loss

The following conversion factors shall be used to convert the values of load loss measured at 50Hz to their corrected values at 60Hz.

Conversion values are given below to convert the measured eddy and stray loss separately if a magnetic field program was available to calculate at least the winding eddy losses. Otherwise a conversion factor is given below for the sum of eddy + stray losses.

Eddy Loss (50 to 60 Hz): 1.44
Stray Loss (50 to 60 Hz): 1.23
Eddy + Stray (50 to 60 Hz): 1.34

The voltage to be applied on the transformer shall be such that the resulting current in the transformer is equal to the rated current. For transformers larger than approximately 10 MVA, the impedance voltage is nearly proportional to frequency. In the case of the test performed at 50 Hz on a 60 Hz transformer, the applied voltage would be nearly 5/6 of the impedance voltage of the transformer corresponding to the 60 Hz operation.

Similarly, the 60 to 50Hz frequency conversion of load loss shall be the reciprocal of the above mentioned 50 to 60 Hz values.

Since the value of each of the conversion factors is an average value for the different types of tank wall shielding, this would add 1% uncertainty to the accuracy of the measurement.

Example:
Measured Losses at 50Hz:
  Total Load Loss = 142.4 kW
  I^2R = 124.6 kW
  Eddy+Stray = 17.8 kW
Corrected Losses for 60Hz
  Eddy+Stray = 17.8 ×1.34 = 23.9 kW
  Total Load Loss = 124.6 + 23.9 = 148.5 kW

B3. Temperature Rise Test

The following current calculations shall be applied to achieve the correct rated frequency loss. The injected current for the initial estimate of the heatrun current shall be adjusted so that the ohmic loss is increased to offset the decreased eddy and stray loss with 50Hz operation. Similarly, the injected current for the winding rise test must be adjusted so that the ohmic loss is increased to offset the decreased eddy loss with 50Hz operation.

Heat Run Current: $$I_{SC,50} = I_{SC,60} \cdot \sqrt{\frac{P_0 + \left(P_{I2R} + P_{e+s} \cdot 1.34\right)}{P_0 + \left(P_{I2R} + P_{e+s}\right)}}$$

Winding Rise Current: $$I_{R,50} = I_{R,60} \cdot \sqrt{\frac{P_{I2R} + 1.44 \cdot P_e}{P_{I2R} + P_e}}$$

Where:

$I_{SC,60}$ = heat run current for 60Hz
$I_{SC,50}$ = adjusted heat run current for 50Hz
$I_{R,60}$ = rated current for 60Hz
$I_{R,50}$ = adjusted rated current for 50Hz
P_0 = no load loss at 60Hz (measured at 50Hz & corrected to 60Hz)
P_{I2R} = measured ohmic loss at 50Hz
P_{e+s} = measured winding eddy + stray loss at 50Hz
P_e = measured winding eddy loss at 50Hz

Example:

$I_{SC,60} = 272.0$ A
$I_{R,60} = 246.6$ A
$P_0 = 14.4$ kW
$P_{I2R} = 124.6$ kW
$P_{e+s} = 17.8$ kW
$P_e = 4.3$ kW

$$I_{SC,50} = 272.0 \times \sqrt{\frac{14.4 + \left(124.6 + 17.8 \times 1.34\right)}{14.4 + \left(124.6 + 17.8\right)}} = 277.2A$$

$$I_{R,50} = 246.6 \times \sqrt{\frac{124.6 + 1.44 \times 4.3}{124.6 + 4.4}} = 248.4A$$

The manufacturer shall provide an adequate supply to operate the cooling equipment at the rated frequency.

The measured average oil and average winding rises will be considered accurate for rated frequency condition since the correct rated frequency losses are applied. It should be noted that direct hot spot temperature measurements (e.g. fibreoptic probes) would need to be corrected for winding eddy losses at the rated frequency.

The measured tank temperature rises could be in error by a few degrees C since the stray losses will not be correct and should thus be noted on certified test reports.

Temperature rise tests for 60Hz instead of a rated 50Hz can similarly be done by applying an appropriate current to achieve the rated frequency load loss (i.e. replacing the 1.34 and 1.44 conversion factors with 1/1.34 and 1/1.44 respectively).

B4. Short Circuit Test

Voltage shall be applied such that the transformer is subjected to the calculated symmetrical and asymmetrical currents (calculated for the rated frequency). Thus, in the case of the test performed at 50 Hz on a 60 Hz transformer, the applied voltage would be nearly 5/6 of the voltage required for a 60 Hz operation test.

For large power transformers, it should be considered that mechanical resonances in the windings in the 120Hz range may impact the measured results

B5. Audible Sound Emission

The following conversion factors for both ONAN and ONAF stages shall be used to convert the value of sound level measured at 50Hz to the corrected values at 60Hz.

The manufacturer shall provide an adequate supply to operate the cooling equipment at the rated frequency.

Using these frequency conversion factors requires that the manufacturer verify that neither the core nor the tank plates/stiffeners will experience mechanical resonance at the rated frequency and as well as at the frequency that the measurement is being performed.

Due to the greater uncertainty and the possibility of resonant frequencies, if the converted measured sound level plus the 2dB uncertainty does not meet the guaranteed value, then verification of the sound level at site may be required.

B5.1 ONAN Sound Level Conversion

Voltage should be applied such that the resulting core flux density is equal to the design flux density at the rated frequency of the transformer. For example, in the case of the test performed at 50 Hz on a 60 Hz transformer, the applied voltage should be 5/6 of the voltage corresponding to the 60 Hz operation.

The corrected sound level for 60Hz equals the measured ONAN (no load) sound level at 50Hz plus 3.6 dB.

Since the value of the conversion factor was developed as an average value of actual measurements, this would add 2dB uncertainty to the accuracy of the measurement.

Similarly, the corrected sound level for 50Hz equals the measured sound level at 60Hz minus 3.6dB.

B5.2 ONAF Sound Level Conversion

The measurement will be done with the cooling equipment operated at rated frequency while the core will be excited with non-rated frequency.

The following will be measured:

$LP_{ONAF\text{-}50}$: ONAF Sound Pressure level at 50 Hz (corrected for ambient)
$LP_{ONAN\text{-}50}$: ONAN Sound Pressure Level at 50 Hz (corrected for ambient)

Calculate:

$LP_{ONAN\text{-}60}$: ONAN Sound Pressure Level at 60Hz

Then the ONAF Sound Pressure Level at 60Hz is:

$$LP_{ONAF\text{-}60} = 10 \cdot \log\left[10^{0.1 \cdot LP_{ONAF-50}} - 10^{0.1 \cdot LP_{ONAN-50}} + 10^{0.1 \cdot LP_{ONAN-60}}\right]$$

Similarly, the 60 to 50Hz frequency conversion of ONAF sound level shall be converted as above.

B5.3 Example

Measured Sound Levels:

$LP_{ONAN\text{-}50}$ = 59.5 dBA
$LP_{ONAF\text{-}50}$ = 66.1 dBA

Calculated Sound Levels:

$LP_{ONAN\text{-}60}$ = 59.5 + 3.6 = 63.1 dBA
$LP_{ONAF\text{-}60}$ $= 10 \cdot \log\left[10^{0.1\cdot(66.1)} - 10^{0.1\cdot(59.5)} + 10^{0.1\cdot(63.1)}\right] = 67.2\,dBA$