ENERGY EFFICIENT TRANSFORMERS

MATELEC SAL

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Summary

- Introduction to transformer losses
- New EU regulation 548/2014
- Impact of reduced losses transformers on transformer design
- Comparison of losses between countries
- Losses measurement
- Matelec testing platform
No load and load losses

The no-load loss is the power consumed in the transformer magnetic core, when the secondary circuit is open. This is a permanent consumption as long as the transformer is energized.

The load loss is the internal power consumption due to the current circulating the windings. The consumption is proportional to the absorbed power.
Introduction to transformer losses

Sometimes the total losses of a transformer is expressed as a percentage of the total rated power (for example less than 1% of the rated power).

This also implies indirectly the efficiency of a transformer while operating at full load at unity power factor.
This regulation determines the maximum losses of transformers with 2 thresholds: the first is already applied since July 1 2015 and the second will come into force in July 1 2021.

The regulation is based on the EU ecodesign guideline 2009/125/EC for energy consumption-relevant products.

The directive does not apply on special transformers (instrument transformers, furnace transformers, grounding transformers,...)
New EU regulation 548/2014

- The regulation defines maximum losses level for ground mounted, pole mounted and cast resign transformer having a primary insulation level of ≤24kV and a secondary insulation level of ≤1.1kV.

- Different correction factors will apply in case of 36kV insulation primary, dual voltage transformers, etc...
For the transformers with higher rating than 3150 kVA, an index called Peak Efficiency Index (PEI) is introduced. The methodology for calculating the PEI is based on the ratio of the transmitted apparent power of a transformer minus the electrical losses to the transmitted apparent power of the transformers.
New EU regulation 548/2014
New EU regulation 548/2014

\[ PEI = 1 - \frac{2(P_0 + P_{c0})}{S_r \sqrt{P_0 + P_{c0}} \cdot P_k} \]

+ P0 is the no load losses measure at rated voltage and rated frequency, on the rated tap

+ Pc0 is the electrical power required by the cooling system for no load operation

+ Pk is the measured load loss at rated current and rated frequency on the rated tap corrected to the reference temperature

+ Sr is the rated power of the transformer or autotransformer on which Pk is based
New EU regulation 548/2014

548/2014 regulation official document
Impact of reduced losses transformers on transformer design

- Use of reduced losses grain oriented electrical steel (GOES) for lower no load loss
- Increased conductor weight for lower load loss
- No impact on transformer testing as per IEC 60076-1
- Increase in transformer cost
Impact of reduced losses transformers on electrical distribution utilities

- Lower network losses and lower TCO
- Higher initial investment
- Lower CO$_2$ emissions
## Comparison of losses between countries

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<td>BOck</td>
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<td>3250</td>
<td>COck</td>
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<td>4600</td>
<td>BOck</td>
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<td>730</td>
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<td>1100</td>
<td>10500</td>
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<td>Load</td>
<td>No load</td>
<td>Load</td>
<td>No load</td>
</tr>
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<tr>
<td><strong>250kVA 24kV</strong></td>
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C. Load loss and Impedance measurement.

The purpose for this measurement is to verify guarantees, design calculations, and manufacturing quality.

The measurements must be done at rated frequency, and depending on the standard, be measured or corrected to the rated current.

Procedure

Fig: 4 The principal measuring circuit.

To take these measurements we have to short-circuit the low-voltage side and supply the power at the high-voltage side at the principal tap position. The supply voltage is raised until the current is at the required level according to the specified standard or specification.

The readings have to be taken as quickly as possible, because the windings tend to warm up due to current and too high losses are obtained in the measurement. Impedance, or impedance voltage, is also measured during the load-loss test. The ratio of the measured voltage to the rated voltage of the winding, multiplied by 100, is the percent impedance voltage of the transformer. This quantity is commonly called “percent-impedance” or, simply, “impedance”.

In the laboratory, we have the instrumentation as shown in figure 5

Fig: 5
D. No-load loss and excitation current

The purpose for this measurement is to verify that the core loss \( P_q \) and the no-load current \( I_q \) meet the guaranteed values at rated voltage and to prove the quality of the core steel.

Procedure

The measurements must be taken for rated frequency at 100% of rated voltage.

Following values are taken: voltage (RMS and average value), current and power.

A convenient working (usually the LV) is connected to the test equipment, the transformer is energized, and the meters are read. Practically, some important characteristics of the magnetic circuit must be considered in order to get accurate, meaningful core loss test results. Since magnetic materials are not linear over the typical working flux density used in electrical equipment, a transformer core energized by a sine wave draws a distorted current waveform from the supply lines.

If this distorted current wave flows through significant impedance in the test equipment, it will cause a distorted, non-sinusoidal voltage to be applied at the transformer terminals.

This non-sinusoidal voltage will cause a non-sinusoidal flux with a lower than normal peak value to flow in the core steel and the resulting core loss will be different from the loss in actual service.

Therefore we have to take care of this problem.

In the IEC 60076, they have introduced a simplified equation for this correction:

\[
\frac{P_1}{P_0} = 1 + b \left( \frac{U'}{U} \right)
\]

where:

- \( P_1 \) is the measured loss
- \( P_0 \) is the corrected loss
- \( U \) is the mean value
- \( U' \) is the rms value

The constants \( a \) and \( b \) for an oriented core sheet are 0.5. These constants are used for corrections for both 50 and 60 Hz transformers and we will have:

\[
P_1 = P_0 \left( 1 + \frac{d}{U} \right)
\]

\[
d = \frac{U' - U}{U'}
\]

To use this simplified equation the difference between \( U \) and \( U' \) must not differ more than 3%.
3- TESTING, OPERATION, INSTALLATION AND MAINTENANCE

3.1. Transformer Tests

The IEC 60076 classifies the transformer tests as follows:
- Routine tests,
- Type tests,
- Special tests.

Matelec has the following test platforms:
- Two for distribution transformers (routine, type and special tests)
- One for power transformers (routine, type and special tests)
- One dedicated acoustic room for sound level measurement.

Matelec laboratories are equipped with up-to-date facilities and instruments to perform the complete set of tests except the short circuit test.

Additional routine tests for transformers with Um > 72,5 kV:
- Determination of capacitances windings to earth and between windings,
- Measurement of d.c. insulation resistance between each winding to earth and between windings,
- Measurement of dissipation factor (tan δ) of the insulation system capacitances,
- Measurement of dissolved gases in dielectric liquid from each separate oil compartment except diverter switch compartment,
- Measurement of no-load loss and current at 50% and 110% of rated voltage (IEC 60076-1; § 11.5).

Figure 44 — Routine test procedure

3.1.1. Routine Tests

Routine tests for all transformers:
- Measurement of winding resistance (IEC 60076-1; § 11.2),
- Measurement of voltage ratio and check of phase displacement (IEC 60076-1; § 11.3),
- Measurement of short-circuit impedance and load loss (IEC 60076-1; § 11.4),
- Measurement of no-load loss and current (IEC 60076-1; § 11.5),
- Dielectric routine tests (IEC 60076-1; § 11.6),
- Tests on on-load tap-changers (IEC 60076-1; § 11.7),
- Check of core and frame insulation for liquid-immersed transformers with core or frame insulation (IEC 60076-1; § 11.12).
3.1.2. Type tests

- Temperature rise type test (IEC 60076-2)
- Dielectric type tests (IEC 60076-3)
- Determination of sound level (IEC 60076-10) for each method of cooling for which a guaranteed sound level is specified.
- Measurement of the power taken by the fan and liquid pump motors.
- Measurement of no-load loss and current at 90% and 110% of rated voltage.

3.1.3. Special tests

- Measurement of D.C. insulation resistance each winding to earth and between windings.
- Determination of capacitances windings to earth, and between windings.
- Measurement of frequency response (Frequency Response Analysis or FRA) (IEC 60076-18).
- Measurement of zero-sequence impedances on three-phase transformers (IEC 60076-4 116).
- Dielectric special tests (IEC 60076-3).
- Winding hot-spot temperature-rise measurements (see temperature-rise type test).
- Determination of transient voltage transfer characteristics (Annex B of IEC 60076-3).
- Short-circuit withstand test (IEC 60076-5), usually performed either in KEWA – The Netherlands or in CESI – Italy.
- Measurement of dissolved gases in dielectric liquid.