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

Introduction to transformer losses

- 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

New EU regulation 548/2014

- 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,…)

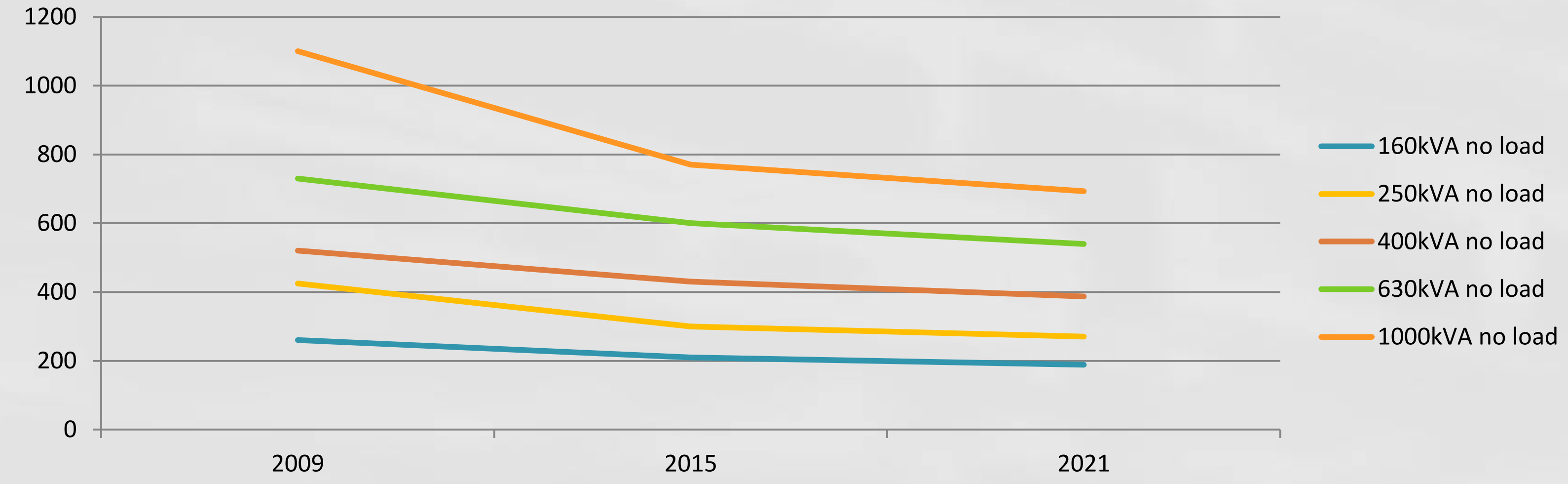
New EU regulation 548/2014

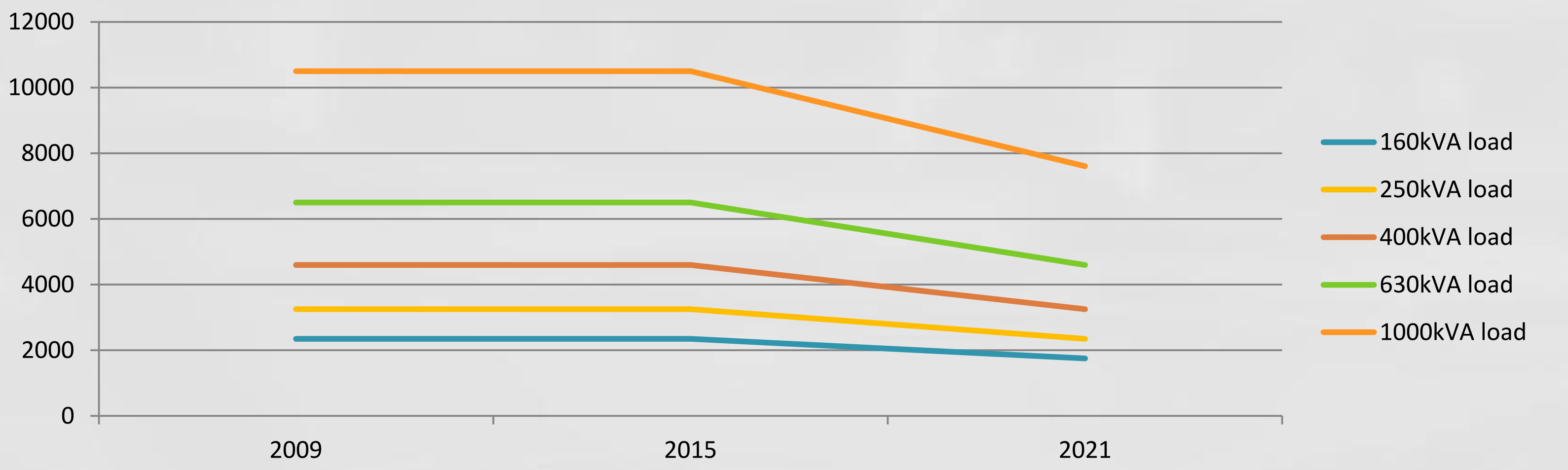
- The regulation defines maximum losses level for ground mounted, pole mounted and cast resign transformer having a primary insulation level of ≤24kV and a secondary insulation level of ≤1.1kV
- Different correction factors will apply in case of 36kV insulation primary, dual voltage transformers, etc…

New EU regulation 548/2014

- 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

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

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

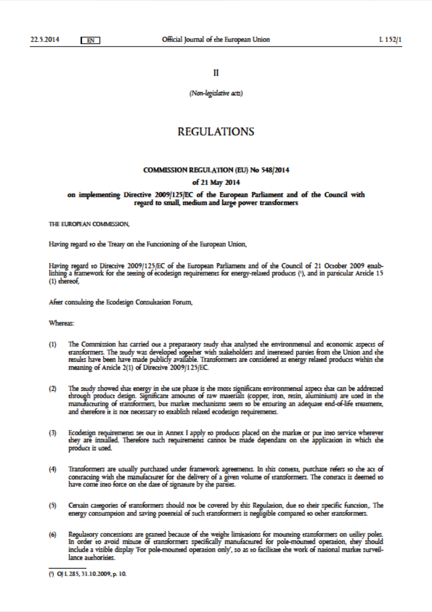
+ Pc0 is the electrical power required by the cooling system for no load operation

+ 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


22.5.2014 EN Official Journal of the European Union L 152/1

II

(Non-legislative acts)

REGULATIONS

COMMISSION REGULATION (EU) No 548/2014

of 21 May 2014

on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (1), and in particular Article 15 (1) thereof,

After consulting the Ecodesign Consultation Forum,

Whereas:

(1) The Commission has carried out a preparatory study that analysed the environmental and economic aspects of transformers. The study was developed together with stakeholders and interested parties from the Union and the results have been have made publicly available. Transformers are considered as energy related products within the meaning of Article 2(1) of Directive 2009/125/EC.

(2) The study showed that energy in the use phase is the most significant environmental aspect that can be addressed through product design. Significant amounts of raw materials (copper, iron, resin, aluminium) are used in the manufacturing of transformers, but market mechanisms seem to be ensuring an adequate end-of-life treatment, and therefore it is not necessary to establish related ecodesign requirements.

(3) Ecodesign requirements set out in Annex I apply to products placed on the market or put into service wherever they are installed. Therefore such requirements cannot be made dependant on the application in which the product is used.

(4) Transformers are usually purchased under framework agreements. In this context, purchase refers to the act of contracting with the manufacturer for the delivery of a given volume of transformers. The contract is deemed to have come into force on the date of signature by the parties.

(5) Certain categories of transformers should not be covered by this Regulation, due to their specific function,. The energy consumption and saving potential of such transformers is negligible compared to other transformers.

(6) Regulatory concessions are granted because of the weight limitations for mounting transformers on utility poles. In order to avoid misuse of transformers specifically manufactured for pole-mounted operation, they should include a visible display 'For pole-mounted operation only', so as to facilitate the work of national market surveillance authorities.

(1) OJ L 285, 31.10.2009, p. 10.

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

	2009			2015			2021			
	No load	Load	Index	No load	Load	Index	No load	Load	Index	
160kVA 24kV	260	2350	B0Ck	210	2350	A0Ck	189	1750	A0-10% Ak	
250kVA 24kV	425	3250	C0Ck	300	3250	A0Ck	270	2350	A0-10% Ak	
400kVA 24kV	520	4600	B0Ck	430	4600	A0Ck	387	3250	A0-10% Ak	
630kVA 24kV	730	6500	B0Ck	600	6500	A0Ck	540	4600	A0-10% Ak	
1000kVA 24kV	1100	10500	C0Ck	770	10500	A0Ck	693	7600	A0-10% Ak	

	EDL-Lebanon		PEDE-Syria		MOE-Iraq		MEW-Oman		SEC-KSA	
	No load	Load	No load	Load	No load	Load	No load	Load	No load	Load
160kVA 24kV	460	2350								
250kVA 24kV	650	3250			450	4100	500 (200k)	3000 (200k)	380 (200k)	2200 (200k)
400kVA 24kV	930	4600	750	3850	670	5400			520 (300k)	3200 (300k)
630kVA 24kV	1300	6500	940	5600	1000	8350	1000 (500k)	4500 (500k)		
1000kVA 24kV	1470	9400	1400	9500	1230	12400	1500	8000	1100	9000

Losses measurement (load losses)

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

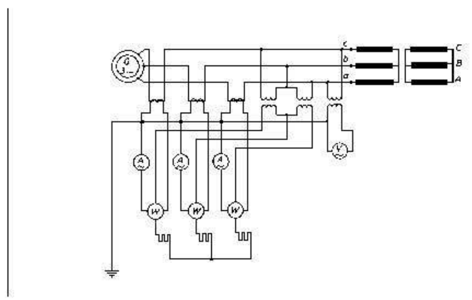


Fig.: 4 The principal measuring circuit.

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

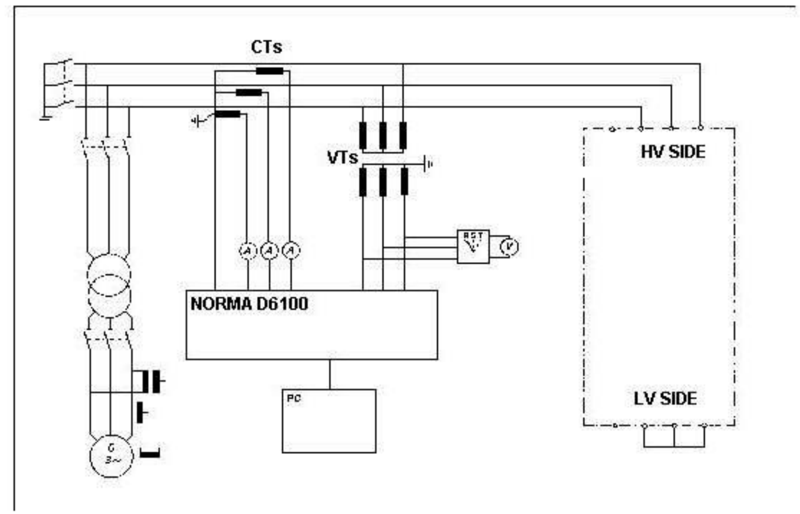


Fig.:5

Losses measurement (no-load losses)

D- No-load loss and excitation current

The purpose for this measurement is to verify that the core loss P_0 and the no-load current I_0 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 winding (usually the LV) is connected to the test equipment, the transformer is energized, and the meters are read. Realistically, 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 densities 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

$$P_0 = \frac{P_m}{a + b\left(\frac{U}{U'}\right)^2}$$

U' mean value and U is rms value , Po is the corrected Losses and Pm are the measured Losses

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:

$$P_0 = P_m \cdot (1 + d)$$

were $d = \frac{U' - U}{U'}$

To use this simplified equation the difference between U and U' must not differ more than 3%.

In the laboratory, we have the instrumentation as shown in figure 6.

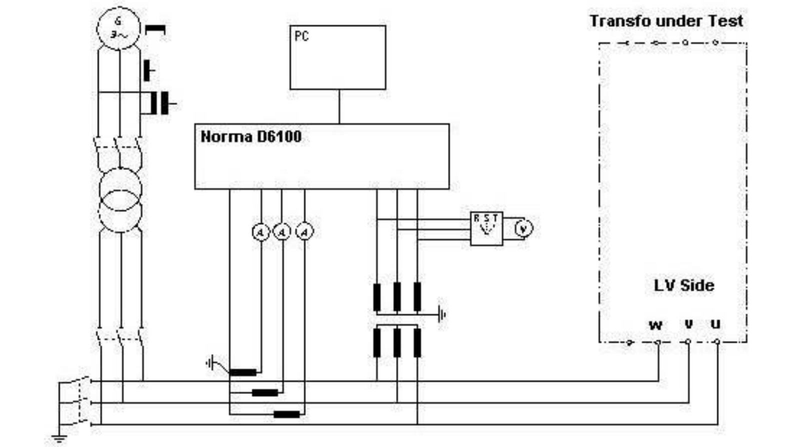


Fig.: 6

MATELEC testing platform

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.

Measurement of winding resistance	Measurement of voltage ratio and check of vector group	Measurement of short-circuit impedance voltage	Measurement of no-load loss and no-load current	Applied voltage dielectric test	Induced overvoltage dielectric test

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 60076-3; § 11 12),
- 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)

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) of the insulation system capacitances,
- Measurement of dissolved gasses in dielectric liquid from each separate oil, compartment except diverter switch compartment,
- Measurement of no-load loss and current at 90 % and 110 % of rated voltage (IEC 60076-1; § 11.5).

MATELEC testing platform

Figure 47 - Calibration lab

Figure 48 - Paint aging test (salt spray)

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.

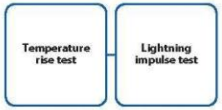


Figure 45 – Type tests procedure

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 dissipation factor (tan delta) of the insulation system capacitances (IEEE 62-1995, IEEE C57.19.01)
- Measurement of frequency response (Frequency Response Analysis or FRA), (IEC 60076-18)
- Measurement of zero-sequence impedance(s) on three-phase transformers (IEC 60076 - § 11.6)
- 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 KEMA – The Netherlands or in CESI - Italy
- Measurement of dissolved gasses in dielectric liquid

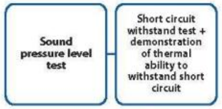


Figure 46 – Special tests procedure