SLOVENSKI STANDARD
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Močnostni transformatorji - 19. del: Pravila za določanje negotovosti meritve izgub močnostnih transformatorjev in dušilk

Power transformers - Part 19: Rules for the determination of uncertainties in the measurement of the losses on power transformers and reactors

Leistungstransformatoren - Teil 19: Regeln für die Bestimmung von Unsicherheiten in der Messung der Verluste von Leistungstransformatoren und Drosselspulen

Transformateurs de puissance - Partie 19: Règles pour la détermination des incertitudes de mesure des pertes des transformateurs de puissance et bobines d’inductance

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Power transformers - Part 19: Rules for the determination of uncertainties in the measurement of the losses on power transformers and reactors (IEC/TS 60076-19:2013 , modified)

Transformateurs de puissance - Partie 19: Règles pour la détermination des incertitudes de mesure des pertes des transformateurs de puissance et bobines d'inductance (IEC/TS 60076-19:2013 , modifiée)

Leistungstransformatoren - Teil 19: Regeln für die Bestimmung von Unsicherheiten in der Messung der Verluste von Leistungstransformatoren und Drosselspulen (IEC/TS 60076-19:2013 , modifiziert)

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Foreword

This document (EN 60076-19:2015) consists of the text of IEC/TS 60079:2013 prepared by IEC/TC 14 "Power transformers", together with the common modifications prepared by CLC/TC 14 "Power transformers".

The following dates are fixed:

• latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2016-06-25
• latest date by which the national standards conflicting with this document have to be withdrawn	(dow)	2018-06-25

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Endorsement notice

The text of the International Standard IEC/TS 60079:2013 was approved by CENELEC as a European Standard with agreed common modifications.

COMMON MODIFICATIONS

Introduction

***Modify** the first paragraph as follows:*

The losses of the transformers (no- load and load losses) are object of guarantee and penalty in the majority of the contracts and play an important role in the evaluation of the total (service) costs and therefore in the investments involved. Furthermore, regional regulations, such as the European Union directive for EcoDesign, may also pose requirements on establishment of reliable values for losses.

***Modify** the third and fourth paragraphs as follows:*

Corrections and uncertainties are also considered in IEC 60076-8 where some general indications are given for their determination.

This European Standard deals with the measurement of the losses that from a measuring point of view consist of the estimate of a measurand and the evaluation of the uncertainty that affects the measurand itself. The procedures can also be applied to loss measurements on power transformers and reactors as evaluation of the achievable performance of a test facility in the course of prequalification processes, as estimations of achievable uncertainty in the enquiry stage of an order or prior to beginning final testing at manufacturer´s premises and for evaluations of market surveillance measurements.

***Add** before the fifth paragraph:*

Evaluation of uncertainty in testing is often characterized as “top-down” or “bottom-up”, where the first one relies on inter-laboratory comparisons on a circulated test object to estimate the dispersion and hence the uncertainty. The latter method instead relies on the formulation of a model function, where the test result y is expressed as a function of input quantities. This function is often the formula used for the calculation of the result. The “bottom-up” method is applied in this Document.

***Replace** the sixth paragraph by:*

It is recommended that guarantee and penalty calculations should refer to the best estimated values of the losses without considering the measurement uncertainties, based on a shared risk concept, where both parties are aware of and accept the consequences of non-negligible measurement uncertainty.

In cases where the losses are required to conform to stated tolerance limits, it is recommended that the estimated uncertainty is less than the tolerance limit. This situation will occur for example in market surveillance activities. In lieu of other specifications it can be noted that 3 % is often used as estimate for the required uncertainty.

***Modify** the eighth paragraph as follows:*

Standards mentioned in the text but not indispensable are listed at the end of the document.

Replace *the last paragraph by:*

This European document is based on IEC/TS 60076-19. The technical content of the TS was not changed, but small numerical mistakes and consistent use of symbols in Annex A were corrected. The introduction was modified to enhance clarity.

1 Scope

Modify *the first paragraph as follows:*

This European Standard illustrates the procedures that should be applied to evaluate the uncertainty affecting the measurements of no-load and load losses during the routine tests on power transformers.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 60076-1:2011, *Power transformers – Part 1: General* (IEC 60076-1:2011)

EN 60076-2:2011, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers* (IEC 60076-2:2011)

Annex A
(informative)

Example of load loss uncertainty evaluation for a large power transformer

A.4 Model function of the measurand and deviation correction (see 7.2)

A.4.2 Correction of known systematic deviations

***Modify** the paragraph after the first equation as follows:*

The remaining corrective term is given by the following equation: (erroneous K_C replaced by F_D)

***Replace** the second and the third equations by the following ones:*

$$F_D = \frac{1}{1-\left(\Delta_{\varphi V} - \Delta_{\varphi C}\right)\cdot \tan\varphi}$$

$$P_2 = k_{CN} \cdot k_{VN} \cdot P_W \cdot F_D$$

A.5 Results of the measurements

A.5.1 Load loss measurements

***Modify** the paragraph after Table A.2 as follows:*

The estimate of the phase angle between voltage and current results (see 7.2 and A.6.1):

***Replace** the first equation by:*

$$\varphi = \arccos\left(\frac{P_W}{I_M U_M}\right) - \Delta_{\varphi V} + \Delta_{\varphi C} = \arccos\left(\frac{6,625}{3,608 \times 86,60}\right) - \left(\frac{0,09}{100} + \frac{0,11}{100}\right) \cdot \frac{180}{\pi} = 88,782 - 0,115 = 88,670°$$

***Modify** the paragraph after the first equation as follows:*

The corresponding tanφ is therefore equal to 43,087.

***Replace** the second equation by:*

$$F_D = \frac{1}{1-\left(\Delta_{\varphi V} + \Delta_{\varphi C}\right)\cdot \tan\varphi} = \frac{1}{1-(0,09/100+0,11/100)\cdot 43,087} = 1,0943$$

Replace *the third equation by:*

$$P_2 = k_{\mathrm{CN}} \cdot k_{\mathrm{VN}} \cdot P_{\mathrm{W}} \cdot F_{\mathrm{D}} = 60 \cdot 200 \cdot 6{,}625 \cdot 1{,}0943 = 86\,997 \text{ W}$$

Add *after the third equation:*

NOTE This result differs slightly from the result obtained with the full formula given in clause A.4.1 because of the simplifications introduced in A.4.2.

A.6 Estimates of the single contributions to the uncertainty budget

A.6.3 Instrument transformer phase displacement uncertainties (see 10.3)

***Replace** the first, second and third equations by the following ones:*

$$u_{\Delta\varphi C} = \frac{0{,}02}{\sqrt{3}} = 0{,}011\,5 \text{ crad}$$

$$u_{\Delta\varphi V} = \frac{0{,}010}{\sqrt{3}} = 0{,}005\ 8 \text{ crad}$$

***Add** after the second equation:*

and

$$u_{\Delta\varphi} = \sqrt{u_{\Delta\varphi V}^2 + u_{\Delta\varphi C}^2} = \sqrt{0{,}011\,5^2 + 0{,}005\,8^2} = 0{,}012\,9$$

NOTE In some cases, in the calibration certificates the uncertainty is directly indicated with a given confidence level and therefore the standard uncertainties can be directly obtained from these data.

A.6.4 Power analyzer uncertainties (see 10.5)

***Modify** the first paragraph as follows:*

According to the manual for the instrument used, the accuracy on power measurement is obtained by the combination of a number of terms:

***Modify** the third paragraph after the first equation as follows:*

The accuracy determined in accordance with the above relation resulted in ±0,91 %.

***Modify** the paragraph before the last equation as follows:*

According to the manual for the instrument used, the accuracy for voltage measurement is ±0,18 %, which corresponds to the following standard uncertainty:

A.6.5 Corrective term uncertainty (see 10.3.2)

***Modify** the first paragraph as follows:*

The uncertainty u_{FD} related to the phase displacement correction can be evaluated with the following simplified relations:

***Replace** the first and the second equations by the following ones:*

$$u_{FD} \approx u_{\Delta\varphi} \cdot \tan\varphi$$

$$u_{FD} = 0,012\,9 \cdot \tan\varphi = 0,012\,9 \cdot 43,087 = 0,56\ \%$$

A.6.6 Uncertainty of the resistance at temperature θ_2 (see 10.8)

***Modify** the first paragraph as follows:*

The standard uncertainty due to the measuring instruments is assumed equal to 0,35 % and that attributable to the winding temperature estimate equal to 2 K, with the latter deemed to be negligible.

A.7 Uncertainty of the load loss measured at ambient temperature (see 7.4)

***Modify** the first paragraph and Table A.4, fifth row, last cell, as follows:*

The uncertainties that affect the load loss at ambient temperature can be estimated using the results of the previous elaborations and are summarized in Table A.4.

Table A.4 – Uncertainty contributions

Quantity	Estimate	Standard uncertainty	Sensitivity coefficient	Uncertainty contribution (%)
CT ratio error	η_C	u_C	1	-
VT ratio error	η_V	u_V	1	-
Power meter	P_W	u_P	1	0,53
Phase displacement	$\dfrac{1}{1-(\Delta\varphi v-\Delta\varphi c)\tan\varphi}$	u_{FD}	1	0,56
Ampere meter	I_M	u_{IM}	2	0,24

***Replace** the equation by:*

$$u_{P2} = \sqrt{u_P^2 + u_{FD}^2 + u_{IM}^2} = \sqrt{0,53^2 + 0,56^2 + 0,24^2} = 0,81\ \%$$

A.8 Expanded uncertainty of the measured load loss (see 7.4)

***Replace** the first and second equations by the following ones:*

$$U_{P2} = 2\ u_{P2} = 2\ \cdot\ 0,81 = 1,61\ \ \%$$

$$\dot{U}_{P2} = \frac{U_{P2}}{100} P_2 = \frac{1,61}{100} 86,997 = 1,4\ \ \text{kW}$$

***Modify** the second paragraph after Equation 2 as follows:*

If the uncertainty is given in relative value, the load loss at ambient temperature 24,2 °C is to be expressed as follows:

Replace *the third and the fourth equations by the following ones:*

$$87{,}0\ \text{kW} \pm 1{,}6\ \%$$

$$87{,}0\ \text{kW} \pm 1{,}4\ \text{kW}$$

Modify *the last paragraph as follows:*

The result shall be also completed with the indication of the coverage factor, which for the example made was k = 2 (confidence level of about 95 %).

A.9 Uncertainty for reported load loss at reference temperature (see 7.5)

Replace *the text under A.9 as follows:*

The additional loss at ambient temperature is given by:

$$P_{a2} = P_2 - I_N^2 \cdot R_2 = 86\ 997 - 69\ 500 = 17\ 497\ \text{W}$$

The absolute uncertainty of the measured loss and $I_N^2 R$ loss are obtained as follows:

$$\dot{u}_{P2} = \frac{u_{P2}}{100} P_2 = \frac{0{,}80}{100} 86\ 997 = 696\ \text{W} \quad \text{and} \quad \dot{u}_{R2} = \frac{u_{R2}}{100} I_N^2 R_2 = \frac{0{,}35}{100} 69\ 500 = 243\ \text{W}$$

The absolute uncertainty of the additional loss at temperature θ_2 is given by (see Table 3):

$$\dot{u}_{Pa2} = \sqrt{\dot{u}_{P2}^{\ 2} + (I_N^2 R_2 \cdot u_{R2})^2} = \sqrt{696^2 + 243^2} = 737\ \text{W}$$

The reported load loss at reference temperature is calculated for copper conductors with t=235, reference temperature $\theta_r = 75$ °C and ambient temperature $\theta_2 = 24{,}2$ °C is given by:

$$\frac{t+\theta_r}{t+\theta_2} = 1{,}196 \qquad \frac{t+\theta_2}{t+\theta_r} = 0{,}836 \qquad I_N^2 R_2 \frac{t+\theta_r}{(t+\theta_2)^2} \cong 0{,}004\,6\ I_N^2 R_2$$

The reported loss at the reference temperature is thus given by:

$$P_{LL} = 1{,}196\ I_N^2 R_2 + 0{,}836\ P_{a2} = 83\ 122 + 14\ 627 = 97\ 749\ \text{W}$$

The various contributions to the absolute uncertainty are calculated according to Table 4:

For $I_N^2 R_2$ loss: $\dfrac{t+\theta_r}{t+\theta_2} I_N^2 R_2 u_{R2} = 1{,}196 \cdot 69\,500 \cdot 0{,}35/100 = 291 \text{ W}$

For additional loss: $\dfrac{t+\theta_2}{t+\theta_r} \dot{u}_{Pa2} = 0{,}836 \cdot 737 = 616 \text{ W}$

For mean winding temperature: $\dfrac{t+\theta_r}{(t+\theta_2)^2} I_N^2 R_r\, u_{\theta 2} = 0{,}004\,6 \text{ x} \cdot 69\,500 = 320 \text{ W}$

The combined absolute standard uncertainty is given by:

$$\dot{u}_{LL} = \sqrt{(1{,}196\, I_N^2\ R_2\, u_{R2})^2 + (0{,}836\, \dot{u}_{Pa2})^2 + (0{,}004\,6\, I_N^2\ R_2\, u_{\theta 2})^2} = \sqrt{291^2 + 616^2 + 320^2} = 753 \text{ W}$$

The expanded absolute uncertainty is obtained as:

$$\dot{U}_{LL} = 2\, \dot{u}_{LL} = 2 \cdot 0{,}753 = 1{,}51 \text{ kW}$$

which corresponds to a coverage probability of approximately 95 %.

The relative standard uncertainty is then:

$$u_{LL} = \frac{\dot{u}_{LL}}{P_{LL}} 100 = \frac{753}{97\,749} 100 = 0{,}77 \text{ \%}$$

and the expanded relative uncertainty:

$$U_{LL} = 2\, u_{LL} = 2 \times 0{,}77 \approx 1{,}5 \text{ \%}$$

which corresponds to a level of confidence of approximately 95 %.

A.10 Presentation of the results

Modify *the second and fourth paragraphs and* ***replace*** *the first and second equations as follows:*

If the uncertainty is given in relative value, the load loss at reference temperature 75 °C is expressed as follows:

$$97{,}7 \text{ kW} \pm 1{,}5 \text{ \%}$$

$$97{,}7 \text{ kW} \pm 1{,}5 \text{ kW}$$

The text shall be also completed with the indication of the coverage factor that for the example made was k = 2 (coverage factor of about 95 %).

NOTE The probability that the loss is higher than (97,7+1,5) kW is therefore 2,5 %.

Annex B
(Informative)

Example of load loss uncertainty evaluation for a distribution transformer

B.4 Model function of the measurand (see 7.2)

***Modify** the first paragraph as follows:*

The model function for load loss referred to rated current and ambient temperature is the following (considering that no voltage transformer is used):

***Replace** the first, second, third and the fourth equations by the following ones:*

$$P_2 = k_{CN}\left(1+\frac{\varepsilon_C}{100}\right)\cdot\frac{P_W}{1+\Delta_{\varphi C}\tan\varphi}\cdot\left[\frac{I_N}{k_{CN}\times I_M}\right]^2$$

$$\varphi = \varphi_M + \Delta_{\varphi C} = \arccos\left(\frac{P_W}{I_M U_M}\right) + \Delta_{\varphi C}$$

$$\frac{1}{1+\Delta_{\varphi C}\tan\varphi}$$

$$P_2 = k_{CN}\cdot\frac{P_W}{1+\Delta_{\varphi C}\tan\varphi}\cdot\left[\frac{I_N}{k_{CN}\times I_M}\right]^2$$

B.5 Results of the measurements

***Replace** the first, second and the third equations as follows:*

$$\varphi = \arccos\left(\frac{P_W}{I_M\cdot U_M}\right) + \Delta_{\varphi C} = \arccos\left(\frac{337{,}5}{4{,}812\cdot\sqrt{3}\cdot 365{,}0}\right) + \frac{0{,}035}{100}\cdot\frac{180}{\pi} = 83{,}63 + 0{,}02 = 83{,}65\,°$$

$$F_D = \frac{1}{1+\Delta_{\varphi C}\tan\varphi} = \frac{1}{1+\dfrac{0{,}035}{100}\cdot 8{,}99} = 0{,}997$$

$$P_2 = k_{CN} \cdot P_W \cdot F_D = 40 \cdot 337{,}5 \cdot 0{,}997 = 13\,460 \text{ W}$$

B.6 Estimate of the single contributions to the uncertainty formation

Modify *the title of B.6.2 as follows:*

B.6.2 Power meter (see 10.5)

Replace *the first, second and the third equations by the following ones:*

$$u_{PW} = \frac{0{,}57}{\sqrt{3}} = 0{,}33\,\%$$

$$u_{IM} = \frac{0{,}42}{\sqrt{3}} = 0{,}24\,\%$$

$$u_{UM} = \frac{0{,}25}{\sqrt{3}} = 0{,}14\,\%$$

B.6.3 Current transformers (see 10.3)

Modify *the second paragraph and Table B.3, second row, last cell, as follows:*

For the type of transformer under test the values of the ratio error and displacement error given by the calibration certificate can be considered, as indicated in Table B.3. Uncertainty statements have been given as standard uncertainty in the table.

Table B.1 – Calibration of the current transformers

Rated ratio	Accuracy class	Ratio error (%)		Phase displacement (centiradians)	
		ε	u_c	Value	$u_{\Delta\varphi_c}$
200/5	0,1	0,0	0,01	+ 0,035	0,01
NOTE The errors reported in the table are those measured including burden and connections corresponding to the instrument used.					

B.6.4 Corrective term uncertainty (see 10.3.2)

Replace *the equation by:*

$$u_{FD} \approx \frac{u_{\Delta\varphi C}}{100} \cdot \tan\varphi \cdot 100 = 0{,}01 \cdot 8{,}99 = 0{,}09\ \%$$