

**Rules for the determination of uncertainties in the measurement
of the losses on power transformers and reactors**

This Technical Report was approved by CENELEC on 2008-03-07.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Foreword

This Technical Report was prepared by the Technical Committee CENELEC TC 14, Power transformers.

The text of the draft was submitted to vote in accordance with the Internal Regulations, Part 2, Subclause 11.4.3.3 (simple majority) and was approved by CENELEC as CLC/TR 50462 on 2008-03-07.

Contents

Introduction.....	5
1 Scope.....	6
2 Normative references	6
3 Definitions	6
4 Symbols	6
4.1 General symbols	6
4.2 Symbols for uncertainty	7
5 Power measurement, systematic deviation and uncertainty	8
6 Procedures for no-load loss.....	8
6.1 General.....	8
6.2 Model function for no-load losses at reference conditions.....	9
6.3 Uncertainty budget.....	10
7 Procedures for load loss.....	11
7.1 General.....	11
7.2 Model function for load loss at reference conditions	11
7.3 Uncertainty budget for measured power P_2 referred to rated current.....	12
7.4 Uncertainty budget for reported load loss	14
8 Three-phase calculations.....	14
8.1 Power.....	14
8.2 Reference voltage (current).....	15
9 Reporting	15
9.1 Uncertainty.....	15
9.2 Traceability	15
10 Estimation of corrections and uncertainty contributions	15
10.1 Ratio error of instrument transformers	15
10.2 Phase displacement of instrument transformers	17
10.3 Power meter.....	21
10.4 Voltage measurement in no-load loss	22
10.5 Ampere meter in load loss measurement.....	22
10.6 Correction to sinusoidal waveform.....	23
10.7 Winding temperature θ at load loss test.....	23
10.8 Winding resistance	24
Annex A (informative) Example of load loss uncertainty evaluation for a large power transformer	26
A.1 Introduction	26
A.2 Transformer rating.....	26
A.3 Measuring method and instrumentation used.....	26
A.4 Model of the measurand (see 7.2)	27
A.5 Results of the measurements	27
A.6 Uncertainty of load loss	28
A.7 Estimates of the single contributions to the uncertainty	30
Annex B (informative) Example of load loss uncertainty evaluation for a distribution transformer	34
B.1 Introduction	34
B.2 Transformer rating.....	34
B.3 Measuring instrumentation	34

B.4	Model of the measurand (see 7.2)	34
B.5	Results of the measurements	35
B.6	Uncertainty of load loss	36
B.7	Estimate of the single contributions to the uncertainty formation	37
Annex C (informative)	General rules for the uncertainty estimate	40
C.1	The basic concepts	40
C.2	Measurements, estimates and uncertainties	40
C.3	Evaluation of the input quantity uncertainties	41
C.4	Evaluation and expression of the expanded uncertainty	44
Annex D (informative)	Sensitivity coefficients for uncertainty contributions due to phase displacement correction of measurements at low power factor	45
D.1	Introduction	45
D.2	Sensitivity factors	46
Annex E (informative)	Model function for load loss temperature correction	51
E.1	General	51
E.2	Model function	51
E.3	Sensitivity coefficients	52
E.4	Estimation of temperature during load loss test	53
E.5	Simplified analysis	53
Annex F (informative)	Measurement of winding resistance	55
F.1	Description of the measurement	55
F.2	Inductive voltage drop	56
Bibliography		58

Figures

Figure D.1	Sensitivity coefficient for uncertainty in power, current and voltage	48
Figure F.1	Equivalent circuit	55

Tables

Table 1	No-load loss uncertainty, general case	10
Table 2	No-load loss uncertainty without correction for phase displacement	11
Table 3	Uncertainty in the general case	13
Table 4	Uncertainty without correction for phase displacement	13
Table 5	Standard and expanded uncertainty for load loss	14
Table 6	Procedures for uncertainty analysis	18
Table A.1	Uncertainty contribution	29
Table A.2	Calibration of voltage and current transformers ratio error	30
Table A.3		31
Table A.4	Calibration of voltage and current transformer phase displacement	32
Table B.1		35
Table B.2	Uncertainty contribution	36
Table B.3		38
Table B.4		38
Table C.1	Combined uncertainties for uncorrelated quantities	43
Table E.1		53

Introduction

Although the efficiency of a power transformer is very high, the losses (no load and load losses) are object of guaranty and penalty in the majority of the contracts. As a matter of fact, considering the long power transformer life (20 years and more) the cost of the losses play an important role in the evaluation of the total (service) costs and therefore in the investments involved.

A further reason that justifies the attention paid to the losses is that from the generation to the final user, the energy is passing through a number of transformers: step up transformers of generation power stations, interconnecting units for transmission systems, distribution transformers for primary systems (from 100 kV to 400 kV), medium voltage to low voltage transformers in small distribution substations (from 10 kV to 20 kV feeders).

The sum of the losses accrued in the transformer chains may be significant and therefore of importance in nationwide efforts to save energy. A large number of European Countries have instituted measures to conserve energy where losses in electric transmission are an important part.

In power transformers the direct measurement of the efficiency is not recommended because of the uncertainty of this method.

The indirect method based on the measurement of the losses is largely preferred even if the conditions in which such losses are measured differ a little from those that occur in operation.

EN ISO/IEC 17025 requires that the result of any measurement shall be qualified with the evaluation of its uncertainty. A further requirement is that known corrections shall have been applied before evaluation of uncertainty.

This document 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 estimate itself.

It is well known that when a test result is expressed as numerical quantity it is not an exact number but suffers from uncertainty.

The uncertainty range depends on the quality of the test installation and measuring system, on the skill of the staff and on the intrinsic measurement difficulties presented by the test objects.

The submitted test results is to be considered the most correct estimate and therefore this value has to be accepted as it stands.

The uncertainty shall not be involved in the judgment of compliance for guarantees, tolerances and penalties thresholds.

Guaranty and penalty calculations should refer to the estimated values without consideration of the measurement uncertainties.

1 Scope

This Technical Report illustrates the procedures and criteria to be applied to evaluate the uncertainty affecting the measurements of no load and load losses during the routine tests on power transformers.

Even if the attention is especially paid to the transformers, the document can be also used for the measurements of reactor losses, when applicable.

2 Normative references

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

EN 60076 series, Power transformers (IEC 60076 series)

EN 60076-1:1996, Power transformers – Part 1: General (IEC 60076-1:1993, mod.)

3 Definitions

For the purposes of this document, the terms and definitions given in EN 60076 apply.

4 Symbols

4.1 General symbols

c	sensitivity factor for contribution to uncertainty, see C.3.4;
F_D	parameter related to correction of power for effect of phase displacement in measuring circuit;
I_M	current measured by the ammeter (normally corresponding to rated current);
I_N	reference current (normally rated current);
k_{CN}	rated transformation ratio of the current transformer;
k_{VN}	rated transformation ratio of the voltage transformer;
P	power;
P_2	power measured at load loss test, but referred to the reference current I_N ;
P_{LL}	load loss at reference conditions and corrected for known systematic deviations in the measurement;
P_{NLL}	no-load loss at reference conditions and corrected for known errors in the measurement;
P_W	power measured by the power meter;
R_1	winding resistance measured at cold winding resistance test according to EN 60076-1, 10.1;
R_2	winding resistance estimated for the load loss test;
R_r	winding resistance at reference temperature according to EN 60076-1, 10.1;
t	parameter related to the thermal coefficient of winding resistance;