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Part 2: Temperature rise for liquid-immersed transformers

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

PROJECT NUMBER: IEC 60076-2 ED4	
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IEC TC 14 : POWER TRANSFORMERS	
SECRETARIAT: United Kingdom	SECRETARY: Ms Stephanie Lavy
OF INTEREST TO THE FOLLOWING COMMITTEES:	PROPOSED HORIZONTAL STANDARD: ☐ Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.
FUNCTIONS CONCERNED: ☐ EMC ☐ ENVIRONMENT ☐ QUALITY ASSURANCE ☐ SAFETY	

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TITLE: Power transformers - Part 2: Temperature rise for liquid-immersed transformers

NOTE FROM TC/SC OFFICERS:

CONTENTS

1	Scope.....	7
2	Normative references	7
3	Terms and definitions	7
4	3.9 8	
5	Temperature rise tests.....	10
6	4.1 General.....	10
7	4.2 Temperature of the external cooling media (air or water).....	11
8	4.2.1 Air temperature.....	11
9	4.2.2 Water temperature.....	13
10	4.3 Test methods for temperature rise determination.....	15
11	4.3.1 General	15
12	4.3.2 Test by short-circuit method for two winding transformers with/without buried tertiary winding	15
13	4.3.3 Infrared (thermo-vision)	18
14	4.3.4 No load temperature rise	18
15	4.3.5 Reconnectable transformers	19
16	4.3.6 Two-winding transformer with a tapping range larger than $\pm 5\%$, or having a rated power exceeding 3150 kVA.	19
17	4.3.7 Multi-winding transformer	19
18	4.4 Determination of liquid temperatures	21
19	4.4.1 Top-liquid temperature	21
20	4.4.2 Bottom and average liquid temperatures.....	21
21	4.4.3 Transformers without external cooling equipment	22
22	4.5 Determination of top, average and bottom liquid temperature rises.....	22
23	4.6 Determination of average winding temperature rise at the instant of shutdown.....	23
24	4.6.1 Determination of winding resistance at the shutdown.....	23
25	4.6.2 Determination of average winding temperature rise and average winding to average liquid temperature gradient.....	24
26	4.7 Determination of the hot-spot winding temperature rise	25
27	4.7.1 General	25
28	4.7.2 Direct measurement during the temperature rise test.....	25
29	4.8 Determination of core temperature rise.....	26
30	4.9 Uncertainties affecting the results of the temperature rise test.....	26
31	4.10 Dissolved gas-in-liquid analysis.....	26
32	4.11 Corrections.....	27
33	Annex A (informative) Hot-spot winding temperature rise determination for OFAF and OFWF cooled transformers based on the top-liquid temperature in tank	28
34	Annex B (informative) Methods to estimate the hot-spot winding temperature rises based on design data and temperature rise test results	30
35	B.1 General.....	30
36	B.2 List of used symbols.....	30
37	B.3 Determination by calculation based on design data	30
38	B.4 Mathematical models for natural and direct forced liquid flow cooling systems based on temperature rise test results.....	31
39	B.4.1 Core type transformers	31
40	B.4.2 Shell type transformers.....	31

50	B.5 Mathematical models for forced liquid flow cooling systems.....	33
51	Annex C (informative) Techniques used in temperature rise testing of liquid-immersed	
52	transformers	34
53	C.1 Winding resistance measurement after shutdown	34
54	C.1.1 Setting of the cooling equipment during the winding resistance	
55	measurement.....	34
56	C.1.2 Procedure for winding resistance measurement.....	34
57	C.2 Extrapolation of winding temperature to the instant of shutdown.....	38
58	C.3 A numerical extrapolation procedure of cooling down curve.....	39
59	Annex D (informative) Dissolved gases analysis for the detection of local overheating.....	44
60	D.1 General	44
61	D.2 Temperature rise test duration.....	44
62	D.3 Sampling of liquid.....	45
63	D.4 Gas analysis and result interpretation.....	45
64	Annex E (informative) Application of optical fibre and thermocouple sensors for hot-	
65	spot measurements in transformer active and structural parts	47
66	E.1 Direct measurement of hot-spot temperature rise	47
67	E.2 Direct measurement of temperature rise in core and structural parts	49
68	E.3 Generic rule for determination of core surface and structural part	
69	temperature rises	51
70	Annex F (Informative) Liquid and Winding exponents.....	52
71	F.1 General	52
72	F.2 Theoretical approach.....	52
73	F.3 Extended temperature rise test approach	54
74	Annex G (Informative) Detection of the end of heat run test sequence with total loss	
75	supply	55
76	Annex H Typical Heat Sink (Informative).....	56
77	H.1 Heat Sink Design.....	56
78		
79	Figure 4.1 – Sensor location around a transformer, AN cooling, figure illustrates a	
80	general piece of cooling equipment, any correlation to a specific type shall be ignored.....	11
81	Figure 4.2 – Sensor location around a transformer, AF cooling, figure illustrates a	
82	general piece of cooling equipment, any correlation to a specific type shall be ignored.....	12
83	Figure 4.3 – Sensor location around a transformer, AF special condition cooling, figure	
84	illustrates a general piece of cooling equipment, any correlation to a specific type shall	
85	be ignored	13
86	Figure 4.5 – Assumed distribution of average liquid of a winding in a stack.....	20
87	Figure B.1 – Temperature rise distribution model for ON cooling methods	32
88	Figure C.1 – Recommended circuit for transformers with a low resistance winding	
89	using two separate direct current sources, one for each winding.....	36
90	Figure C.2 – Alternative recommended circuit using only one direct current source for	
91	both windings.....	37
92	Figure C.3 – Average winding temperature variation after shutdown	38
93	Figure C.4 – Extrapolation of the cooling down curve, using the fitting curve	
94	$\theta_w(t) = A_0 - kt + Be^{-t/T_w}$	43
95	Figure E.1 – Temperature rises above top-liquid temperature (in tank) 65,8 °C of the	
96	zig-zag cooled HV-winding of a 400 MVA ONAF cooled 3-phase transformer, load	
97	current 1,0 pu, tap position (-).....	48

98	Figure E.2 – Coil edges, where the sensors should be located in the edge with the	
99	higher calculated temperature rise	49
100	Figure E.3 – Temperature rises above top-liquid temperature at the end of an 8 h	
101	thermal no-load test at 110 % supply voltage	50
102	Figure F.1 – Transformer exponent estimation plots.....	54
103		
104	Table 1 – Exponents for the corrections of temperature rise test results	27
105	Table A.1 – Hot-spot winding temperature rises for some specific transformers	
106	determined from conventional heat run test data combined with calculated hot-spot	
107	winding temperature rise, and from direct fibre-optic measurements	29
108	Table C.1 – Example of cooling down curve calculation spreadsheet	42
109	Table D.1 – Minimum detectable value S_D of gases in liquid.....	45
110	Table D.2 – Admissible limits for gas rate increases	46
111		
112		

INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 2: Thermal performance measurement and test procedures for liquid-immersed transformers

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International Standard IEC 60076-2 has been prepared by IEC technical committee 14: Power transformers.

This forth edition cancels and replaces the third edition published in 2011. It is a technical revision.

This edition includes the following significant technical changes with respect to the previous edition based on guidance provided by IEC TC 14 AHG 36:

- a) the title is changed to: Thermal performance measurement and test procedures for liquid-immersed transformers;
- b) the scope is changed to: This part of IEC 60076 applies to liquid-immersed transformers, verifies compliance with temperature requirements and gives the methods for temperature rise tests;
- c) the clauses 4, 5, and 6 are moved from edition 2011 to IEC 60076-1 revised document including the temperature rise limits and ambient temperature reference values;

- d) the modalities for the temperature rise test were improved in relation to the new thermal requirements;
- e) the core temperature test and corresponding temperature rise determination is introduced;
- f) annexes B, D and E are modified, and three informative annexes F, G and H are added in order to facilitate the standard application.

The text of this standard is based on the following documents:

FDIS	Report on voting
14/669/FDIS	14/676/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60076 series can be found, under the general title *Power transformers*, on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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POWER TRANSFORMERS –

Part 2: Thermal performance measurement and test procedures for liquid-immersed transformers

1 Scope

This part of IEC 60076 applies to liquid-immersed transformers, verifies compliance with temperature requirements and gives the methods for temperature rise tests.

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.

IEC 60076-1, *Power transformers – Part 1: General*

IEC 60076-8, *Power transformers – Part 8: Application guide*

IEC 60085, *Electrical insulation – Thermal evaluation and designation*

IEC 61181, *Mineral oil-filled electrical equipment – Application of dissolved gas analysis (DGA) to factory tests on electrical equipment*

IEC Guide 115, *Application of uncertainty of measurement to conformity assessment activities in the electrotechnical sector*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60076-1 and the following apply.

3.1 bottom-liquid temperature

θ_b

the temperature of the insulating liquid as measured at the height of the bottom of the windings or to the liquid flowing from the liquid cooling equipment

3.2 bottom-liquid temperature rise

$\Delta\theta_b$

the difference between the bottom-liquid temperature and the external cooling medium temperature

3.3 average liquid temperature

θ_{om}

the average temperature of the top-liquid and bottom liquid temperatures

- 228 **3.4**
 229 **average liquid temperature rise**
 230 $\Delta\theta_{om}$
 231 the difference between the average liquid temperature and the external cooling medium
 232 temperature
- 233 **3.5**
 234 **temperature estimated from resistance measurement**
 235 θ_2
 236 the temperature estimated from resistance measurements at shut down
- 237 **3.6**
 238 **average liquid temperature at shut down**
 239 θ'_{om}
 240 the average temperature of the top-liquid and bottom liquid temperatures at shut down
- 241 **3.7**
 242 **average winding gradient**
 243 g
 244 the difference between the average winding temperature and the average insulating liquid
 245 temperature
- 246 **3.8**
 247 **hot-spot to top-liquid temperature gradient**
 248 $\Delta\theta_{h-o}$
 249 the difference between the hot-spot temperature and the top insulating liquid temperature
- 250 **3.9**
 251 **hottest winding temperature reading at shut down**
 252 θ'
 253 the hottest winding temperature of winding conductors in contact with solid insulation or
 254 insulating liquid at shut down
- 255 **3.10**
 256 **top-liquid temperature at shutdown**
 257 θ'_o
 258 the temperature of the insulating liquid at the top of the tank at shut down, representative of
 259 top-liquid in the cooling flow stream
 260
- 261 **3.11**
 262 **hot-spot factor**
 263 H
 264 a dimensionless factor to estimate the local increase of the winding gradient due to the increase
 265 of additional loss and variation in the liquid flow stream
- 266 **3.12**
 267 **no-load top-liquid temperature**
 268 θ_{co}
 269 the temperature of the top liquid at the end of the no-load temperature rise test measured at
 270 the same tank location as the top-oil temperature defined in 3.8
- 271 **3.13**
 272 **no-load bottom-liquid temperature**
 273 θ_{cb}
 274 the temperature of the bottom liquid at the bottom of the tank at the end of the no-load
 275 temperature rise test measured at the same tank location as the bottom-oil temperature defined

276 in 3.10. If the valves are closed then the location is at the tank height of bottom yoke central
277 line.

278 **3.14**

279 **core temperature rise**

280 $\Delta\theta_c$

281 the temperature gradient between the core and liquid temperatures measured at the end of the
282 no-load test and sum of this gradient and the corresponding oil temperature rise obtained at the
283 total loss.

284 **3.15**

285 **shutdown**

286 the moment when supply current is switched off

287

288

4 Temperature rise tests

4.1 General

The following subclauses describe the procedures for the determination of temperature and temperature rise values during factory testing and also the methods for substituting service loading conditions by equivalent test procedures.

The temperature rise test is the type test carried out to verify the guaranteed temperature rises in insulation liquid and windings as given in IEC 60076-1, Clause 5.4.

A corresponding reverse correction may be applied in cases where altitude of the factory is above 1 000 m and the altitude of the installation site is below 1 000 m.

It is also used to reveal the possible overheated locations inside and outside windings due to high stray fields for the high powers. In addition, as indicated above, the temperature rises obtained during a heat-run test are used for estimating transformer loading capability by application of the relevant thermal models.

During a temperature rise test the following temperatures are possible to measure and determine:

- External cooling medium temperature
- Top-liquid temperature
- Bottom-liquid temperature
- Average liquid temperature
- Average winding temperatures
- Structural parts/tank
- Core temperature
- Hot-spot temperatures, hottest winding temperatures

During the temperature rise test, the transformer shall be equipped with any protective and monitoring devices that would be present in service (for example, gas in oil monitors and Buchholz relay). Any indication from these devices during the test shall be noted and the case investigated.

In the case of a transformer with more than one value of rated power (for example, when two or more cooling methods are provided), a temperature rise test shall be in principle performed for each rated power in order to obtain the corresponding temperature rises and thermal parameters. By agreement between manufacturer and purchaser the number of tests can be reduced if purchaser accepts to use the calculated parameters.

The interpretation of the test results shall be based on the recommended values of temperature rise as specified in IEC 60076-1 Clauses 5.3, 5.4, Annex H.

4.2 Temperature of the external cooling media (air or water)

The external cooling medium is defined by the third letter code in the cooling method (see IEC 60076-1, Clauses 5.2 and 5.3)

4.2.1 Air temperature

For the temperature rise test, the cooling air temperature shall be in the range between 10 °C and the maximum ambient temperature for which the transformer is designed, see Clause 4.2 in IEC 60076-1.

At least four sensors shall be provided, and the lowest of their readings shall be used to determine the ambient temperature for the evaluation of the test results. For tests on large power transformers, 100MVA and above, the number of provided sensors shall be increased to at least six.

NOTE. The number of sensors is recommended to be adjusted in such a way that the expected average of the readings is affected less than 0.5K if any single sensor is disregarded.

Readings should be taken at regular intervals, (e.g., every minute, to be synchronize with other temperature measurements), by automatic continuous recording.

Around a naturally cooled transformer (..AN) equipped with radiators, the ambient sensors shall be placed at the level of the bottom of the radiators, Figure 4.1, for transformers with corrugated tank they shall be placed halfway up of the cooling equipment. The sensors shall be distributed around the transformer tank and 2m away from the cooling equipment or the corrugated tank, Figure 4.1.

NOTE. If the AN cooling stage is part of AN /AF multistage cooling, and if the fans are installed below the radiators and are blowing upwards then it is allowed to keep the ambient air sensor at the position required for AF cooling mode during AN test, see Figure 4.2 below.

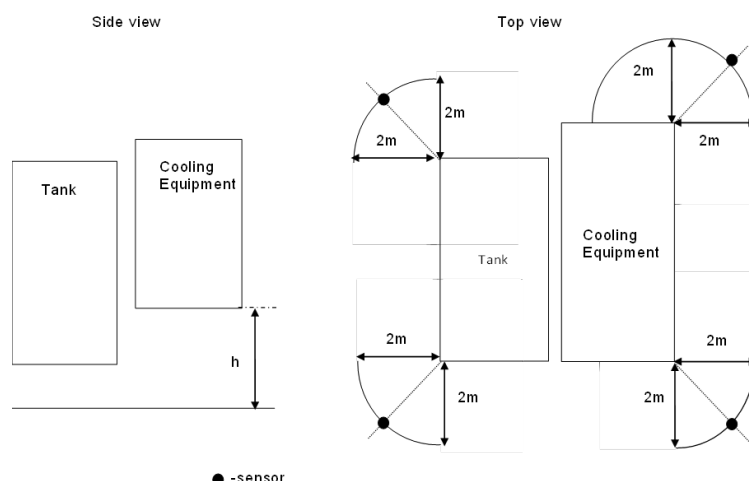


Figure 4.1 – Sensor location around a transformer, AN cooling, figure illustrates a general piece of cooling equipment, any correlation to a specific type shall be ignored

Around a forced-cooled transformer(..AF), the sensors shall be positioned evenly distributed over height and air intake area of the cooling equipment. The sensors shall be placed 0,5m from the air intake of the cooling equipment (the vertical directed air flow would require the sensor location on this axes), Figure 4.2. Attention shall be paid to possible local recirculation of hot air. The transformer should be placed so as to minimize obstructions to the air flow and to provide stable and evenly distributed ambient conditions.

AF special conditions:

- the horizontal directed air flow would require the sensor placing in this plane, Figure 4.3 and Figure 4.4, at the level of lowest fan and 2 m from the air intake in direction as indicated, depending on blowing directions.

Precautions should be taken to minimize variations of cooling-air temperature, during the whole test period. Rapid variation of readings shall be prevented by use of heat sinks or ambient cans, see Annex H, for the temperature sensors of thermal time constant approximately same as the average liquid transformer thermal time constant calculated according to IEC 60076-7 [1].

When the liquid time constant of the transformer (calculated according to IEC 60076-7 [1]) is 2 h or less, the time constant of the containers shall be between 50% and 150% of that of the transformer under test. When the liquid time constant of the transformer under test is more than 2 h, the time constant of the containers shall be within 1 h of the liquid time constant of the transformer under test.

The time constant of a container shall be taken as the time necessary for its temperature to change 6.3 °C when the ambient temperature is abruptly changed 10 °C.

An alternative is to use an ambient temperature sensor with a time constant less than that of the transformer but not less than 30 minutes and the ambient temperature sampling interval is less than 10% of the sensor time constant then any variations may be smoothed by moving averaging over period of transformer time constant.

The sensors should be protected from direct heat radiation from the tank and other sources.

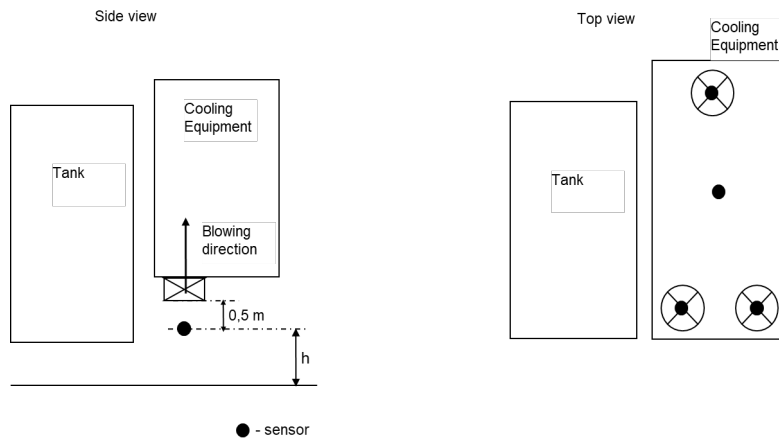


Figure 4.2 – Sensor location around a transformer, AF cooling, figure illustrates a general piece of cooling equipment , any correlation to a specific type shall be ignored

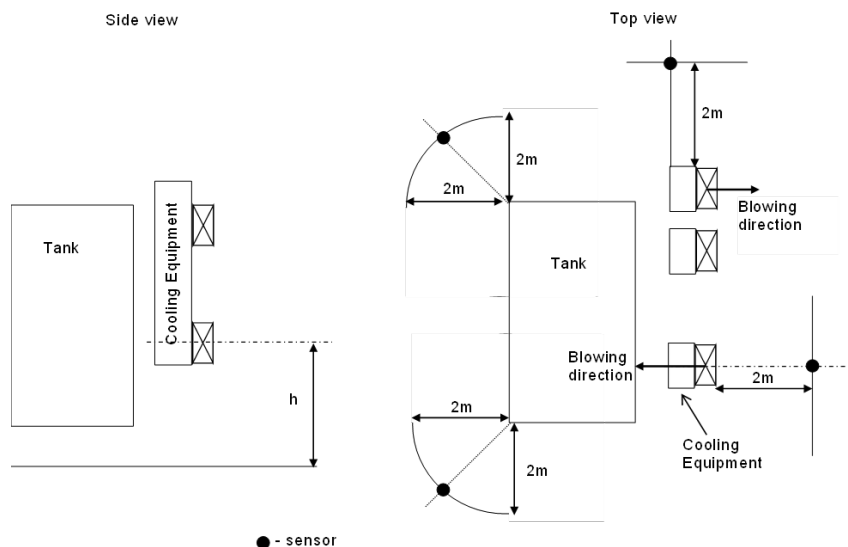


Figure 4.3 – Sensor location around a transformer, AF special condition cooling, figure illustrates a general piece of cooling equipment, any correlation to a specific type shall be ignored

In the case of separate cooling equipment placed at a distance of at least 3 m from the transformer tank, the ambient temperature shall be measured around the cooling equipment applying the same rules given above.

No draft of air, due to open doors, during the test, is allowed. Test should be done as in service with an adiabatically stable environment.

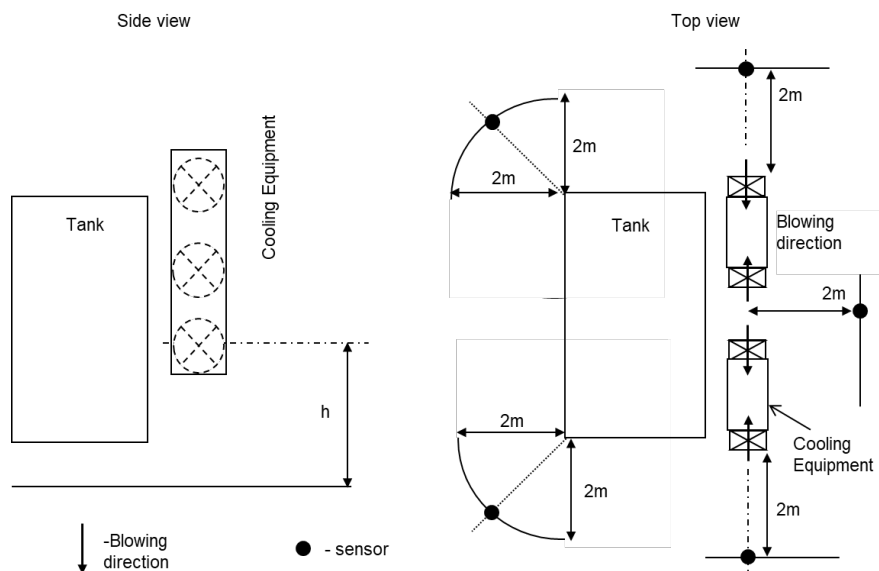


Figure 4.4– Sensor location around a transformer, AF special condition cooling, figure illustrates a general piece of cooling equipment , any correlation to a specific type shall be ignored

4.2.2 Water temperature

For the temperature rise test, the cooling water temperature should be in the range between 5 °C and the maximum water temperature for which the transformer is designed.

The temperature shall be measured at the intake of the cooling equipment. Readings of temperature and rate of water flow shall be taken at regular intervals (e.g., every minute, to be synchronize with other temperature measurements), or by automatic continuous recording.

415 If more than one intake is used the flow weighted average temperature shall be used as external
416 cooling medium.

417 Precautions shall be taken to minimize the variations of water cooling flow and temperature
418 during the test period.

419

4.3 Test methods for temperature rise determination

4.3.1 General

The standard method for the determination of the steady-state temperature rises on the test floor is the equivalent test in short-circuit connection according to 4.3.2 below. In special cases, if agreed, the test can be performed applying rated voltage and current by connection to a suitable load. This is mainly applicable to transformers with low rated power.

A back-to-back method may also be agreed, see IEC 60076-11 for test setup. In this method, two transformers, one of which is the transformer under test, are connected in parallel and excited at the rated voltage of the transformer under test. By means of different voltage ratios or an injected voltage, rated current is made to flow in the windings of the transformer under test.

The purpose of the test is to obtain:

- the top-liquid, bottom-liquid and average liquid temperature rises in a steady-state condition with dissipation of total losses;
- the average winding temperature rise at rated current for the average liquid temperature rise as determined above;
- the hot-spot winding temperature rise at rated current and for the top-liquid temperature rise as defined above.

A transformer core temperature rise cannot be obtained by the standard method used to estimate the winding and liquid temperature rises. Therefore, the special no-load temperature test is defined in 4.3.3. The outcome of this test is core temperature rise over corresponding liquid temperature, e.g. over the corresponding liquid temperature measured at the same location as under the standard temperature test. The temperature rise measurement of structural parts is not usually requested due to complexity of sensor installation and it shall be treated as a special test, details are given in Annex E.

4.3.2 Test by short-circuit method for two winding transformers with/without buried tertiary winding

The provided procedures will consider three different approaches which are applied based on a purchaser need. Some possible setups are listed below.

During this test the transformer is not subjected to rated voltage and rated current simultaneously, but to the measured total losses, previously obtained by two separate determinations of losses, namely load loss at reference temperature and no-load loss (see IEC 60076-1, Clause 10).

For tapping position requirement during temperature rise test see IEC 60076-1, Clause 6.6.

4.3.2.1 Temperature rise test conducted to verify the steady state temperature rise limits

This is achieved in three testing steps:

a) Transformer heating step

In this step the temperature of the transformer is increased to a level closed to expected value to be achieved in step b. In order to reduce the duration of this step one or more of the following approaches may be used.

I. Heating step option 1, manufacturer responsibility

the radiator/cooler valves shall be operated to prevent full cooling effect, the cooling equipment not fully operated, (as far as it does not hamper the heat transfer between the windings and the liquid as it is case in OD transformers with coolers where always at least one pump shall be hold in operation), and extra losses in excess of the total losses to be supplied (up to 130% of rated current). The condition to be hold up to the calculated top liquid temperature rise steady state value is reached. Once the expected (precalculated) top-liquid temperature rise is reached the valves shall be opened, cooling equipment operated in the intended service mode, and the supply losses corrected to the total losses by supplying a corresponding test current. Accelerated temperature rise test for distribution transformer may include isolation of the radiating heat tank surfaces.

II. Heating step option 2, specified by the purchaser considering direct measurements of the winding temperature

test starts by injection of an overload current equal to 130% of rated level corresponding to the considered cooling mode for 8 hours prior changing supply current to the total losses as explained in step b below. The test shall be run with the cooling equipment operated according to intended service mode during the complete temperature rise test. If the test is conducted by following this approach then from recorded temperature curves during 8 hours will be possible to estimate the corresponding transient parameters like the time constants.

b) Total loss injection step

Unless not differently specified, the top-liquid, bottom-liquid and average liquid temperature rises are established when the transformer is subjected to a test current corresponding to the total losses of the transformer (see IEC 60076-1, Clause 10). The test current will be above rated current to the extent necessary for producing an additional amount of loss equal to the no-load loss at rated voltage, and the winding temperature rise will be correspondingly elevated.

The liquid temperatures and cooling medium temperature are monitored, and the test is continued until steady-state liquid temperature rises are established.

This part of the test may be terminated when the rate of change of top-liquid temperature rise has fallen below 1 K/h for a minimum of three consecutive hours and the hourly rate of change is not increasing during this period. If discrete readings have been taken at regular intervals, the mean value of the readings during the last hour is taken as the result of the test. If continuous automatic recording is applied, the average value during the last hour is taken.

NOTE An alternative method to estimate the steady state temperature rises prior reaching the above defined end of this part of test is given in Annex G.

c) Rated current injection

After the top-liquid, bottom-liquid and average liquid temperature rises have been established, the test shall be continued without a break with the test current reduced to rated current for the winding combination connected. This condition is maintained for duration between 60 and 90 minutes, during which time continuous temperature records of top-liquid, bottom-liquid, winding hot-spot and external cooling medium should be taken at least every 1 min.

At the shutdown, the resistances of the windings are determined according to 4.6.1.