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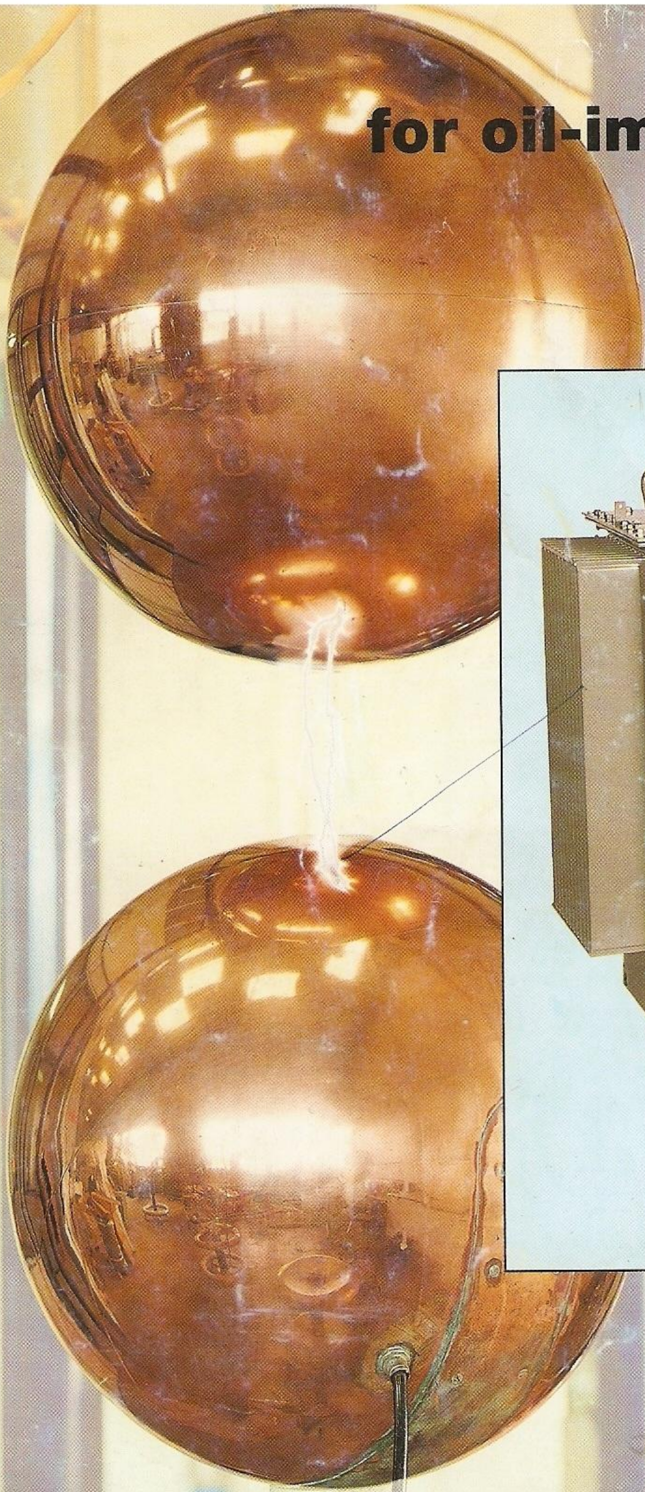
GROUPE SCHNEIDER

Test Guide : for oil-immersed distribution transformers (50 to 3,150 kVA)



Contents

Presentation of the France Transfo factories

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France Transfo's internationally recognised and highly esteemed expertise is today exported to more than 80 countries throughout the world.
Over the past 15 years, France Transfo has produced and sold 350,000 transformers or the equivalent of the entire installed power of a major European country.

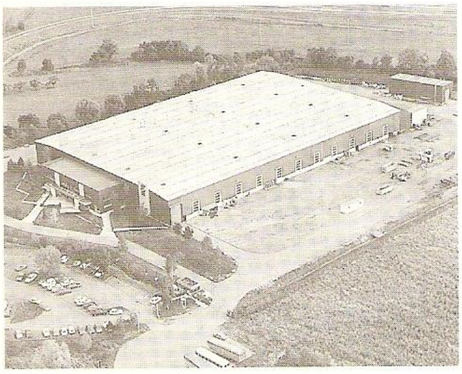
Production sites

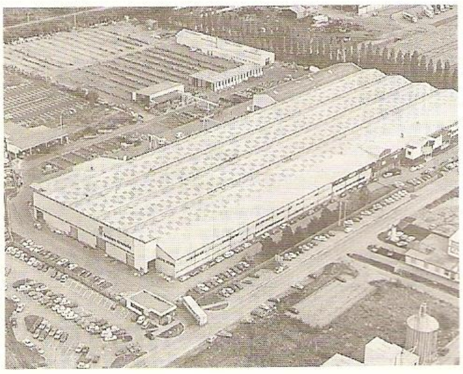
France Transfo currently has three production sites in the Lorraine region to the North of Metz, including one of Europe's largest production facilities for cast resin transformers.
The factories are located close to one another in order to benefit from the synergy of resources and expertise right through from the project design stage to the despatch of finished goods.
These purpose-built, modern production units are regularly refitted and updated in the constant pursuit of optimum quality and safety.

■ **the Maizières-Lès-Metz factory (1970)**
Site of France Transfo's head office.
Area : 25,000 m^2
Production : oil-immersed distribution transformers up to 5,000 kVA and 36 kV.

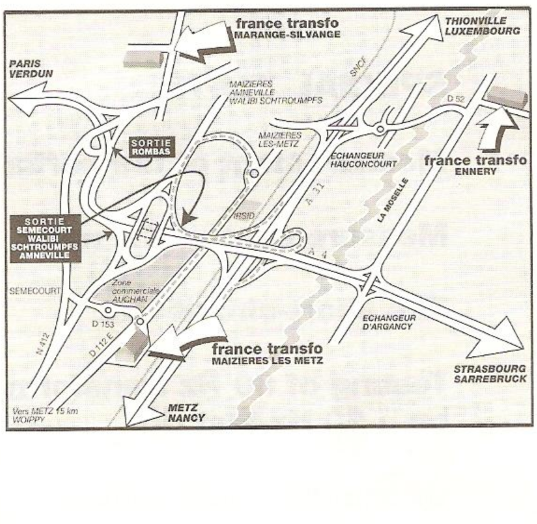
■ **the Ennery factory (1985)**
Area : 15,000 m^2
Production :
- oil-immersed power transformers of between 5 and 60 MVA up to 123 kV
- Trihal cast resin transformers of between 100 kVA and 15 MVA up to 36 kV

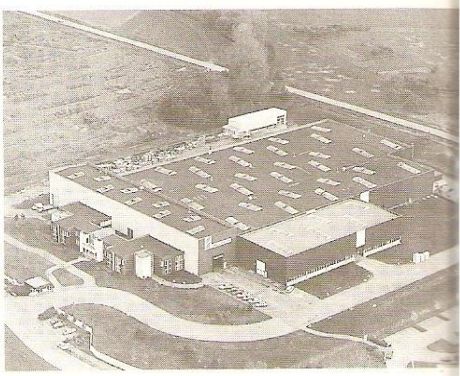
■ **the Marange-Silvange factory (1980)**
Area : 11,000 m^2
Production : tanks, heat exchangers and all metal accessories required for transformers produced on the other 2 sites.





Location of the 3 factories





Production facilities

Engineering and design facilities are computer-linked between the technical, sales and production departments at each of the factories to ensure manufacturing reliability.

The "oil-immersed distribution transformers" activity of the Maizières factory comprises the following main manufacturing sections :

■ **electrical steel section**
The magnetic cores are cut from very wide sheets of electrical steel using a series of slitters and core cutting machines.

■ **windings section**
This section has a series of winding machines for MV (Medium voltage) and LV (Low voltage) coils for all types of conductors ; foil, strips, round wire (aluminium and copper)

■ **treatment section for the active part**
Before being placed in the tank, oven dry the active parts of the transformer.

■ **filling installation section**
This installation enables the transformers to be vacuum filled at ambient temperature, from tanks of mineral or silicone oil.

Product range

France Transfo's product range comprises :

✔ **oil-immersed distribution transformers** for an insulation voltage level ≤ 36 kV :
- pole mounted for powers of 50 to 160 kVA
- standard pad-mounted type for powers of 100 to 3,150 kVA
- low-noise pad-mounted type of 250 to 1,000 kVA
- standing substation type of 100 to 160 kVA

✔ **"TRIHAL" cast resin transformers** up to powers of ≤ 15 MVA and voltages ≤ 36 kV.

✔ **power transformers** up to 60 MVA and 123 kV

✔ **special transformers** : neutral point reactor coils, zero sequence generators, short-circuit limiting reactors, motor start autotransformers, HV rectifier sets for power supply systems of electrostatic precipitators, etc.

Standards

Transformers are designed and tested in accordance with the procedures described in the international standard IEC 76 and as well as in other national standards.
In the appendix are listed most of the national standards corresponding to these specifications.

Quality system

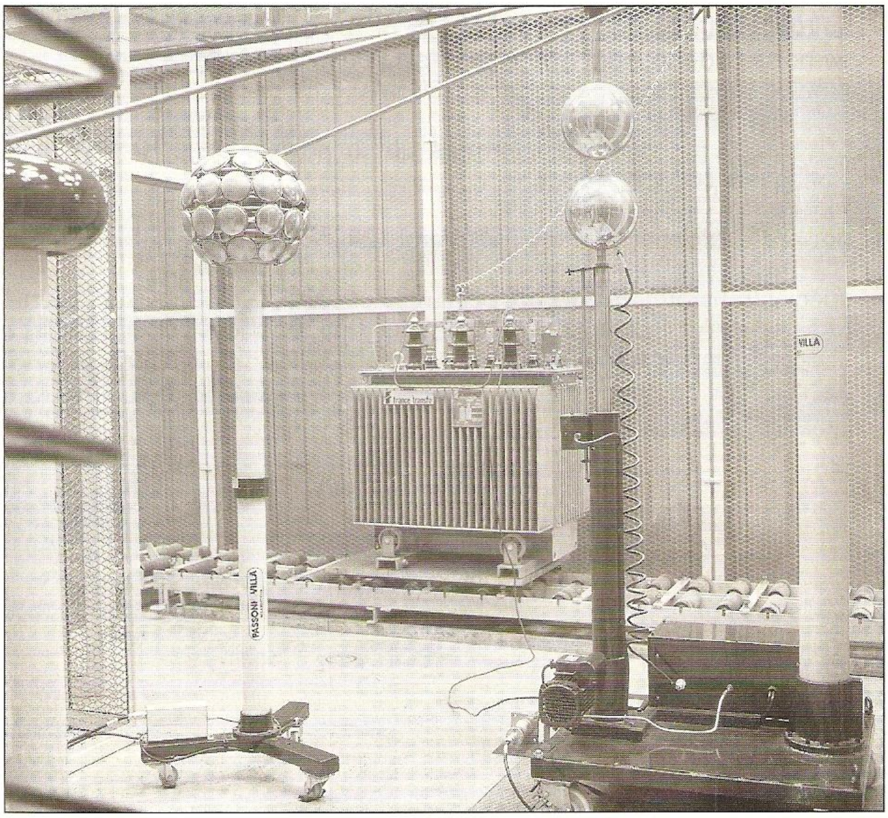
All France Transfo transformers are manufactured in accordance with a procedural quality system certified by AFAQ (the French Association for Quality Assurance) to be in conformity with international standard ISO 9001.

The international standard ISO 9001 defines the supplier's obligations to the customer in terms of quality, service, design and adaptation of its equipment in line with technology.

For example, it defines the following requirements for tests; measurements, calibration procedures, etc.

This international quality assurance standard includes, amongst other things : internal audits on products and processes by the manufacturer, self-checks and analyses, corrective actions, the quality of suppliers, etc.

At France Transfo, quality is managed by the Quality Assurance department and the operators on the production lines and by the AFAQ which performs an annual audit of the factory to award or withdraw its ISO 9001 certification.



Definition

A static electrical energy transducer intended to transform an alternating current system into one or several alternating current systems of the same frequency, but generally of different current and voltage.

The transformer receives a primary current I1 at a primary voltage U1, and transforms it to a secondary current I2, different from the primary current, at a secondary voltage U2.

■ operating principle

"A winding subject to a variable flux, generated by a variable voltage via a cross section of a given magnetic core, induces an electromotive force across its terminals proportional to the number of turns in the winding".

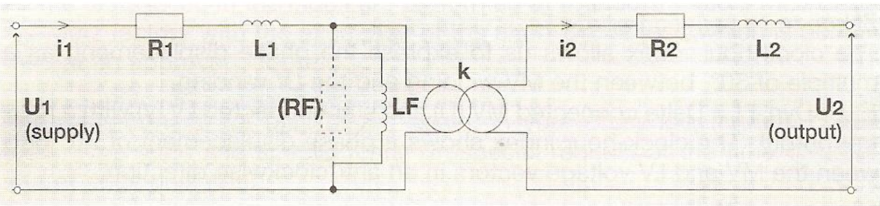
This electromotive force determines the voltage across the terminals of the transformer according to the Boucherot equation :

$$U = 4{,}44\ \mathrm{Bmax} \times N \times S \times f$$

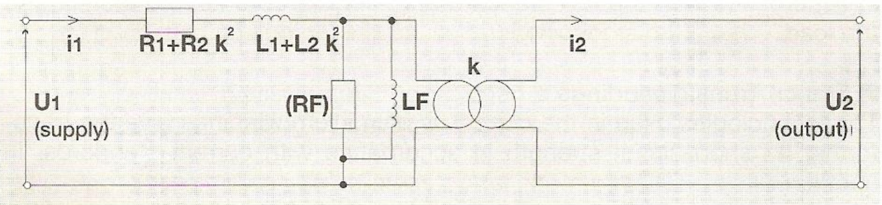
with
- U = voltage across the terminals of the primary or secondary winding
- Bmax = the maximum value of the magnetic field in the magnetic core
- N = the number of turns in the primary or secondary winding
- S = magnetic core cross-sectional area
- f = supply frequency of the transformer expressed in Hertz

■ diagramatical representation of a transformer

Any multi-phase circuit is a combination of single phase circuits and consequently, we can diagramatically represent the transformer in single phase as follows :



N.B.: The impedance of the secondary winding can be referred to the primary winding by multiplying it by the square of the transformation ratio "k". We therefore have :



The magnetic core

This comprises grain-oriented electrical steel on which are laid 2 windings. One of these has current I_1 running through it, the other has current I_2 running through it.
It is characterised by the **no-load losses (Po)** : these combine losses due to hysteresis, Eddy currents and Joule effects (insignificant) as well as dielectric losses (insignificant).
The choice of the quality of the steel sheeting as well as the cutting and assembly method used determine the performance level of the magnetic core.

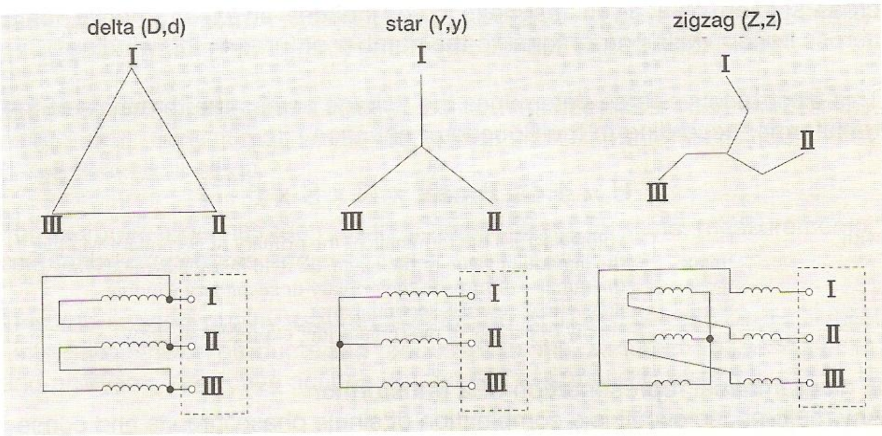
The windings

The windings are characterised by :

■ **the transformation ratio, "k"**, corresponding to the ratio of the primary and secondary voltages

$$k = \frac{U_1}{U_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$$

■ **the connection arrangement :**



The connection of the highest voltage (MV) is in upper case and that of the lowest voltage in lower case (LV). If there is a neutral terminal, we have :
YN or yn
ZN or zn
The clock-hour index allows us to express the phase displacement, as a multiple of 30°, between the MV winding and the LV winding.
E.g. : Dyn 11 = Delta connected MV (D) and star connected LV (y) with a neutral output. The clock-hour index shows a phase displacement of 30° between the MV and LV voltage vectors in an anti-clockwise direction.

■ **the load losses (Pcc) :**
Also called copper losses (even for aluminium transformers !). They comprise Joule or ohmic losses (RI^2) and Eddy current losses.
These losses are expressed at the standard reference temperature of 75°C in accordance with the IEC standard and are proportional to the square of the load.

■ **France Transfo windings :**
The technologies used in the copper or aluminium windings give the transformer its short-circuit strength in accordance with current standards. In addition :
- autoclave drying eliminates all traces of humidity from the active part of the winding
- vacuum filling impregnates the windings and eliminates any air from the tank.

These two procedures give the transformer excellent performance levels (lightning impulse withstand).

■ **dielectric liquids :**
The most commonly used dielectric liquids at France Transfo are of mineral oil type (O1). The PCB[1)] and PCBT[2)] contents are guaranteed to be less than or equal to the minimum limit for measurement of 2 ppm (parts per million)

1) (Polychloro Biphenyls contained in Askarels)
2) (Polychloro Benzyl Toluenes, contained in Ugilec)

The test

Transformers are tested to ensure that their electrical and thermal characteristics are in conformity with those specified on the order.

Three different types of test exist :
- routine tests
- type tests
- special tests

This guide is intended to give you an insight into these different types of tests and into the test methods used at France Transfo for oil immersed distribution transformers produced at its MAIZIERES-LES-METZ factory.

Test equipment at the MAIZIERES-LES-METZ unit

- 3 production line-integrated test rigs for routine tests and lightning impulse tests.
- 2 test rigs for customer-requested acceptance tests. These are used for routine tests, type tests and two special tests (measurement of partial discharge level and noise level)
- 1 dedicated equipment testing laboratory used for the testing of materials received and for R&D and type-approval of new products.

Lastly, each manufacturing section has its own specific testing resources and procedures to ensure the quality of components and sub-assemblies.

All the tests listed in the index are performed at France Transfo's Maizieres-lès-Metz factory with the exception of the short circuit test, which is performed at an approved laboratory.

The transformers are only tested again, in your presence, (routine check tests, type tests and special tests) on special request at the time of order and at additional cost.

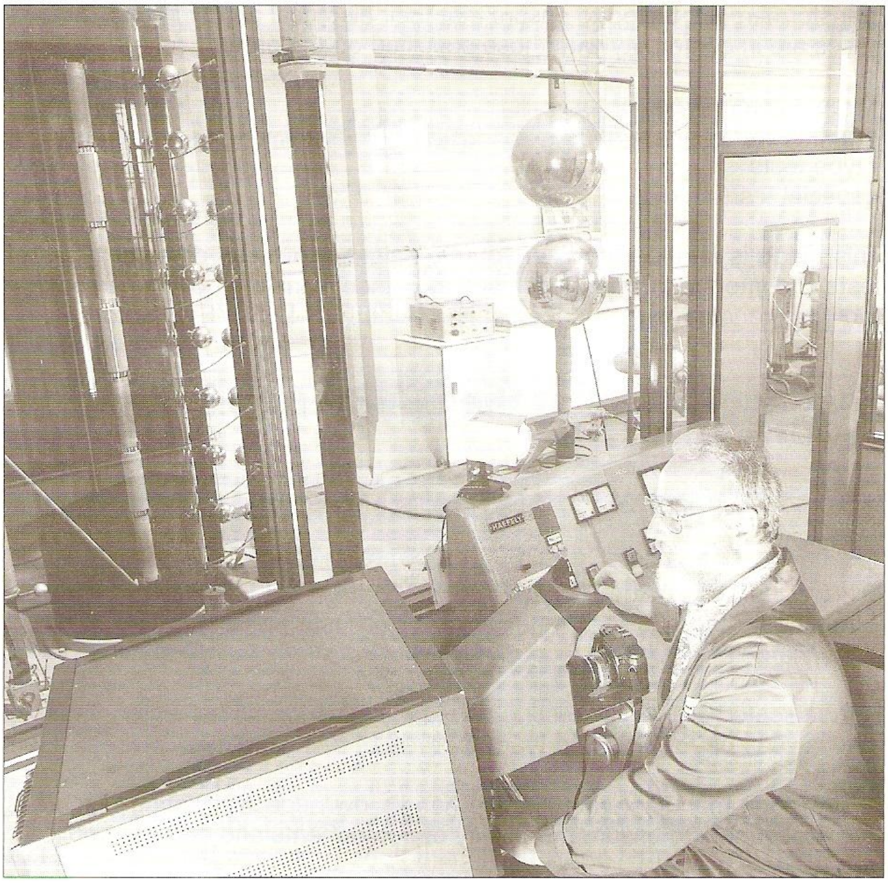
Safety recommendations in testing areas

Transformer test areas are clearly marked. Once within these zones, all equipment can be live, with exposed parts. There is therefore a risk that contact with this equipment will cause fatal electrocution.

Access to these areas is strictly forbidden to any unauthorised person from outside the "Testing" department.

Visitors may only enter these areas under the supervision of authorised testing department personnel, after having first been informed of the inherent dangers in the installation, when no test sequence is taking place.

The following pages give for each test :
- on the left hand page : a summary of the main standards requirements
- on the right hand page : the method used by France Transfo.



Glossary

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Reference	Symbols	Units
1) Rating plate		
Rated power	Sn	VoltAmpere (VA) or kiloVoltAmpere (kVA) or MegaVoltAmpere (MVA)
Rated frequency	Fn	Hertz or kiloHertz (Hz or kHz)
High voltage	MV	kiloVolt (kV)
Low voltage	LV	Volt or kiloVolt (V or kV)
Temperature	°C	degrees Celsius (°C)
Temperature rise	K	Kelvin
No-load losses	Po	Watt or kiloWatt (W or kW)
Load losses	Pcc	Watt or kiloWatt (W or kW)
No-load current	Io	Ampere (A)
Rated current	IN	Ampere (A)
Short circuit current	Icc	Ampere (A)
Impedance voltage	Ucc	Volt (V)
Power factor	$\cos\varphi$	percentage (%)
Magnetic field	B	Tesla (T)
Number of turns	N	
2) Routine tests		
● Measurement of no-load losses		
Corrected no-load losses	Po	Watt (W)
First wattmeter reading	dW1	Watt (W)
Second wattmeter reading	dW2	Watt (W)
Constant	Cte	
Power correction	k	Watt (W)
Approximation	Δ	percentage (%)
● Measurement of load losses		
Currents in the 3 windings	I_1, I_2, I_3	Ampere (A)
Measured power	Pmeas	Watt (W)
Special losses = additional losses	Ps	Watt (W)
● Resistance of windings		
Resistance of MV and LV	R_{MV}, R_{LV}	ohm (Ω)
Joules losses	ΣRI^2	Watt (W)
3) Type tests		
● Temperature rise tests		
Total losses	Pt	Watt (W)
Average current	Iave	Ampere (A)
Ambient temperature	$T°_{amb}$	°Celsius (°C)
● Lightning impulse tests		
Sweep time		microsecond (*s)
4) Special tests		
● Partial discharge level measurement		
Transformer voltage class	Um	KiloVolt (kV)
Apparent charge	q	picoCoulomb (pC)
● Noise level measurement		
Background noise		decibel (dB)
Weighted (A) acoustic pressure level	Lp(A)	decibel (A)
Weighted (A) acoustic power level	Lw (A)	decibel (A)

The standard

This standard is taken from IEC standard 76-3 (1980).

Definitions

- ***uniform insulation of a transformer winding*** *: this is the insulation of a winding for which all the terminals connected to a transformer's terminals, have the same power frequency withstand voltage.*
- ***Um voltage*** *: this is the highest voltage of a system to which the winding can be connected, in view of it's insulation level. In practice, it refers to the voltage of the transformer's class of insulation.*

Test description

The type of induced voltage test used, depends on the type of transformer winding.

The induced voltage test described in the standard, specifies that an alternating voltage with a near-sinusoidal waveform must be applied to the terminals of the transformer.
The test voltage must be twice the rated voltage and must not exceed the minimum applied overvoltage at the power frequency (see the table below), between the line terminals of a three-phase winding.

The test frequency must be greater than the rated frequency in order to avoid saturation of the magnetic core (excessive magnetising current).
The test lasts 60 seconds at full voltage for all test frequencies less than or equal to twice the rated frequency, unless otherwise specified by the customer.

When the test frequency exceeds twice the rated frequency, the test duration should be :

[120 x (rated frequency / test frequency)] seconds,
with a minimum of 15 s.

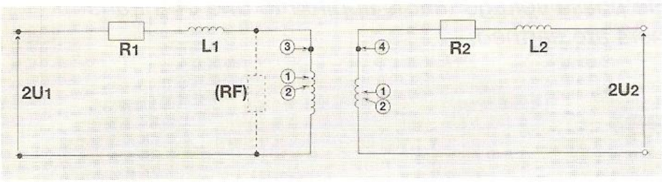
Three phase windings are preferably tested with balanced voltages induced in the three phases of the winding. If the winding has a neutral output, this may be earthed during the test.
The induced voltage test is considered satisfactory if the test voltage does not collapse in any way.

system highest voltage for the transformer Um, in kV	power frequency applied overvoltage in kV
≤ 1,1	3
3,6	10
7,2	20
12,0	28
17,5	38
24,0	50
36,0	70

Induced voltage dielectric test

Test objective

This test highlights whether any fault exists between the turns of the windings (e.g. : fault between ① and ②, ③ and ④) or if there is a fault between phases.



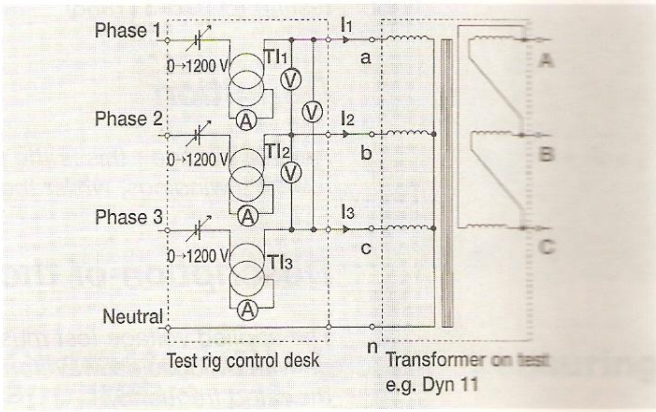
Test procedure

With the MV winding open circuited, a voltage of 2 x U_{rated} is applied to the LV winding ; to avoid saturation of the transformer's magnetic core, the frequency used for the test is 200 Hz or 150 Hz depending on the test rig used.

The maximum test duration is :

- (120 x 50) / 200 = 30 s. for a test frequency of 200 Hz.
- (120 x 50) / 150 = 40 s. for a test frequency of 150 Hz.

Test rig diagram



The transformer is considered to have passed when there is no voltage collapse or variation in current.

The standard

This summary of the test standard is taken from the IEC publication on dielectric testing IEC 76-3 (1988)

Definition

Applied voltage : this is the single phase voltage that is applied to one of a transformer's windings, whilst the others are earthed.

Description of the test

The applied voltage test must be performed using a single phase alternating voltage with a sinusoidal waveform at an appropriate frequency equal to at least 80% of the rated frequency.

The full test voltage must be applied for 60 seconds between the winding under test and all the terminals of the other windings, the magnetic core, the frame and the tank or enclosure of the transformer, connected together to earth.

The test is considered as satisfactory if the test voltage remains constant.

system highest voltage for the transformer Um, in kV	*minimum power frequency applied overvoltage in kV*
≤ 1,1	3
3,6	10
7,2	20
12,0	28
17,5	38
24,0	50
36,0	70

Applied voltage dielectric test

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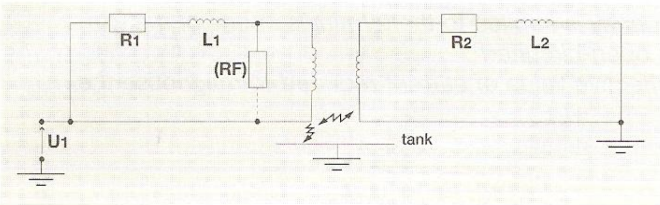
Test objective

Testing the dielectric strength of the transformer (insulating properties of the oil and the windings) at the power frequency (50 Hz), and that of the winding relative to both earth and to the other windings.
The transformer's schematic diagram is modified as follows :

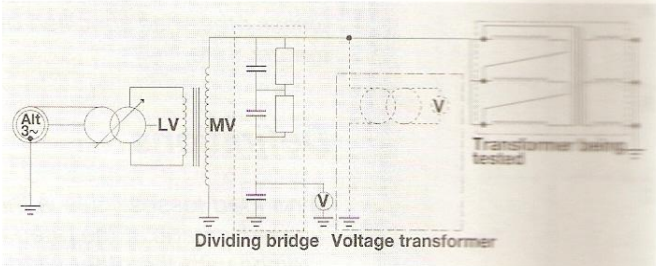


Test procedure

The applied voltage test is performed using a single phase 50 Hz power supply at a voltage specified in the standard, according to the transformer's class of insulation.
The voltage is applied successively to each winding for 60 s. whilst all the terminals of the other windings and the metal parts of the transformer are earthed.

The voltage measurement is taken directly using a voltage divider or a voltage transformer.

Test rig diagram



Characteristics of the measuring apparatus

Voltage transformer : transformation ratio = 1,000
Voltmeter (for the voltage transformer) or kilovoltmeter (for the dividing bridge)

The standard

This measurement procedure is described in standard IEC 76-1 (1993)
All the values measured during this test are expressed for the principal tapping unless otherwise specified by the customer, with the transformer initially at ambient temperature.

Definitions

- ***no load losses** : this is the active power absorbed by the transformer when the rated voltage at the rated frequency is applied to the terminals of one of the windings with the other windings open-circuited*
- ***no load current** : this is the effective value of current required to magnetise the magnetic core.*

Test description

The no load losses and current must be measured on one of the windings (with the other winding(s) open-circuited) :

- *at the rated frequency and rated voltage, if the test is performed on the principal tapping,*
- *at the rated frequency and at a voltage equal to the appropriate tapping voltage, if the test is performed on another tapping.*

Tolerances

Certain values are subject to manufacturing variations and to errors of measurement and cannot be determined with absolute accuracy.

This is why, in order to guarantee the performance of transformers, the "International Electrotechnical Committee" has set tolerances to be complied with in its standard 76-1 §9, that are valid for all three phases distribution transformers.

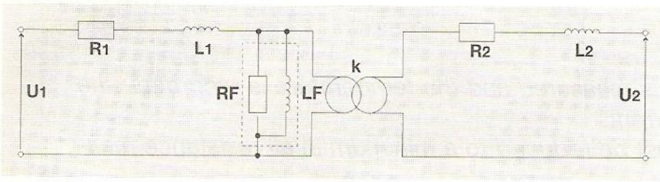
Values	*Tolerances*
1. No load losses	*+15% of the declared values on condition that tolerances on total losses are complied with*
2. No load current	*+30% of the value declared by the manufacturer*
3. Total losses (Po + Pcc)	*+10% of the declared values*

Measurement of no load losses and no load current

Test objective

- characterising the no load losses and the no load current of the transformer
- checking that the characteristics are in conformity with the current standard

In real terms, no load losses are generated by the area marked within the dotted line below :



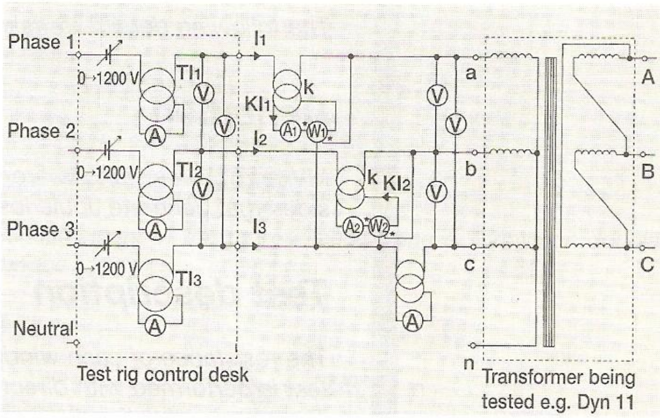
Test procedure

The low voltage (LV) winding is supplied with the rated voltage at the rated frequency, with the medium voltage (MV) winding open-circuited.
The no load losses are measured using a 2 Wattmeters method with an reversing switch (Aaron's method), whereas the no load current is measured using a current transformer and an ammeter on each phase.

NB : the values measured on transformers with several LV windings are obtained on the winding with the highest voltage, in other words the one offering the best accuracy.

Test rig diagram

Voltmeters and ammeters integrated on the test rig enable the values to which the transformer is subjected to be measured at any point in time.



For reasons of efficiency, 3-position switches are used in order to reduce the number of voltmeters (V), ammeters (A) and wattmeters (W) that are required.

Test calculations

Measured no load losses = [(W1 ± W2) x Cte] - k

k = meters consumption (of the test certificate)

This correction corresponds with the power consumed by the metering devices and can be expressed in the form (U^2 / R).

The constant "Cte" depends on the ratings of the measuring apparatus

E.g. : for a test rig assembly comprising a current transformer with a 5/5 ratio and an ammeter with a rating of 5 on a scale of 100 graduations, the constant therefore becomes :

$$Cte = (5/5) \times (5/100) = 0,05$$

Tolerances

The application of small tolerances on the no load losses is negotiable at the time of the request for tender.

The standard

The following details are taken from IEC standard 76-1 (1993)

Definition

MV and LV resistances are internal transformer resistances from the MV and LV sides that generate Joule losses proportionally to the square of the current.

Test description

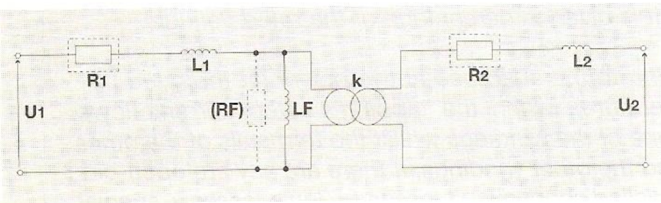
The resistance of each winding is measured and the temperature is recorded ; the test is performed with direct current.
The effects of self-induction must be reduced to a minimum in all resistance measurements.

For oil immersed transformers, the test starts once the transformer's dielectric fluid has been left to rest ; the average oil temperature is then determined by considering it to be equal to that of the winding.

Measurement of the resistance of MV and LV windings

Test objective

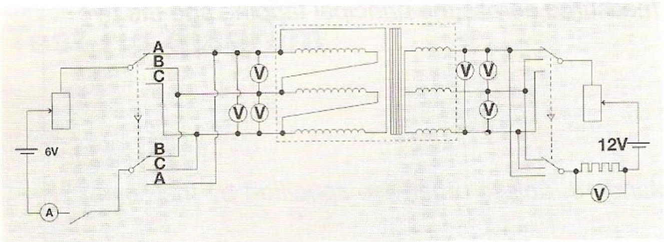
To measure the resistance in ohms of each of the windings of the transformer.
These resistances are shown within the dotted lines in the following diagram :



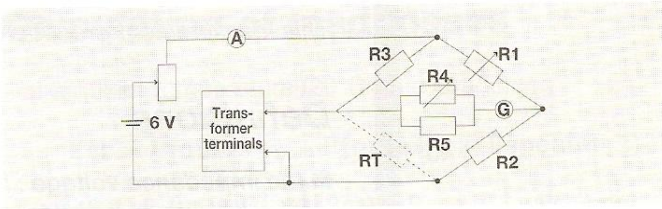
Test procedure

Ambient temperature is recorded during this test.
Measurement of the resistance of the MV between phases is performed with direct current either using the voltampere method for large resistances (of around 1 ohm) or with a micro-ohmmeter.
Measurement of the resistance of the LV winding is performed with direct current either using 2 microvoltmeters and a shunt, or using a Thompson double bridge.

Test rig diagram



Measurement of MV and LV resistances using the voltampere method



Measurement of the LV resistance using a Thompson double bridge

with

$$R_T = (2/3) \times r$$

for delta connected windings

$$R_T = 2 \times r$$

for star connected windings.

R_T being the equivalent resistance between phases and r the resistance of one of the transformer's windings.

The calculations

$$R = (U / I)$$

For the Thompson bridge, we have :

$$\frac{R3}{RT} = \frac{R1}{R2}$$

if R1 = R4 and R2 = R5.

The standard

This measurement procedure is described in IEC standard 76-1 (1993)

Definitions

- ***the impedance voltage** : is the voltage that must be applied to the line terminals of a winding in order to give the rated current when the terminals of the other windings are short-circuited. It is given in percentage of the rated voltage.*

- ***load losses** : these correspond to the absorbed active power (at the rated frequency and reference temperature), when the tapping's rated current flows through the line terminals of one of the windings whilst the terminals of the other winding are short-circuited and the other windings, if there are any are open-circuited. These losses are also called short-circuit losses (= Joule losses + special losses)*

Test description

Impedance voltages and load losses must be measured with a supply current of at least 50% of the tapping's rated current.
The measured value of these losses must be multiplied by the square of the ratio between the rated current of the tapping and the current used for the test.

The measurement must be made quickly to avoid temperature rises introducing any significant errors ; the temperature difference of the oil from top to bottom must be sufficiently low to enable determination of the average temperature with the required accuracy.

For transformers with a tapped winding whose tapping range is greater than +/-5%, the impedance voltage must be measured across the principal tapping and the two end tappings.

Tolerances

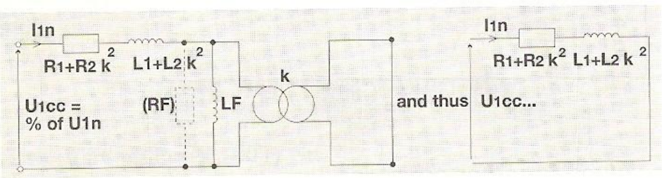
Tolerances are taken from the standard, unless otherwise specified by the customer.

Values	Tolerances
1.b) Partial losses : (No-load or load losses)	+ 15 % of each of the partial losses, on condition that the tolerance on the total losses is complied with (+10 % of the declared values)
3. Short circuit voltage a) on the principal tapping	± 7.5 % of the value declared by the manufacturer if the impedance voltage value (Ucc) is ≥ 10 %. ± 10 % of the value declared by the manufacturer if Ucc is < 10 %
b) on the other tappings	± 10 % of the value declared by the manufacturer if Ucc is ≥ 10 % ± 15 % of the value declared by the manufacturer if Ucc is < 10 %

Test objective

- Measurement of the transformer's load losses (Pcc)
- Measurement of the impedance voltage (Ucc)

Equivalent circuit :

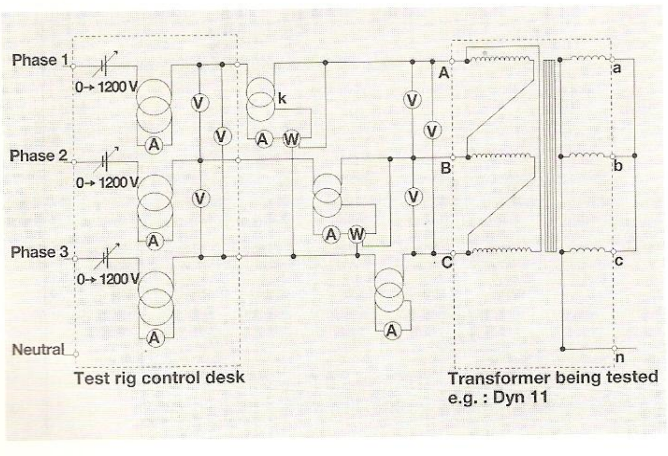


Test procedure

The Medium Voltage winding is supplied at the rated frequency of 50 Hz and at a voltage that gives a current as near as possible to the rated current, whilst the Low Voltage winding is short-circuited.
The load losses are measured using 2 wattmeters, the impedance voltage and current are measured by their respective measuring devices.
The impedance voltage is expressed as a percentage of the rated voltage.

$$\text{Ucc} (\%) = (\text{Ucc measured/Urated}) \times 100$$

Test rig diagram



The test procedure and the apparatus used are identical to those used for measurement of no-load losses.

Calculation of load losses

- at ambient temperature (20°C on average)

$$\text{Pcc} = \text{Pjoules}_{MV} + \text{Pjoules}_{LV} + \text{Pspecial}$$

$$= \left[(3/2) \times R_{MV} \times I^2\right] + \left[(3/2) \times R_{LV} \times I^2\right] + \text{Pspecial}$$

with R_{MV}, R_{LV} = resistances between phases

In the case of Delta connected windings :

$$\text{Pjoules} = 3 \times r \times (I/\sqrt{3})^2 = \boxed{(3/2) \times R_T \times I^2 \text{ with } R_T = (2/3) \times r}$$

In the cas of star connected windings :

$$\text{Pjoules} = 3 \times r \times I^2 = \boxed{(3/2) \times R_T \times I^2 \text{ with } R_T = 2 \times r}$$

The special losses (or stray losses) are mainly composed of Eddy current losses.

- **at the reference temperature** (75°C for immersed type transformers)

The Joules losses (or resistive losses) vary according to the temperature whereas the special losses are inversely proportional to the temperature.

$$\boxed{\text{Pcc}_{75°C} = (K \times \text{Pj}_{T°amb.}) + (1/K \times \text{Ps}_{T°amb.})}$$

K = temperature correction constant
- for copper : K = (235+75) / (235+T° amb.).
- for aluminium : K = (225+75) / (225+T° amb.).

The standard (cont.)

■ *Standard values for impedance voltage in Europe, according to harmonisation document H 428.S1.*

Rated power (Sn) in kVA	*Impedance voltage expressed as a percentage of the applied rated voltage for the winding*
50 ≤ Sn ≤ 630	*4*
630 ≤ Sn ≤ 2500	*6*

■ *Standard impedance voltage values for other countries*

In accordance with IEC publication 76-5 (1982), the impedance voltage applied to a tested transformer is deduced from the following table :

Rated power (Sn) in kVA	*Impedance voltage expressed as a percentage of the applied rated voltage for the winding*
Sn ≤ 630	*4*
630 < Sn ≤ 1250	*5*
1250 < Sn ≤ 3150	*6,25*
3150 < Sn ≤ 6300	*7,15*

The impedance voltage Ucc

The impedance voltage comprises a reactive component, Ux, and Ur, which unlike Ux is dependent on temperature.

This can be expressed in terms of the rated values as follows :

$$(Ucc\%)^2 = (Ux\%)^2 + (Ur\%)^2$$

with $Ur\% = (Pcc \times 100) / Sn$
$Ucc\% = (Ucc \times 100) / Un$

E.g. : at ambient temperature of 20°C, and at a reference temperature of 75°C, we have, always given in percentage :

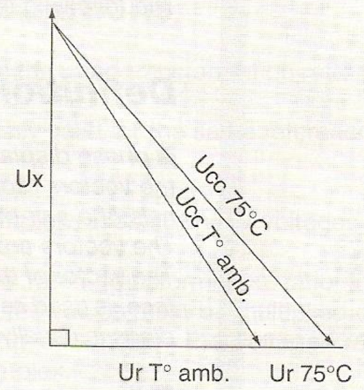
$$(Ucc_{75°C})^2 = (Ux)^2 + (Ur_{75°C})^2$$

$$(Ucc_{75°C})^2 - (Ur_{75°C})^2 = (Ux)^2$$

$$(Ucc_{75°C})^2 - (Ur_{75°C})^2 = (Ucc_{20°C})^2 - (Ur_{20°C})^2$$

Ucc at 75°C can therefore be expressed in the following manner :

$$Ucc_{75°C} = 100 \times \sqrt{\left(\frac{Ucc_{20°C}}{Un}\right)^2 - \left(\frac{Pcc_{20°C}}{Sn}\right)^2 + \left(\frac{Pcc_{75°C}}{Sn}\right)^2}$$



The standard

The following information is taken from IEC standard 76-1 (1993)

Definitions

■ ***phase displacement in a three phase winding** : this is the phase angle between the vectors representing the MV and LV voltages across the corresponding terminals of a pair of windings.*
The vectors are considered to turn counter-clockwise.
The vector of the MV winding, which 1st phase is oriented at 12 o'clock on the clock face, is used as a reference, and the phase displacement between all the other windings is usually expressed relative to this using a clock-hour figure.

■ ***the vector group** : this is the conventional notation indicating the connection arrangement of the MV and LV windings and their relative phase displacements, expressed as a combination of letters and clock-hour figures.*

Description of measurements

The transformation ratio is measured on each transformer tapping. The vector group of three phase transformers, as well as the polarity of single phase transformers must be checked.

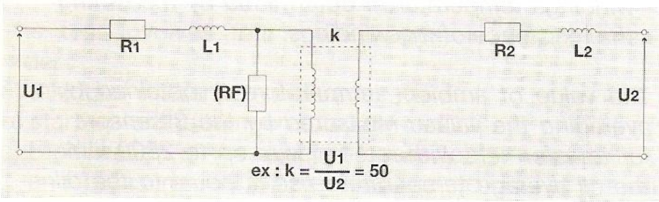
Tolerances

Values	***Tolerances***
2. No-load transformation ratio : *– for the principal tapping*	*The lowest of the following two values :* *a) ± 0.5 % of the ratio specified by the manufacturer* *b) ± 10 % of the real percentage of the impedance voltage*
– on other tappings	*Must be subject to an agreement between the customer and the supplier, but the ratio must be greater than whichever is smallest of a) or b).*

Test objectives

- To check the conformity of the transformer connection arrangement with that stated
- To check the conformity of the transformation ratio, k, on each tapping compared with the guaranteed values.

The part of the transformer studied during this test lies within the dotted line on the following diagram :



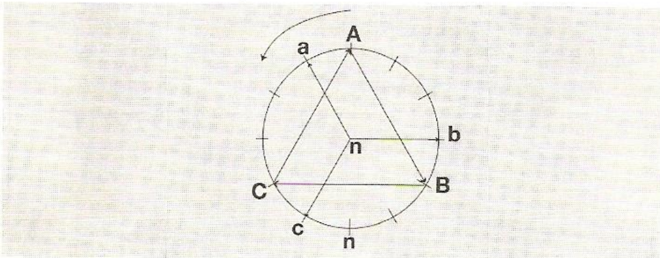
Test procedure

The vector group is checked and the transformer ratio is measured on each tapping with a voltage of 110 or 220 V applied on the MV side.

The measurement involves comparing the phase displacement of the MV voltage with the LV voltage for each phase.
This operation is performed using a Vettiner bridge, that opposes the voltages in the phases in order to compare their moduli. The bridge is balanced by adjustment of the dials to give null deflection on the galvanometer. The ratio is then read off the dials. The connection is correct when the ratio is identical on each phase.

Example : Dyn11 connection

- the MV side of the transformer is delta connected
- the LV side is star connected with a neutral terminal



Measurement of the transformation ratio

The vector group and the transformation ratio are identical to those defined by the manufacturer when :

$$\frac{\|\overrightarrow{AB}\|}{\|\overrightarrow{an}\|} = \frac{\|\overrightarrow{BC}\|}{\|\overrightarrow{bn}\|} = \frac{\|\overrightarrow{CA}\|}{\|\overrightarrow{cn}\|} = \frac{\text{[modulus of the MV voltage on the same leg]}}{\text{[modulus of the LV voltage on the same leg]}}$$

The calculations

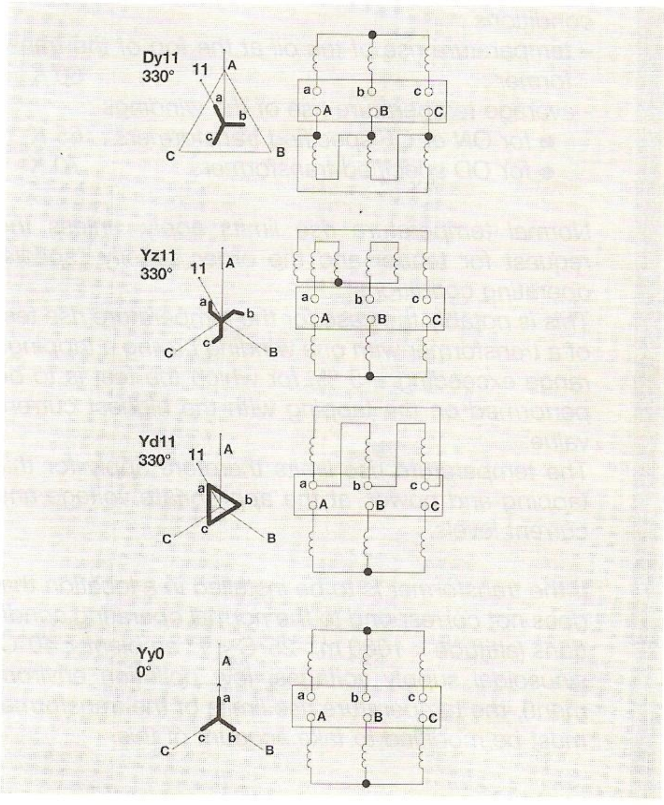
Calculation of the rated transformation ratio for each tapping :
This ratio is only valid for the same reference voltage.

Example :
Simple or complex ratios of MV/LV voltages

To obtain the rated transformation ratio for Yd or Dy connections, the values must be multiplied or divided by $\sqrt{3}$ depending on whether the voltages measured are simple or complex.
For Yy or Dd connections, the rated transformation ratio is not modified.

Usual connections

The most common connections in Europe are :



The capital letters denote to the highest voltage winding.

The standard

This test is detailed in IEC standard 76-2 (1993)

Test objective

Determination of the temperature rise of the oil and the transformer's MV and LV windings.

Test procedure

A transformer is specified according to its cooling mode (ONAN , ONAF, ODWF) both inside and outside of the transformer.
Its specification and rating plate must therefore give information on the power levels for which the transformer complies with the temperature rise limits.

The standard defines the temperature rise values and the characteristics of oil immersed transformers that are guaranteed and tested at the specified conditions :

- *temperature rise of the oil at the top of the transformer : 60 K*
- *average temperature rise of the windings :*
  - *for ON or OF specified transformers : 65 K*
  - *for OD specified transformers : 70 K*

Normal temperature rise limits apply, unless the request for tender and the order specify "special operating conditions".
This is notably the case for the temperature rise test of a transformer with one winding having a tappings range exceeding ± 5 %, for which the test is to be performed on the tapping with the highest current value.
The temperature rise limits therefore apply for this tapping and power, at the appropriate voltage and current levels.

If the transformer is to be installed in a location that does not correspond to the normal operating conditions (altitude < 1000 m, -25°C < T° ambient < 40°C, sinusoidal supply voltages, low pollution environment), the temperature rise limits of the transformer must be modified to take account of this.

Test description

The transformer must be equipped with its protection devices.
Three temperatures (T°) are measured at regular intervals :

- *ambient cooling air T° using at least three sensors.*
- *oil T° in the upper part of the transformer using thermometer pocket passing through the lid.*
- *windings temperature : determined by measuring the resistance of the windings.*

The value of ambient temperature is obtained by averaging the values measured by the 3 sensors ; for transformers with rated power up to 2500 kVA, the oil average temperature rise is equal to the oil temperature rise recorded at the upper part of the tank and multiplied by 0,8.
For practical reasons, the standard method for determining temperature rise in the factory is the short circuit test. Nonetheless, a method involving the back-to-back testing of two parallel connected transformers can also be used. During this short circuit test, the transformer is not subjected to the rated voltage and rated current at the same time. Instead it is subjected to the total calculated losses : the sum of the load losses at the reference temperature and the no-load losses.

Test objectives

- to determin the temperature rise of the oil (ΔT oil)
- to determin the temperature rise of the MV and LV windings
- to confirm the rated power of the transformer

Test procedure

The test involves four main stages, in chronological order :

a) taking of reference measurements
b) start-up of the temperature rise test
c) Stabilisation of the injected losses to the transformer, and measurement of the temperature rise of the oil (operation at total losses)
d) operation at rated conditions, during 1 hour, in order to determinate the MV/LV windings temperature rise

At least 24 hours before taking reference measurements, the transformer is placed in a suitable area to ensure uniform temperature of its windings and oil.

a) taking of cold reference values :
These values enable determination of the MV and LV resistances as well as the reference oil temperature, when the transformer is not live and when it is at ambient temperature.
These resistance measurements at ambient temperature are used to calculate the temperature rise in the windings.

■ Measurement of the reference MV resistance
A "superposing of direct current" type assembly is used. Once the current in the windings has stabilised, measurements are taken of the current, the voltage and the oil temperature of the transformer.

■ Measurement of the reference LV resistance between phases, to produce the cooling curve.
Since resistance values are of the order of a milliohm, the measurement is performed between 2 phases using a Thompson bridge or using a voltampere method with a shunt.

■ Measurement of the LV resistance between phase and neutral at ambient temperature, in the case of superposition
For this measurement the 3 LV phases are short-circuited and the measurement method is the same as that of the LV resistance between phases.

■ Measurement of the transformer temperature
A sheathed sensor is placed through the transformer lid. The temperature measured corresponds to the maximum oil temperature.

b) Starting of the temperature rise test :
The transformer LV terminals are short-circuited and the MV windings are energized from a variable voltage three phase supply. Provision for superposition of a d.c. current is made when necessary.

The total measured losses are injected overnight, and are monitored using the 2 wattmeters method

The standard (cont.)

The test has a dual objective :
- *determination of the temperature rise of the oil, at steady state, with dissipation of the total losses*
- *determination of the average temperature rise of the windings at the rated current In.*

The test is therefore performed in two stages :

- ***injection of the total losses** : the transformer is subjected to a voltage such that the measured active power is equal to the transformer's total losses at a test current greater than In.*
  The oil and air temperatures are monitored throughout the test which is carried out until the oil temperature reaches steady state.

- ***injection of the rated current** : once steady state has been reached the test must be continued with the current reduced to the rated current and maintained at this for one hour during which the oil and air temperatures are constantly monitored. At the end of this test the windings' resistances are measured, either quickly after disconnecting the supply and short-circuits, or without cutting off the supply, using the superposition method.*

N.B. : A reference measurement is taken of the resistances (R1, Θ_1) of all the windings at ambient temperature and at steady state.
The temperature of the LV winding Θ_2, and its resistance R2 are determined by the equation :

$$\Theta_2 = (R2/R1)\ (X + \Theta 1) - X$$

with X = 235°C for copper
X = 225°C for aluminium

Corrections

Results must be corrected if the specified values of power or current cannot be obtained during the test ;

- *the temperature rise of the oil above ambient temperature during the test is then multiplied by :*

$$[\text{total losses / test losses}]^{x}$$

with x = 0.87 or 0.9 or 1 depending on the transformer's cooling mode

- *the average temperature rise of the windings above the average oil temperature, on the other hand is multiplied by :*

$$[\text{rated current / test current}]^{y}$$

with y = 1.6 or 2 depending on the transformer's cooling mode

c) checking steady state and measuring the oil temperature rise :
Readings are taken of :

- the current on each phase and the power ; this power corresponds to the total losses to within ± 20%.
- the oil temperature (T°), the MV windings temperature and ambient air temperature.

The maximum temperature rise of the oil is defined by :

$$\Delta T^\circ \text{ oil} = T^\circ \text{ oil} - T^\circ \text{ ambient}$$

In practice, the ambient temperature is obtained by averaging the readings of the three thermometers located respectively 1 m away and half way up the transformer tank, immersed in glasses of oil to avoid fluctuations in air temperature due to draughts.

When steady state is reached with different losses to the total losses (Pt), the result is corrected :

$$\Delta T^\circ \text{ oil} = \Delta T^\circ \text{ measured } (Pt/P)^x$$

with :
ΔT° oil = temperature rise of the oil at total losses
ΔT° measured = temperature rise of the oil at the measured power
x = 0.8 or 0.9 or 1 according to the transformer's cooling mode

d) operation under rated conditions (for one hour)
To perform this measurement, the injected current is set at the rated value (In).

The transformer is run at this value for one hour, after which the following readings are taken :
- the injected current and power
- the temperature of the oil and of ambient air
- the MV resistance, by measuring the current and voltage of the direct supply.

The temperature rise of the MV windings can be calculated using the following formula :

$$\Delta T \text{ MV} = [(Rc/Ro) \times (K + to)] - K - t_a + 0{,}8\,(\Delta Th_{PT} - \Delta Th_{RN})$$

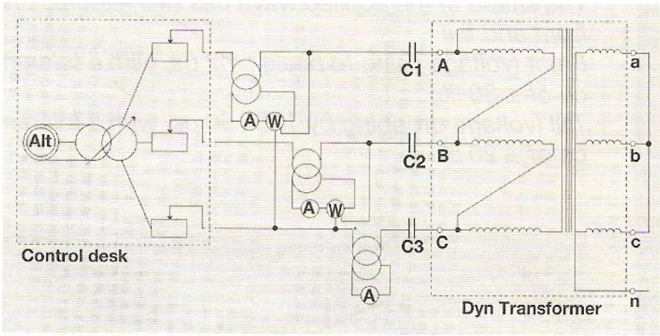
c = resistance at operating temperature measured using the direct power supply
Ro = resistance at ambient temperature measured using the same method
to = reference ambient temperature
K = temperature coefficient
t_a = average ambient temperature during operation at rated conditions
ΔTh_{PT} = temperature rise of the oil at total losses, measured by the sheathed sensor
ΔTh_{RN} = temperature rise of the oil during rated operation, measured by the sheathed sensor

The LV resistance is measured :
- **either between phase and neutral**, taking the reading using a Thompson bridge connected to the direct supply. The LV temperature rise is then calculated using the previous equation with LV reference values.
- **or between phases** : using the Thompson bridge or using a voltampere meter and a shunt.

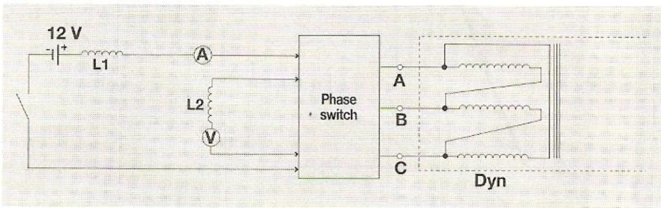
The alternating and direct supplies are turned off and the short-circuit is removed to take the resistance reading between the phases, every 15 seconds for 8 minutes.
These resistance readings at regular time intervals are used to produce the cooling curve.
The value of resistance at t=0 is obtained by extrapolation enabling the temperature rise of the LV winding to be determined.

Test rig diagram

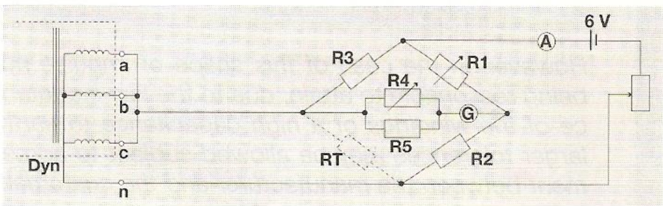
– of the alternating supply :



– of the MV direct supply
(to be added to the alternating supply rig to measure MV resistances at operating temperature)



– of the LV direct supply
(to measure the LV resistance between phase and neutral ; RT)



Key : G = galvanometer
L1, L2 : filtering reactors

The standard

The test methods and tolerances that follow are taken from IEC standard 76-3 (1980)

Test objective

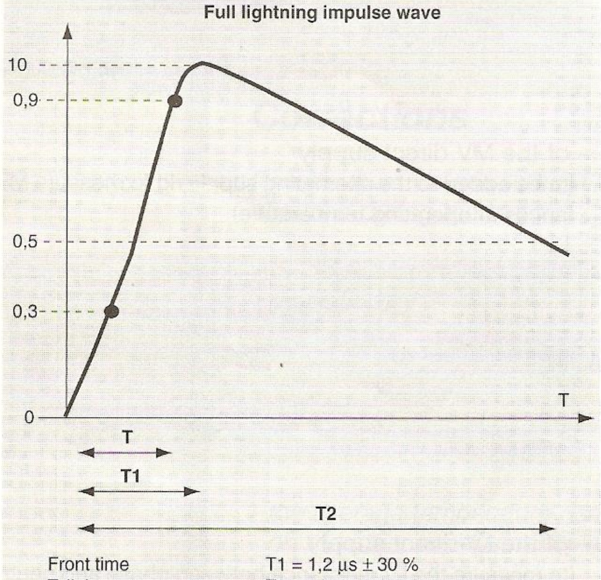
The full or chopped-wave lightning impulse test, applied to a winding's line terminals aims to check the impulse withstand at each line end relative to earth and to the other windings as well as that along the tested winding.

Description of the full-wave lightning impulse test

■ General

In the case of oil immersed transformers, the impulse test voltage is normally of negative polarity and is applied to the transformer insulation (see table of values on p32)
The shape of the applied wave has two features : its front and tail :
Front (voltage rising to peak) : 1.2 µs, with a tolerance of ± 30 %
Tail (voltage dropping by 1/2) : 50 µs, with a tolerance of ± 20 %

Full lightning impulse wave



Front time	T1 = 1,2 µs ± 30 %
Tail time	T2 = 50 µs ± 20 %
Relation betweenT1 et T	T1 = 1,67 T

However, in the case of this shape of impulse not being reasonable to attain, due to the low inductance of the windings or a high capacitance to earth, larger tolerances may be allowed subject to agreement between the manufacturer and the customer.

■ Test sequence

The standard sets out the test sequence composed of a calibration impulse of between 50 and 75 % of the full voltage followed by 3 impulses at full voltage.
This test impulse sequence is successively applied across the line terminals of the tested winding.
For three phase transformers, the tank and the other line terminals of the winding must be connected to earth either directly or indirectly via a low impedance, e.g. a current measuring shunt.
If the winding has a neutral output, then it must be connected to earth or to a low impedance and the tank connected to earth.

■ Recording measurements

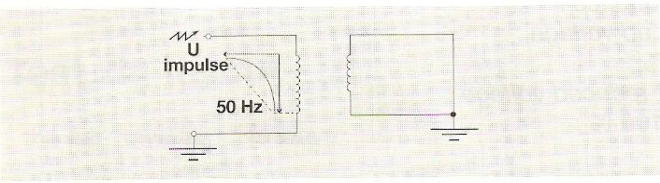
The oscillographic data recorded during the tests must clearly show the shape of the applied impulse voltage (time taken for voltage to rise to peak, time taken to drop by half), the scanning time and the selected attenuator.
The recording must include an oscillogram of the current in the winding to earth and be as sensitive as possible to enable any faults to be detected.

■ Test criteria

If there is no noticeable difference in the voltage and current curve recordings of the reduced and full voltage tests, then it is considered that the insulation has withstood the test without any damage.
However, should there be any doubt concerning the interpretation of any differences between the oscillograms, three full voltage impulses must again be applied, or the whole impulse test procedure repeated.

Test objective

Checking the lightning impulse withstand of each winding relative to earth, relative to the other windings and along the tested winding.
This test may be diagramatically represented by :



N.B. : At high frequency, the test voltage is spread exponentially along the length of the tested winding ; however, at low frequency (e.g. 50 to 60 Hz, etc.) the voltage is spread evenly along the winding.

Description of the full-wave lightning impulse test

The impulse wave is applied to each of the MV windings whilst short circuiting the others to earth through a shunt, with the LV and the tank being earthed.

In other words, any terminal to which the impulse is not applied is earthed either directly or indirectly through a measuring shunt.
Impulse waves of negative polarity are applied (in order to reduce the risk of a random external breakdown in the test circuit), that are characterised by the standard 1.2 / 50 wave.

Initially, the transformer is subjected to a calibrating impulse at 50% of the full impulse voltage.
Each winding tested is then subjected to 3 calibrating impulses followed by 3 more impulses at full impulse voltage magnitude.

Standard sphere gaps or calibrated voltage divider are used to calibrate the impulse voltage to be applied.

During each test, two values are simultaneously recorded using an oscilloscope, at the appropriate sweep speeds :
- the applied voltage
- the primary current resulting from the propagation of the impulse wave along the windings.

For practical reasons, a set of attenuators are used to adjust the oscillograph peak deflection at full voltage and at the calibrating voltage in order to make the obtained traces easy to compare.

The impulse test report includes a print out of the oscillograms recorded during the test.
The traces are examined to determine whether the transformer has passed or failed the test.
In the instance of a fault, this may be seen as an increase in the magnitude of current and / or a deformation in the voltage caused by :
– either an earthing fault
– or short-circuit between turns.

The standard (cont.)

Description of the chopped-wave impulse withstand test

This chopped-wave lightning impulse test is a specific test applied to the line terminals of a winding.
It is recommended to combine this test, when required, with the full-wave lightning impulse test, in the following sequence :
- one full-wave impulse at reduced voltage ;
- one full-wave impulse at 100 % ;
- one chopped-wave impulse at reduced voltage ;
- 2 chopped-wave impulses at 100 % ;
- 2 full-wave impulses at 100 %.

The peak value of the chopped-wave impulse defined by the standard, for each type of MV transformer voltage, must be the same as for the full-wave impulse test.

In practice, the manufacturers apply the same rules concerning the impulse generator and measurement devices as for the full-wave lightening impulse test, simply adding a spark-gap chopping device, and adapting the current attentuators as appropriate.
The voltage must be chopped at between 2 and 6 µs.

As for the full-wave lightning impulse test, the detection of faults during the chopped wave impulse test is performed by comparing the oscillograms taken before and after the chopped impulse wave.

Impulse voltage values defined in the standards

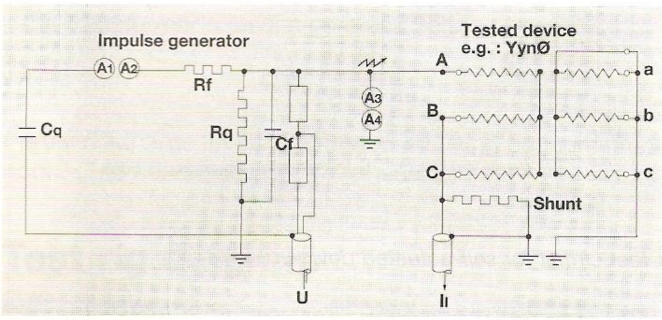
Rated insulation level in kV	*3,6*	*7,2*	*12*	*17,5*	*24*	*36*
rated voltage at the power frequency in kV at 50 Hz, 1 mn	*10*	*20*	*28*	*38*	*50*	*70*
impulse voltage in kV (list 2 of table 1 in IEC standard 76-3-1 (1987)	*40*	*60*	*75*	*95*	*125*	*170*

Description of the chopped-wave lightning impulse test

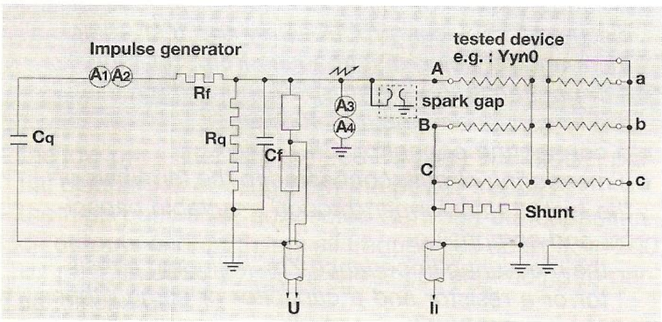
With the exception of the measurement that is performed with a spark-gap, the test method is the same as for the full wave impulse test.

Test rig layout

- the full-wave impulse wave



- the chopped-wave impulse wave



Impulse voltage values

rated insulation level in kV	3,6	7,2	12	17,5	24	36
rated voltage at the power frequency in kV, at 50 Hz, 1 mn	10	20	28	38	50	70
impulse voltage in kV	40	60	75	95	125	170

The standard

Most of the test procedure is described in IEC standard 270 (1981)
For the purposes of this standard, partial discharges are considered as electrical discharges occurring in an insulating medium, generally occurring as individual impulses that cause the dielectric properties to deteriorate.
Partial discharges originate from sharp edges and points on metal surfaces and electrically stressed cavities within solid insulation.

Definitions

- ***Partial discharges :*** *electrical discharges that only partially bridge the insulation between conductors.*
- ***the apparent charge :*** *expressed in pico-Coulombs (pC), is considered to be the charge, which if injected across the terminals of the tested transformer, would give the same reading on the measuring device as the partial discharge.*
- ***the quadratic flow :*** *the sum of the squares of the apparent charges over a time interval, divided by the time interval :*

Quadratic flow =

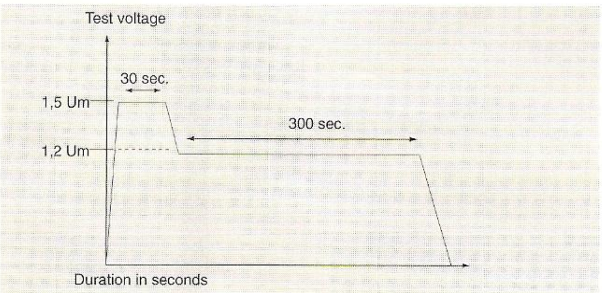
$$[1/T] \; [(q_1^2 + q_2^2 + q_3^2 \ldots\ldots + q_n^2)]$$

- ***the partial discharge test voltage :*** *the voltage applied to the test transformer as specified for each type of transformer in the standard.*

Method of applying the test voltage

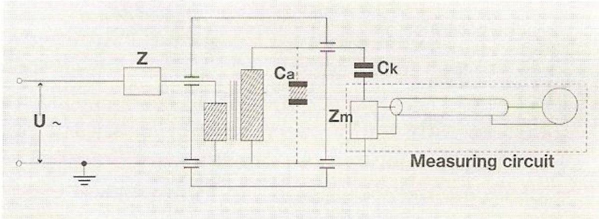
The partial discharge test voltage applied to the transformer must be as near sinusoidal as possible and be of greater frequency than the rated frequency, in order to avoid an excessive magnetising current during the test.

The voltage applied to the transformer's line terminals, must follow the cycle shown below :



Test circuit and measuring devices

Whatever type of test circuit and measuring device are used, they must first be calibrated.
Unless otherwise specified by the customer, the transformer will be tested at ambient temperature and the insulator surfaces will be clean and dry.
The standard gives a number of test circuits of which France Transfo has decided to use the following :



Test circuit for self-actuated devices

This diagram represents a test circuit in which the voltage is induced in the power transformer.
The circuit comprises :

- ***a source of alternating voltage***
- ***an impedance or Filter Z :*** *blocking out the discharge impulses produced by the test equipment and reducing disturbances from the source.*
- ***a capacitance, Ca :*** *corresponding to the capacitive impedance of the transformer*
- ***a connecting capacitor, Ck.***
- ***a measuring circuit,*** *connected to the terminals of the tested transformer through a suitable capacitor and comprising :*
  - *the measuring impedance Zm, including a resistor or a resistor and a capacitor or some other more complex filtering device*
  - *coaxial connecting cables*
  - *the measuring device and display unit : this sets the pass band of the measuring circuit and displays the partial discharges.*

The partial discharges produced by the transformer cause transfer of charge within the test circuit and current impulses across the impedance Zm.
This impedance, together with the transformer and the connecting capacitor, determine the duration and shape of the measured impulses.
These impulses are then smoothed and amplified to provide the discharge detector with the transformer's quadratic flow value

Measurement of partial discharge level

Test objectives

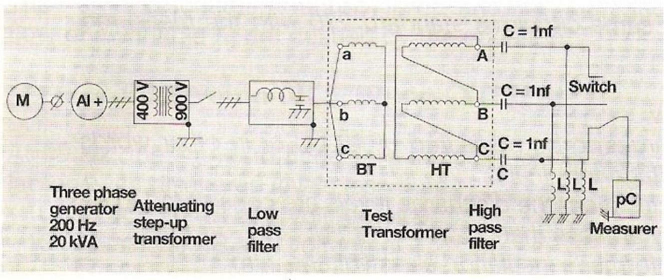
The objective of this test is to determine the overall dielectric condition of the transformer

Test procedure

The transformer is energised with no load at a frequency of 200 Hertz.
The following voltage levels are applied to the MV :
- rated voltage Un.
- the transformer's insulation class voltage Um.
- 1.2 Um.
- 1.5 Um.

Partial discharge levels are measured using capacitances connected between each MV phase and earth.

Test rig diagram



- the low pass filter lets the 200 Hz pass and blocks partial discharges coming from the power supply.
- the high pass filter, connected between the capacitance outputs and earth lets all frequencies apart from 200 Hz past, in other words all those corresponding to partial discharges.
  The capacitors are rated for high voltages, 50 kV, whilst themselves being free of any partial discharge.
- the discharge detector, connected to a 3-way switch enables measurements on each phase to be taken in accordance with the standard.
  The measurement range is usually in the pass band between 10 and 500 kHz.

The standard (cont.)

Calibration

Before taking any partial discharge measurements a calibration procedure must be performed. This is because the measured pulses are attenuated both in the windings and in the measurement circuit.
To do this, simulated pulses are injected using a calibrated discharge generator connected across the transformer's terminals.

Measurement sensitivity and permissible partial discharge levels :

Partial discharge measurements are subject to greater errors than other types of measurements performed during High Voltage tests.
The measurements are affected on one hand by many unquantifiable parameters and on the other by the raw background value that must not exceed 50 % of the specified acceptable partial discharge level. However, when the intensity of the specified partial discharges is less than or equal to 10 picoCoulombs (pC), a background noise level of up to 100 % of the specified value is acceptable.
Since actual voltage values are not specified in IEC publication 270, we have chosen to use the following values taken from the EDF (French Electricity Board) specification HN 52S07 dated May 1978.
This standard recommends the same circuit as standard 270 with the measured values being :
- either the apparent charge
- or the quadratic discharge flow
The test rig must enable discharges to be measured of 10 pC or in other words $10^{-20} C^2/s$ across the Medium Voltage terminals.
In conformity with the EDF specification, the discharge levels are considered to be satisfactory when, at 50 Hz, they are less than :
- 50 pC or $10^{-18} C^2/s$ at the transformer's insulation class voltage, Um
- 100 pC or $10^{-17} C^2/s$ at 1.2 Um

Calibrating

A discharge calibrator connected across the Medium Voltage terminal and earth, sends out calibrated impulses.
When the observed value on the detector is identical to that generated by the reference calibrator, this means that the signal is not being attenuated.
The partial discharge value is then calculated directly from the reading measurement.
Otherwise, i.e. when the reading from the detector is not the same as that sent out by the impulse calibrator, the voltage attenuation must be measured and added to each measurement value.

The admissible partial discharge level

Level 0 quadratic flow, in accordance with the standard, corresponds to 10^{-20} C^2/s at 50 Hz
The Partial Discharge level (PD) in dB and the quadratic flow of a variable X, are defined by the equation :

$$\text{PD level in dB} = 10 \log (X/10^{-20})$$

At 50 Hz, the standard considers transformers as satisfactory with discharge levels less than :
- 10^{-17} C^2/s = 20 dB at a voltage of Um
- 10^{-18} C^2/s = 30 dB at a voltage of 1.2 Um

For f = 50 x 4 = 200 Hz
→ the PD level in dB at 200 Hz

$$= 10 \log (4X/10^{-20}) = 10 \log 4 + 10 \log (X/10^{-20})$$
$$= 6 \text{ dB} + \text{PD level at 50 Hz}$$

Consequently, at 200 Hz, transformers are considered satisfactory when the partial discharge levels are less than :
- 26 dB or 4 10^{-18} C^2/s at a voltage of Um ;
- 36 dB or 4 10^{-17} C^2/s at a voltage of 1.2 Um.

The standard

The test procedure is described in IEC standard 551 (1987)

Definitions

- **the sound pressure level, Lp** : *this is the value expressed in decibels (dB), equal to 20 times the decimal logarithm of the ratio of the given acoustic pressure and the reference acoustic pressure ; the reference acoustic pressure being 20 µPascals.*

- **the sound power level, Lw** : *this value is expressed in dB, equal to 10 times the decimal logarithm of the ratio of the given acoustic power and the reference acoustic power ; the reference acoustic power being 1 picoWatt.*

- **the ambient noise level** : *this is the weighted level (A) of the acoustic pressure when the transformer is de-energised.*

Measuring devices

Measurements must be performed using a class 1 sound level meter. In addition, the background noise level must be measured immediately before and after the measurement is performed on the transformer.

If the difference between the Lp of the background noise and the sum of the levels resulting from the background noise and the transformer is ≥ 10 dB, the background noise levels may only be measured from one measurement position without it being necessary to apply any correction to the noise level measured for the device.

If the difference is between 3 and 10 dB, the corrections in the table below must be applied.

Moreover, if the difference is less than 3 dB the test will not be accepted unless the level resulting from the background noise and the noise of the transformer are less than the guaranteed values.
Should this be the case, a lower value will be taken for this difference and a total level reduced by 3 dB could be considered as the upper limit of the acoustic pressure level in this position.
This condition must be included on the official test report.

Correction for the effect of background noise

Depending on the above mentioned acoustic pressure levels that are taken from each of the measurement positions, a correction may be performed for the effect of background noise, in accordance with the following table :

Difference between the measured Lp of the device in service and the Lp of the background noise alone in dB	***Correction to be subtracted from the measured Lp of the device in service to obtain the Lp due to the device in dB***
3	*3*
4 à 5	*2*
6 à 8	*1*
9 à 10	*0,5*

Test objective

Comparing the noise generated by the transformer with that set in the standard.

Test procedure

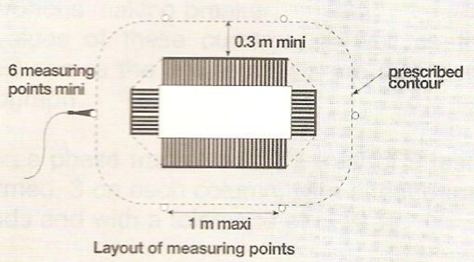
The noise is caused by magnetostriction of the core, the reactors and their associated cooling devices.

Once the background noise has been measured, power is supplied to the transformer under no load, at the rated voltage and frequency, with the tapping selector on the principal tapping.
The sound pressure level is then measured at various points around the transformer.

The noise level can be expressed in two ways :

- in terms of the (A) weighted **sound pressure level Lp** measured using a sound level meter at a defined distance from the transformer.
  The value obtained is the quadratic average of the measured values :
- at 1/3 and 2/3 of the tank height when this is greater than 2.5 m : otherwise, the measurement is performed at half the tank height.

- at a minimum distance of 30 cm from the transformer (the recommended perimeter distance).
  Measuring points should be spaced at an interval of at most 1 meter and at least such that the test has a minimum of 6 measuring points.



Layout of measuring points

- in terms of the device's (A) weighted **sound power level, Lw,** calculated from the sound pressure using the following equation :

$$Lw\ (A) = Lp\ (A) + 10 \log S - X$$

Lw (A) = the weighted acoustic power level in dB (A)
Lp (A) = the sound pressure in dB (A)
X = correction for background noise (see previous page)
S = the equivalent surface area in m², defined by the equation : S = 1.25 x H x P
with H = the transformer height in metres
P = the length of the measuring perimeter at a distance of max. 30 cm, in meters
1.25 = empirical factor designed to take account of the acoustic energy radiated by the top of the transformer or the coolers.

The sound power takes account of the geometry of the transformer and enables a noise level to be expressed independently of the distance from the transformer at which it is measured ; it is therefore possible to compare it between transformers.

The standard

This test is summarised in IEC standard 76-5 (1982 and amendment 2 dated 1994). It specifies that transformers must be designed and built to withstand the thermal and mechanical consequences of external short-circuiting without suffering any damage.

General

The transformer must have previously been subject to the routine tests and accessories need not necessarily be mounted for this test.
If the windings are fitted with tappings, the reactance, X and the resistance, R must be measured for positions corresponding to the tappings that will be subjected to the short-circuit test.
At the start of the short-circuit tests, the average winding temperature must be between 0 and 40°C.

■ **Short circuit current :**
The short-circuit current is characterised by :
- **an initial asymmetric value** equal to $k.\sqrt{2} \times Icc_{symmetric}$ where $k.\sqrt{2}$ is dependent on the ratio of the reactance and the resistances X/R (see the table below)
  This peak current, lasting for a duration that is less than one cycle, is the source of electromagnetic forces generated in the transformer.

- **a symmetric value** of short circuit current, that will mainly cause thermal effects in the transformer.
  This current is dependent among other things on the short-circuit voltage.
(e.g. : $Icc_{symmetric}$ for Ucc 4 % = 25 x In).

The symmetric short circuit current is calculated taking account of the short circuit impedance and the network impedance, for transformer with a rated power of > 3150 kVA, and also for those ≤ 3150 kVA, if the network impedance is greater than 5 % of the short circuit impedance (otherwise, the network impedance is ignored).

The accepted tolerance between the specified values and the measured values is ± 10 % for the symmetric short-circuit current, and ± 5 % for the peak current value.

Values of the factor $k.\sqrt{2}$

X/R	1	1,5	2	3	4	5	6	8	10	≥14
$k.\sqrt{2}$	1.51	1.64	1.76	1.95	2.09	2.19	2.27	2.38	2.46	2.55

■ **apparent power :**
The apparent short circuit power of the network where the transformer is installed, may be specified by the buyer in his request for tender, in order to give the value of Icc symmetric that is to be used in the calculation and in the tests.
If the short circuit power level is not specified, the values given in the table below may be used :

The highest network voltage in kV	The apparent short circuit power in MVA
7.2 - 12 - 17.5 and 24	500
36	1000

■ **Tapping selector switch**
This device must be able to withstand the same short circuiting overcurrents as the windings.

■ **The neutral terminals**
The neutral terminal of zigzag or star connected windings must be designed to withstand the highest overcurrent that could pass through it.

■ **temperature**
The maximum winding temperature after short circuiting must not exceed 250°C for copper and 200°C for aluminium.

Short circuit test in an independent laboratory

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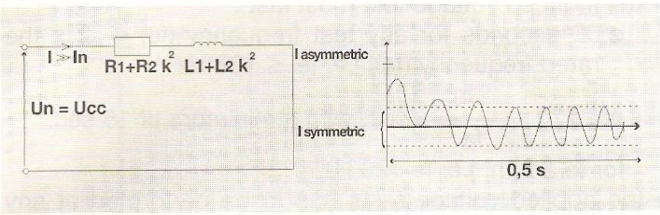
Test objective

To confirm that the transformer can withstand the short circuit currents defined in the standard.
The test rig layout is identical to the test for short circuit losses, but the transformer is subjected to Ucc = Un, or in other words to a high short circuit current :



e.g. : for a transformer with Ucc = 4 % (when measuring Pcc), the short circuit withstand current can reach :
|| I symmetric || = 25 In
By choosing the making time at U = 0 :
I asymmetric = k. $\sqrt{2}$ x 25 In
The transformer is then subjected to :
1) high electrodynamic forces, since the Force = constant x I^2
2) then high temperature in the windings

Test procedure

To obtain the short circuit current, one of the transformer's windings is supplied a voltage that must not exceed 1.15 times its rated voltage, with the other winding short circuited.

Moreover, the making time of the peak initial value in the winding of the phase being tested, must be set using a synchronous making breaker;
The values of these currents as well as the voltage applied across the line terminals are recorded using an oscillograph.

For three phase transformers, a total of 9 tests must be performed, 3 on each column, with a test duration of 0.5 seconds and with a tolerance of ± 10 %.

Unless otherwise specified by the customer, the tests on each of the phases for transformers with tappings are performed on various tapping positions :
- 3 tests on the position corresponding to the highest transformation ratio on one of the end phases.
- 3 tests on the principal tapping on the middle phase
- 3 tests on the position corresponding to the lowest transformation ratio on the other end phase.

After each of the tests, the impedance values are measured and compared with the original values.

Fault detection and test sanctions

After the test, the transformer and, as applicable the DGPT2 gas detector protection device, must be inspected.
The short circuit reactance measurement and the oscillograms taken at different stages of the tests must be examined to find any anomalies.
The transformer is again subjected to routine tests and notably to dielectric tests which are performed at 75 % of their original value, after which the tank is removed to inspect the active part of the transformer in order to find any visible faults.

(e.g. a fault may be seen in the connection position, there may be deformation of the windings, etc.)

The transformer is deemed to have passed the short circuit test if :
- the routine tests are repeated with success
- measurements during the short circuit tests and inspection after tank removal show no sign of a fault.
- the short circuit reactance measured after the tests differs from that measured initially by :

- **no more than 2 %** for concentrically wound transformers. However, when the winding conductor is made from foil, a higher limit of 4 % can be used for transformers with a Ucc of at least 3 % after agreement between the manufacturer and the buyer.
- **or by more than 7.5 %** for concentric, oblong wound transformers with a Ucc of at least 3 %. The value of 7.5 % can be reduced by agreement between the manufacturer and the purchaser.

Testing 60 Hz transformers on a 50 Hz test rig

The test rigs have a 50 Hz supply, and testing 60 Hz transformers requires a few adaptations to be made.

Measurement of the impedance voltage and load losses :

- The impedance voltage as a percentage (Ucc%) has two components : active and reactive

Active voltage :

$$Ur\ \%\ (60\ \text{Hz et}\ 75°\text{C}) = 100\ \frac{Pcc}{Sn}$$

Reactive voltage :

$$Ux\ 60\ \text{Hz} = \frac{60}{50}\sqrt{Ucc^2\ (\text{ambient, 50 Hz}) - Ur^2\ (\text{ambient})}$$

and

$$Ucc\%\ (60\text{Hz}\ 75°\text{C}) = \sqrt{Ur^2\ (60\text{Hz, }75°\text{C}) + Ux^2\ (60\ \text{Hz})}$$

Pcc = load losses at 75°C and 60 Hz
Sn = rated power

- Joule effect losses (resistive) are independent of the frequency.
  Special losses (stray) Ps are mainly losses due to Eddy currents, that are inversely proportional to the resistivity and directly proportional to the square of the frequency.
  Therefore the special losses Ps2, at temperature Θ2 and frequency fb, and losses Ps1 at temperature Θ1 and frequency fa are in a ratio of :

$$\frac{Ps_2}{Ps_1} = \frac{X + \Theta 1}{X + \Theta 2}\ \frac{fb^2}{fa^2}$$

with X = 235 for copper and 225 for aluminium.

Measurement of no-load losses

The no-load losses are virtually the same as the losses in the magnetic core. Losses in the core are due to hysteresis and to Eddy currents.
At constant induction the hysteresis losses vary proportionally with the frequency and those due to Eddy currents vary proportionally to the square of the frequency.

To remain at constant induction, at 50 Hz we will apply a voltage of **U = Un x (50/60).**

Losses at 60 Hz (Pv_{60}) are calculated using losses measured at 50 Hz (Pv_{50}) by :

$$Pv_{60} = 1{,}32 \times Pv_{50}$$

In the same way, no-load current at 60 Hz is deduced from the one at 50 Hz by :

$$Io_{60} = 1{,}1 \times Io_{50}$$

Dielectric tests

- the induced voltage test must last :
  - 60 seconds for any test frequency (fe) ≤ 2 x the rated frequency (fn), i.e. fe ≤ 120 Hz
  - $\left[120 \times \frac{fn}{fe}\right]$ sec. with a minimum of 15 sec.

  for fe ≥ 2 fn, i.e. fe 120 Hz.
- the applied voltage tests has to be performed at any appropriate frequency at least equal to 80 % fn.

Consequently, for fn = 60 Hz, the test frequency must be :
fe ≥ 0,8 x 60 or in other words fe ≥ 48 Hz.
Therefore testing at 50 Hz is valid without increasing the test duration.

Temperature rise test

Using the simulated loading method, or so-called short circuit method, a current is injected into the transformer so as to generate the total losses (Pt) equal to the sum of the no-load losses and the load losses.
Once steady state has been reached, the supply voltage is reduced to obtain the losses in the windings for In and fn.
When testing at 50 Hz instead of 60 Hz, the current is adjusted to achieve the required losses using the equation :

$$Pcc_{60} = Pj\frac{X + \Theta_2}{X + \Theta_1} + Ps_{50}\ \frac{X + \Theta_1}{X + \Theta_2}\ \frac{60^2}{50^2}$$

To obtain the same losses at 50 Hz as at In and 60 Hz, it is necessary to inject a current of :

$$I = \sqrt{\frac{Pcc_{60}}{Pcc_{50}}}\ In$$

Measurement of the noise level

Since the sound power is proportional to the square of the frequency, the increase in noise level is of approximately **10 log (60/50)² = 1.6 dB**
It is therefore possible to estimate the noise level of a transformer at 60 Hz through a 50 Hz test at the same induction but there will be a small increase in the measurement uncertainty.

Test certificate n° 626692-01

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Product	: *Ground mounted distribution transformer*	Rated power	: *630* kVA
Type	: *Step down - Indoor - Three-phase*	Rated frequency	: *50* Hz
Standard	: *IEC 76*	Total mass	: *1940* kg
Dielectric	: *Oil*	Mass of dielectric	: *345* kg
Type of cooling	: *ONAN*	Year	: *1997*

Maximum ambient according to IEC. 76	: *50* °C	Altitude service : *X < 1000 m*
Maximum dielectric temperature rise	: *50* ° K	
Maximum winding temperature rise	: 55 °K	

Rated voltage : HV *15000 V* Curents : 24.25 A
Tappings : HV *15375 V - 14625 V*

Insulation : *24 kV (125/50)* Applied voltage : *50 kV* Duration : *60 s*

Rated voltage : LV *410 V* Currents : *887.1 A*

Insulation : *1.1 kV (0/3)* Applied voltage : *3 kV* Duration : *60 s*

Connection : *Dyn11* | Induced voltage : *30000 V* | Duration : *40 s* | Frequency : *150 Hz*

Remarks: *Thermic class A*
Test procedures N° MOD/IQ/ESS008. - Tightness test 100 g/cm²/6 h mini statisfactory.
France Transfo guarantees that the PCB content of the mineral oil used in its new transformers is below the detection level specified in IEC 997 standardized method, i.e. 2 ppm.

	Po	IV/IN	PCC at 75°C	UCC at 75°C	PV+PCC at 75°C	Transformation ratio Principal tapping	Other
Guarantee	*1300 W*	*1.80 %*	*6500 W*	*4.00 %*	*7800 W*	*± 0.38 %*	*± 1 %*

Rated voltage ratio

HV/LV
1 - *37.50*
2- *36.58*
3- *35.67*

Resistances at 20.0 °C

	HV	LV
	3.089 Ω	0.00196 Ω
	3.135 Ω	0.00199 Ω
	3.057 Ω	0.00194 Ω
Averages	3.094 Ω	0.00196 Ω
ΣRI^2	2728 W	2318 W
$\Sigma R1^2$ 75 °C	3341 W	2839W

No-load losses / **Results**

Hz	U(V)	I1(A)	I2(A)	I3(A)	IV(A)	dW1±dW2	cte	k	Po	ΔPo	IV/IN	ΔIV/IN
50	*410*	*9.20*	*8.72*	*9.20*	*9.04*	*1254*	*1*		*1254 W*	*-3.54 %*	*1.02 %*	*-43.39 %*

Load losses at 20.0 °C (HV/LV) / **Results at 75 °C**

U(V)	I1(A)	I2(A)	I3(A)	cte	dW1±dW2	cte	k	Pmes	PCC	ΔPCC	UCC	ΔUCC
570.0	*24.25*	*24.24*	*24.25*	*1*	*5679*	*1*		*5679*				
570.0			*IN = 24.25 A*					*5679*	*6697 W*	*3.03 %*	*3.84 %*	*-3.95 %*

Issued on

Po+PCC	*7951 W*	ΔPo+PCC	*1.94 %*

Efficiency	Voltage regulation
cos φ 0.8 : *98.447 %*	cos φ 0.8 : *3.092 %*
cos φ 1.0 : *98.754 %*	cos φ 1.0 : *1.131 %*

Test manager *M. RONAT*

Bibliography and correspondence of standards

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IEC	International publications (International Electrical Commission)	IEC 76-1	IEC 76-2	IEC 76-3	IEC 76-4	IEC 76-5	IEC 296	IEC 354	IEC 270	IEC 551	
HD	European harmonisation document (European electrical standards commission)	HD 398-1	HD 398-2	HD 398-3	HD 398-4	HD 398-5				HD 399 S2	HD 428 S1
	Power transformers : General	■									
	Power transformers : Temperature rises		■								
	Power transformers : Insulation levels and tests			■							
	Power transformers : Tappings and connections				■						
	Power transformers : Short circuit withstand					■					
	Specifications for unused mineral insulating oil						■				
	Loading guide for oil immersed transformers							■			
	Measurement of partial discharge levels								■		
	Determination of the noise levels of transformers									■	
France											
NFC 52-100	Power transformers :	■	■	■	■	■					
NFC 52-112-1	Three phase oil-immersed transformers of between 50 and 2,500 kVA, with a highest voltage not exceeding 24 kV exceeding 24 kV										■
NFC 52-112-3	Three phase oil-immersed transformers of between 50 and 2,500 kVA, with a highest voltage not exceeding 24 kV exceeding 36 kV										■
NFC 52-112-4	Determination of the power characteristics of a transformer with non-sinusoidal load currents										■
NFC 52-101	Unused mineral insulating oil for transformers						■				
Germany											
DIN 42 500	Drehstrom-Öl - Verteilungstransformatoren, 50 Hz, 50 bis 2500 kVA										■
VDE 0532 Teil 1	Allgemeines	■									
VDE 0532 Teil 2	Übertemperaturen		■								
VDE 0532 Teil 3	Isolationspegel und Spannungsprüfungen			■							
VDE 0532 Teil 4	Ansapfungen und Schaltungen				■						
VDE 0532 Teil 5	Kurzschlußfestigkeit					■					
VDE 0532 Teil 7	Bestimmung der Gerüschpegel									■	
	Belastbarkeit von Öltransformatoren							■			
VDE 0370	Neue Isolieröle für Transformatoren										
Belgium											
NBN C 52-223	Three phase distribution transformers	■	■	■	■	■					
NBN - HD 428.1 S	Three phase oil-immersed transformers of between 50 and 2,500 kVA, with a highest voltage not exceeding 24 kV exceeding 24 kV										■
	Loading guide for oil immersed transformers							■			
NBN C 27 101	Specification for unused mineral insulating oil						■				
NBN C 52 001	Measurement of the noise levels of transformers									■	
Angleterre											
BS 171	Powers transformers	■	■	■	■	■					
BS 148	United Kingdom										
BS7735-94								■			

Bibliography and correspondence of standards (cont.)

IEC	International publications (International Electrical Commission)	IEC 76-1	IEC 76-2	IEC 76-3	IEC 76-4	IEC 76-5	IEC 296	IEC 354	IEC 270	IEC 551	
HD	European harmonisation document (European electrical standards commission)	HD 398-1	HD 398-2	HD 398-3	HD 398-4	HD 398-5				HD 399 S2	HD 428 S1
Spain											
UNE 20-101	Transformadores de potencia	■	■	■	■	■					
UNE 20-110	Guida de carga para transformadores sumergidos en aceite							■			
UNE 21-315	Medida de los niveles de ruido de los transformadores									■	
UNE 21-320/5	Prescripciones para aceites minerales aislantes nuevos						■				
UNE 20-138	Transformadores trifásicos para distribución en baja tensión de 25 a 2 500 kVA, 50 Hz										■
UNE 5201											
UNE 5204 D											
Italy											
CEI 14-4	Transformatori di potenza	■	■	■	■	■					
CEI 10-1	Oli minerali isolanti per trasformatori						■				
Denmark											
DEFU	Technical regulations for distribution transformers	■	■	■	■	■		■		■	
Sweden											
SS 427 01 01	Power transformers (except for differences with clause 2 of IEC 76-1 and clause 5 of IEC 76-3)	■	■	■	■	■					
SS IEC 551	Measurement of transformers sound levels									■	
SS 427 01 06	Oil immersed power transformers - Loading capacity							■			
SS 427 02 01	Distribution transformers										
Holland											
NEN 2761	Energietransformatoren. Algemeen	■									
NEN 2762	Energietransformatoren. Temperatuurverhoging		■								
NEN 2763	Energietransformatoren. Isolatieniveaus en diëlektrische proeven (in voorbereiding)			■							
NEN 2764	Energietransformatoren. Aftakkingen en schakelingen				■						
NEN 2765	Energietransformatoren. Kortsluitskerte					■					
NEN 3184	Energietransformatoren	■									
NEN 3541	Kortsluitsterke van energietransformatoren met vermogens tot en met 1600 kVA (vervallen).										
Norway											
NEN 05.71	Norske normer for krafttransformatorer : power transformers	■	■	■	■	■					
Austria											
ÖVE-M 20, TEIL 1	Allgemeines	■									
ÖVE-M 20, TEIL 2	Übertemperaturen		■								
ÖVE-M 20, TEIL 3	Isolationspegel und Spannungsprüfungen			■							
ÖVE-M 20, TEIL 4	Anzapfungen und Schaltungen				■						
ÖVE-M 20, TEIL 5	Kurzschlußfestigkeit					■					
Portugal	No particular standards references										
Finland	No particular standards references										

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Due to the evolution of standards and materials, the present document will bind us only after confirmation from our technical department.

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