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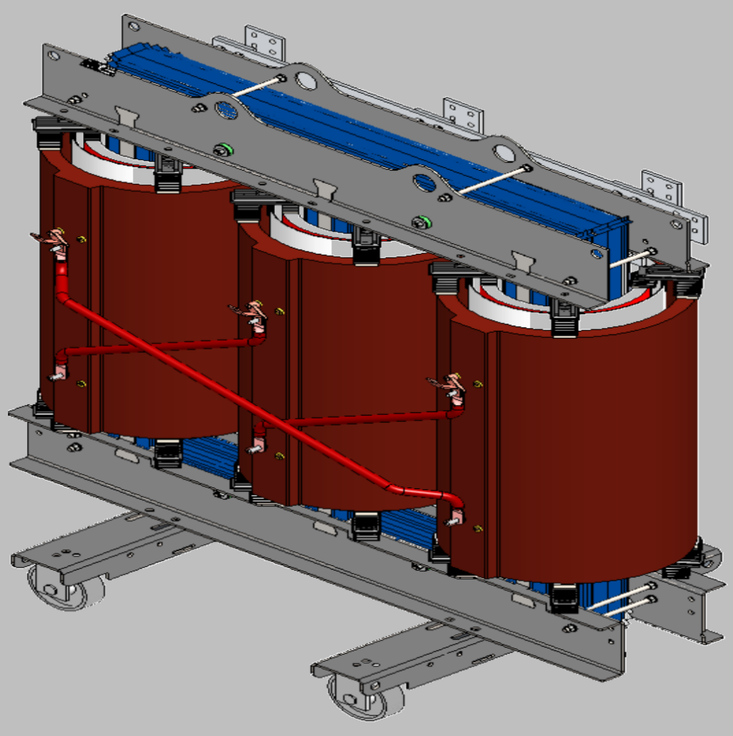
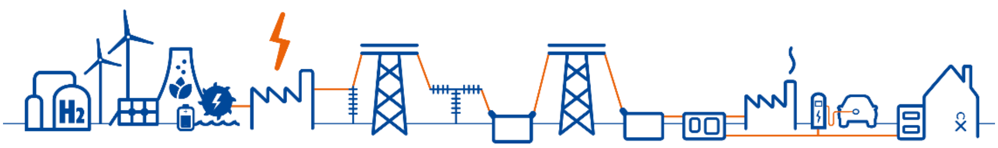
Test description for dry-type transformers
chapter for routine tests





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Test lab cast resin transformers
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1. Scope

This is a general test description for dry-type transformers at SGB and will apply if no specific customer requirements are given for the individual tests.
Special customer standards or values are not included in this description.
If not indicated, the description is exemplary for a three-phase transformer with two winding systems.
Auxiliary parts of the transformer are also not included, except as indicated e.g., temperature sensors.

The scope of this chapter describes “routine” tests, this means the standard requires these tests on each transformer (see IEC 60076-1:2011 chapter 3.11.1).

2. Standards

Part 11: Dry-type transformers
IEC 60076-11:2018

Replacement for
DIN EN 60726
(VDE 0532-726):2003-10

with reference to:

IEC 60076-1:2011	Power transformers - General
IEC 60076-3:2013	Insulation levels, dielectric tests and external clearances in air
IEC 60076-16:2011	Transformers for wind turbine application
IEC 60076-19:2013	Determination of uncertainties in the measurements of losses
IEC 60270:2000	High voltage test techniques – Partial discharge measurements
EN 50588-1:2015	Medium power transformers 50 Hz, with highest voltage for equipment not exceeding 36 kV – General requirements
EN 50629:2015	Energy performance of large power transformers (Um > 36 kV or Sr ≥ 40 MVA)

Others:

EC Directive 2009/125/EC of 21 October 2009	on the Ecodesign of energy related products
Regulation EC No. 548/2014 of 21 May 2014	to implement the EC Directive 2009/125/EC

3. Separate-source AC withstand voltage test

3.1. Standard

IEC 60076-11:2018 clause 14.2.5 // part 3 clause 10

3.2. Aim

This insulation test ensures that the quality of the insulation between the windings and the earthed parts, core, core clamping, etc. is correct. Furthermore, the constructive coordination is checked.

3.3. Test

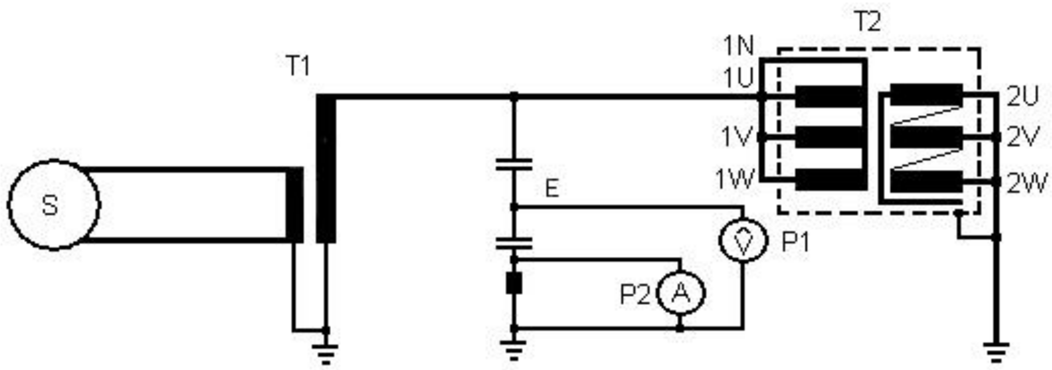
The test is applied using AC voltage and is to be carried out with a single phase-AC voltage supply that is as much as possible sinusoidal and does not fall below 80% of the rated frequency. The full test voltage has to be applied for 60s between all connected windings and auxiliary wirings. All other terminals and the core of the transformer, including the temperature sensors, will be shorted and grounded.

The test level complies with IEC 60076-11:2018 (clause 11.1, table 3).
If the transformer has an installation altitude higher than 1000m, the test level shall be corrected according to IEC 60076-11:2018 (clause 11.2, table 4).
For auxiliary wiring the test level is 2 kV.

3.3.1. Tapping position for test

During the test, all windings are shorted. Therefore, the tapping position is of no consequence.
Usually it is the tapping position with the highest turns (tap 1).

3.3.2. Test setup



picture 1: test setup for separate-source AC withstand voltage test

S: electricity supply
T_1: high voltage transformer
T_2: transformer to be tested

E: voltage divider
P_1: peak volt meter
P_2: ampere meter (measurement shunt)

3.3.3. Commonly used measuring devices for testing

measuring devices	manufacturer	type	range / accuracy	frequency	class
High Voltage Tester	ETL Prüftechnik	UH28C	5 kV/100 mA	50-60 Hz	n.a.
Hygro-/Thermometer	Greisinger electronic	GFTH95	0-70 °C 10-95 % r.F.	n.a.	n.a.
Peak voltage meter Measuring capacitor	MPS MWB	SMG CM80	100 kV 80 kV	50/60 Hz 50/60 Hz	n.a.
Peak voltage meter Measuring capacitor	MPS MPS	SMG MK200	200 kV 200 kV	50/60 Hz 50/60 Hz	n.a.

table 1: Commonly used measuring devices

3.3.4. Recorded values for the test

The test voltage, test frequency and test duration are documented in the test certificate.

3.4. Test criteria

The test is passed if no break down of the test voltage occurs.

4. Measurement of voltage ratio and check of phase displacement

4.1. Standard

IEC 60076-11:2018 clause 14.2.2 // part 1 clause 11.3

4.2. Aim

- Checking voltage ratio "ü" from HV to LV
- Determining deviations from the measured data to the desired values and documenting them
- Proving polarity as well as vector group

4.3. Theoretical principal

Firstly, the desired value for the single-phase translation is determined.
Additionally, the voltage is being converted phase to phase in the phase voltage and the HV phase voltage is being divided by the LV phase voltage.

On a Dyn (10kV/400 V) circuit e.g. $\ddot{U} = \frac{U_1}{U_2/\sqrt{3}} = \frac{10kv}{400/\sqrt{3}} = 43.30$

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

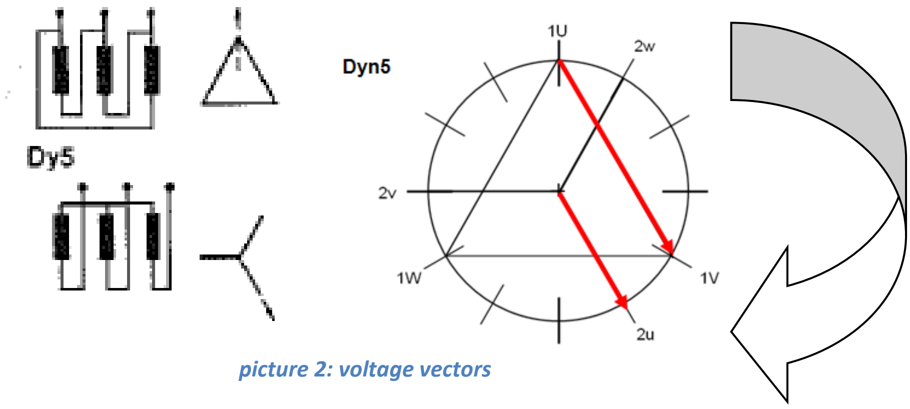
N_1 = number of windings primary side, N_2 = number of windings secondary side

formula 1: Voltage ratio formula for transformers

Afterwards the connections for the single-phase measurement will have to be determined.
This is mandatory to prove the accuracy of the polarity and the vector group. To do that the phase angle will be determined via the characteristic number of the group vector.

On a Dyn5 e.g. $\varphi = 5 * 30° = 150°$

This means that each phase of the LV winding is shifted 150° clockwise from the phase of the HV.



picture 2: voltage vectors

If you now draw a vector diagram with the circuits, it is possible to find two parallel vectors. In this case 1U-1V to 2N-2U. So, if it is measured in single phase, the phase deviation has to be 0°. If this applies the correct vector group is proven.

On certain circuits an additional theoretic, artificial neutral point has to be created.

4.4. Measurement

The measurement of the voltage ratio in proportion to "ü" and of the phase angle ϕ is conducted via a voltage ratio measurement bridge.

Via a measurement program the direct aberration is shown from the desired values of the voltage ratio and of the vector group, respectively the phase angles.

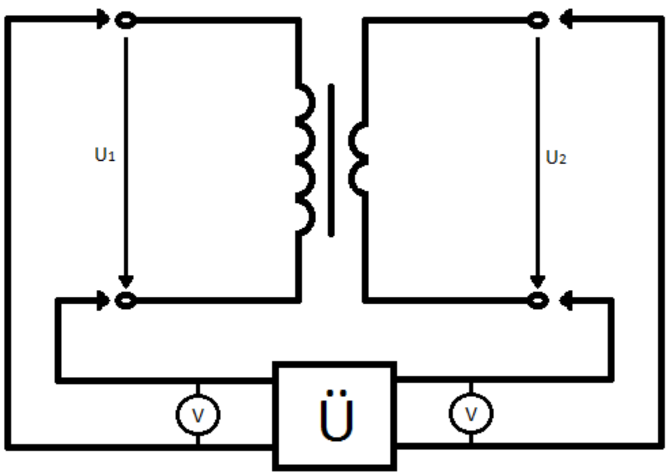
The measurement is conducted with a voltage between 10V - 230V AC (depending on the bridge), in single phase.
In the process, the HV winding is fed, which leads to the induction of voltage in the LV winding.
This voltage is measured and is compared with the fed voltage.
The result is compared with the desired values and the difference in percentage is displayed.
Through measuring between phase to phase or between a phase and the neutral point, the phase angle will be also controlled.

4.4.1. Tapping position for measurement

Between the measurements, all HV taps are to be measured during this test.

- In case of an LV tap, it is necessary to measure the HV nominal tap to the LV tap.

4.4.2. Test setup



picture 3: test setup for the measurement of the voltage ratio

U1: supply voltage of the bridge U2: secondary voltage transformer being tested

4.4.3. Commonly used measuring devices for measurement

measuring devices	manufacturer	type	range / accuracy	frequency	class
Transformer Turns Ratio Meter	HAEFELY / Tettex	TTR 2796	Ratio 0.8 - 100 101 – 1,000 -> ± 0.03 % 1,001 – 1,500 -> ± 0.05 % 1,501 – 2,000 -> ± 0.05 % 2,001 – 4,000 -> ± 0.05 % 4,001 – 13,000 -> ± 0.05 % 13,001 – 20,000 -> ± 0.20 % Phase ± 180 ° -> ± 0.05 °	50/60 Hz	n.a.
Winding Analyser	HAEFELY / Tettex	WA 2293	Ratio 1.0 - 100 -> 0.05 % 100 – 2,000 -> 0.1 % 20,000 – 100,000 -> 1 % Phase (Ratio) 1.0 - 500 -> ± 0.25 ° 500 – 10,000 -> ± 1.00 ° Phase (Clock number) 1.0 - 500 -> ± 0.05 °	50/60 Hz	n.a.
universal measuring instrument	Omicron	CPC 100 CP TD1 CP SB1			n.a.

table 2: Commonly used measuring devices

4.4.4. Recorded values for the measurement

All tap settings of the transformer are measured and the results are documented and given in percentage from "ü".

4.5. Test criteria / Maximum values

The test is not seen as passed if the voltage ratio deviates more than ± 0.5% (or 10% of the short circuit impedance if lower) in principal tapping, from the guaranteed values according to Standard IEC 60076-1 (clause 10 limiting deviation, table 1, section 2).

The customer specified vector group has to be proven.

5. Measurement of the resistance of the windings

5.1. Standard

IEC 60076-11:2018 clause 14.2.1 // part 1 clause 11.2

5.2. Aim

- Recognizing poor / faulty contacts
- Determining issues / damage in the windings
- Resistance data is needed for the calculation of the short-circuit losses at the reference temperature

5.3. Measurement

Before measurement the external cooling medium temperature shall not have change more than 3°C in 3 hours previous to testing.

To keep the influence of the reactance as low as possible, the measurement is conducted using direct current.

The measurement is conducted either with a resistance measurement bridge or an automatic program.

Both systems are based on current-voltage measurements.
For this measurement, a steady current is fed through one connection, on the other connection amperage and voltage are measured. Finally, the resistance is calculated using Ohm's law as shown in the formula below.

$$R = \frac{U}{I}$$

R= ohmic resistance U=voltage I=current

formula 2: ohmic law

The fed current is about ${}^{1}/_{15}$ of the rated current. If the amperage would be too high or would flow for too long, the windings would heat up and falsify the measurements.

Approximately the first 30 seconds of the resistance measurement are not valid, because the current flowing through the turns has to stabilize.

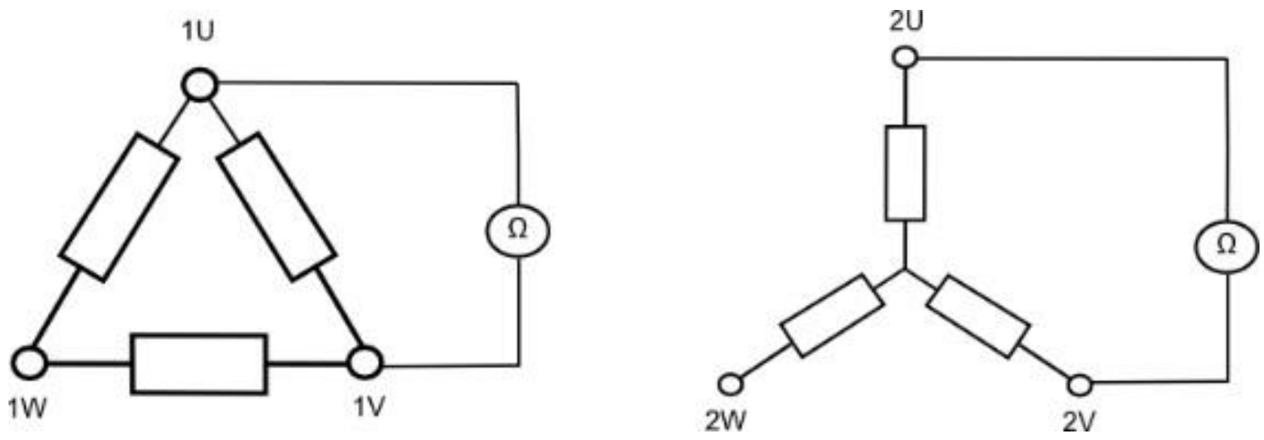
After the resistance measurement, the induced AC withstand voltage test is carried out. Due to the fact that the core has become saturated because of the use of DC current. The induced AC withstand voltage test counters the saturation and the core is demagnetized (degaussing).

5.3.1. Tapping position for measurement

If the HV tapping range is between ±5% of rated voltage, only the principal tap shall be measured. Otherwise as a typetest, the taps with the highest and lowest number of turns will also measured.

- In the case of an LV tap, it is necessary measure the tap.

5.3.2. Test setup



picture 4: phase to phase resistance

During this measurement, the ohmic resistance (real resistance R) of all windings is measured. It is always measured phase to phase e.g. U–V, U-W, V-W.

The connection for the measurement is usually as close as possible to the winding.

5.3.3. Commonly used measuring devices for measurement

measuring devices	manufacturer	type	range / accuracy	frequency	class
Micro Ohmmeter	TINSLEY	5895	0.1 µΩ – 10 µΩ -> 0.2 % 10 µΩ – 100 Ω -> 0.1 % 0.1 A - 10 A DC	DC	n.a.
Winding Analyser	HAEFELY / Tettex	WA 2293	0.1 µΩ – 300 µΩ -> 0.1 % ± 0.5 µΩ 300.1µΩ - 30kΩ -> 0.1 % 30.01kΩ - 300Ω -> 1 %	DC	n.a.
Micro Ohmmeter	IBEKO Power AB - DV Power	RMO40T	0.1 µΩ – 2 kΩ -> ±(0.1 % rgd + 0.1 % FS) 2kΩ - 10kΩ -> ±(0.2 % rgd + 0.1 % FS) 5mA - 40A DC	DC	n.a.
Micro Ohmmeter	IBEKO Power AB - DV Power	RMO60T	0.1 µΩ - 2kΩ 5mA - 60A DC ±(0.2% rgd + 0.2% FS)	DC	n.a.
universal measuring instrument	Omicron	CPC 100 CP TD1 CP SB1		DC	n.a.
Hygro-/Thermometer	Greisinger electronic	GFTH95	0-70 °C 10-95 % r.F.	n.a.	n.a.

table 3: Commonly used measuring devices

5.3.4. Recorded values for the measurement

The measured resistance values are documented in Ω.

The actual temperature θ_{meas} is written into the protocol to give a relation to the reference temperature for the short-circuit measurement.

Measurement uncertainty in %.

5.4. Test criteria / Maximum values

Not applicable

6. Induced AC withstand voltage test

6.1. Standard

IEC 60076-11:2018 clause 14.2.6 // part 3 clause 11.2 (IVW)

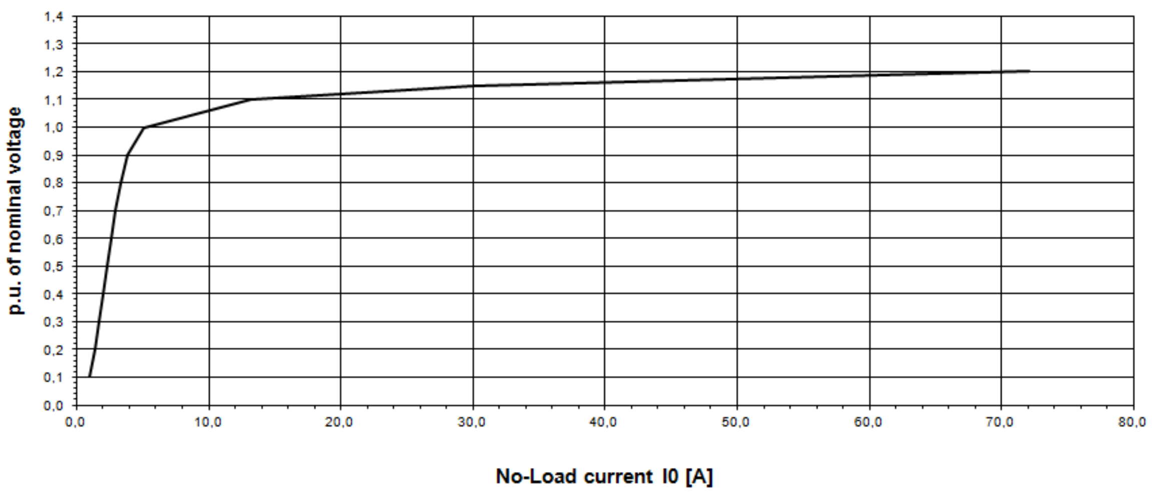
6.2. Aim

Checking of the inner insulation of the windings, insulation between the single windings and layers and between the windings of single phases.

6.3. Test

The test is conducted with double the rated voltage (2xU_R), the duration of the test is calculated after formula 3, but not less then 15 sec.
The test voltage is usually fed at the winding with the lowest rated voltage, via the induction of the transformer it is ensured that double the rated voltage can be found on all windings.

The test frequency has to be at least doubled the rated frequency f_R to prohibit saturation of the core. If the core would be brought into saturation, the magnetizing current will rise disproportionally (see picture belowpicture 5).



picture 5: no-load characteristics

$$test\ duration\ [s] = 120 \cdot \frac{rated\ frequency}{test\ frequency}$$

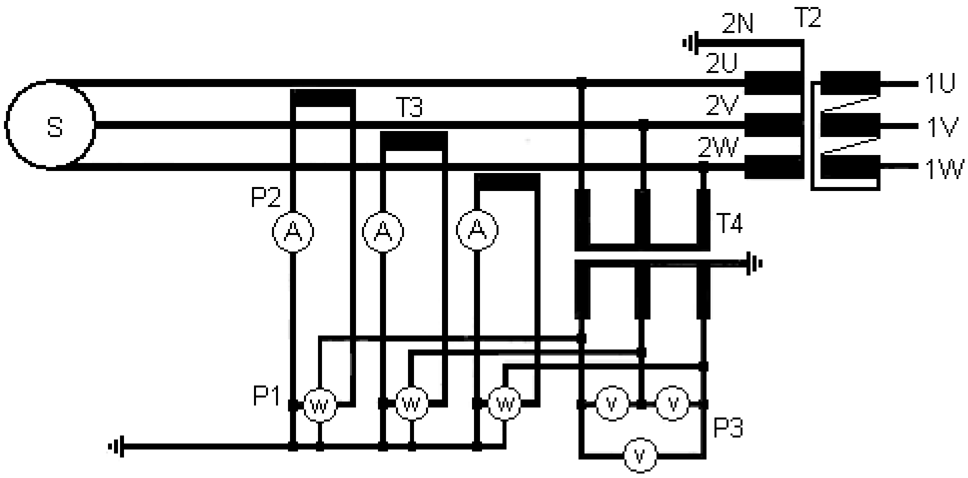
formula 3: calculation of the duration for the induced AC withstand voltage

The test at the SGB-test facility is made with a test frequency of 200 Hz for 2 min. (during the initial testing), to assure a higher level of security.

6.3.1. Tapping position for testing

It is only necessary to reach the rated turn voltage.
Therefore, the tapping position is of no significance. Usually it is the principal tapping position.

6.3.2. Test setup



picture 6: Test setup for induced AC withstand voltage test

S: electricity supply
T2: transformer to be tested
T3: current transformer
T4: voltage transformer

P1: wattmeter
P2: amperemeter (I_{RMS})
P3: voltmeter (U_{RMS})

6.3.3. Commonly used measuring devices for testing

measuring devices	manufacturer	type	range / accuracy	frequency	class
Precision Power Analyzer	ZIMMER	LMG 500	U rms 1000 V / I rms 32 A U pk 3200 V / I pk 120 A	DC - 10 MHz	0.01-0.03
LV-current-transf.	H&B	Ti 48	2.5-500 A/5 A	50/60 Hz	0.1
HV-voltage-transf.	epro	NVRD 40	2-40 kV/100 V	50/60 Hz	0.02
HV-current-transf.	epro	NCO 60	1-600 A/5 A	50/60 Hz	0.01

table 4: Commonly used measuring devices

6.3.4. Recorded values for the test

The test voltage, test frequency and test duration are documented in the test certificate.

6.4. Test criteria

The test is passed if no break down of the test voltage occurs.

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7. Measurement of the no-load losses and current

7.1. Standard

IEC 60076-11:2018 clause 14.2.4 // part 1 clause 11.5

7.2. Aim

Measurement and documentation of the no-load current I_0 and the no-load losses P_0

7.3. Theoretical principal

The following losses arise during no-load measurements
- Iron losses P_{Fe} in the core and other constructive parts
- Dielectric losses in the insulation

As the iron losses P_{Fe} account for a much larger percent of total losses than the dielectric losses, the dielectric losses can be omitted from the formula, so the following formula applies:

$$P_0 = P_{Fe}$$

Iron losses are caused by hysteresis losses in the magnetization.

Eddy currents do not have as much of an influence in modern transformers using individually insulated core iron sheets.

7.4. Measurement

The measurement of no-load losses and of the no-load current are made using the same test setup as for the induced over voltage test (clause 6). It is carried out with the rated voltage U_R and the rated frequency f_R. The measurement voltage is applied as close to U_R as possible.

The measured losses are corrected after IEC 60076-1 clause 11.5

$$P_0(P_C) = P_M * (1 + d) \qquad d = \frac{U' - U}{U}$$

P_0=iron losses	U'=rectified value
P_M=measured losses	U=arithmetic average of

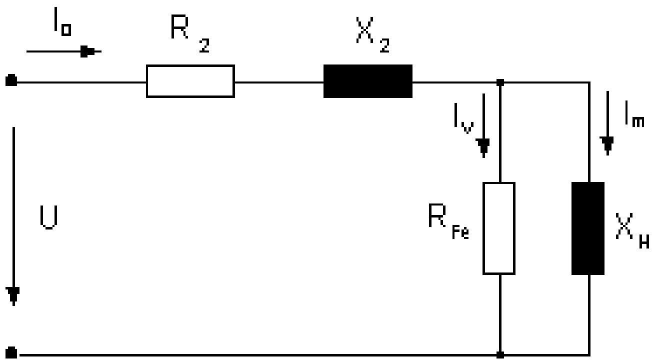
formula 4: Calculation of the corrected iron losses

The no-load losses do not have to be named at a reference temperature, because with rising temperature the losses will accordingly decrease.
This is due to the fact that the core in a warm state, is slightly easier to magnetize and because of this, less losses will occur.

7.4.1. Tapping position for measurement

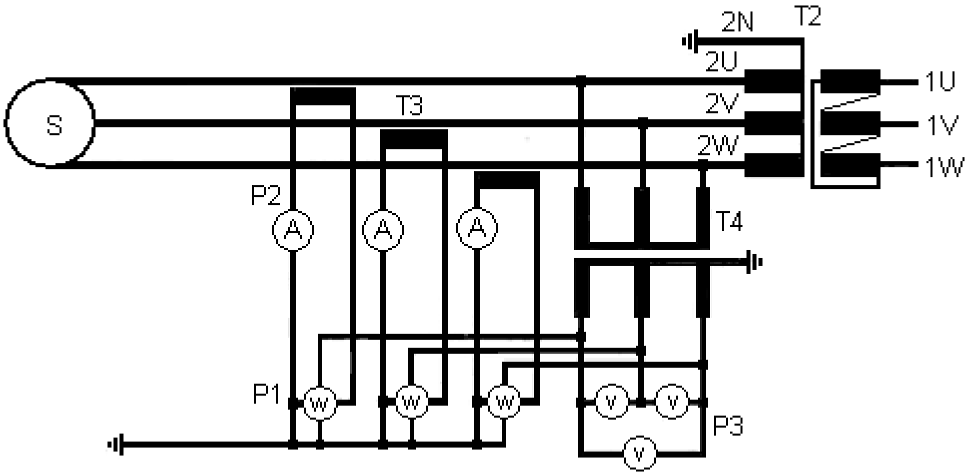
It is only necessary to reach the rated turn voltage.
Therefore, the tapping position is of no significance. Usually it is the principal tapping position.

7.4.2. Equivalent circuit diagram for a transformer in no-load



picture 7: transformer in no-load

7.4.3. Test setup



picture 8: Test setup for measurement of no-load losses and of no-load current

S: electricity supply

T2: transformer to be tested	P1: wattmeter
T3: current transformer	P2: amperemeter (I_{RMS})
T4: voltage transformer	P3: voltmeter (U_{RMS})

7.4.4. Commonly used measuring devices for measurement

measuring devices	manufacturer	type	range / accuracy	frequency	class
Precision Power Analyzer	ZIMMER	LMG 500	U rms 1000 V / I rms 32 A U pk 3200 V / I pk 120 A	DC - 10 MHz	0.01-0.03
LV-current-transf.	H&B	Ti 48	2.5-500 A/5 A	50/60 Hz	0.1
HV-voltage-transf.	epro	NVRD 40	2-40 kV/100 V	50/60 Hz	0.02
HV-current-transf.	epro	NCO 60	1-600 A/5 A	50/60 Hz	0.01

table 5: Commonly used measuring devices

7.4.5. Recorded values for the measurement

Voltage [V], amperage [A] and corrected losses [W] for all phases (in R.M.S.) are recorded.
The no-load current is given in a percentage of the rated current.

Measurement uncertainty in %.

7.5. Test criteria / Maximum values

- Following Standard IEC 60076-1 (clause 10 limiting deviation, table 1, section 1).

The total losses are only allowed to differ a max. of 10 % and the no-load respectively short-circuit losses only a max. of 15% from the guaranteed value.
If the no-load current is bindingly given, it is allowed to differ a max. of +30 % of the values (section 5 in table 1).

Or

- Agreement between supplier and purchaser

Or <u>if the transformer is for the European market</u>

- The maximum Value for the no-load losses P_0 must be made in accordance with Standard EN 50588-1 table 4 (if applicable table 5 and 6) or table 8 or
  Standard EN 50629 table A.1

8. Measurement of the short-circuit impedance and the short-circuit losses

8.1. Standard

EN 60076-11:2018 clause 14.2.3 // part 1 clause 11.4

8.2. Aim

- Determination of the short-circuit voltage / impedance in percent (U_K or ez) at a reference temperature.
- Determination of the short-circuit losses (P_L) at a reference temperature.

Short-circuit voltage = The voltage, at which primary and secondary rated current I_R flows, if one of the sides of the transformer is shorted.

8.3. Measurement

The system with the lower current (e.g. HV) is fed and the other system/s are short-circuited. This also depends on the various loading cases of the transformer.

A current between 50% and 100% of the rated current of the connected windings is fed. In our testing facility, we prefer to use 60% of the rated current when possible as through years of experience we have found this to be an optimum percent at which to take the measurement due to the ability to reach the measuring current faster, thus preventing the warming of the transformer and it also brings the measurement adequately over the IEC minimum of 50%.
It is imperative that the measurement be carried out as swiftly as possible, because the windings will heat up due to the current and the measured data is then falsified.
Due to the fact that during operation the short-circuit losses will increase through heating of the windings, P_L and ez are given at the reference temperature.

The connection for the measurement is usually as close as possible to the winding (similar connection as in chapter 5 Measurement of the resistance of the windings.

The reference temperature is calculated using the average winding-temperature rise limits from all windings, as given in IEC 60076-11 (clause 10.1, table 2) + 20 or if the winding-temperature rise is differnet from table 2 then average winding-temperature rise limits from all windings + yearly average temperature of the external cooling medium.

$$\text{reference temperature } \theta_{ref} = \text{ average temperature rise of windings } \Delta\theta w + 20°C$$

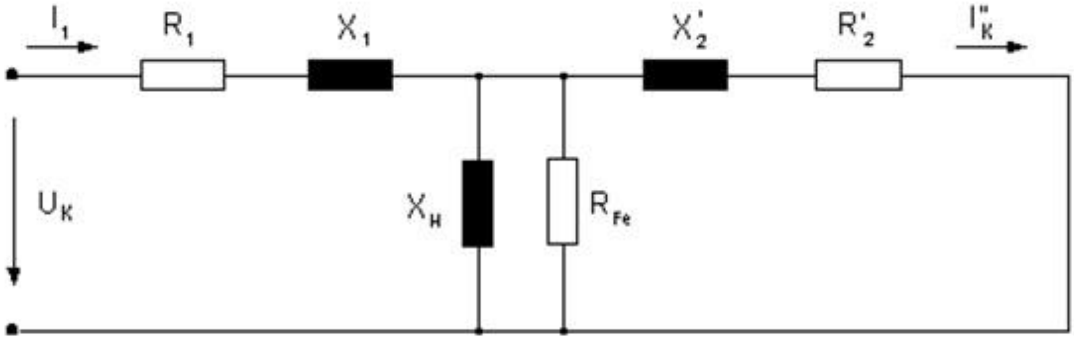
e.g. $class\ of\ insulation\ F\ \triangleq 100\ Kelvin \qquad reference\ temperature = 100K + 20°C = 120°C$

8.3.1. Tapping position for measurement

If the HV tapping range is between ±5 % of rated voltage, only the principal tap shall be measured. Otherwise as a typetest, the taps with the highest and lowest number of turns will also measured.

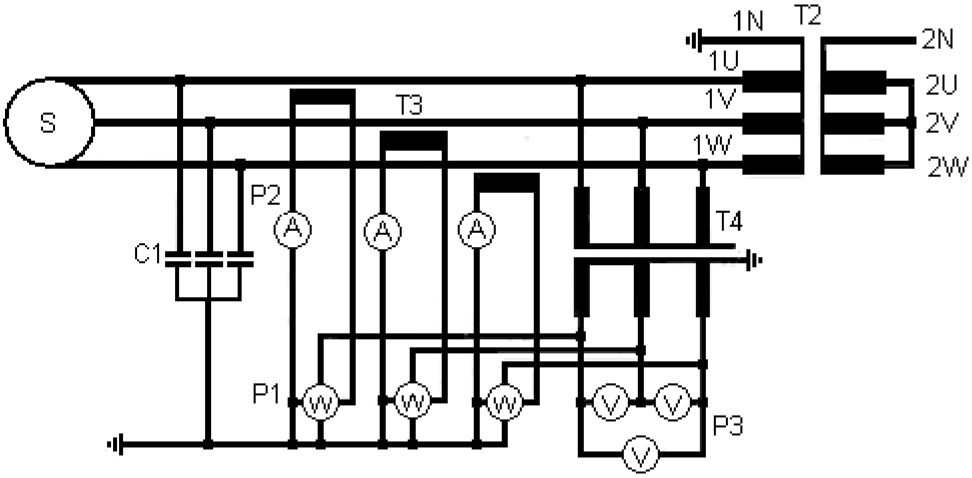
- In case of an LV tap, it is necessary measure the tap.

8.3.2. Equivalent circuit diagram for transformer in load



picture 9: transformer in short-circuit

8.3.3. Test setup



picture 10: test setup of the short-circuit measurement

S: electricity supply
T2: transformer to be tested
T3: current transformer
T4: voltage transformer

C1: capacitor bank
P1: wattmeter
P2: amperemeter (I_{RMS})
P3: voltmeter (U_{RMS})

8.3.4. Commonly used measuring devices for measurement

measuring devices	manufacturer	type	range / accuracy	frequency	class
Precision Power Analyzer	ZIMMER	LMG 500	U rms 1000 V / I rms 32 A U pk 3200 V / I pk 120 A	DC - 10 MHz	0.01-0.03
LV-current-transf.	H&B	Ti 48	2.5-500 A/5 A	50/60 Hz	0.1
HV-voltage-transf.	epro	NVRD 40	2-40 kV/100 V	50/60 Hz	0.02
HV-current-transf.	epro	NCO 60	1-600 A/5 A	50/60 Hz	0.01

table 6: Commonly used measuring devices

8.3.5. Recorded values for the measurement

All voltages [V], amperages [A] and losses [W] (in R.M.S.) are then recorded.
Measurement uncertainty in %.

8.4. Calculations to determine P_L and ez at the reference temperature

Because the measurement is carried out at between 50% und 100% of the rated current, the measured values have to be calculated first. This is possible as losses increase quadratically with the current.

$$P_{L\ cold}(at\ I_R) = P_{meas} * \left(\frac{I_{R\ HV}}{I_{meas}}\right)^2$$

formula 5: calculation of short-circuit losses at measured temperature

To calculate the losses in relation to the temperature, the ohmic part of the losses (I^2R) and the additional losses (P_Z) are determined (reactance in picture 9: transformer in short-circuit).
With the previous data, a calculation for the additional losses can be accomplished, so foremost, the ohmic part of the losses are calculated.
This is calculated via the ohmic law through conversion.

$$\{P = U * I\} \quad \& \quad \{U = R * I\} \quad \triangleq \quad P = I^2 * R$$

formula 6: conversion of the ohmic law

To do that, the average of the three measurements are taken (clause 5 Measurement of the resistance of the windings) and are multiplied by the appropriate rated squared current.
Additionally, the factor 1.5 is necessary, because the resistance values and the current are related in phase to phase. Through calculation to phase values the factor 1.5 results. Finally, only the ohmic losses of HV and LV have to be added.

$$\sum I^2 R_{cold} = \left(I_{R\ HV}{}^2 * average\ R_{HV} * 1{,}5\right) + \left(I_{R\ LV}{}^2 * average\ R_{LV} * 1{,}5\right)$$

formula 7: calculation of the ohmic losses at measured temperature

Because now the losses in general, as well as the ohmic losses are known, the difference between both, forms the additional losses (P_Z)

$$P_{Z\ cold} = P_{L\ cold} - \sum I^2 R_{cold}$$

formula 8: calculation of additional losses at measured temperature

So, the ohmic losses and the additional losses are now known. For the next step both losses are calculated to the reference temperature.
To put that into a formula only the material constant is needed.

$$\theta_K = by\ Al = 225 \qquad \theta_K = by\ Cu = 235$$

picture 11: material constant of Al and Cu

With the constant, the losses will either be calculated up or down.
The ohmic parts (I^2R) are caused by the winding itself.
Due to that fact, they are calculated upwards.

$$\sum I^2 R_{hot} = \sum I^2 R_{cold} * \frac{\theta_K + \theta_{ref}}{\theta_K + \theta_{meas}}$$

formula 9: calculation of the ohmic losses at a reference temperature

The additional losses (P_Z) are caused by all non-ohmic losses. E.g. core magnetization, eddy currents, etc.

$$P_{Z\ hot} = P_{Z\ cold} * \frac{\theta_K + \theta_{meas}}{\theta_K + \theta_{ref}}$$

formula 10: calculation of additional losses at a reference temperature

The sum of both tests, results in the total short-circuit losses (P_L) at the reference temperature

$$P_{L\ hot} = \sum I^2 R_{hot} + P_{Z\ hot}$$

formula 11: calculation of short-circuit losses at reference temperature

Now that the losses are known, the calculation of the short-circuit voltage, respectively the short-circuit impedance, can be carried out in percent.
For that, the measurement voltage for the short-circuit test again has to be related to the rated current, because of the linear behavior of current and voltage this is very easy. Afterwards using the same formula, the voltage in percent of the rated voltage is stated.

$$ez_{cold} = \frac{I_{R\ HV}}{I_{meas}} * U_{meas} * \frac{100\%}{U_{R\ HV}}$$

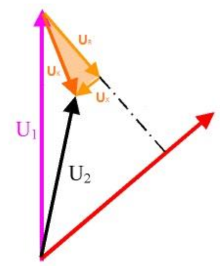
formula 12: calculation of short-circuit voltage at measured temperature

To give the (ez) at the reference temperature this value is divided again into the ohmic part (er) and an imaginary part (ex) (similar to(P_Z)).
To do that, the proportion of the rated apparent power of the transformer and the short-circuit losses at measured temperature are used.

$$er_{cold} = \frac{P_{L\ cold} * 100\%}{S_R}$$

formula 13: calculation of the ohmic parts of short-circuit voltage at measured temperature

The imaginary part (ex) is derived from the Kappic triangle but is seen as being independent of the temperature.



$$ex = \sqrt{ez_{cold}^2 - er_{cold}^2}$$

formula 14: calculation of the imaginary part ex

picture 12: Kappic triangle

To now determine the ohmic part (er) of the short-circuit voltage, the same calculation as for (er_{cold}) will be used, but now the losses are at the reference temperature.

$$er_{hot} = \frac{P_{L\,hot} * 100\%}{S_R}$$

formula 15: calculation of the ohmic parts of the short-circuit voltage at a reference temperature

To now finally determine the short-circuit voltage at the reference temperature, the ohmic parts (er) and the imaginary parts (ex) are being summed up using the Kappic triangle.

$$ez_{hot} = \sqrt{ex^2 + er_{hot}{}^2}$$

formula 16: calculation of the short-circuit voltage at a reference temperature

In the test protocol these calculated values are given in the section "Measurement of short-circuit impedance and load loss ":

- Load losses at rated current P_L at I_R [W]
- Additional losses P_Z [W] *
- Ohmic losses I^2R [W] *
- Load losses P_L [W] *
- Imaginary impedance ex [%] *
- Ohmic impedance er [%] *
- Short-circuit impedance ez [%] *

* (calculated to the reference temperature)

8.5. Test criteria / Maximum values

- Following Standard IEC 60076-1 (clause 10 limiting deviation, table 1, section 1).

The total losses are only allowed to differ a max. of 10 % and the no-load respectively short-circuit losses only a max. of 15 % from the guaranteed value.

If the no-load current is bindingly given, it is allowed to differ a max. of + 30 % of the values (section 5 in table 1).

Or

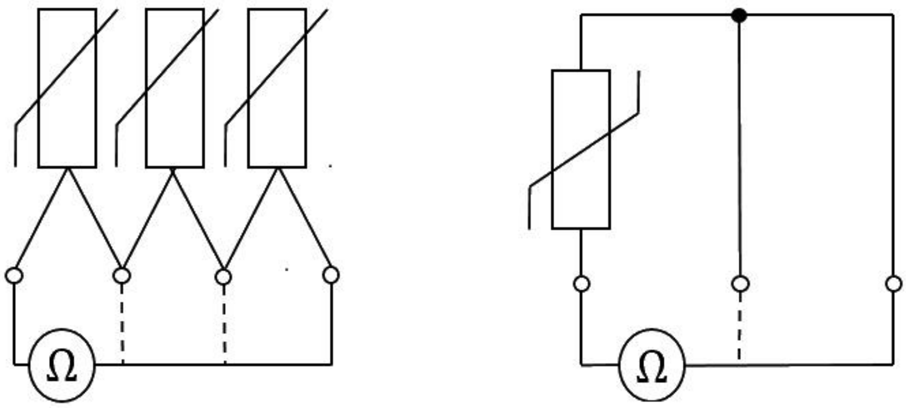
- Agreement between supplier and purchaser

Or if the transformer is for the European market

- The maximum Value for the load losses P_L must be made in accordance with Standard EN 50588-1 table 4 (if applicable table 5 and 6) or table 8 or
  Standard EN 50629 table A.1

9. Control of the temperature sensors

To ensure that all temperature sensors that are installed in the transformer function faultlessly, their resistances are measured after the routine test with an ohmmeter and documented (in Ω) in the test protocol.



picture 13: connection of temperature sensors

9.1. Commonly used measuring devices for measurement

measuring devices	manufacturer	type	range / accuracy	frequency	class
Multimeter	FLUKE	Fluke-87-V	1000V/10A/50MΩ	DC	0.1-1.0

table 7: Commonly used measuring devices

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10. Partial discharge measurement

10.1. Standard

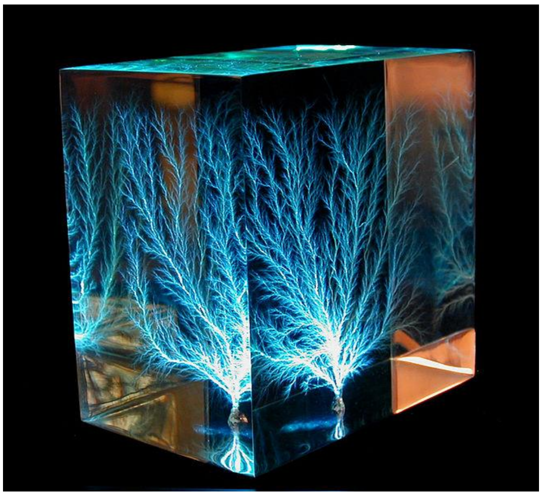
IEC 60076-11:2018 clause 14.2.7 // EN 60270 // IEC 60076-3:2013

10.2. Aim

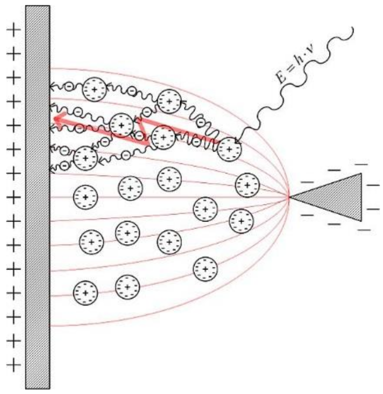
- Proof of quality of the insulation (cast)
- Detection of defects (e.g. missing contact washers, constructive parts that are not grounded)

10.3. Theoretical principal

Partial discharge (also **Pre-discharge**) is a term in the electrotechnical field. It is primarily about the form and characteristics of classes of insulation. If in high voltage insulations or alongside air distances highly inhomogeneous field profiles occur, it can lead to a transgression of dielectric strength levels relating to the type of material. In this state of an incomplete electric break down in the insulation between the electrodes, discharges are identified. Such partial discharges (abbreviated also referred to as "PD") mostly occur in insulation with ac voltage being applied.

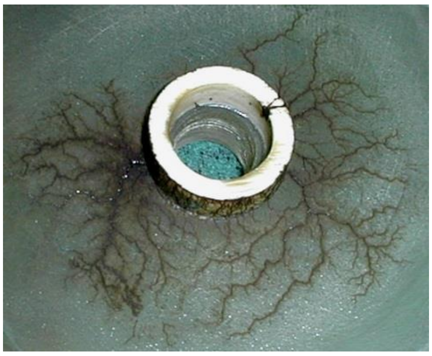


picture 14: Lichtenberg-figure in an ashlar of acryl. Actual size: 76mm × 76mm × 51mm



picture 15: schematic display of the development of partial discharge in a sharp point-plate arrangement generated through incoming radiation

Consequences of PD: These discharges can cause a complete break down of insulation over time. Looking at the safety of a company and the life span of a transformer, a transformer is not allowed to show any elevated PD-values (max. 10 pC).



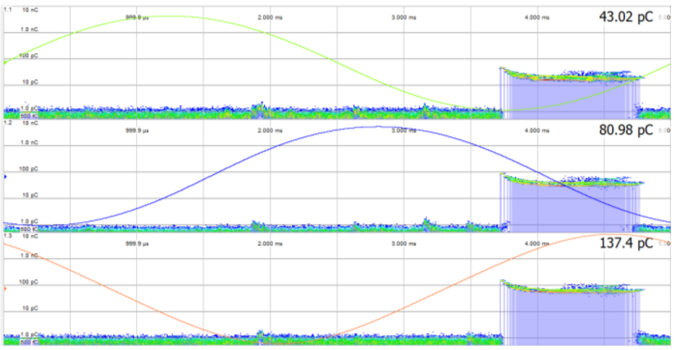
picture 16: the sliding discharge on a board out of polycarbonate leading to the destruction of the insulator

10.3.1. Possible reasons for PD

- electric free floating constructive parts in the transformer (e.g. bad grounding connection)
- material or constructive mistakes (e.g. bad contact, missing contact washers)
- dimensioning faults
- casting
- spikes on HV or grounded parts within the electrical field
- there are many various reasons that a transformer can have elevated levels of PD, from insignificant to serious

10.3.2. Outer partial discharges (corona)

Outer partial discharges are discharges from the surfaces of free electrodes of metal into the surrounding air space. They generally originate at sharp edged parts, at which the power of the field is highly increased. This phenomenon is commonly seen on high voltage wires with an audible and sometimes visible corona discharge. Also St. Elmo´s fire is placed into this category. Outer pre-discharges can be prohibited through a rounded design of all edges, as well as field controlling rings (e.g. at high voltage cascades).



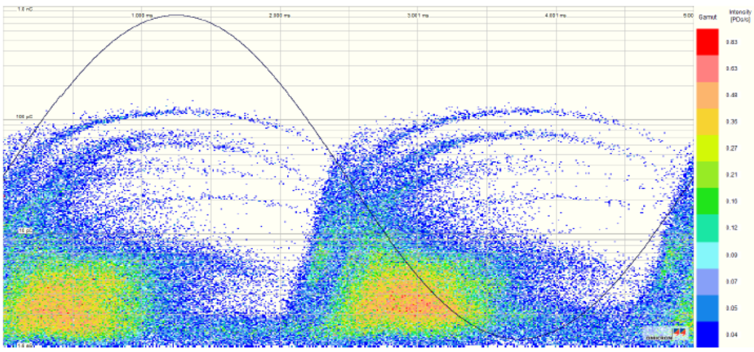
In the PD-Measuring Software, corona has a special form.
(PD-pattern)

In most cases, corona changes the PD value linear with the voltage

picture 17: corona PD pattern

10.3.3. Inner partial discharges

In general, all partial discharges that are not audible or visible are considered to be inner partial discharges. Insulating mediums can be a solid, liquid or gaseous.
Discharges occur, where homogeneities of the medium lie under strong field influence, for example in the case of gas bubbles, which are located in an insulating fluid, for example oil, or in cast resin. These gas bubbles, consisting of air, carbon dioxide (e.g. in case of influence of humidity at the hardening of polyurethane resin) or oil decomposition gases, has an inferior dielectric constant compared to the surrounding oil, which leads to an increase of field power. The insulating characteristics of the gas bubble are disturbed by the locally lower electrical strength, which results in partial discharges. As well as not correctly connected built-in parts in building elements, which have been produced through cast resin or treatment (switching power supply transformers, high tension cascades) leading to partial discharges. Other examples include transformer windings which are not sealed, made of enameled copper wire, used in switching power supply transmissioners and flimsily winded membrane capacitors for applications of ac voltage.
Inner partial discharges, because of ultraviolet radiation and ionization can, in the long run, cause damage the surrounding insulating material and therefore have to be avoided.

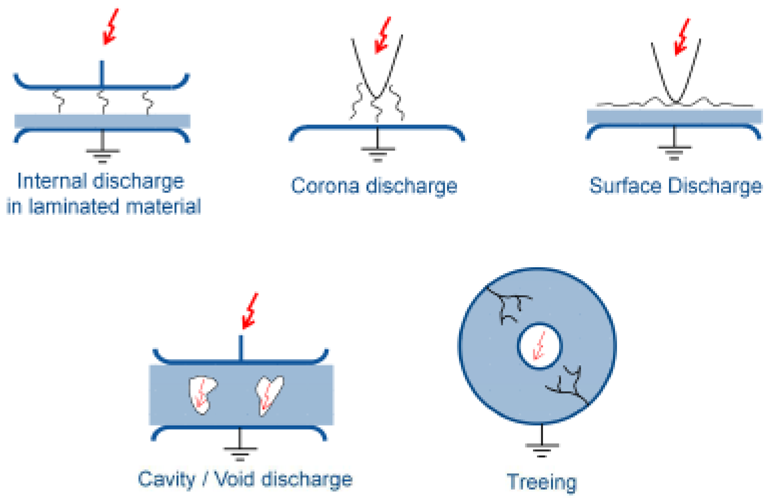


picture 18: inner PD pattern

In the PD-Measuring Software, internal PD has a special form. (PD-pattern)
In most cases, in a small voltage range the PD value doesn't change dramatically while the voltage is changing. The PD inception voltage is higher than the PD extinction voltage.

10.3.4. PD classification:

On a transformer, you can have a mixed form of PD sources.



picture 19: PD classification

10.4. Measurement

All windings with an Um ≥ 3.6 kV are to be tested.

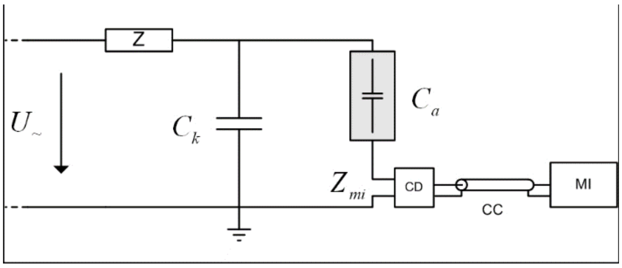
10.4.1. Measurement chamber

The measurement is carried out in a faraday cage, shielding the transformer from incoming electromagnetic fields. Furthermore, the test bay has to be of an adequate size, to ensure enough distance from the transformer to coupling-capacitors, the voltage source, walls, etc., prohibiting disturbances of the electric field during the execution of the measurement.

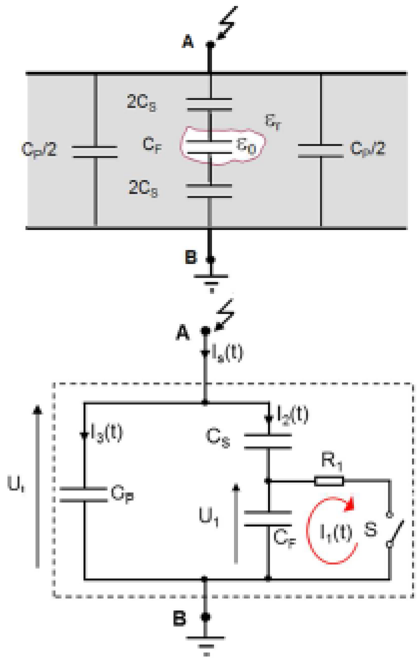
10.4.2. Connection

The voltage supply is applied in the same way as the induced over voltage test (clause 6).

Three coupling-capacitors (voltage divider) C_k are connected to the HV-windings.
PD- and voltage signals are separated via a quadripole/measuring impedance under the coupling-capacitor. The quadripole is connected via a fiber optic cable to the measurement PC.



picture 20: test setup on HV side



picture 21: Equivalent circuit diagram for apparent charge

10.4.3. Tapping position for measurement

The test shall be performed in the principal tap.

10.4.4. Measurement Frequency band

According to IEC 60270, we measure in a wide band $f_{center} = 250\ kHz$ $f\Delta = 300\ kHz$

This means we measure discharges (apparent charge) with a Bandwidth between 100kHz and 400kHz.
For this, the pulse resolution time Tr is 5µs – 20µs or with active integrator Tr < 1µs

Note: Narrow band can also used (Bandwidth 9kHz – 30kHz Frequency range between 50kHz – 1MHz)

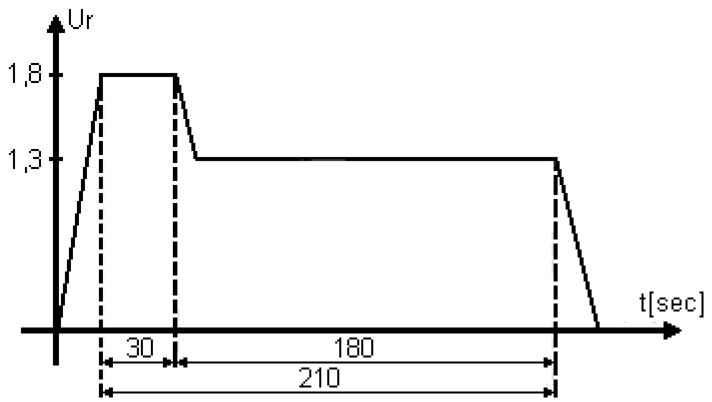
10.4.5. Calibration

Before the actual measurement can take place, a calibration of the measurement circle is necessary. Therefore, a defined PD-impulse with a PD charge calibrator is fed between each conducted phase of the transformer and the earth. This value then has to be divided through the value received on the measurement device. The result of this calculation is called a “calibration factor“. With this factor, all measurement results are multiplied incl. the base interference level (performed by the software).

The charge calibrator we use has a pulse repetition frequency of 300 Hz and a pulse rise time from < 4 ns

10.4.6. Measuring duration and voltage levels

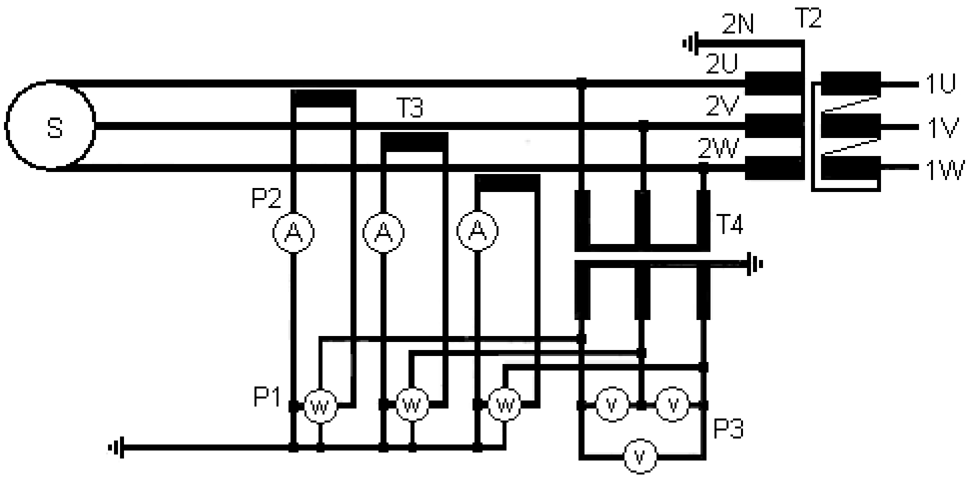
The measurement is carried out over a time of 210 seconds, where in the first 30 seconds it is tested with a voltage U_{meas} of 1.8 x U_{rated}.
For the other 180 seconds U_{meas} = 1.3 x U_{rated} (picture).



picture 22: voltage-time diagram for PD-measurement

10.4.7. Test setup

10.4.8. for supplying



picture 23: Test setup for measurement of partial discharge

S: electricity supply

T2: transformer to be tested

T3: current transformer

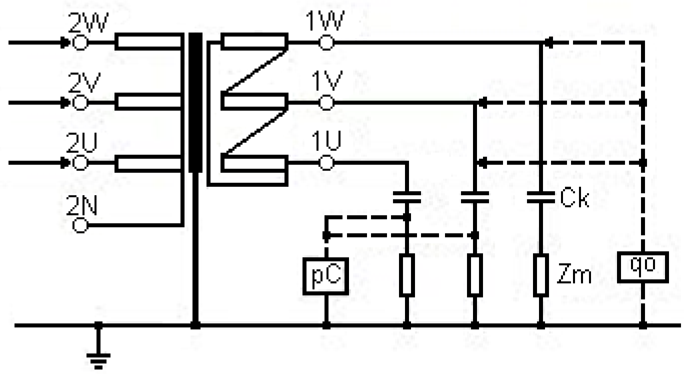
T4: voltage transformer

P1: wattmeter

P2: amperemeter (I_{RMS})

P3: voltmeter (U_{RMS})

10.4.9. for measuring



Ck = couple-capacitors

Zm = measurement impedance

pC = measurement device with reading of pC

q0 = PD charge calibrator (only to be used previous to testing)

picture 24: test setup of the PD-measurement

10.4.10. Commonly used measuring devices for measurement

measuring devices	manufacturer	type	range / accuracy	frequency	class
PD-measurement system	Omicron	MCU502 4xMPD600 3xMPP600	500 fC - 3nC	0 - 32 MHz	0.01-0.03

table 8: Commonly used measuring devices

10.4.11. Recorded values for the measurement

The background level and the maximum PD values within the 180 sec. for all phases in [pC], are then recorded in the test protocol.

10.5. Test criteria / Maximum values

- The Background level should not exceed the half of the value of the maximum PD level.
- The partial discharge level is allowed a maximum of 10pC with correction factor.

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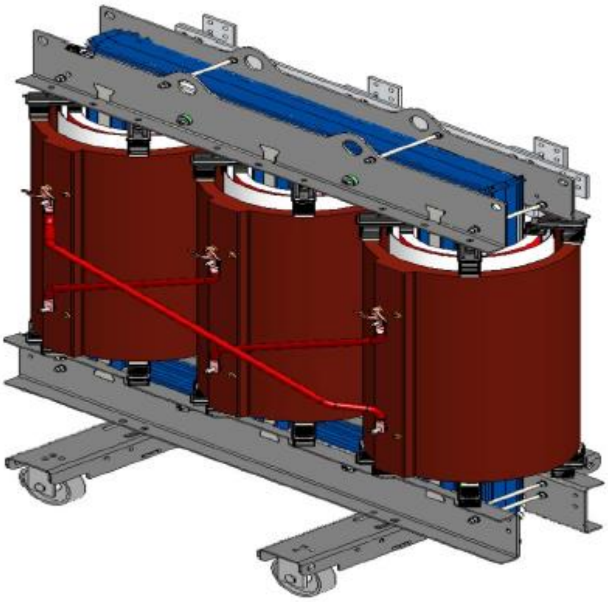
11.Appendix

11.1. Example test certificate

Test certificate for 3 Phase dry-type transformer

SGB

Customer:	XY		
Customer order nr.:	1234		
Date of order:	xx.xx.xxxx		
Customer item no.:	123456		
Customer specification:	XY		
SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456
page:	1 of 11		

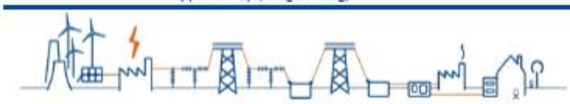


Example pictures and schematics refer to a standard transformer. Deviations from the actual product may be possible.

page:

Approved by / Regensburg,

Remarks



SGB Starkstrom - Gerätebau GmbH
Ohmstraße 10, DE-93055 Regensburg
Test Lab Cast Resin Transformers
www.sgb-smit.com

Technical data

3 Phase dry-type transformer according to Standard IEC 60076-11:2018

Eco Design regulation 548/2014 // 2009/125/EG

SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456
Protection // Mass dry-type transformer:		IP00 / Indoor // 6851 kg	

Maximum altitude [m]:	1000	manufacturing year :	2.2020
Max. temp. of cooling medium [°C]:	55	Manufacturer:	SGB Starkstrom - Gerätebau GmbH

Kind: PT | Service: Continue

Environment class: E2 | Climate class: C2 | Fire class: F1

Max. dur. of short circuit [sec.]: 2 | Î E / Î N: 6,7 | $T_{o,s}$ [sec.]: 0,31 | Magnetic flux density B [T]: 1,649

Corematerial: Grain-oriented electrical steel | Mass [kg]: 4288,2

	HV	LV		
Rated power [kVA]:	3900	3900		
	+2x 750V (2,5 %)			
Rated voltage [V]:	30000	690		
	-2x 750V (2,5 %)			
Rated current [A]:	75,06	3263,3		
Um/LI/AC [kV]:	36 / 170 / 70	1,1 / 8 / 3		
Insulation class:	F	F	Frequency [Hz]:	50,00
Max. temperature rise [K]:	85	85	Vector group:	Dyn11
Conductor material / Mass [kg]:	Al / 681	Al / 699	Cooling:	AF
Continuous short-circuit current [kA]:	0,66	28,88		

SGB Starkstrom - Gerätebau GmbH
Ohmstraße 10, DE-93055 Regensburg
Test Lab Cast Resin Transformers
www.sgb-smit.com

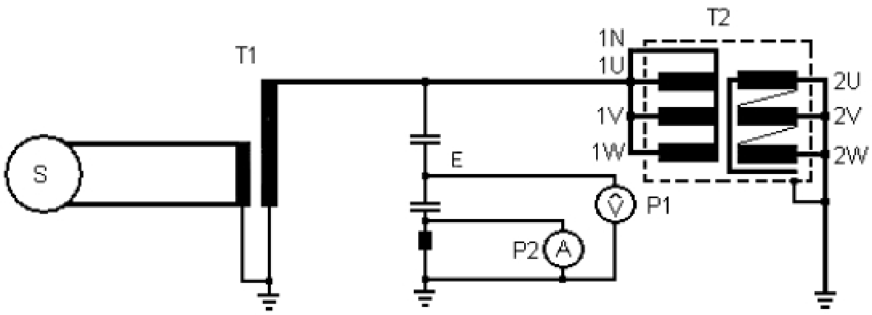
Routine testing

(according to Standard IEC 60076-11:2018)

SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456

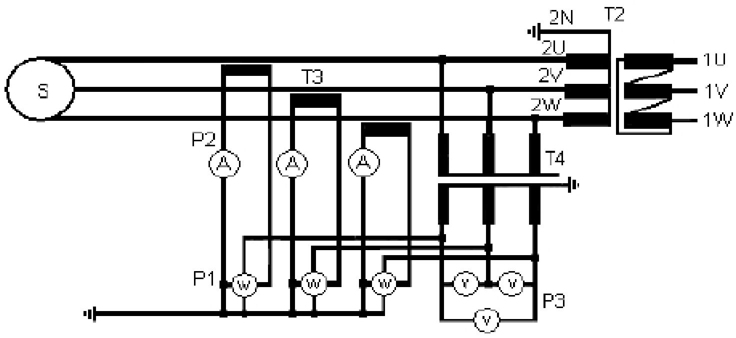
Dielectric tests

	[kV]	[Hz]	[sec.]
Separate-source AC withstand voltage test HV:	70,0	50	60
Separate-source AC withstand voltage test LV:	3,0	50	60
Separate-source AC withstand voltage test of auxiliary wiring:	2,0	50	60



Example pictures and schematics refer to a standard transformer. Deviations from the actual product may be possible.

Induced AC withstand voltage test LV:	1,380	200	30



Example pictures and schematics refer to a standard transformer. Deviations from the actual product may be possible.

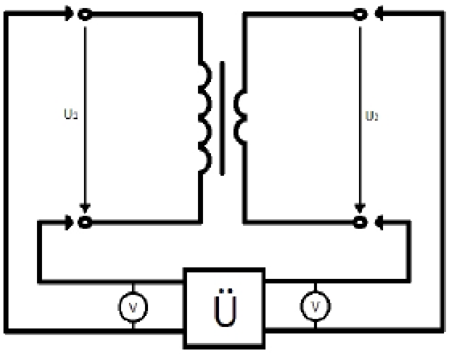
Routine testing

(according to Standard IEC 60076-11:2018)

SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456

Measurement of voltage ratio and check of phase displacement

connection HV / LV:		31500/690	30750/690	30000/690	29250/690	28500/690
deviation in [%]:	Phase U	-0,03	-0,03	-0,03	-0,03	0,01
	Phase V	-0,01	-0,01	-0,02	-0,01	0,01
	Phase W	-0,01	-0,02	-0,02	-0,02	-0,01
deviation Phase displacement [°]:	Phase U	0,02	0,02	0,02	0,02	-0,03
	Phase V	-0,01	-0,01	-0,01	-0,01	-0,03
	Phase W	-0,03	-0,03	-0,03	-0,03	-0,04



Example pictures and schematics refer to a standard transformer. Deviations from the actual product may be possible.

Routine testing

(according to Standard IEC 60076-11:2018)

SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456

Measurement of winding resistance

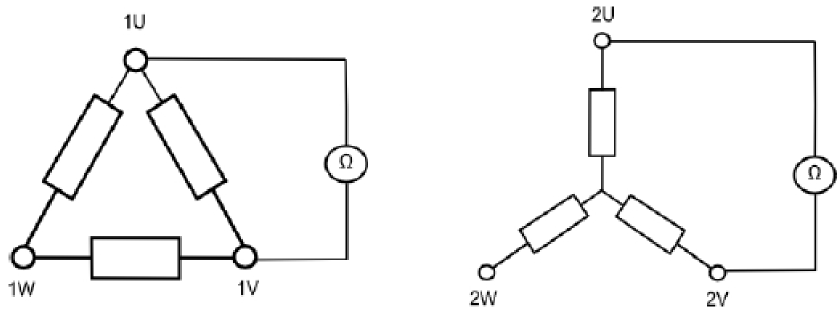
connection:	HV	30,000 kV
	1U - 1V	1,71755
Measured values in [Ω]:	1U - 1W	1,71922
	1V - 1W	1,72478

connection:	LV	0,690 kV
	2U - 2V	0,0003740
Measured values in [Ω]:	2U - 2W	0,0003892
	2V - 2W	0,0003753

Temperature 22,0°C

Used measuring instruments:

Winding Analyzer 2293 Nr. 179742



Example pictures and schematics refer to a standard transformer. Deviations from the actual product may be possible.

Routine testing

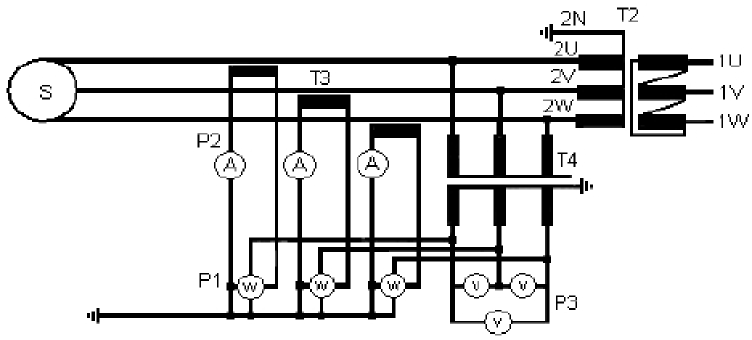
(according to Standard IEC 60076-11:2018)

SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456

Measurement of no-load loss and current

Voltage [V]:	Currents [A]:	Losses [W]:	connection LV 690 V & Frequency 50 Hz
U_{12} 689,9	I_1 5,567	P_1 1459	Io [%]: 0,155 Po [W]: 4507
U_{23} 690,7	I_2 3,994	P_2 1166	
U_{31} 689,3	I_3 5,590	P_3 1882	
$\bar{U}$ 690,0	$\bar{I}$ 5,050	$\sum$ 4507	

The measurement uncertainty is max. ± 0,31% | Used measuring instruments:
Precision Power Analyzer: Zimmer LMG 500 Nr. 12891605
Current-transformer: H&B Ti48 Nr. 81 K 163 | H&B Ti48 Nr. 81 K 164 | H&B Ti48 Nr. 81 K 165



Example pictures and schematics refer to a standard transformer. Deviations from the actual product may be possible.

Routine testing

(according to Standard IEC 60076-11:2018)

SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456

Measurement of short-circuit impedance and load loss

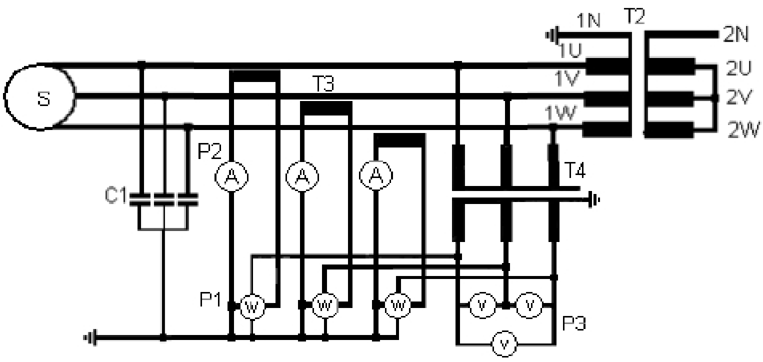
connection HV 30 kV & Frequency 50 Hz; LV 690 V short-circuit at 3900 kVA

Voltage [V]:	Currents [A]:	Losses [W]:
U_{12} 1754	I_1 38,79	P_1 4421
U_{23} 1756	I_2 39,14	P_2 3574
U_{31} 1749	I_3 38,65	$-P_3$ 1062
$\bar{U}$ 1753	$\bar{I}$ 38,86	$\sum$ 6933

Pl at Ir & 22,0 °C [W]: 25866

Losses & ez at 120 °C			
Pz [W]:	3770	ex [%]:	11,27
I^2R [W]:	28774	er [%]:	0,83
Pl [W]:	**32543**	**ez [%]:**	**11,30**

The measurement uncertainty is max. ± 0,23% | Used measuring instruments:
Precision Power Analyzer: Zimmer LMG 500 Nr. 12891605
Voltage-transformer: EPRO NVRD 40 Nr. 2/08/5855 | EPRO NVRD 40 Nr. 2/08/5856 | EPRO NVRD 40 Nr. 2/08/5857
Current-transformer: EPRO NCO 60 Nr. 2/08/5847 | EPRO NCO 60 Nr. 2/08/5848 | EPRO NCO 60 Nr. 2/08/5850



Example pictures and schematics refer to a standard transformer. Deviations from the actual product may be possible.

Routine testing

(according to Standard IEC 60076-11:2018)

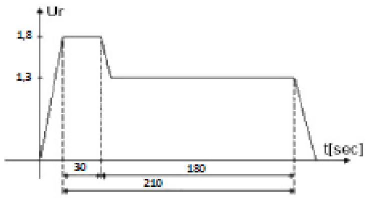
SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456

Measurement of partial discharge

Testing voltage

Frequency 200 Hz

30 sec.	[kV]	180 sec.	[kV]
1,8 * UrHV	54,00	1,3 * UrHV	39,00
1,8 * UrLV	1,242	1,3 * UrLV	0,897



Test results in pC:

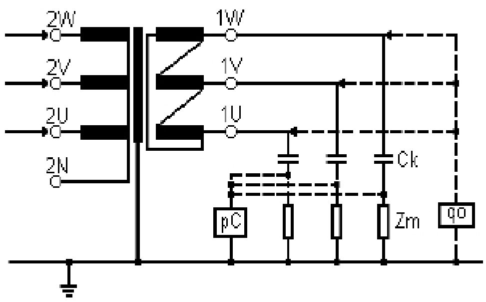
Testing voltage	1U	1V	1W
1,3 * Ur	1	1	1
Background level	1	1	1

Measuring circuit

Measurement in tap: 3 | 30 kV

Calibration factor Kü (qo/q): 2,9

Measurement device bandwidth [kHz]: 100 - 400



Example pictures and schematics refer to a standard transformer. Deviations from the actual product may be possible.

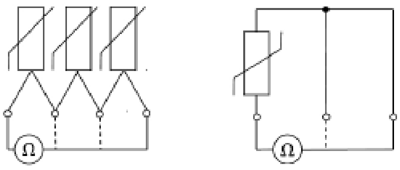
Routine testing

(according to Standard IEC 60076-11:2018)

SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456

Temperature sensor resistance measurement (at 22,0°C):

1-2-3 PT 100/3 LV Phase U 109/109 Ω
4-5-6 PT 100/3 LV Phase V 109/109 Ω
7-8-9 PT 100/3 LV Phase W 109/109 Ω
11-12-13 PT 100/3 LV Phase U reserve 109/109 Ω
14-15-16 PT 100/3 LV Phase V reserve 109/109 Ω
17-18-19 PT 100/3 LV Phase W reserve 109/109 Ω
21-22-23 PT 100/3 Core Phase V 109/109 Ω
24-25-26 PT 100/3 Core Phase V reserve 109/109 Ω



Example pictures and schematics refer to a standard transformer. Deviations from the actual product may be possible.

Remarks

more information?
see general test description

Measurement carried out in Protection IP00

Tested by, Date of test

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page

SGB Starkstrom - Gerätebau GmbH
Ohmstraße 10, DE-93055 Regensburg
Test Lab Cast Resin Transformers
www.sgb-smit.com

Appendix

SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456

Test results / 3.1 Acceptance test certificate according to DIN EN 10204:2004

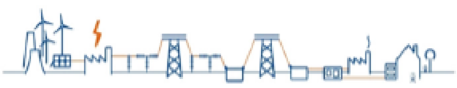
Routine testing — Test passed

Dielectric tests

		Test passed
Separate-source AC withstand voltage test / HV / LV / of auxiliary wiring:	70 / 3 / 2 [kV]; 50 [Hz]; 60 [sec.]	✓
Induced AC withstand voltage test LV:	1,38 [kV]; 200 [Hz]; 30 [sec.]	✓

	Guarantee values:	tolerance:	Measured values:	deviation:	Test passed
Measurement of voltage ratio and check of phase displacement					
Ratio at connection HV / LV [%]:	30000/690	± 0,50	-0,03		✓
Measurement of winding resistance at 22,0 °C					
Measurement of winding resistance HV LV	--	--	--	--	✓
Measurement of no-load loss and current at 50 Hz					
Po [W]:	4750	+0,0%	4507	-5,12%	✓
Io [%]:			0,155		✓
Measurement of short-circuit impedance and load loss at 120 °C					
Pl at 3900 kVA; HV/LV [W]:	34031	+0,0%	32543	-4,37%	✓
ez at 3900 kVA; HV/LV [%]:	10,55	±18,0%	11,30	7,10%	✓
Po + Pl [W]:	38781	+0,0%	37050	-4,46%	✓
PEI (at k[PEI] 0,37 = 1451 kVA) [%]:	99,348	--	99,379	0,03%	✓
Measurement of partial discharge					
PD max. HV at 1,3 x Rated voltage [pC]: (Background level 1 [pC])	≤10	--	1		✓

Approved by / Regensburg,



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Appendix

SGB order number:	123456789/10	Serial-number:	123456
Type:	DTTH1NG 3150/30	Wd. number:	123456

EU-Declaration of Conformity

Hereby we declare that the product designated above (serial number), in regards to its design and build and the model placed into circulation by us, corresponds to the designated EU Directive below. In the case of a modification to the product that is not coordinated with us, this Declaration shall become invalid.

The conformity with the following directives / regulations is declared:

- **DIRECTIVE 2009/125/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products**

- **COMMISSION REGULATION (EU) No 1783/2019 of 1 october 2019 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers**

Applied harmonized standards are especially:

Other standards applied are:

- EN 60076-11:2018

Head of Engineering
Cast Resin Transformers
Starkstrom - Gerätebau GmbH

Teamleader Test Lab
Cast Resin Transformers
Starkstrom - Gerätebau GmbH

Regensburg,

SGB Starkstrom - Gerätebau GmbH
Ohmstraße 10, DE-93055 Regensburg
Test Lab Cast Resin Transformers
www.sgb-smit.com

11.2. Example rating plate

Type: DTTH1NG 3150/30 | Serial-number: 123456 | Customer item no.: 123456

Standard: IEC 60076-11:2018 | Eco Design regulation 548/2014 // 2009/125/EG

Customer specification: XY

Rated power [kVA]:	3900	3900	
Rated voltage [V]:	+2x 750V (2,5 %) 30000 -2x 750V (2,5 %)	690	
Rated current [A]:	75,1	3263,3	
Um / LI / AC [kV]:	36 / 170 / 70	1,1 / 8 / 3	
Insulation class / Max. temperature rise [K]:	F / 85	F / 85	
Conductor material / Mass [kg]:	Al / 681	Al / 699	
Continuous short-circuit current [kA]:	0,66	28,88	

Protection / Mass dry-type transformer: IP00 Indoor / 6851 kg | Maximum altitude: 1000 m

Environment class: E2 | Climate class: C2 | Fire class: F1 | Kind: PT | Service: Continue

Max. dur. of short circuit [sec.]: 2 | Î E / Î N: 6,7 | $T_{0.5}$ [sec.]: 0,31

PI at 3900 kVA; HV/LV [W]:	32543,5		Frequency [Hz]:	50
ez at 3900 kVA; HV/LV [%]:	11,30	at 120°C	Vector group:	Dyn11
			Cooling:	AF
Po [W]: 4506,83 || PEI (k[PEI] 0,37) [%]: 99,379			manufacturing year :	2.2020

Corematerial: Grain-oriented electrical steel | Mass [kg]: 4288,2

3 Phase dry-type transformer

STARKSTROM-GERÄTEBAU GmbH
Ohmstraße 10
DE-93055 Regensburg

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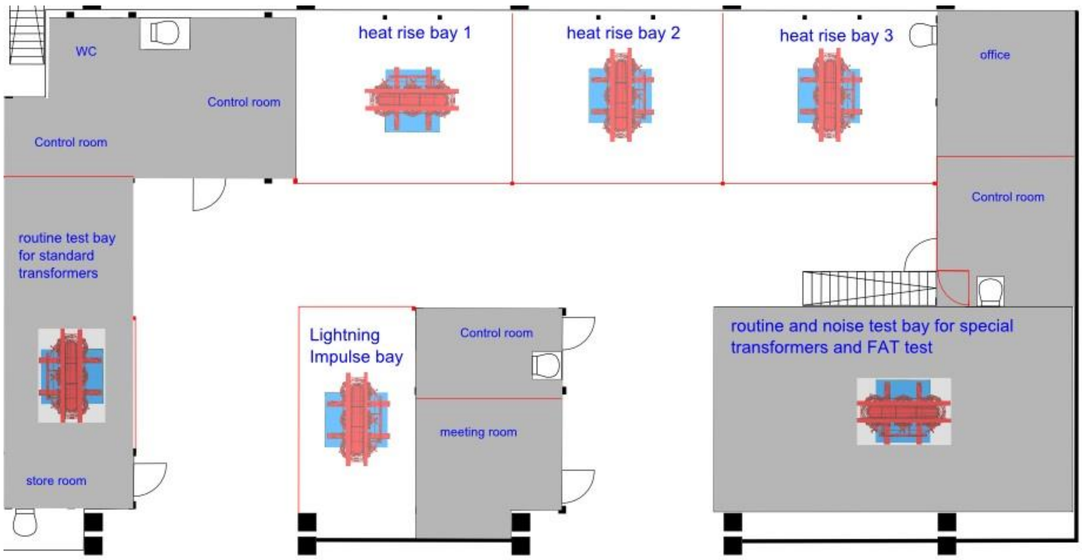
11.3. Example calibration list

Kalibrierung von Meßgeräten im GTP

Calibration of measuring equipment in test field distr. transformer

Meßgeräte	Measuring devices	Hersteller Manufactur	Typ type	F.-Nr.: Ser.-No.:	Meßbereich Range	Frequenz frequency	Klasse class	Standort location	Letzte Kalibrierung Calibration	Nächste Kal. Next cal.	STATUS	Kalibrierungsart
HS-Span.-Wandler	HV-voltage-transf.	epro	NVRD 40	2/06/5855	2-40 kV/100V	50/60 Hz	0,02	Routine	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	epro	NVRD 40	2/06/5856	2-40 kV/100V	50/60 Hz	0,02	Routine	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	epro	NVRD 40	2/06/5857	2-40 kV/100V	50/60 Hz	0,02	Routine	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	epro	NCO 60	2/06/5847	1-600 A/5 A	50/60 Hz	0,01	Routine	27.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	epro	NCO 60	2/06/5848	1-600 A/5 A	50/60 Hz	0,01	Routine	27.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	epro	NCO 60	2/06/5850	1-600 A/5 A	50/60 Hz	0,01	Routine	27.12.2013	Dez 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	H&B	TI 48	81 K 163	2,5-500 A/5 A	50/60 Hz	0,1	Routine	23.12.2013	Dez 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	H&B	TI 48	81 K 164	2,5-500 A/5 A	50/60 Hz	0,1	Routine	23.12.2013	Dez 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	H&B	TI 48	81 K 165	2,5-500 A/5 A	50/60 Hz	0,1	Routine	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	epro	NVOS 30	2/06/5343	2-20 kV/100V	50/60 Hz	0,02	Schallmessraum,Noise & PD	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	epro	NVOS 30	2/06/5345	2-20 kV/100V	50/60 Hz	0,02	Schallmessraum,Noise & PD	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	epro	NVOS 30	2/06/5346	2-20 kV/100V	50/60 Hz	0,02	Schallmessraum,Noise & PD	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	epro	NCO 30	2/06/5339	1-50 A/5 A	50/60 Hz	0,01	Schallmessraum,Noise & PD	27.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	epro	NCO 30	2/06/5340	1-50 A/5 A	50/60 Hz	0,01	Schallmessraum,Noise & PD	27.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	epro	NCO 30	2/06/5341	1-50 A/5 A	50/60 Hz	0,01	Schallmessraum,Noise & PD	27.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	MWB	NUZG 35	73/485997	3-35 kV/100V	50/60 Hz	0,005	Wärmelauf, Heat Rise 1+2	09.10.2013	Okt 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	MWB	NUZG 35	73/485998	3-35 kV/100V	50/60 Hz	0,005	Wärmelauf, Heat Rise 1+2	09.10.2013	Okt 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	MWB	NUZG 35	73/485999	3-35 kV/100V	50/60 Hz	0,005	Wärmelauf, Heat Rise 1+2	14.10.2013	Okt 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	MWB	VXO 60	64/220564	1-600 A/5 A	50/60 Hz	0,05	Wärmelauf, Heat Rise 1+2	07.10.2013	Okt 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	MWB	VXO 60	64/220563	1-600 A/5 A	50/60 Hz	0,05	Wärmelauf, Heat Rise 1+2	07.10.2013	Okt 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	RITZ	NOSW 60 M	205006	1-600 A/5 A	50/60 Hz	0,05	Wärmelauf, Heat Rise 1+2	07.10.2013	Okt 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	H&B	TI 48aS	8003181	2,5-250 A/5 A	50/60 Hz	0,1	Wärmelauf, Heat Rise 1+2	17.09.2013	Sep 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	H&B	TI 48	6712115	2,5-250 A/5 A	50/60 Hz	0,1	Wärmelauf, Heat Rise 1+2	17.09.2013	Sep 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	H&B	TI 48aS	8003180	2,5-250 A/5 A	50/60 Hz	0,1	Wärmelauf, Heat Rise 1+2	17.09.2013	Sep 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	RITZ	KSW 73	509 43038	100A/5A	50/60 Hz	0,2	Wärmelauf, Heat Rise 1+2	29.01.2015	Jan 2018	In Ordnung	Werkskalibrierung
NS-Strom-Wandler	LV-current-transf.	RITZ	KSW 73	509 43039	100A/5A	50/60 Hz	0,2	Wärmelauf, Heat Rise 1+2	29.01.2015	Jan 2018	In Ordnung	Werkskalibrierung
NS-Strom-Wandler	LV-current-transf.	RITZ	KSW 73	509 43040	100A/5A	50/60 Hz	0,2	Wärmelauf, Heat Rise 1+2	29.01.2015	Jan 2018	In Ordnung	Werkskalibrierung
HS-Span.-Wandler	HV-voltage-transf.	epro	NVRD 40	2/06/5858	2-40 kV/100V	50/60 Hz	0,02	Wärmelauf, Heat Rise 3+4	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	epro	NVRD 40	2/06/5853	2-40 kV/100V	50/60 Hz	0,02	Wärmelauf, Heat Rise 3+4	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Span.-Wandler	HV-voltage-transf.	epro	NVRD 40	2/06/5854	2-40 kV/100V	50/60 Hz	0,02	Wärmelauf, Heat Rise 3+4	23.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	epro	NCO 60	2/06/5852	1-600 A/5 A	50/60 Hz	0,01	Wärmelauf, Heat Rise 3+4	27.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	epro	NCO 60	2/06/5849	1-600 A/5 A	50/60 Hz	0,01	Wärmelauf, Heat Rise 3+4	27.12.2013	Dez 2016	In Ordnung	ÖKD
HS-Strom-Wandler	HV-current-transf.	epro	NCO 60	2/06/5851	1-600 A/5 A	50/60 Hz	0,01	Wärmelauf, Heat Rise 3+4	27.12.2013	Dez 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	epro	NCD 3000d	2/01/2152	10 - 3000 A	50/60 Hz	0,1	Wärmelauf, Heat Rise 3+4	01.10.2013	Okt 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	epro	NCD 3000d	2/01/2153	10 - 3000 A	50/60 Hz	0,1	Wärmelauf, Heat Rise 3+4	01.10.2013	Okt 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	epro	NCD 3000d	2/01/2154	10 - 3000 A	50/60 Hz	0,1	Wärmelauf, Heat Rise 3+4	01.10.2013	Okt 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	RITZ	KSW 73	509 43041	150A/5A	50/60 Hz	0,2	Wärmelauf, Heat Rise 3+4	29.01.2015	Jan 2018	In Ordnung	Werkskalibrierung
NS-Strom-Wandler	LV-current-transf.	RITZ	KSW 73	509 43042	150A/5A	50/60 Hz	0,2	Wärmelauf, Heat Rise 3+4	29.01.2015	Jan 2018	In Ordnung	Werkskalibrierung
NS-Strom-Wandler	LV-current-transf.	RITZ	KSW 73	509 43043	150A/5A	50/60 Hz	0,2	Wärmelauf, Heat Rise 3+4	29.01.2015	Jan 2018	In Ordnung	Werkskalibrierung
NS-Strom-Wandler	LV-current-transf.	H&B	TI 48a	8001958	2-2500 A/5 A	50/60 Hz	0,1	Messgerätschrank	05.09.2013	Sep 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	H&B	TI 48a	8000931	2-2500 A/5 A	50/60 Hz	0,1	Messgerätschrank	05.09.2013	Sep 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	H&B	TI 48a	6710365	2-2500 A/5 A	50/60 Hz	0,1	Messgerätschrank	06.09.2013	Sep 2016	In Ordnung	ÖKD
NS-Strom-Wandler	LV-current-transf.	GOSSEN	SSW2	PT 35	5-800 A/5 A	50 Hz	0,2	Messgerätschrank	16.09.2013	Sep 2016	In Ordnung	DKD
NS-Strom-Wandler	LV-current-transf.	GOSSEN	SSW2	PT 219	5-800 A/5 A	50 Hz	0,2	Messgerätschrank	16.09.2013	Sep 2016	In Ordnung	DKD
NS-Strom-Wandler	LV-current-transf.	GOSSEN	SSW2	PT 258	5-800 A/5 A	50 Hz	0,2	Messgerätschrank	16.09.2013	Sep 2016	In Ordnung	DKD
Schallpegelkalibrator	Acoustical Calibrator	B&K	4231	2229272	94,0 dB	1000 Hz	1	Schallmessraum,Noise & PD	03.11.2015	Nov 2016	In Ordnung	DKD
Schwingungskalibrator	Calibrator	B&K	4294	2481778	10ms-2/10mms/10um	159,2 Hz	--	Messgerätschrank	15.04.2016	Apr 2017	In Ordnung	DKD
Isolationsmeßgerät	Ins. resist. - meter	GOSSEN	Metriso 5000	PT 1104	0-20000 MOhm	DC	1,5	Routine	06.01.2016	Jan 2017	In Ordnung	DKD
Isolationsmeßgerät	Ins. resist. - meter	GOSSEN	Metriso 5000 A	UP 821	10 k Ohm - 1 TOhm	DC	2	Messgerätschrank	08.03.2016	Mrz 2017	In Ordnung	DKD
Hochspannungsprüfer	High Voltage Tester	ETL Prüftechnik	UH28A	0000200119200143	5 kV/100 mA	50 Hz	1,5	Wagen für Vorprüfungen	15.02.2016	Feb 2017	In Ordnung	DKD
Hochspannungsprüfer	High Voltage Tester	ETL Prüftechnik	UH28C	2-000668-413	5 kV/100 mA	50-60 Hz	1,5	Routine	08.01.2016	Jan 2017	In Ordnung	DKD
Multimeter	Multimeter	FLUKE	Fluke-87-V	92920143	1000V/10A	50-60 Hz	0,1-1,0	Routine	07.01.2016	Jan 2017	In Ordnung	DKD
Multimeter	Multimeter	FLUKE	Fluke-87-V	28150413	1000V/10A	50-60 Hz	0,1-1,0	Wärmelauf, Heat Rise, allgemein	09.02.2016	Feb 2017	In Ordnung	DKD
Multimeter	Multimeter	FLUKE	Fluke-87-V	20070205	1000V/10A	50-60 Hz	0,1-1,0	Wagen für Vorprüfungen	07.11.2015	Nov 2016	In Ordnung	DKD
Multimeter	Multimeter	GOSSEN	Metrahit185	M43911028	1000 V/10 A	50-60 Hz	0,05-0,5	Endkontrolle	20.03.2014	Mrz 2017	In Ordnung	DKD
Druck/Termo/Barometer	Hygro-/Thermo-/Barometer	Greisinger electronic	GFTB 200	34902589	-50-100°C 0% - 100% Rel. Luftfeuchte 10,0 - 1100,0 hPa			Stosspannungsplatz	25.01.2016	Jan 2017	In Ordnung	Werkskalibrierung
Feuchtemessgerät	Hygro-/Thermometer	Greisinger electronic	GFTH95	000355-01	0-70 °C 10-95% r. F.			Routine	07.01.2016	Jan 2017	In Ordnung	DKD
Digitalthermometer	Digitalthermometer	Greisinger electronic	GTH175	GIT-P-123	-199,9 - 199,9°C	--	0,1	Wagen für Vorprüfungen	15.02.2016	Feb 2017	In Ordnung	DKD
Übersetzungsmessgerät	Transfomer Turns Ratio Meter	HAEFELY / Tettex	TTR 2796	176880	0,8 - 20000 10,08% - ±0,15%	50/60 Hz	0,05	Wärmelauf, Heat Rise 3+4	17.03.2016	Mrz 2017	In Ordnung	KEMA
Übersetzungsmessgerät	Transfomer Turns Ratio Meter	HAEFELY / Tettex	TTR 2796	177498	0,8 - 20000 10,08% - ±0,15%	50/60 Hz	0,05	Wärmelauf, Heat Rise 1+2	11.05.2016	Mai 2017	In Ordnung	KEMA
Wicklungsanalysator	Winding Analyser	HAEFELY / Tettex	WA 2293	179742	siehe Zertifikat	50/60 Hz	siehe Zertifikat	Routine	24.09.2015	Sep 2016	In Ordnung	KEMA
Wicklungsanalysator	Winding Analyser	HAEFELY / Tettex	WA 2293	182721	siehe Zertifikat	50/60 Hz	siehe Zertifikat	Wagen für Vorprüfungen	14.01.2016	Jan 2017	In Ordnung	Werkskalibrierung
Wicklungsohmmeter	Micro Ohmmeter	IBEKO Power AB - DV Power	RMO40T	15RG418		DC	0,2	Wärmelauf, Heat Rise 1+2	19.03.2016	Mrz 2017	In Ordnung	DKD
Wicklungsohmmeter	Micro Ohmmeter	IBEKO Power AB - DV Power	RMO40T	15RG428		DC	0,2	Wärmelauf, Heat Rise 1+2	28.10.2015	Okt 2016	In Ordnung	Werkskalibrierung
Wicklungsohmmeter	Micro Ohmmeter	IBEKO Power AB - DV Power	RMO40T	15RG438		DC	0,2	Wärmelauf, Heat Rise 1+2	04.03.2016	Mrz 2017	In Ordnung	DKD
Wicklungsohmmeter	Micro Ohmmeter	IBEKO Power AB - DV Power	RMO60T	2955778	0,1 µOhm - 2000 Ohm	DC	0,2	Wärmelauf, Heat Rise 3+4	12.01.2016	Jan 2017	In Ordnung	DKD
Wicklungsohmmeter	Micro Ohmmeter	IBEKO Power AB - DV Power	RMO60T	2955748	0,1 µOhm - 2000 Ohm	DC	0,2	Wärmelauf, Heat Rise 3+4	01.02.2016	Feb 2017	In Ordnung	DKD
Wicklungsohmmeter	Micro Ohmmeter	IBEKO Power AB - DV Power	RMO60T	2955758	0,1 µOhm - 2000 Ohm	DC	0,2	Wärmelauf, Heat Rise 3+4	12.01.2016	Jan 2017	In Ordnung	DKD
Wicklungsohmmeter	Micro Ohmmeter	IBEKO Power AB - DV Power	RMO40T	1251058	0,1 µOhm - 2000 Ohm	DC	0,2	Wagen für Vorprüfungen	18.05.2015	Mai 2016	In Ordnung	DKD
Wicklungsohmmeter	Micro Ohmmeter	TINSLEY	5895	275986	0,1µOhm-100 Ohm	DC	0,1	Testarbeitsplatz fahrbar	12.05.2015	Mai 2016	In Ordnung	DKD
Wicklungsohmmeter	Micro Ohmmeter	TINSLEY	5895	276024	0,1µOhm-100 Ohm	DC	0,1	Routine	11.12.2015	Dez 2016	In Ordnung	DKD
Universalmeßgerät	universal measuring instrument	Omicron	CPC 100 CP TD1 CP SB1	[illegible]	siehe Zertifikat	siehe Zertifikat	siehe Zertifikat	Messgerätschrank	25.08.2015	Aug 2016	In Ordnung	Werkskalibrierung
TE-Kalibrator	PD-Calibrator	Omicron	CAL 542 Version B	[illegible]	1 - 100 pC	100 Hz	--	Schallmessraum,Noise & PD	11.07.2015	Jul 2016	In Ordnung	Werkskalibrierung
TE-Kalibrator	PD-Calibrator	MPS	TPE	200095	5-500 pC	100 Hz	--	Schallmessraum,Noise & PD	07.09.2015	Sep 2016	In Ordnung	Werkskalibrierung
TE-Kalibrator	PD-Calibrator	MPS	TPE	215116	5-50 pC	100 Hz	--	Schallmessraum,Noise & PD	07.09.2015	Sep 2016	In Ordnung	Werkskalibrierung
Scheitelspannungsmessgerät	Peak voltage meter	MPS	SMG	211117	200 kV	50/60 Hz	2,0	Wärmelauf, Heat Rise 3+4	26.10.2015	Okt 2016	In Ordnung	Vor Ort Kalibrierung
Messkondensator	Measuring capacitor	MPS	MK200	211165	200 kV	50/60 Hz						
Scheitelspannungsmessgerät	Peak voltage meter	MPS	SMG	211166	100 kV	50/60 Hz	2,0	Routine	26.10.2015	Okt 2016	In Ordnung	Vor Ort Kalibrierung
Messkondensator	Measuring capacitor	MWB	CM80	08.106428	80 kV	50/60 Hz						
Datenerfassungssystem	Data Acquisition Unit	YOKOGAWA	DA100-13-1F 2x DU100-12 DT300-11	91LB10637 91L537210 / 91L537214 91MC19218	0-250°C		0,1K	Wärmelauf, Heat Rise 1	11.01.2016	Jan 2017	In Ordnung	DKD
Datenerfassungssystem	Data Acquisition Unit	YOKOGAWA	DA100-13-1F 2x DU100-12 DT300-11	91LB10638 91L339418 / 91L339417 91L339413	0-250°C		0,1K	Wärmelauf, Heat Rise 2	11.01.2016	Jan 2017	In Ordnung	DKD
Datenerfassungssystem	Data Acquisition Unit	YOKOGAWA	DA100-13-1F 2x DU100-12 DT300-11	12A529584 12A418884 / 12A418881 12A424349	0-250°C		0,1K	Wärmelauf, Heat Rise 3	14.01.2015	Jan 2016	In Ordnung	DKD
Datenerfassungssystem	Data Acquisition Unit	YOKOGAWA	DA100-13-1F 2x DU100-12 DT300-11	91L339416 91L537213 / 91L537212 91MC19217	0-250°C		0,1K	Wärmelauf, Heat Rise 4	07.01.2016	Jan 2017	In Ordnung	DKD
Bildschirmschreiber	Temperature recorder	JUMO	Logoscreen nt	102300002				Wärmelauf, Heat Rise, allgemein	07.12.2015	Dez 2016	In Ordnung	DKD
Präzisions-Leistungs-Messgerät	Digital-powermeter	ZIMMER	LMG 500	02910810	U rms 1000 V / I rms 32 A U pk 3200 V / I pk 120 A	DC - 10 MHz	0,01-0,03	Wärmelauf, Heat Rise 4	05.01.2016	Jan 2017	In Ordnung	DKD
Präzisions-Leistungs-Messgerät	Precision Power Analyzer	ZIMMER	LMG 500	12471508	U rms 1000 V / I rms 32 A U pk 3200 V / I pk 120 A	DC - 10 MHz	0,01-0,03	Schallmessraum,Noise & PD	06.08.2015	Aug 2016	In Ordnung	Werkskalibrierung
Präzisions-Leistungs-Messgerät	Precision Power Analyzer	ZIMMER	LMG 500	12881605	U rms 1000 V / I rms 32 A U pk 3200 V / I pk 120 A	DC - 10 MHz	0,01-0,03	Routine	19.05.2016	Mai 2017	In Ordnung	Werkskalibrierung
Präzisions-Leistungs-Messgerät	Precision Power Analyzer	ZIMMER	LMG 500	12891605	U rms 1000 V / I rms 32 A U pk 3200 V / I pk 120 A	DC - 10 MHz	0,01-0,03	Wärmelauf, Heat Rise 1	18.05.2016	Mai 2017	In Ordnung	Werkskalibrierung
Präzisions-Leistungs-Messgerät	Precision Power Analyzer	ZIMMER	LMG 500	02920810	U rms 1000 V / I rms 32 A U pk 3200 V / I pk 120 A	DC - 10 MHz	0,01-0,03	Wärmelauf, Heat Rise 3	07.01.2016	Jan 2017	In Ordnung	DKD
Präzisions-Leistungs-Messgerät	Precision Power Analyzer	ZIMMER	LMG 500	05520606	U rms 1000 V / I rms 32 A U pk 3200 V / I pk 120 A	DC - 10 MHz	0,01-0,03	Messgerätschrank	05.05.2015	Mai 2016	In Ordnung	DKD
Präzisions-Leistungs-Messgerät	Precision Power Analyzer	ZIMMER	LMG 310	80703497	U rms 1000 V / I rms 30 A U pk 2000 V / I pk 60 A	DC - 1 MHz	0,05	Messgerätschrank	05.03.2015	Mrz 2016	In Ordnung	DKD
Präzisions-Leistungs-Messgerät	Precision Power Analyzer	ZIMMER	LMG 310	80104401	U rms 1000 V / I rms 30 A U pk 2000 V / I pk 60 A	DC - 1 MHz	0,05	Wärmelauf, Heat Rise 2	16.02.2016	Feb 2017	In Ordnung	DKD
Stoßspannungsmesssystem	Imp. voltage test system	High Volt	SMC 2000-400 MIAS 100-14-2B	924751 906223 905843	10 - 400 kV 20 kJ			Stosspannungsplatz	27.10.2015	Okt 2016	In Ordnung	Vor Ort Kalibrierung
Frequenzanalysator	FRANALYZER	OMICRON	FRANALYZER	AK914L	5Hz-2MHz	5Hz-2MHz		Messgerätschrank	17.07.2015	Jul 2016	In Ordnung	DKD

11.4. Test lab layout



picture 25: test lab layout

picture 26: routine and heat rise bays

picture 27: PD and sound chamber

11.5. List of pictures, formulas, tables and sources

LIST OF PICTURES:

LIST OF FORMULAS:

LIST OF Tables:

list of sources:

- ***D.J. Kraaij - Die Prüfung von Leistungstransformatoren***
- ***Wikipedia***
- ***IEC***
- ***Omicron***