PREFACE

Test procedures and equipment used for the testing and measurement of power transformers at AREVA Gebze factory are dealt in the scope of this booklet.

The electrical characteristics and dielectric strength of the transformers are checked by means of measurements and tests defined by standards (e.g. TS, IEC, DIN/VDE, ANSI, NEMA, BS….. etc.) and by the requirements of customers specifications.

Summary of the tests and measurements processes are given as follows:

**ROUTINE TESTS:**

1. Measurement of voltage ratio and check of vector relationship 3
2. Measurement of winding resistance 6
3. Measurement of impedance voltage and load loss 8
4. Measurement of no-load loss and current 11
5. Dielectric tests 13
6. Separate-source voltage withstand test 15
7. Induced over-voltage withstand test 16
8. Partial discharge measurement 19
9. Test on on-load tap changer 22

**TYPE TESTS AND SPECIAL TESTS**

10. Temperature rise test 23
11. Measurement of zero-sequence impedance 27
12. Measurement of voltage and current harmonics 29
13. Measurement of insulation resistance 30
14. Measurement of capacitance and tan δ 31
15. Lightning impulse test 32
16. Switching impulse test 36
17. Measurement of acoustic sound level 38

List of tests and measuring equipment of the test field 41

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1. **MEASUREMENT OF VOLTAGE AND CHECK OF VECTOR RELATIONSHIP**

The voltage ratio (i.e. turn ratio) of the transformer is the ratio of voltages at no-load.

**Purpose of the measurement:** verification of no-load voltage ratios specified by the specification and detection of any problem within the coils or tapping connections.

Measurements are carried out on all taps and on all phases.

**Measuring Circuit**

Turn ratio measurement is performed by two separate methods;

1. measurement by bridge method
2. measurement of voltage ratios

1. Turn ratio measurement is carried out by means of a voltage ratio measuring bridge in one-phase basis between the winding pairs. Measurements are repeated at all phases and all taps. During measurement only the turn ratio between the windings in which same magnetic flux flows. In other words, the turn ratio can be measured between the winding pairs, which are in parallel in vector diagrams (figures 1-1, 1-2, 1-3). The supply voltage is 220 V a.c. and error of the bridge is less than ± 0,1%.

![Figure 1-1: Measurement of voltage ratio measuring bridge](image)

- Transformer to be measured
- The transformer with adjustable taps
- Zero indicator
- U₁ – The supply voltage of the bridge and H.V. winding (220 V, 50 Hz)
- U₂ – The induced voltage in L.V. winding

The theoretical turn ratio of the transformer is adjusted on the tapped transformer of the bridge. % error indicator knob is adjusted until the balance is reached in the zero indicator. The reading from the error indicator scale shows the difference (deviation) between the actual turn ratio and turn ratio in %.

\[
Deviation = \left(\frac{measured \ turn \ ratio}{theoretical \ turn \ ratio}\right) \cdot \%100
\]

2. Voltage ratio measurements are generally performed by the digital instruments produced for this purpose. In addition to voltage ratio measurement, the determination of the vector group
(connection group) and current measurements can be performed with these instruments, it is necessary that the instrument must have 3-phase system for vector group determination. The method of comparing the voltages of dual vectors enables the measurement of phase shifting between the vectors.

The deviation in the turn ratio shall be $< \pm 0.5\%$.

**Vector Group**

In multiphase transformers, primary and secondary connections can be either star (Y), delta (D) or zigzag (Z), depending on the type of the transformer. The phase angle between the primary and secondary windings changes between $0^\circ$ and $360^\circ$. In vectorial denotation, when H.V. windings shows 12 (0), the numbers of the other windings in the connection group show the number of the clock in comparison with real or imaginary neutral point. For example, in Dyn5 connection group H.V. winding is Delta (D), L.V. winding is Star (Y) and there is a phase displacement of 150 ($5 \times 30^\circ$) between the windings. When the vector of H.V. shows 12 (0), the vector of L.V. shows 5 ($150^\circ$ lag).

The connection group is defined only for three-phase transformers. In connection group denotation, the H.V. winding is shown first (as a reference) than the other windings are as followed up.

The vector diagrams is also checked at the same time. The correct connection of the measurement cables between the transformer and between the bridge verifies the vector relationship, otherwise it is not possible to balance the bridge.

Besides the above mentioned, the check of vector relationship and the check of polarity also could be done using a voltmeter. In this method AC or DC voltages could be applied.

The wiring connections related with the AC method are given in standards as in details. An example to this method is illustrated in a phase diagram as below:

**Example** : Vector group: Dyn5

*Measuring procedure:*

1- three phase voltage is applied to ABC phase
2- the voltage between any two phases is measured (e.g. AB)
3- A and n terminals are short-circuit
4- the voltage between B and a’ is measured
5- the voltage between C and c’ is measured

*Figure 1-2: Measuring of vector group*

As it can be seen from the phase diagram, to obtain Dyn5 vector group the following condition should be realised:

$$C \ c' > AB > B \ a'$$

The other vector relationships can be checked by using the same principles.
<table>
<thead>
<tr>
<th></th>
<th>Yy0</th>
<th>Dd0</th>
<th>Dz0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td><img src="image1" alt="Yy0 Symbol" /></td>
<td><img src="image2" alt="Dd0 Symbol" /></td>
<td><img src="image3" alt="Dz0 Symbol" /></td>
</tr>
<tr>
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<td><img src="image4" alt="Yd1 Symbol" /></td>
<td><img src="image5" alt="Dy1 Symbol" /></td>
<td><img src="image6" alt="Yz1 Symbol" /></td>
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<tr>
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<td><img src="image9" alt="Yz5 Symbol" /></td>
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<tr>
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<td><img src="image12" alt="Dz6 Symbol" /></td>
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<tr>
<td>11</td>
<td><img src="image13" alt="Yd11 Symbol" /></td>
<td><img src="image14" alt="Dy11 Symbol" /></td>
<td><img src="image15" alt="Yz11 Symbol" /></td>
</tr>
</tbody>
</table>

**Figure 1-3: Connection symbols for three-phase transform**
2. MEASUREMENT OF WINDING RESISTANCE

Although, the winding resistance values are not the guaranteed values given to the customers, they are needed in connection with the load loss measurement when the load losses are corrected to correspond to the reference (e.g. 75°C) temperature. The resistance measurement will also show whether the winding joints are appropriate and the windings are correctly connected.

The winding resistances that vary with the temperature strongly, are the ohmic/d.c. resistance’s of a winding and the resistance is computed as follows:

\[
R_2 = R_1 \cdot \frac{235 + t_2}{235 + t_1} \quad \text{for copper} \]

\[
R_2 = R_1 \cdot \frac{225 + t_2}{225 + t_1} \quad \text{for aluminium}
\]

where;

- \( R_2 = \) winding resistance at \( t_2 \) temperature
- \( R_1 = \) winding resistance at \( t_1 \) temperature

Therefore, wherever the winding resistances are stated, the temperatures during the measurement must be given.

The resistances between all pairs of phase terminals at all tapping connections are measured. During the measurement of the resistance, winding temperature should be correctly measured.

Direct current can be obtained from a constant-current supply or from a battery unit. The value of the direct current should be high enough to ensure correct measurement and should be low enough to prevent any effects on the winding temperature. In practice this value should be greater than 1.2 x \( I_0 \) and less than 0.1 x \( I_n \). The time constant of the measurement circuit will depend on the ratio of \( L/R \).

When the test object is assumed to be composed of a \( R \) resistance and \( L \) inductance which is series connected to it, \( U \) voltage applied to this circuit will be:

\[
i = \frac{U}{R} (1 - e^{-\frac{t}{\tau}}) \quad \text{where time coefficient depends on } L/R \text{ ratio.}
\]

If the measuring current increases, it leads to the reduction of inductance due to saturation of the core, these enables the current to reach the steady state condition in a short time.

After switching on the supply voltage to the measurement circuit, it should be waited until the current becomes stationary, otherwise measurement errors will be occurred.

Measurement Circuit

Winding resistances can be measured by any of the following methods, by current-voltage method or by bridge method. Measuring sensitivity can be increased by using the digital measuring instruments. The circuit of the measurement by current-voltage method is given in figure 2-1.

In the current-voltage measuring method, by applying the winding current through the reference resistance in the system, the voltage drops occurred in both resistances. This voltage drop values of reference and winding resistances are compared to determine the value of unknown resistance (winding resistance) which can be read directly from the bridge instrument.

It is necessary to care, in order to avoid very high voltages during the switching on and off the circuit, the voltmeter shall not be kept in the circuit during this time.
In the bridge method measurement, the principle is the comparison of unknown resistance with a known resistance. This will be accomplished to make the current flowing through Galvanometer to zero by bringing the arms of the bridge into equilibrium. The lower resistances with (<1 ohm) are measured by Thomson (Kelvin) Bridge, the resistances with relatively higher (≥1 ohm) are measured by Wheatstone Bridge. By this means, the measurement errors are minimized.

\[ R_x = R_N \cdot \frac{R_1}{R_2} \]

\( R_1 = R_3 \) and \( R_2 = R_4 \)

The resistance measured by Wheatstone Bridge method.

\[ R_x = R_N \cdot \frac{R_1}{R_2} \]
3. MEASUREMENT OF IMPEDANCE VOLTAGE AND LOAD LOSSES

Short-circuit (load) losses and short-circuit impedance voltage are guaranteed and reported values by the manufacturer to customers. Short-circuit impedance voltage is an important parameter specially for the parallel operation of the transformers, whereas short-circuit losses are important from economical point of view.

This measurement is carried out to determine the load losses of the transformer and the impedance voltage at the rated frequency and rated current. The measurements are made separately for each winding (e.g., between 1st and 2nd winding for a two-winding transformer, and between 1st and 2nd, between 1st and 3rd and between 2nd and 3rd winding for a three-winding transformer). If the tapping range is more than 5%, the measurements are repeated on the extreme tapping also.

**Measurement Circuit**

![Circuit for the load-loss measurement](image)

1- Synchronous generator  
2- Supply transformer  
3- Current transformers for measurement  
4- Voltage transformers for measurement  
5- Power analyser  
6- Test object  
C- Compensation capacitors

*Figure 3-1: Circuit for the load-loss measurement*
Rated current is generally applied to the H.V. winding while L.V. winding is short-circuited. Test current should be close to the value of $I_{N}$ rated current as much as possible. And the voltage waveform should be in sinus-form with rated frequency. The voltage, current and load losses for each phase should be measured during the test.

In case that the generator could not supply the system, the reactive power is encountered by using the capacitor banks.

The readings have to be taken as quickly as possible to prevent the temperature changes in the windings and the applied current should be between 25 %...... to 100 % of rated current. So that the measurement errors are minimized.

Since the circuit is entirely inductive in large power transformers and reactors the power factor of the system ($\cos \varphi$) would be very small. ($\cos \varphi = 0.015...0.003$ or $90 - \varphi = 1^\circ....10$ min.), the measurement errors arising from measurement transformers will be comparatively high.

In such cases the results of the measurements must be corrected by a correction factor.

**Correction Factor**

$$P_{K1} = P_{K2} \cdot \left( 1 - \frac{E(\%)}{100} \right)$$

$P_{K1}$: corrected losses

$P_{K2}$: loss reading from wattmeter

$E(\%)$: total error

$$E(\%) = E_d(\%) + E_i(\%) + E_u(\%)$$

$E_d(\%)$: measurement error

$E_i(\%)$: current transformer turn ratio error

$E_u(\%)$: voltage transformer turn ratio error

$$E_d(\%) = \left[ 1 - \frac{\cos \varphi}{\cos(\varphi - \delta)} \right] \cdot 100$$

where;

$E_d(\%) = 0.0291 \cdot (\delta_i - \delta_u) \cdot \tan \varphi$

$\delta_i$: current transformer phase displacement error

$\delta_u$: voltage transformer phase displacement error

Since, phase displacement errors in measurement transformers are given in minutes.

If the measuring current is different than the “$I_{N}$” (rated current), short circuit impedance and load-losses are calculated referring the rated current as follows:

$$U_k = U_{km} \cdot \frac{I_N}{I_m}$$

$U_{km}$ = Measured short circuit impedance

$P_k = P_{km} \cdot \left( \frac{I_N}{I_m} \right)^2$

$P_{km}$ = Measured load losses

$I_m$ = Measured current

$P_k$ = Load losses at rated current

$U_k$ = Short-circuit impedance at rated current

According to the standards, the measured value of the losses are evaluated at a reference temperature (e.g. 75°C). The measuring temperature ($t_m$) losses are corrected to the reference temperature (75°C) according to the standards as follows;
The d.c. losses $P_{dc}$ at the measuring temperature "$t_m$" are calculated using the resistance values $R_{HV}$ and $R_{LV}$ obtained in the resistance measurement: $R_{HV}$ and $R_{LV}$ between line terminals.

DC losses = at $t_m$ measuring temperature $P_{dc} = 1,5 \left( I_1^2 \cdot R_{HV} + I_2^2 \cdot R_{LV} \right)$

Additional losses = at $t_m$ measuring temperature $P_{ac} = P_{km} - P_{dc}$

The load losses at reference temperature:

$$P_k = P_{dc} \cdot \frac{t_s + 75^\circ C}{t_s + t_m} + P_{ac} \cdot \frac{t_s + t_m}{t_s + 75}$$

where; $t_s : 235^\circ C$ for copper (acc. To IEC)

$225^\circ C$ for aluminium (acc. To IEC)

The short-circuit impedance:

At measuring temperature ($t_m$)

$$u_{km} = 100 \cdot \frac{U_{km}}{U_N} \ [\%]$$

$$u_{RM} = 100 \cdot \frac{P_{km}}{S_N} \ [\%] \ \text{“ohmic component”}, \quad u_{xm} = \sqrt{u_{km}^2 - u_{RM}^2} \ [\%] \ \text{“inductive component”}$$

At reference temperature of ($75^\circ C$):

$$u_R = 100 \cdot \frac{P_k}{S_N} \ [\%], \quad u_k = \sqrt{u_R^2 + u_{xm}^2} \ [\%]$$

Load losses and short-circuit impedance voltages measurements and corrections must be done at rated and extreme taps.

If the short-circuit losses and voltage of a transformer measured at frequency which is different form rated frequency, the following correction must be applied:

Short-circuit impedance voltage: $U_k = U_{km} \cdot \frac{f_N}{f_m}$

short-circuit losses: $P_k = P_{dc} + P_{ac} \cdot \left(\frac{f_N}{f_m}\right)^2$

Where:

$U_{km}$: short-circuit imp. voltage at $f_m$ meas. freq. $U_k$: short-circuit imp. voltage at $f_m$ meas. freq.

$P_{ac}$: additional losses at $f_m$ meas. freq. $P_k$: total short-circuit losses at $f_N$ rated freq.
4. MEASUREMENT OF NO-LOAD LOSSES

The no-load test is performed when one of the windings is unconnected to power supply (usually the H.V. winding) while the other winding is supplied with rated voltage at rated frequency. Then the no-load losses \( P_0 \) and the no-load current \( I_0 \) are measured. The test is usually carried out between 90 % - 115 % of \( U_N \) voltage at equal interval and corresponding values to the rated voltages are determined.

**No-Load Losses and No-Load Current**

The following losses occur at no-load:
- Iron losses in the transformer core and other metal parts
- Dielectric losses in the insulation’s
- Load losses caused by the no-load current

Since the last two mentioned losses are relatively very low, they can be ignored. So that the no-load losses are only the iron losses.

**Measurement circuit:**

1- Synchronous generator
2- Supply transformer
3- Current transformers
4- Voltage transformers
5- Power analyser
6- Test object

*Figure 4-1: Circuit for the no-load measurement*
Because the losses are to be determined under standard conditions, it is necessary to apply a wave shape correction whereby the losses are corrected to correspond to test conditions where the supply voltage is sinusoidal. In case of non-uniform waveform, the effective value of voltage \( U \) is different than the mean value \( U' \). There is no need for correction, if the voltmeter readings are the same for all.

The test voltage wave shape is satisfactory if the difference between readings \( U' \) and \( U \) are less than 3 %.

The test voltage \( U' \) is adjusted by the “mean value” voltmeter. Then the hysterisis losses can be measured correctly. But the Eddy-current losses should be corrected.

\[
P_m = P_o \cdot (P_1 + k \cdot P_2)
\]

\( P_m \): measured losses

\( P_o \): no-load losses at sinusoidal voltage

\( k = \left( \frac{U'}{U} \right)^2 \)

\( P_1 \): ratio (as a percentage) of hysterisis losses to total iron losses

\( P_2 \): ratio (as a percentage) of Eddy-current losses to total iron losses

It is assumed that for cold oriented steel sheets at 50 and 60 Hz, \( P_1 = P_2 = 50 \% \) This yields

\[
P_o = \frac{P_m}{P_1 + k \cdot P_2}
\]

where; \( P_1 = P_2 = 0.5 \)

According to IEC 60076-1; \( P_m = P_o \cdot (1+d) \) where; \( d = \left( \frac{U' - U}{U'} \right) \)

During the no-load loss measurement, the r.m.s value of no-load current is also measured at the same time. For a three-phase transformer, the average of the three phase currents is taken.

During the measurements the connections of the transformer shall be as foreseen in the service.

The transformer could be magnetised by d.c. before performing the no-load test. Therefore, the transformer shall be supplied with a higher voltage during a suitable duration (a few minutes) for demagnetisation of the core then the measurement shall be made.

Since the no-load currents are not symmetrical and generally not equal in magnitude. They have also different phase angles in three phases, so that the indications on the wattmeters will not be equal. The indication on one wattmeter can be zero (0) or even reach to (-) negative value.

If the measurement are being made on delta connected windings, one of the current can be absolutely greater and the other two can be smaller and their magnitude approximately equal to each other. On star connected windings, the measured current on the middle phase can be smaller and the outer phase currents can be greater.

When the analysis is made on phase currents, due to non-linear and dissymmetrical structure of the core, dissymmetrical distortion will be also detected on the currents, which are happened as current harmonics. (Please see the harmonic measurement section). The measurements are made normally at room temperatures.
5. DIELECTRIC TESTS

The standard dielectric requirements are verified by dielectric tests. They shall, where applicable and otherwise agreed upon be performed in the sequence as given below:

- **switching impulse test**: the test is intended to verify the switching impulse withstand strength of the line terminals and its connected winding(s) to earth and other windings and along the windings.

- **lightning impulse test**: the test is intended to verify the impulse withstand strength of the transformer, when the impulse is applied to its line terminals.

- **separate source withstands voltage test**: the test is intended to verify the AC withstands strength of the line and neutral terminals and their connected windings to earth and other windings.

- **induced AC withstand voltage test (short ACSD and long duration ACLD)**: the test is intended to verify the AC withstand strength of the each line terminal and its connected winding(s) to earth and other windings, the withstand strength between phases and along the winding(s) under test.

- **partial-discharge measurement**: it verifies partial-discharges free operation of the phases and along the winding(s) under test.

Transformer windings are identified by their maximum operating voltage $U_m$ and their corresponding insulation levels. Insulation levels and applicable dielectric tests are given in the table below.

<table>
<thead>
<tr>
<th>Category of winding</th>
<th>Highest voltage for equipment $U_m$ kV</th>
<th>Tests</th>
<th>Lightning impulse (LI)</th>
<th>Switching impulse (SI)</th>
<th>Long duration AC (ACLD)</th>
<th>Short duration AC (ACSD)</th>
<th>Separate source AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform insulation</td>
<td>$U_m \leq 72,5$</td>
<td>routine</td>
<td>type (note 1)</td>
<td>not applicable</td>
<td>not applicable (note 1)</td>
<td>routine</td>
<td>routine</td>
</tr>
<tr>
<td>Uniform and non-uniform</td>
<td>$72,5 &lt; U_m \leq 170$</td>
<td>routine</td>
<td>not applicable</td>
<td>special</td>
<td>routine</td>
<td>routine</td>
<td>routine</td>
</tr>
<tr>
<td></td>
<td>$170 &lt; U_m &lt; 300$</td>
<td>routine</td>
<td>routine (note 2)</td>
<td>routine</td>
<td>special (note 2)</td>
<td>routine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\geq 300$</td>
<td>routine</td>
<td>routine</td>
<td>routine</td>
<td>special</td>
<td>routine</td>
<td></td>
</tr>
</tbody>
</table>

**Note 1**: In some country, for transformer with $U_m \leq 72,5$ kV, LI tests are required as routine tests, and ACLD tests are required as routine or type tests.

**Note 2**: If the ACSD test is specified, the SI test is not required.

The transformers which have one or more non-uniformly insulated windings, the test voltages for induced voltage test, and for the switching impulse test if used, are determined by the winding with the highest $U_m$ value, and the windings with lower $U_m$ values may not receive their appropriate test voltages. This discrepancy should normally be accepted. If the ratio between the windings is variable by tappings, this should be used to bring the test voltage for the winding with lower $U_m$ voltage as close as possible to the appropriate value.

The details of the partial discharge are given in section 8.
If LI is requested to include the chopped wave in this case the peak value of the chopped impulse shall be 10 % higher than for the full impulse ( i.e 10 % more ).

For transformers with a high-voltage winding having $U_m > 72.5 \text{kV}$, lightning impulse tests are routine tests for all windings of the transformer.

**Repeated dielectric tests:**

For transformers which have already been in service and have been refurbished or serviced, dielectric tests shall be repeated at test levels of 80 % of the original values, unless otherwise agreed upon, and provided that the internal insulation has not been modified. Long duration AC induced test ( ACLD ) shall always be repeated at 100 % test level. Repetition of tests required to prove that new transformer, having been factory tested, is always performed at 100% of test level.
6. **SEPARATE-SOURCE VOLTAGE WITHSTAND TEST**

The purpose of the test is testing the insulation between the windings and the insulation between windings and earthed parts (tank, press iron, etc.), under the temporary and switching over-voltages conditions which may be occurred during the service.

**Test Circuit**

![Test Circuit Diagram](image)

- **1-** Transformer with adjustable voltages
- **2-** Current transformer and Ammeter
- **3-** Input voltage voltmeter of test transformer
- **4-** Test transformer
- **5-** Capacitive voltage divider
- **6-** Voltmeter (r.m.s. value)
- **7-** Voltmeter (Peak value $\sqrt{2}$)
- **8-** Transformer under test

*Figure 6-1: Test circuit for separate-source voltage withstands test*

The tests, which are made with separate source voltage, shall be made at rated frequency or at a frequency not less than the 80 percent of the rated frequency. This allows the testing of 60 Hz transformers at 50 Hz. The waveform of voltage must be sinusoidal as much as possible and must be single phase.

The voltage is measured using a capacitive voltage divider in conjunction with voltmeter response to peak values. The peak voltmeter indicates the peak value divided by $\sqrt{2}$. The test duration is one minute. The test voltage is applied to the winding which is going to be tested (all terminals of this winding is short-circuited) while the terminals of the other windings are connected to each other, the windings that are not under test voltage, tank and core also should be grounded. Secondary winding terminals of the bushing type CT’s shall be connected to each other's and grounded in order to prevent unwanted sparkings.

The current should remain constant during the test.

The test is successful if no collapse of the test voltage occurs.

This test is applied to the uniformly insulated windings and to the star point (neutral point) of the graded insulated (non-uniform) windings. Every point of the windings to which the voltage applied; is tested with the test voltage.

The line terminals of non-uniform insulated windings are tested by induced overvoltage withstand test (section 7).
7. **INDUCED OVERVOLTAGE WITHSTAND TEST**

The purpose of the test is testing the insulation between the phase windings, turns, coils, tapping leads and terminals, for non-uniformly insulated windings also the insulation between these parts and earth, under the temporary and switching over-voltages conditions to which the transformer may be subjected during its life time.

Normally, the excitation voltage is applied to the terminals of the low voltage winding while the terminals of the other windings are left open or grounded in one point.

Since the test voltage is much higher than the rated voltage, the frequency of the test voltage is chosen at least two times greater than the rated frequency without causing the over saturation in the core.

The test voltage is measured with capacitive voltage divider connected to H.V. terminal or the test voltage can be read from the voltmeter through voltage transformer in the low voltage side, which is calibrated with the voltage divider. Another method is to measure the test voltage from the peak value voltmeter, which is connected to the test tap of H.V. condenser bushings. The peak voltmeter indicates the peak value divided by √2.

The test duration not being less than 15 seconds is determined by the following formula;

\[
120 \text{ second} \times \frac{\text{Rated frequency}}{\text{Test frequency}}
\]

If no flashover voltage collapse and abnormal increase in the current occurs during the test, then the test said to be satisfactory.

**Short duration induced AC voltage test (ACSD):**

a) Uniformly insulated windings

Test connection is essentially the same as in service, a three phase symmetrical voltage is supplied. The test voltage is generally twice as the rated voltage. However, the voltage between line terminals of any winding shall not exceed the rated short duration power frequency withstand voltage. The tappings of the transformer should be accordingly.

The voltage is measured from terminals to earth or between terminals of the low voltage winding using precision voltage transformers.

**Test circuit**

1- synchronous supply gen.
2- test transformer
3- current transformer and ammeter
4- voltage transformer and voltmeter
5- transformer under test

*Figure 7-1: Test circuit for induced over-voltage withstands test on uniformly insulated winding*
**Transformers with** $U_m < 72.5\, \text{kV}$ normally, no partial discharge measurements are performed during this test. Test duration and voltage are explained above.

**Transformers with** $U_m > 72.5\, \text{kV}$ this transformers shall all, if not otherwise agreed, be tested with partial discharge measurement. The partial discharge performance shall be controlled according to the time sequence for the application of the voltage as shown in figure 7.2:

$$U_2 = 1.3 \cdot U_m / \sqrt{3} \quad \text{phase – earth and} \quad U_2 = 1.3 \cdot U_m \quad \text{phase - phase}$$

**b) non-uniformly insulated windings:**

For three phase transformers, two test sets are required:

1. A phase-to-earth test with rated withstand voltages between phase and earth with partial discharge measurement.

2. A phase-to-phase test with earthed neutral and with rated withstand voltages between phases with partial discharge measurement. The test shall be carried out in accordance with uniformly windings (subclause a).

On single-phase transformers, only a phase-to-earth test is required.

The test sequence for three phase transformer consist of three single-phase applications of test voltage to the individual phases with different points of the winding connected to earth at each time.

At this type of windings, induced overvoltage test and separate source voltage withstand test (at the phase terminals) are performed in the same time.

For the three single-phase tests for the phase-to-earth insulation: $U_2 = 1.5 \cdot U_m / \sqrt{3}$

For the partial discharge performance evaluation, during the phase-to-phase test, measurements should be taken at $U_2 = 1.3 \cdot U_m$. For $U_m = 420\, \text{kV}$ and $550\, \text{kV}$ transformers with test values of $460\, \text{kV}$ and $510\, \text{kV}$, the PD evaluation level should be reduced to $U_2 = 1.2 \cdot U_m$ during the phase-to-phase test and $U_2 = 1.2 \cdot U_m / \sqrt{3}$ during the phase-to-earth test.
Test circuit

1- synchronous supply gen.
2- test transformer
3- current transformer and ammeter
4- voltage transformer and voltmeter
5- transformer under test
6- Capacitive voltage divider

Figure 7.3: Test circuit for induced over-voltage withstands test on non-uniformly insulated winding of a three-phase transformer

The test circuit given in fig. 7.3 is for the transformer which HV neutral point is insulated according to 1/3 of the test voltage.

Long duration induced AC voltage test (ACLD):

Uniformly and non uniformly insulated windings.

Three- phase transformer shall be tested either phase-to-phase in a single-phase connection or in a symmetrical three-phase connection.

The neutral terminal (if present) of the winding under test shall be earthed. The other separate windings, if they are star-connected they shall be earthed at the neutral, and if they are delta-connected they shall be earthed at one of the terminals or earthed through the neutral of the supplying voltage source. The duration and the voltage levels are given in fig. 7-4.

A : 5 min
B : 5 min
C : test duration
D : for Um>300 kV  60 min
   for Um<300 kV  30 min
E : 5 min

Um : Highest voltage for equipment

Şekil 7.4: Long duration induced overvoltage test voltage – time curve

During the whole application of the test voltage, partial discharges shall be measured. The details of the PD measurement are explained in section 8.

The voltages to earth shall be ;

\[ U_1 = 1.7 \cdot U_m / \sqrt{3} \quad \text{and} \quad U_2 = 1.5 \cdot U_m / \sqrt{3} \]

The partial discharge measurements shall be performed at all HV terminals.

The details of the evaluation of the tests and partial discharge measurements are given in standards (e.g IEC 60076 – 3)
8. PARTIAL DISCHARGE MEASUREMENT

The purpose of this test is to measure the partial discharges in the test object produced by the application of AC voltages during the tests. This test gives a comprehensive information about the quality of the insulating materials and the design.

The followings are determined during the measurement of partial discharges;

- To determine the existence of a definite partial discharge in the test object at a predetermined voltage.
- By increasing the applied voltage at where the partial discharging begins (partial discharge inception voltage) and by decreasing the applied voltage at where the partial discharging extinguishes (partial-discharge extinction voltage).
- To determine the magnitude of the partial discharge at a predetermined voltage.

The mentioned partial discharges (which do not cause flashover between the electrodes) are the discharges in a certain area of the insulation between the conductors of the test object. These discharges may occur in the gaps of the insulating environment, in the gaps of the solid-materials or in the contact surfaces of two different insulations. This discharge can be captured as a single current impulse in the outer region. Although these discharges do not cause permanent deteriorations in the insulating media since their energy is relatively small, the thermal energy of the discharges shall cause depreciation, aging and deterioration in the insulating media.

The electrical discharge magnitude at the partial discharge point is not a direct measurement for deterioration of the insulating material in this region. Besides the numerical value, the intensity and the waveform of the impulse, regional discharge concentration, the manufacturing and the placing of the insulation also effects the situation.

The above evaluations prove that the “partial discharge” measurement is a implementary method to check the quality of whole insulation.

Creation of partial discharge and measured magnitudes

In a insulation arrangement, an analogue schematic drawing about the partial discharge takes place in a certain region is shown below.

As it can be seen in the figure 8.1, the impulse occurred in the discharge point produces $\Delta U$ voltage across the line terminals. This yields a measurable “q” charge in the measurement impedance.

This is called apparent charge and is given as $pC$ (Pico-Coulomb). This apparent charge is not equal to the charge in the fault region but it is proportional, however this proportion could not be fixed yet.

In the measurements; $\Delta U$ voltage drop, the average value of the partial-discharge current, the partial-discharge power, number of impulses in a time interval, and the inception and extinction voltages of the partial discharge can also be determined.
**Measurement principle and circuit**

Partial discharge measurement principles in a transformer and a produced circuit, according to IEC-Publication 60270, are explained below.

**Figure 8.2: Connection circuit for partial discharge measurement**

- 1- supply generator
- 2- supply transformer
- 3- test transformer (test object)
- 4- voltage transformer and meas. Circuit
- 5- Filter
- 6- measuring impedance
- 7- selector switch
- 8- measuring equipment and oscilloscope
- 9- calibration generator

**U:** applied voltage  
**Z:** supply circuit impedance  
**R:** discharge resistance  
**G:** discharge gap  
**C₁:** capacitance of discharge region  
**C₂:** capacitance of the insulation series connected with the discharge region
The circuit that is given at figure 8.2 is a very useful method called BUSHING TAP.

The calibration of the circuit has to be made before starting the measuring. For this reason first of all a calibration generator is needed. Calibration generator is producing a $q_0$ charge, with a definite value. It is connected parallel to the test object. The $q_0$ charge, which is produced by calibrator, is observed from the measuring equipment. This operation must be repeated for all terminals of the transformer.

$$K = \frac{q_0}{q_{om}}$$

$K$ : correction factor
$q_0$ : the charge produced by the calibrator
$q_{om}$ : the charge observed at measuring equipment

P.S.: It must be noted that the transformer must be de-energized during the calibration process.

After the transformer has been energised, the value of partial discharge that was observed from the measuring equipment, is multiplied by the correction factor ($K$) of every terminal and the apparent partial discharge value is found.

$$q = q_{om} \cdot K$$

$K$ : correction factor
$q_{om}$ : the charge observed at measuring equipment
$q$ : the real apparent charge

The wide-band or narrow-band measuring equipment’s are used for partial discharge measurement. Wide-band consists of the frequency spectrum from 40 kHz up to several 100 kHz, and narrow-band frequency spectrum is between 9÷10 kHz.

i.e.: 0,2 MHz, 0,5 MHz, 1,9 MHz.

The wide-band measuring equipments are to much effected from environmental influences where as narrow-band ones is effected considerably little.

The partial discharge measurements of the transformer is made during the induced voltage test.

Test and measuring circuit, test duration and voltage levels, and evaluation criterions are given section 7, induced overvoltage test.
9. OPERATION TESTS ON ON-LOAD TAP CHANGER

After the tap-changer is fully assembled on the transformer, the following tests are performed at (with the exception of clause b) 100% of the rated auxiliary supply voltage:

a) 8 complete operating cycles with the transformer not energised.

b) 1 complete operating cycle with the transformer not energised, with 85% of the rated auxiliary supply voltage.

c) 1 complete operating cycle with the transformer energised at rated voltage and frequency at no-load.

d) 10 times tap-changer operations with ±2 steps on either side of the principal tappings with as for as possible, the rated current of the transformer, with one winding short-circuited.
10. TEMPERATURE RISE TEST

The purpose is, to check that the temperature rises of the oil and windings do not exceed the limits agreed on or specified by the standards.

The supply and measuring facilities as well as the measuring circuits are the same as in the load loss measurement (section 3) and in the measurement of windings resistance (section 2).

Simplified temperature distribution diagram is given in figure 10-1.

![Temperature Distribution Diagram](image)

**Figure 10.1: A simplified temperature distribution for a transformer**

- $\theta_o$ = maximum oil temperature (under cover)
- $\Delta \theta_o$ = maximum oil temperature rise $\Delta \theta_o = \theta_o - \theta_a$
- $\theta_a$ = ambient temperature
- $\theta_w$ = the average winding temperature
- $\Delta \theta_w$ = the average winding temperature rise $\Delta \theta_w = \theta_w - \theta_a = \Delta \theta_{wo} + \Delta \theta_{oavg}$
- $\theta_g$ = temperature of oil going into the cooler
- $\theta_c$ = temperature of oil coming from the cooler
- $\theta_{w\text{ max}}$ = maximum winding temperature
- $R$ = cooler
- $\theta_{oavg}$ = the average oil temperature rise
- $\Delta \theta_{wo}$ = the temperature difference between winding and oil
- $\Delta \theta_{oavg}$ = the average oil temperature
- $\theta_{hs}$ = hot-spot temperature
a) The measurement procedure

The necessary precautions should be taken for the effects (i.e. warm or cool air circulation) which would affect the transformer under temperature-rise test.

The current and voltage measuring principles, during this test, are the same as in the load loss measurement (section 3). The temperature rise test will, unless otherwise specified, be carried out on the maximum current tapping.

Since, it is necessary to record the temperature rises and the ambient temperature through the test, thermometers are placed in a thermometer pocket in the cover, in and going out of the cooler and 1 to 2 meter away from the transformers. The temperatures in these thermometers are measured and recorded when the transformer is in cold position before starting the test. Before starting the test, the winding temperature (cold resistance measurement) is measured and recorded.

The transformer is supplied with a voltage and current which constitute the sum of short-circuit losses at the maximum loss tap and no-load losses in order to achieve to the service conditions. For a multi-winding transformer, the temperature rise requirement refer to rated power in all windings simultaneously if the rated power of one winding is equal to the sum of the rated powers of other windings.

In certain cases, if it suits, first part of the test can be a few hours shortened by switching of the cooling system.

The maximum values of the current and the voltage during the supply are as follows;

Supply current \[ I_d = I_N \cdot \sqrt{\frac{P_o + P_k}{P_k}} \]

Supply voltage \[ U_d = U_k \cdot \sqrt{\frac{P_o + P_k}{P_k}} \]

in which;

\[ I_N = \text{Rated current (the current of the tap in which the test is performed)} \]

\[ P_o = \text{No-load losses} \]

\[ P_k = \text{Load losses} \]

The test is performed separately in two parts:

a) Total loss injection (1. Part of the test) : Supplied with total losses. The test is continued until a steady-state oil temperature rise is established (i.e. the difference between top oil temperature and ambient temperature is less than 1 °C for 3 hour). This period is called as first part of the test. The supply values and the temperatures of different points are recorded at suitable time intervals.

b) Rated current injection (2. Part of the test) : When the top oil temperature rise has been established, the test shall immediately continue with rated current supply one hour. This period is called as second part of the test. The supply values and the temperatures are recorded as above. At the end of one hour, supply is disconnected and the hot-resistance of windings are measured. The test connection is changed for carrying out the resistance measurement and after the inductive effects have disappeared the resistance time-curves are measured for a suitable period of time than by extrapolation method the resistance value of the winding at the instant of switching off the supply is determined.

After disconnection of the test current, the pump circulation and fan ventilation are continued.

b) Measurement of ambient temperature (Temperature of cooling air or water)

The cooling ambient temperature is measured by means of at least three thermometers or thermocouples. Measurement is done by placing the thermometer or thermocouple in a container filled with oil which has 2 hour time-constant. Containers should be protected against any air circulation and thermic ray. They should be replaced 1 and 2 m away from the three sides of the transformer at a height of half way up the transformer coolers.
For forced-air cooled transformers the temperature of the incoming air is measured. If water is used as cooling medium, the water temperature at the intake of the cooler (in the thermometer pocket) is the reference temperature.

The values of cooling ambient temperature (cooling air or water temperature) taken at every 1/2 hour in the last quarter of the test are used for temperature rise calculations.

c) Determination of the temperature rise of oil

The top oil temperature is measured by a thermometer placed in an oil filled thermometer pocket on the cover. The difference between the max. measured temperature and ambient temperature is:

\[ \Delta \theta_o = \theta_o - \frac{1}{2} (\theta_o - \theta_c) \]

the average oil temperature

\[ \Delta \theta_{avg} = \theta_{avg} - \theta_a \]

the average oil temperature rise

The temperature of oil coming in and going out of the cooler is measured by means of thermometers which are fitted to the pipes of the cooler. When the transformer has separate cooler, oil inlet and outlet temperatures are measured on the inlet and outlet pipes near to the transformer tank.

If the test object during the test can not be supplied by the current which encounter the total losses of the insufficient power, in this case test losses (ensuring that not less than the 80 percent of the total losses) are computed as follows:

\[ \Delta \theta_{ON} = \Delta \theta_{OM} \left( \frac{P_N}{P_M} \right)^X \]

\[ \Delta \theta_{ON} : \text{total-losses temperature rise at } P_N \text{ (rated value)} \]
\[ \Delta \theta_{OM} : \text{test-losses temperature rise at } P_M \text{ (test value)} \]
\[ X : \text{for distribution tr. (natural cooling, rated power < 2500 kVA)} = 0.8 \]
\[ \text{ON-cooling} = 0.9 \quad \text{OF and Water cooling} = 1.0 \]

\[ \theta_2 = \frac{R_2}{R_1} (235 + \theta_1) - 235 \]

where

\[ \theta_2 : \text{Winding temperature at the instant of switching off} \]
\[ \theta_1 : \text{Winding (cold)} \text{ temperature at the beginning of the test (average oil temperature)} \]
\[ R_2 : \text{the resistance at } \theta_2 \text{temperature} \]
\[ R_1 : \text{the resistance at } \theta_1 \text{temperature} \]

P.S.: For aluminum windings 225 K should be taken instead of 235 K.

When the supply of I_N rated current for 1 hour is the second part of the test, the temperature of oil decreases during this time. The relation between the temperature of the winding and the average temperature of the oil shall be calculated with this decreased temperature.
Then:

\[ \Delta \theta_{\text{wo}} = \theta_2 - \theta_{\text{avg}(I_N)} \]

where;

\( \Delta \theta_{\text{wo}} \): the temperature difference between winding and oil
\( \theta_2 \): winding temperature
\( \theta_{\text{avg}(I_N)} \): the average oil temperature at the end of 1 hour \( I_N \) supply

The temperature \( \theta_{\text{avg}(I_N)} \): oil temperature rise is determined as in clause c)

The difference between the winding temperature and the average oil temperature in the second part of the test is as follows:

\[ \theta_\text{w} = \frac{\theta_{\text{wo}} + \Delta \theta_{\text{oavg}}}{2} \]

If the \( I_N \), rated current, can not be reached because of insufficient supply system, the difference between the temperature of the winding and the temperature of the oil is corrected as follows:

\[ \Delta \theta_{\text{woN}} = \Delta \theta_{\text{woM}} \cdot \left( \frac{I_N}{I_M} \right)^{1.6} \]

where:

\( \Delta \theta_{\text{woN}} \): the temperature difference at the \( I_N \) rated current
\( \Delta \theta_{\text{woM}} \): the temperature difference at the test current \( I_M \)
\( \gamma \): exponent \( \text{ON and OF cooling} = 1.6 \)
\( \text{OD cooling} = 2.0 \)

The maximum temperature occurring in any part of the winding insulation system is called the “hot-spot temperature”. This parameter represents the thermal limitation of loading of the transformer. The winding hot-spot temperature rise versus ambient is computed as follows:

\[ \theta_{\text{hs}} = \theta_{\text{avg}} + C_{\text{hf}} \cdot \Delta \theta_{\text{wo}} \]

\( C_{\text{hf}} \): hot-spot factor

Hot-spot factor is 1.1 in distribution transformers and 1.3 in medium size power transformers.

When the transformer is supplied with total losses in the first part of the test, there is no need to make any correction if the test frequency is different than the rated frequency, but for the loading with rated current for one hour in the second part of the test, the correction must be made in accordance with the below equation:

\[ I_M = I_N \sqrt{\frac{P_{\text{dc}} + \left( \frac{f_N}{f_M} \right)^2 \cdot P_{\text{ac}}}{P_{\text{dc}} + P_{\text{ac}}}} \]

\( I_M \): test current
\( f_M \): test frequency
\( P_{\text{dc}} \): dc losses
\( I_N \): rated current
\( f_N \): rated frequency
\( P_{\text{ac}} \): additional losses
11. MEASUREMENT OF ZERO-SEQUENCE IMPEDANCE

The zero-sequence impedance is usually measured for all star or zig-zag-connected windings of the transformer. The measurement is carried out by supplying with rated frequency between the parallel connected phase terminals and the neutral terminal. The zero-sequence impedance per phase is three times the impedance measured in this way.

\[ Z_o = 3 \cdot \frac{U_o}{I} \quad \Omega / \text{Phase} \]

Zero-sequence impedance is related with connection group and manufacturing properties. Zero-sequence impedance consists of two parts as \( R_o \) (real) and \( X_o \) (imaginary), due to \( R_o \ll X_o \), \( R_o \) can be neglected. This yields the zero sequence impedance equals to zero-sequence reactance.

Zero-Sequence impedance, only winding which star point is brought out can be measured. Measurement is done at principal tapping when the active part of the transformer is installed in the tank.

The value of zero-sequence impedance is infinity for the windings which are delta connected or the star point is not brought out.

When the other winding of the transformer is delta connected or a delta connected tertiary winding exists, in the measurement of zero-sequence impedance, the star point of the transformer can be loaded up to max. rated current. At this instant, the \( U_o \) test voltage will be between 15 % and 27 % of the phase-neutral voltage of the transformer. In cases where counter magnetic flux does not exists e.g. in star-connected transformers which do not have tertiary windings, this test current shall be max. \( 0.3 \times I_n \) to avoid excessive temperature of metallic constructional parts.

It can be said that for the transformers which both windings are star connected and which star points are brought out, there are two different zero-sequence impedance's.

a- No-load zero-sequence impedance \( Z_{00} \)

When one of the star-connected windings is measured, the terminals of the other winding is left open.

b- Short-circuit zero sequence impedance \( Z_{0K} \)

When one of the star-connected windings is measured, the terminals of the other winding and the star point terminals are short circuited.
Zero-sequence impedance may be given as a percentage of the rated phase impedance. In this case:

\[ z_o = Z_o \cdot \frac{I_N}{U_N} \]

- \( z_o \) = relative zero-sequence impedance (%)
- \( I_N \) = rated phase current (A)
- \( U_N \) = rated phase-neutral voltage (V)
- \( Z_o \) = Zero-sequence impedance (\( \Omega \) phase)
12. MEASUREMENT OF THE CURRENT AND VOLTAGE HARMONICS

Generally at the rated current the ratio of the current harmonics to the rated current is less than 1%. Therefore; this is not so important for the transformer operators, but this measurement can be required to have an idea about the value.

The magnitude of harmonic component, depends on the core material, the degree of the excitation, the design of the core, the connections of the windings and the impedance of the supply circuit.

The measurement of current and voltage harmonics is made during the measurement of no-load losses and no-load current (section 4). Circuit diagram of harmonics measurement is given in fig. 12.1.

The supply voltage waveform in the test laboratory shall be exactly sinusoidal. The supply voltage form may differ from sinusoidal form due the deterioration’s in the no-load current. In order to overcome this event, the magnetic characteristics of the test generator and transformer stay in the linear region, by choosing the appropriate connection-groups. Since the measuring voltage and measuring current are taken through voltage and current transformers to the analyzer, the operation regions of the measuring transformers shall be linear not to produce additional harmonics.

Measurements are made for each phase. Usually 3rd, 5th, 7th and 9th harmonics which are comparatively stronger, are measured.

The effective value of the no-load current is:

\[ I_{\text{eff}} = \sqrt{\sum_{i=1}^{n} I_i^2} \]

![Figure 12.1: Circuit diagram of harmonic measurement](image.png)

1- Current transformer
2- Voltage transformer
3- Analyzer
4- Test object
13. MEASUREMENT OF INSULATION RESISTANCE

The purpose of the measurement is to determine the leakage current of the insulation resistance. This current is changing with the moisture, impurity contents and temperature of the insulation.

Beside the result of the measurements, the comparison of the periodical measurement give the information about the condition of the insulation. In order to compare they must be at the same temperature (for example at 20 °C reference temperature).

“Time resistance method” in the insulation resistance measurement is one of the best methods, that is simple and gives correct results.

The insulation resistance is measured by means of an insulation resistance meter which apply a voltage 1000 V dc or 5000 V dc. Each winding is measured separately by connecting the voltage between the winding to be tested and earth. While the other windings are connected to the guard circuit of the test instrument. The temperature and humidity are recorded during the test.

The Resistance values \( R_{15} \), \( R_{30} \), \( R_{45} \) and \( R_{60} \) are taken at 15 s, 30 s, 45 s and 60 s after apply the voltage. Furthermore, the ratio of the insulation resistance \( R_{60} \) to the insulation resistance \( R_{15} \) (or \( R_{30} \)) is stated as absorption ratio in the test report.

Readings are referred to 20 °C by multiplying the value at transformer oil temperature \( \theta \) (ambient) by correction factor given in table below:

<table>
<thead>
<tr>
<th>( \theta ) °C</th>
<th>Correction factor</th>
<th>( \theta ) °C</th>
<th>Correction factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10</td>
<td>0,13</td>
<td>35</td>
<td>2,80</td>
</tr>
<tr>
<td>-5</td>
<td>0,18</td>
<td>40</td>
<td>3,95</td>
</tr>
<tr>
<td>0</td>
<td>0,25</td>
<td>45</td>
<td>5,60</td>
</tr>
<tr>
<td>5</td>
<td>0,36</td>
<td>50</td>
<td>7,85</td>
</tr>
<tr>
<td>10</td>
<td>0,50</td>
<td>55</td>
<td>11,20</td>
</tr>
<tr>
<td>15</td>
<td>0,75</td>
<td>60</td>
<td>15,85</td>
</tr>
<tr>
<td>20</td>
<td>1,0</td>
<td>65</td>
<td>22,40</td>
</tr>
<tr>
<td>25</td>
<td>1,40</td>
<td>70</td>
<td>31,75</td>
</tr>
<tr>
<td>30</td>
<td>1,98</td>
<td>75</td>
<td>44,70</td>
</tr>
</tbody>
</table>
14. CAPACITANCE AND TAN δ MEASUREMENT “INSULATION POWER FACTOR TEST”

All insulating materials used in practice have slightly small dielectric losses at rated voltage and at rated frequency. These losses are fairly low for good insulating materials. This loss changes proportionally with the square of the applied voltage. Insulation, in terms of basic circuits elements, is shown in figure 14.1.

As it can be seen from figure 14.1 the angle $\delta$ between the total current "$I"$ and capacitive current "$I_c"$ is a basic value.

Insulation angle is dependent on the thickness, the surface and the properties of the insulation material (the pores, impurities and humidity which cause the ionization in the insulation material).

Generally, the conditions and the reasons will cause a decrease in the dielectric withstand of the insulation. For this reason, the power factor measurement of the insulation at certain frequency gives a basic idea about the insulation. The measurements to be made during the service are one of the most important indications, showing the ageing of the insulation and the contamination of the oil.

The active losses of the circuit is as follows;

$$P = U \cdot I \cdot \cos \varphi = U^2 \cdot C \cdot \omega \cdot \tan \delta$$

Capacitance, $\tan \delta$, active losses and $\cos \varphi$ can be measured by bridge methods or power factor ($\cos \varphi$) measuring instrument at definite voltages.

Measurement is performed between the windings and the tank, and the test temperature is recorded; then according to desired reference value the necessary corrections are done.
15. LIGHTNING IMPULSE TEST

The purpose of the impulse voltage test is to confirm that the transformer insulation’s withstand the lightning overvoltages which may occur in service.

The power transformers used in high voltage systems at any time may be affected by the atmospheric discharges. The magnitudes of the lightning overvoltages always depend on the impulse current and the impulse impedance where the lightning impulse occurs. This value is several times of operating voltage.

Impulse voltage is produced by a “impulse voltage generator” in the laboratory. For oil type transformers, this impulse voltage is stated as with (-) negative polarity and the waveform at the line terminal shall be $T_{front} / T_{tail} = 1.2 \pm 30\% / 50 \pm 20\% \mu S$. Besides the full waveform (figure 15.1) in chopped wave at the tail, the chopping time shall be between $2...6 \mu S$. (figure 15.2).

\[
T_1 = 1.2 \pm 30\% \mu S \\
T_2 = 50 \pm 20\% \mu S
\]

![Figure 15.1: Full wave lightning impulse](image1)

![Figure 15.2: Chopped wave at the tail](image2)

\[
T_c = 2...6 \mu S
\]
Lightning impulse voltages are applied to the line terminals successively. The number and application method of the lightning impulse voltages are stated in the standards. The other line terminals and the neutral line terminal shall be grounded directly or through a small resistance (fig. 15.3 and 15.4).

In three-phase transformers, unless it has been agreed on a particular tapping, impulse test are performed at the two extreme tappings and the principal tapping. Each phase tests are performed at min., max. and principal tapping.

Sometimes in the LV windings of the higher rated transformers, it might not be possible to reach half time-value on tail as it is defined in the standards. In such cases, suitable resistances may be connected between the windings which are not under the test and the ground. The resistance’s must be so selected, according to IEC 60076-3, that the voltage of these terminals of the windings against the ground must not be greater than the 75% of the test voltages of the winding terminals and the value of the resistance must be maximum 500Ω

Figure 15.3 : Connection diagram for the lightning impulse test

Some connection diagrams used for lightning impulse test are given in figure 15-4.
The voltage dividers used for measuring of impulse voltages generally are made of three types.

1. Ohmic voltage divider
2. Capacitive voltage divider
3. Mixed (ohmic capacitive) voltage divider

Although the types are changing according to the aim and place of using the most widely used voltage divider is \( R \) damped capacitive voltage divider.

To measure the impulse currents, non-inductive, ohmic resistances are used. Usually its value varies from \( 0 \to 20 \Omega \).

Coaxial cables are used to transmit the measurement signals to peak-value voltmeter and to the oscilloscope.

If the application of chopped-wave is foreseen; a system which chopped the wave is added to the impulse circuit. In modern impulse voltage circuits, this is usually a "Multiple chopping device".

In beginning impulse voltage test is started with a value of 50 percent of the test voltage which waveform is determined by the oscillogame. After obtaining the form which is acceptable according to the standards, first a "Reference Impulse" which has the magnitude of 50 percent of the test voltage, is applied, then "Full Impulse" which has a value of 100% are applied at certain times which the standards are stated.

The magnitudes of applied voltages are determined numerically on the peak-value voltmeter through a voltage divider. Besides, the time-change of the applied voltage, and the changes of the current leaking from the winding under test to the earth or the capacitive current leaking from the windings which are under test, to the earth; are detected with photographs by means of an oscilloscope.

For the evaluation of the impulse voltage tests, the evaluation of oscillographic records is a most widely and most used method that is stated in the standard. For evaluation purposes, the oscillographic record of the reference waveform which has small magnitude (50% ......75%) should completely coincide with the oscillographic record of the wave form which has full magnitude (100%).

In some cases, there might be inconsistencies in the oscillogrammes due to the effects caused by the arrangement of the test circuit, external disturbances and/or earthing circuit. Such deviation should not be considered as indication of a failure.
Differences in the instant of firing of the stages in the impulse generator may give rise to initial high frequency oscillations in the front part of the voltage waveform.

Small differences in the wave pattern because of the chopping time may cause deviations after chopping. These should not be considered as symptom for any failure.

If the impulse voltage to the neutral points is requested in technical specifications; the method of impulse voltage application on this point are stated by two ways in the standards.

a) The application of a voltage, which will produce a determined impulse voltage magnitude in the neutral point, to the parallel connected line terminals.

b) The direct application of determined impulse voltage to the neutral point.

When an impulse is applied to the neutral terminal “stated in b”, a voltage waveform which has longer front duration (up to 13 $\mu$S) is permissible according to the standards.
16. SWITCHING IMPULSE TEST

The purpose of the switching impulse test is to secure that the insulation between windings, between windings and earth, between line terminals and earth and between different terminals withstand the switching overvoltages which may occur in service.

The switching impulse voltage is simply produced by conventional impulse voltage generator. The polarity of the voltage is negative, and form of the voltage shall be $T_1 / T_d / T_2 \geq 200/200/500 \ \mu S$ according to IEC 60076.3 (fig. 16.2).

Test conditions determine the choice of transformers tapping, see clause 5.

Because of the high saturation of core (increasing of the flux density) during the switching impulse test, after each test impulse, to bring the transformer core to the normal beginning condition (demagnetized), a few impulse tests which have small magnitude and positive polarity, are applied to provide the duration needed for the next impulse voltage.

The switching impulse test is carried out on each line terminal of a three-phase winding in sequence. During the application, neutral terminal is grounded, the windings which are not under test are left open (grounded from one point). This connection type is like the one in the induced overvoltage withstand test. The voltage distribution on the winding is linear like in the induced overvoltage withstand test and the voltage magnitudes of the windings, which are not under test, are induced according to the turn ratio. It must be noticed that at this instance the voltage between the phases will be 1.5 times of the phase-to neutral voltage.

The test connections in three-phase transformers vary with the core design (three of five-legged), the limit of the voltage between the phases, the position of the delta connected windings whether it is open or closed.

Figure 16.1: Test circuit for the switching impulse test
Test is first performed with a decreased voltage which is 50% of the test voltage, then it is carried out with full value impulse voltages the number of which is stated in the standards. The peak value of the voltage is measured by an impulse voltmeter. The change of voltage waveform and winding current are determined by means of an oscilloscope. The faults which may occur during the test are determined by comparison of current and voltage oscillographic records. The sudden collapses (flashover) in the voltage and abnormal sound effects show the damage in the insulation of the transformer. The variation in the voltage waveform and the increase of sound due magnetic saturation of the core must not be considered as reasons for any fault.

\[
\begin{align*}
\text{Front time} & : T_1 \geq 20 \ldots < 250 \mu S = 1,67 T \\
\text{Ninety – percent time} & : T_d \geq 200 \mu S \\
\text{Time to first voltage zero} & : T_2 \geq 500 \mu S
\end{align*}
\]

*Figure 16.2: Waveform of switching impulse voltage*
17. MEASUREMENT OF ACOUSTIC SOUND LEVEL

The purpose of the sound level measurement is to check that the sound level of the transformer meets the specification requirements, or guaranteed values given by the transformer manufacturer.

The principal sound sources in transformers are:

a) core sound: caused by magnetostriction and inter-laminar magnetic forces.
b) load sound: caused by electromagnetic forces in the windings, tank wall, and magnetic shields.
c) cooling equipment sound: caused by fans and pumps.

The predominant source of transformer sound is the core. The core sound depends on the flux density in the laminations and the magnetic properties of the core steel. The low-frequency and tonal nature. It occurs at twice the power frequency. Magnetic forces within the core will create vibration and sound.

Load sound is the sound emitted by a loaded transformer in addition to its no-load sound. It is caused by electromagnetic forces resulting from leakage fields. The load sound is proportional to the fourth power of the current. The sources of this sound are the vibration of the tank walls, magnetic shields, and the windings.

The core and winding sound dominates the intermediate freq. range between 100 and 600 Hz.

Sound produced by the cooling fans (aerodynamic and motor/bearing sound) is usually broadband in nature. Factors that affect the total fan sound output, include type speed, blade design, number of fans, and the arrangement of radiators. Pump sound is normally not significant if the fans are running, although low frequency sound may be present.

The definitions have been given in IEC 60076 – 10.

The transformer must be located at the test site so that the free distance from the transformer to reflecting objects is sufficiently large. It has to stand on a floor directly on its rollers, so that no vibration will occur. All the accessories must be fixed tightly on the transformer.

The feeding of the transformer must be in sinus form at rated voltage and frequency.

When the tank height is less than 2.5 m the microphone is located at half of the tank height. When the height of the tank is greater than 2.5 m the microphone position in the vertical direction shall be at 1/3 and 2/3 of the transformer tank height. The cooling equipments only energized, the microphone shall be on a horizontal plane at half of the height for cooler structures with an overall height of less than 4m and for cooler structures with an overall height of more than 4m the microphone positions shall be used which are horizontal plane at 1/3 and 2/3 of the height. The measurement is carried out alone all the circumference of the transformer. The max. distance between the measuring points will be not more than 1 m.

The distance of the microphone from the principal radiation surface will be selected as follows:

1) If the fans of the cooling unit are switched-off, or they are assemble 3 m away from the transformer, then the microphone must be 0.3 m away from the principal radiation surface.

2) If the cooling unit is switched-on (the pumps and the fans working) the microphone must be 2 m away from the principal radiation surface.

The test object shall be energized as follows:

a) transformer energized, cooling equipment and any oil circulating pumps out of service.
b) transformer energized, cooling equipment and any oil circulating pumps in service.
c) transformer energized, cooling equipment out of service, oil circulating pumps in service.
d) transformer unenergized, cooling equipment and any oil circulating pumps in service.
Before starting the transformer sound level measurement the background noise level is measured. If the difference between background noise level and the noise level of the transformer is more than 8 dB (A), no correction at the noise level of the transformer is needed. If the difference is between 3 dB (A) and 8 dB (A), a correction is needed acc. to the standards. No measurement shall be made, if the difference between background noise level and the transformer noise level is less than 3 dB. The correction factor for the effect of background noise level to the transformer noise level is the in the below table as per IEC 60076-10:

<table>
<thead>
<tr>
<th>The difference between the background and transformer noise level</th>
<th>The difference between the background noise levels before and after the tests</th>
<th>decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{pA0} - I_{bgA}$</td>
<td>$I_{bgA} - I_{bgA}$</td>
<td>$I_{bgA}$</td>
</tr>
<tr>
<td>≥ 8 dB</td>
<td>-</td>
<td>Accept test</td>
</tr>
<tr>
<td>&lt; 8 dB</td>
<td>&lt; 3 dB</td>
<td>Accept test</td>
</tr>
<tr>
<td>&lt; 8 dB</td>
<td>&gt; 3 dB</td>
<td>Repeat test</td>
</tr>
<tr>
<td>&lt; 3 dB</td>
<td>-</td>
<td>Repeat test</td>
</tr>
</tbody>
</table>

The corrected average A-weighted sound pressure level, $\overline{I}_{pA}$, shall be calculated by using equation as follows:

$$\overline{I}_{pA} = 10 \log \left[ 10^{0.1I_{pA0}} - 10^{0.1I_{bgA}} \right] - K$$

$\overline{I}_{bgA}$: The lower of calculated average background noise

$\overline{I}_{pA0}$: Measured average sound level

K: Environmental correction factor

The characteristics of the measuring equipment are described at the international standards. The noise level of the transformer is measured acc. to IEC 60076-10, NEMA standards using the evaluation of the weighting curve A.

The principle of parameters influencing noise are either internal (frequency, flux, mass, quality of magnetic material and operation) or external (distance). According to the laws of acoustics, the volume of sound decreases with the square of the distance "d" from the assumed point source, ie the centre of the equivalent hemisphere;

$$L_{p(d)} = L_{p(2m)} - 20. \log(\frac{d}{2})$$

where; $d$ is in metres.

Other things the sound volume varies with the square of the frequency;

$$L_{p(f)} = L_{p(50\,\text{Hz})} + 20. \log(\frac{f}{50\,\text{Hz}})$$

where; $f$ is test frequency.
Figure 17.1: The position of the location of microphones at noise level test
Testing Laboratory : 1

Rotating Machines

Machinery 1
Generator : S = 5000 kVA synchronous
           U = 6000 V
           I = 833 A
           f = 16 2/3 ÷ 50 Hz

Motor : P = 800 kW direct current

Generator : S = 2000 kVA synchronous
            U = 6000 V
            I = 192 A
            f = 100 ÷ 200 Hz

Machinery 2
Generator : S = 3000 kVA
            U = 6300 V
            I = 275 A
            f = 16 2/3 ÷ 50-60 Hz

Motor : P = 1250 kW Asynchronous

Test Transformers

Transformer 1 S = 6000 / 6000 / 1500 kVA
                U = 6300 V / 700..40000 V / 1000 V
                I = 550 A / 660......87 A / 866 A

Transformer 2 S = 4000 kVA
                U = 6300 V / 700..40000 V
                I = 367 A / 660......58 A

Transformer 3 S = 20000 kVA
                U = 34500 (40000) V / 77000 (88000) V
                I = 335 A / 150 A

Transformer 4 S = 16000 kVA
                U = 700 ..... 38000 / 6300 V

Transformer 5 S = 5000 kVA Booster transformer
                U = 6000 ± 10 % V
COMPENSATION CAPACITOR BANKS

BANK 1: Group of capacitors with the following values.
- 13 groups, each of them with the rated voltage of 6.3 kV, totally 15.6 MVAr
- 2 groups, each of them with the rated power 6x100= 600 kVAr and the rated voltage of 6.3 kV, totally 1.2 MVAr.

Bank 1 Rated power: 16.800 kVAr
Continuous operation: 20.300 kVAr
Power of 10 hours: 23.800 kVAr

BANK 2: 216 pc. capacitors, each of them with the rated power of 200 kVAr, and the rated voltage of 7.32 kV they can be connected to the system either with one phase or three phases (Δ or Y)

Bank 2 Rated power: 43.200 kVAr
Continuous operation: 52.270 kVAr
Power of 10 hours: 61.340 kVAr

BANK 3: 180 pc. capacitors, each of them with the rated power of 300 kVAr, and the rated voltage of 7.32 kV they can be connected to the system like Bank 2, either with one phase or three phases (Δ or Y).

Bank 3 Rated power: 54.000 kVAr
Continuous operation: 65.300 kVAr
Power of 10 hours: 76.600 kVAr

MEASUREMENT TRANSFORMERS

Precision current transformers

3 pcs current transformers: 5-10-25-50-100-250-500-1000-1500 A/5A
30 VA, Class 0,1, 30 kV, 50/60 Hz
Manufacturer: Messwandlerbau, Bamberg

3 pcs current transformers: 25-50-75-100-250-500-750-1000-1250-1500 A/ 5A
15 VA Class 0,05, 30 kV, 50/60 Hz
Manufacturer: Messwandlerbau, Bamberg

3 pcs current transformers: 5-10-20 A/5 A
30 VA Class 0,2, 73 kV, 50/60/200 Hz
Manufacturer: Messwandlerbau, Bamberg

3 pcs current transformers: 100-250-500-800-1000 A/5 A
30 VA, Class 0,1, 73 kV, 50/60/200 Hz
Manufacturer: Ritz

3 pcs current transformers: 5 A/5 A
15 VA, Class 0,2, 45 kV, 200 Hz
Manufacturer: Ritz
### Precision voltage transformers

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 pcs voltage transformers</td>
<td>3000 V/100 V, 30 VA, Class 0.1, 50/60 Hz</td>
<td>AEG</td>
</tr>
<tr>
<td>3 pcs voltage transformers</td>
<td>10000 V/100 V, 30 VA, Class 0.1, 50/60 Hz</td>
<td>AEG</td>
</tr>
<tr>
<td>3 pcs voltage transformers</td>
<td>30000 V/100 V, 30 VA, Class 0.1, 50/60 Hz</td>
<td>AEG</td>
</tr>
<tr>
<td>3 pcs voltage transformers</td>
<td>3000 V/100 V, 15 VA, Class 0.05, 50/60 Hz</td>
<td>Messwandlerbau</td>
</tr>
<tr>
<td>3 pcs voltage transformers</td>
<td>10000 V/100 V, 15 VA, Class 0.05, 50/60 Hz</td>
<td>Messwandlerbau</td>
</tr>
<tr>
<td>3 pcs voltage transformers</td>
<td>30000 V/100 V, 15 VA, Class 0.05, 50/60 Hz</td>
<td>Messwandlerbau</td>
</tr>
<tr>
<td>3 pcs voltage transformers</td>
<td>60000/√3 V/100/√3 V, 30 VA, Class 0.2, 50/60/200 Hz</td>
<td>Ritz</td>
</tr>
<tr>
<td>3 pcs voltage transformers</td>
<td>66000/√3 V/100/√3 V, Isolation Cl. 73 kV, 30 VA, Class 0.1, 50/60/200 Hz</td>
<td>Ritz</td>
</tr>
</tbody>
</table>

### ALTERNATING VOLTAGE TESTING EQUIPMENT'S

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-voltage test transformer</td>
<td>U= 350 kV/0.4 kV, 1-phase S= 100 kVA I = 0.3 A/250 A f = 50 Hz</td>
<td>AEG</td>
</tr>
<tr>
<td>High-voltage test transformer</td>
<td>U= 600 kV/3 kV 1-phase S= 600 kVA I = 1 A/200 A f = 50 Hz</td>
<td>AEG</td>
</tr>
<tr>
<td>Capacitive voltage divider</td>
<td>350 kV/0.1 kV, 50-200 Hz</td>
<td>AEG</td>
</tr>
<tr>
<td>Capacitive voltage divider</td>
<td>800 kV/0.1 kV, 50-200 Hz Capacitance: 100 pF</td>
<td>Haefely</td>
</tr>
<tr>
<td>Voltmeter 2 pcs</td>
<td>$U / \sqrt{2} - U_{\text{eff}}$ Voltmeter Digital</td>
<td>Haefely</td>
</tr>
<tr>
<td></td>
<td>Class 0.5, 50-200 Hz</td>
<td>Haefely</td>
</tr>
</tbody>
</table>
### IMPULSE VOLTAGE TESTING EQUIPMENT'S

**Impulse voltage generator**
- No of stage: $n = 10$
- Max. stage voltage: $U_L = 200 \text{ kV}$
- Max. total voltage: $U = 2000 \text{ kV}$
- Max. total power: $W = 200 \text{ kJ}$
- Capacitance per stage: $C = 1 \mu\text{F}$
- Manufacturer: Passoni+Villa

**Multiple chopping device**
- 8- stage
- Capacitance: 6000 pF/ stage
- Lightning impulse voltage: ±1800 kV
- Manufacturer: Passoni+Villa

**Voltage divider**
- $R$-damped capacitive voltage divider
- Lightning impulse voltage: ±2000 kV
- Switching impulse voltage: ±1450 kV
- Capacitance: 400-1600 pF
- Manufacturer: Passoni+Villa

**Ohmic voltage divider**
- Lightning impulse voltage: ±300 kV
- Manufacturer: Passoni+Villa

**Loading capacitor**
- Capacitance: 5 nF
- Lightning impulse voltage: ±500 kV
- Manufacturer: Passoni+Villa

**Oscilloscope**
- Two channel
- Type: 721
- Accuracy: ±1%
- Manufacturer: Haefely

**Impulse voltage voltmeter**
- Accuracy: ±1%
- Voltage: ±1600 V peak
- Manufacturer: Passoni+Villa

**Digital Imp. Meas.System**
- Type: TR-AS 200-12
- Manufacturer: Dr. Strauss

**Impulse Calib. System**
- KAL 1000 + Software IEC 1083-1 and IEC 60060-2
- KAL 1000- RIG (Unit step vol. Gen.) IEC 60060-2
- Manufacturer: Dr. Strauss

### MEASURING BRIDGES

**Schering measuring bridge**
- Type: 2801
- Accuracy: 0.5%
- Capacitance: $0......10^5 \mu\text{F}$, tan $\delta : 0......350\%$
- Manufacturer: TETTEX

**Press gas condensator**
- Capacitance: 50 pF
- Voltage: 400 kV a.c.
- Manufacturer: TETTEX

**Ratio measuring bridge**
- Accuracy: ±0.1%
- Voltage: 220 V a.c.
- Measuring range: 1........1000
- Manufacturer: Hartmann+Braun
## MEASURING INSTRUMENTS

### Resistance measuring equip.
- **Transformer test system**
  - **Type**: 2281
  - **Accuracy**: 0,1%
  - **Measuring range**: $10^{-6}$......$10^2$ Ω
  - **Manufacturer**: TETTEX

- **Transformer test system**
  - **Type**: 2285 c
  - **Accuracy**: 0,06 %
  - **Measuring range**: $10^{-6}$......$5 \times 10^2$ Ω
  - **Manufacturer**: TETTEX

### Ratio measuring instrument
- **Transformer test system**
  - **Type**: 2791 and 2 pcs 2793 + 2794
  - **Accuracy**: 0,1%
  - **Measuring range**: 0,18.........2000
  - **Manufacturer**: TETTEX

### Resistance measuring instrument
- **Digital Low resistance ohmmeters**
  - **Type**: DLRO
  - **Accuracy**: 0,25%
  - **Measuring range**: 0,2 mΩ......20Ω
  - **Manufacturer**: BIDDLE INSTRUMENTS

### Digital Thermometer
- **20 Channels, programmable**
  - **Type**: DR 130
  - **Manufacturer**: YOKOGAWA

### Power measuring unit (Wattmeter-Voltmeter-Ampermeter) 2 pcs
- **Wide Band Power Analyzer**
  - **Type**: D 6133 T
  - **Accuracy**: 0,1%
  - **Manufacturer**: NORMA

### Voltmeter-mean value
- **Digital, Interface**
  - **Accuracy**: 0,1%
  - **Manufacturer**: NORMA

### Voltmeter
- **Type**: 3478 A **Digital, Interface**
  - **Accuracy**: 0,1%
  - **Manufacturer**: Hewlett Packard

### Partial discharge measuring equipment
- **Type**: 9120
  - **Manufacturer**: TETTEX

### Radio Noise Meter
- **Measuring range**: 0,1 µV - 0,1 V
- **Type**: EM- 7535
  - **Manufacturer**: Electro - Metrics
### Insulation resistance meas. instruments
- **Voltage**: 5000 V. d.c.
- **Measuring range**: 500.000 MΩ
- **Type**: SH2
- **Manufacturer**: MEGGER

### Wave analyzer
- **Measuring range**: Wave Analyzer 15 Hz......50 kHz
- **Type**: 3581 A
- **Manufacturer**: HEWLETT PACKARD

### Noise measuring equipment
- **Meas. instrument**: type 2033
- **1/3-1/3 octave filter**: type 1625
- **Microphone**: type 4145
- **Recorder**: type 2317
- **Calibrator**: type 4230
- **Manufacturer**: Brüel & Kjaer

### Vibration meas. equipment
- **Meas. range**: 1.....1000ms⁻² ,100 Hz.......10 kHz
- **Type**: 2513
- **Calibrator**: 4294
- **Manufacturer**: BRÜEL & KJAER

### Loss-factor meas. equipment
- **Meas. range**: 0 ÷ 12 kV
- **Type**: M2H
- **Manufacturer**: DOBLE Engineering Company

### Oscilloscope
- **6- Channel**: Type 11401
- **Manufacturer**: TEKTRONIX
- **2- Channel**: Type TDS 340
TESTING LABORATORY : 2

ROTATING MACHINES

Machinery 1

Generator : S = 500 kVA synchronous
U = 1000 V
I = 288 A
f = 100 ÷ 200 Hz

Motor : P = 500 kW direct current

TEST TRANSFORMERS

Transformer 1 : S = 1500 kVA
U = 1500........ 40500 V / 1000 V
I = 308........21,4 A / 866 A
Manufacturer : AREVA

Transformer 2 : S = 1600 kVA Variable transformer
U = 6000 / 1070...15 V
I = 154 A / 866 A
Manufacturer : Bernard+Bonnefond

Transformer 3 : S = 500 kVA
U = 72500 / 29000 V
I = 3,98 A / 9,95 A
Manufacturer : AREVA

COMPENSATION CAPACITOR BANKS

108 pc. capacitors, each of them with the rated power of 200 kVAr, and the rated voltage of 2,6 kV they can be connected to the system either with one phase or three phases (Δ or Y) totally 21,6 MVAr

Rated power : 21.600 kVAr
Continuos operation : 26.200 kVAr
Power of 10 hours : 30.500 kVAr

MEASUREMENT TRANSFORMERS

Precision current transformers

3 pcs current transformers : 5-10-25-50-75-100-250-500-1000-1250 A / 5A
15 VA, Class 0,05, 45kV, 50/60 Hz
Manufacturer : EPRO Gallspach
Precision voltage transformers

3 pcs voltage transformers
- 3300 – 12000 – 24000 - 36000 V/100 V
- 15VA, Class 0,05, 50/60 Hz
  Manufacturer: EPRO Gallspach

ALTERNATING VOLTAGE TESTING EQUIPMENT'S

Series Resonant
- U= 400 kV, 1-phase
- S= 1600 kVA, I = 4 A, f = 50 Hz
  Manufacturer: HIGH VOLT

Capacitive voltage divider
- 400 kV, 50-200 Hz
  Manufacturer: HIGH VOLT

Voltmeter 1 pcs
- \[ U / \sqrt{2} - U_{\text{eff}} \] Volimeter Digital
  Class 0,5
  Manufacturer: HIGH VOLT

IMPULSE VOLTAGE TESTING EQUIPMENT'S

Impulse voltage generator
- No of stage: n = 10
- Max. stage voltage: \[ U_i = 100 \text{ kV} \]
- Max. total voltage: \[ U = 1000 \text{ kV} \]
- Max. total power: \[ W = 100 \text{ kJ} \]
  Manufacturer: HIGH VOLT

Multiple chopping device
- 4- stage
- Capacitance: 4000 pF/ stage
- Lightning impulse voltage: \(-1000 \text{ kV} \) / \(+800 \text{ kV} \)
  Manufacturer: HIGH VOLT

Voltage divider
- R-damped capacitive voltage divider
- Lightning impulse voltage: \(\pm 1000 \text{ kV} \)
- Switching impulse voltage: \(\pm 800 \text{ kV} \)
- Capacitance: 800 pF
  Manufacturer: HIGH VOLT

Digital Imp. Meas.System
- Type: TR-AS 200-12
  Manufacturer: Dr. Strauss

MEASURING BRIDGES

Resistance measuring equip.
- Transformer test system
  Type: 2292
  Accuracy: 0,05%
  Measuring range: 0,002…20000 Ω
  Manufacturer: TETTEX

Ratio measuring instrument
- Transformer test system
  Type: 2793
  Accuracy: 0,1%
  Measuring range: 0,8........9999
  Manufacturer: TETTEX
<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power measuring unit</td>
<td><strong>Wide Band Power Analyzer</strong></td>
</tr>
<tr>
<td></td>
<td>Type: D 6000</td>
</tr>
<tr>
<td></td>
<td>Accuracy: 0.1%</td>
</tr>
<tr>
<td></td>
<td>Manufacturer: NORMA</td>
</tr>
<tr>
<td>Partial discharge measuring equipment</td>
<td>Frequency: 100 kHz ÷ 400 kHz</td>
</tr>
<tr>
<td></td>
<td>Measuring range: 1 pC...100,000 pC</td>
</tr>
<tr>
<td></td>
<td>Type: LDIC 6</td>
</tr>
<tr>
<td></td>
<td>Manufacturer: LEMKE</td>
</tr>
<tr>
<td>Noise measuring equipment</td>
<td>Type: 2260</td>
</tr>
<tr>
<td></td>
<td>Manufacturer: Brüel &amp; Kjaer</td>
</tr>
<tr>
<td>Frequency Response Analyzer (FRA)</td>
<td>Type: M1100 B</td>
</tr>
<tr>
<td></td>
<td>Manufacturer: DOBLE Engineering Comp.</td>
</tr>
</tbody>
</table>