Condition-based maintenance of power transformers

The predictive and condition-based maintenance is nowadays accepted as the most efficient solution to guarantee the proper operation of critical assets. In both electrical power generation, T & D and industry applications, power transformers are essential and require the right maintenance policy.

Due to the high cost of the on-line monitoring systems and the need of performing scheduled shutdowns for other different reasons as mechanical revisions, the off-line tests provide a cost-efficient, safe way to proper transformer maintenance.

The ETP system will guide the operator with messages on the computer’s screen, while an exhaustive set of measurements is performed on the analyzed transformer. Three-phase connection instructions are displayed, as well as wait messages while the secondary windings are discharged automatically.

Each transformer's technical parameters are saved into a database along with the results obtained during successive tests, in order to recall them in the future and to perform their evolution in the time.

Complete three-phase system

The ETP System is composed by four independent measurement modules controlled from a common measurement & analysis software in a PC. Diagnostics are performed by co-relating the measurements done by each module:

- **Turns Ratio**: three-phase measurement of the turns ratio and the excitation current in every position of the tap changer. Results are compared with the theoretical values and the error is shown graphically.
- **Recovery Voltage**: evaluation of the solid and liquid insulation condition through electrical measurements.
- **Winding Resistance**: three-phase measurement of the resistance values in every winding and for every position of the tap changer.
- **Short-circuit Impedance**: evaluation at low voltage of the short-circuit impedance and voltage.

The above measurements are used to evaluate the condition and then predict possible failures at the four main circuits in a transformer:

- **Electrical Circuit**: checking the continuity of the windings, the connections and the tap changer.
- **Geometrical Circuit**: checking the symmetry between the columns of the core, between the windings and the core and between these and the transformer’s enclosure.
- **Magnetic Circuit**: checking the condition of the magnetic core (loose plates, short-circuits, detachment of the magnetic shunt, etc.).
- **Dielectric Circuit**: checking the degradation and the ageing of the solid and liquid insulation.

Testing is a simple, automatic and fully software-guided task. The operation is divided into two main steps: 1) Measurement, which guides the operator to the connections and wait operations, eliminating human errors and ensuring repeatability, and 2) Analysis, by immediately displaying the measured values on the screen as they are acquired by the software. The information can be immediately converted into a complete report and interpreted by an expert to determine whether maintenance operations should be planned or not.

**ETP Trends** software will produce an evolutive view of the transformer’s condition by collecting results from successive tests within any two dates.

**ETP Diaghelp** will apply an expert algorithm to the test results to provide a direct, concise diagnostic of the transformer including alerts, warnings and service recommendations.
**Independent modules**

The four modules that compose the ETP System can also be used separately. For example, you can use the ETP-2 if you only need to evaluate the condition of the liquid isolation (paper & oil). The software will automatically detect the connected module and will enable the corresponding measurement functions only.

The more different modules you connect, the more complete and accurate analysis you will get, naturally. This is particularly important if you also want to use the DiagHelp software for expert diagnostics.

Please note that measurement results determined as 'suspicious' by one of the modules can, in most cases, be confirmed by using other –complementing- module.

Every ETP combination (one or more modules) is delivered with the necessary test leads, calibration certificates and a transport bags, as well as the ETP software and the communications cables.

The characteristics of the individual modules are described along the following pages in this brochure.

The following table provides a brief listing of the failures typically detected by each module:

<table>
<thead>
<tr>
<th>Failure</th>
<th>Detected Damage</th>
<th>ETP-1</th>
<th>ETP-2</th>
<th>ETP-3</th>
<th>ETP-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>General status</td>
<td>● ●</td>
<td></td>
<td></td>
<td>● ●</td>
</tr>
<tr>
<td>Connection</td>
<td>Tap changer breakdown</td>
<td>● ●</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Connection slackening</td>
<td>●</td>
<td></td>
<td>● ●</td>
<td></td>
</tr>
<tr>
<td>Windings displacement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>● ●</td>
</tr>
<tr>
<td>Windings displacement</td>
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<td>Windings displacement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid and Solid Insulation</td>
<td>Degradation of solid dielectric</td>
<td></td>
<td>● ●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid and Solid Insulation</td>
<td>Degradation of liquid dielectric</td>
<td></td>
<td>● ●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid and Solid Insulation</td>
<td>Contamination of the insulation</td>
<td></td>
<td>● ●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid and Solid Insulation</td>
<td>Anomalous aging</td>
<td></td>
<td>● ●</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Understanding the results**

All the measured and calculated parameters are defined, contrasted and delimited by the main international standards (IEEE, IEC). The experience in the diagnostics and the help brought by our diagnostics software ETP DiagHelp allow relating all these parameters quickly, and then determining the issues in the transformer’s condition. However, the basis of the condition based maintenance is the trend analysis. The ETP Trends software provides a quick, graphical view of all the results: every results from successive tests performed in the same transformer is shown in a table and a graph. Thanks to this feature, we can optimize the scheduling of the shutdowns and revisions to be performed on the machine, so reducing intervention cost and downtime.

**Surge Protection Multi-socket**

This optional accessory provides additional protection to your ETP equipment and to the user. It features an interference filter, an overvoltage protection, supply voltage display, thermal-magnetic breaker and an indicator of defective or non-existent ground connection.
Three-phase Turn Ratio and Excitation Current Meter

The ETP-1 module determines the turn ratio on the three phases of power and distribution transformers and autotransformers of any type by applying a test voltage on the high-voltage winding and measuring the resulting voltage on the low-voltage winding. This method also provides the evaluation of other parameters:

- Excitation current I₁
- Phase angle between the test voltage V₁ and the excitation current I₁
- Phase angle between the test voltage V₁ and the measured V₂

The test is performed at low voltage and at the supply’s frequency, which makes the ETP-1 adequate for field testing and for quality assessment in production lines.

The following problems can be detected with the ETP-1:

- Shorted turns
- Interrupted windings
- Magnetic core problems
- Dirty or damaged tap changer

Database storage of results enables individual tracking of each transformer.

### SPECIFICATIONS

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply</td>
<td>230V ac ± 10%, 50Hz ± 5% or 60Hz ± 5%</td>
</tr>
<tr>
<td></td>
<td>115V ac ± 10%, 50Hz ± 5% or 60Hz ± 5%</td>
</tr>
<tr>
<td></td>
<td>350 VA max</td>
</tr>
<tr>
<td>Test signal</td>
<td>Voltage: 115V rms</td>
</tr>
<tr>
<td></td>
<td>Current: &lt; 2A rms</td>
</tr>
<tr>
<td>Measurement ranges</td>
<td>Turn ratio: 0.9:3000, 7 scales</td>
</tr>
<tr>
<td></td>
<td>Resolution: 4 ½ digits</td>
</tr>
<tr>
<td></td>
<td>Accuracy: ± 0.3% reading ± 2 digits</td>
</tr>
<tr>
<td></td>
<td>Current: 3.1:2000 mA rms, 6 scales</td>
</tr>
<tr>
<td></td>
<td>Resolution: 3 digits</td>
</tr>
<tr>
<td></td>
<td>Accuracy: ± 1% reading ± 2 digits</td>
</tr>
<tr>
<td></td>
<td>Phase angle: -180° +180°</td>
</tr>
<tr>
<td></td>
<td>Resolution: 3 digits</td>
</tr>
<tr>
<td></td>
<td>Accuracy: ± 0.15°</td>
</tr>
<tr>
<td>Measurement time</td>
<td>Single-phase: 20 to 35° depending on mode</td>
</tr>
<tr>
<td></td>
<td>Three-phase: 60 to 90° depending on mode</td>
</tr>
<tr>
<td>Measurement modes</td>
<td>High to Low ratio</td>
</tr>
<tr>
<td></td>
<td>High to Tertiary ratio</td>
</tr>
<tr>
<td>Environmental conditions</td>
<td>Temperature: 5° - 35° C / 40° - 95° F</td>
</tr>
<tr>
<td></td>
<td>Humidity: 10 - 80% non-condensating</td>
</tr>
<tr>
<td>Storage</td>
<td>Temperature: 5° - 75° C / 40° - 165° F</td>
</tr>
<tr>
<td></td>
<td>Humidity: 10 - 80% non-condensating</td>
</tr>
<tr>
<td>Physical dimensions</td>
<td>Depth: 40 cm / 16&quot; - Width: 45 cm / 18&quot; - Height: 13.5 cm / 5&quot;</td>
</tr>
<tr>
<td>Test leads</td>
<td>Length: 2 x 8 m / 2 x 26 ft.</td>
</tr>
<tr>
<td></td>
<td>Weight: 13 Kg. / 28 lb.</td>
</tr>
<tr>
<td></td>
<td>Weight: 2 x 6 Kg. / 2 x 13 lb.</td>
</tr>
</tbody>
</table>
Recovery Voltage, Time Constant, and Insulation Resistance Meter

The ETP-2 module measures the recovery voltage (polarisation spectrum) on power and distribution transformers and autotransformers of any type with oil-paper dielectric, calculating the degree of humidity contained in the paper and evaluating the overall condition of the oil-paper system.

These calculations are performed by applying various DC voltage levels through a programmable output during specific time intervals. Calculated parameters are:

- Recovery voltage and Time Constant
- Insulation Resistance
- Polarisation index

The following problems can be detected with the ETP-2:

- Solid dielectric degradation
- Liquid dielectric degradation
- Contaminated insulation

**SPECIFICATIONS**

| Power supply | 230V ac ± 10%, 50Hz ± 5% ÷ 60Hz ± 5%  
| Test signal | 115V ac ± 10%, 50Hz ± 5% ÷ 60Hz ± 5%  
| Test signal | 60 VA max  
| Test signal | Range: 500V / 1000V / 1500V / 2000V  
| Test signal | Current: maximum 5 mA.  
| Test signal | Resolution: 1 V  
| Test signal | Accuracy: ± 1% ± 1 digit  
| Measurement ranges | Recovery Voltage: 0 – 1000V  
| Measurement ranges | Test Voltage: 0 – 2000V  
| Measurement ranges | Insulation:  
| Measurement ranges | Scale 1 @2000V  
| Measurement ranges | Ω  
| Measurement ranges | ± 3% ± 3 digits  
| Measurement ranges | Scale 2 @2000V  
| Measurement ranges | 100 GΩ - 200 GΩ  
| Measurement ranges | ± 5% ± 3 digits  
| Measurement ranges | Scale 3 @2000V  
| Measurement ranges | 200 GΩ - 2TΩ  
| Measurement ranges | ± 20% ± 3 digits  
| Accuracy | Recovery Voltage: ± 3% ± 3 digits  
| Accuracy | Test Voltage: ± 1% ± 3 digits  
| Accuracy | Insulation:  
| Accuracy | Scale 1  
| Accuracy | Ω  
| Accuracy | ± 3% ± 3 digits  
| Accuracy | Scale 2  
| Accuracy | 100 GΩ - 200 GΩ  
| Accuracy | ± 5% ± 3 digits  
| Accuracy | Scale 3  
| Accuracy | 200 GΩ - 2TΩ  
| Accuracy | ± 20% ± 3 digits  
| Used parameters | Recovery Voltage  
| Used parameters | Insulation Resistance  
| Used parameters | Polarisation Index  
| Used parameters | Time Constant  
| Environmental conditions | Temperature: 5º - 35º C / 40º - 95º F  
| Environmental conditions | Humidity: 10 - 80% non-condensating  
| Storage | Temperature: 5º - 75ºC / 40º - 165º F  
| Storage | Humidity: 5 - 80% non-condensating  
| Physical dimensions | Depth: 40 cm / 16" - Width: 45 cm / 18" - Height: 13.5 cm / 5"  
| Physical dimensions | Weight: 10 Kg. / 22 lb.  
| Test leads | Length: 2 x 8 m / 2 x 26 ft  
| Test leads | Weight: 2 x 4 Kg. / 2 x 9 lb.  

**ETP-2**

Recovery Voltage Analysis

Insulation Resistance Analysis
Three-phase Winding Resistance Meter

The ETP-3 is designed to measure very low resistance values on transformer windings or on any load with a strong inductive component. The unit applies the necessary DC current to magnetize the winding and stabilize the current, in order to provide an accurate, repeatable measurement. The software takes into account the connection group and the temperature to calculate simple \((u, v, w)\) and compound \((uv, uw, vw)\) ohmic resistance values referenced to a normalized temperature (temperature-corrected). The ohmic values obtained allow verifying the correct insulation between turns, and to assess the transformer’s specified electrical and mechanical characteristics.

The following problems can be detected with the ETP-3:

- Loose connections
- Tap changer malfunction
- Shorted turns
- Hot spots on the windings

### SPECIFICATIONS

**Power supply**

| 230V ac ± 10%, 50Hz ± 5% Ø 60Hz ± 5% |
| 115V ac ± 10%, 50Hz ± 5% Ø 60Hz ± 5% |
| 450 VA max |

**Test signal**

- Voltage: 24 Vdc max
- Current: 0 - 20A ± 5%

**Used parameters**

**Measurement ranges**

<table>
<thead>
<tr>
<th>Current</th>
<th>Range</th>
<th>Accuracy</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>20A</td>
<td>10mΩ</td>
<td>±0.5% ±2 digits</td>
<td>1μΩ 4 digits</td>
</tr>
<tr>
<td>20A</td>
<td>100mΩ</td>
<td>±0.5% ±2 digits</td>
<td>10μΩ 4 digits</td>
</tr>
<tr>
<td>5A</td>
<td>1Ω</td>
<td>±0.5% ±2 digits</td>
<td>100μΩ 4 digits</td>
</tr>
<tr>
<td>500mA</td>
<td>10Ω</td>
<td>±0.5% ±2 digits</td>
<td>1mΩ 4 digits</td>
</tr>
<tr>
<td>50mA</td>
<td>100Ω</td>
<td>±0.5% ±2 digits</td>
<td>10mΩ 4 digits</td>
</tr>
<tr>
<td>5mA</td>
<td>1000Ω</td>
<td>±0.5% ±2 digits</td>
<td>100mΩ 4 digits</td>
</tr>
</tbody>
</table>

**Measurement modes**

- **Manual**: The user stops the test when the Reading is accepted as reliable.
- **Automatic**: The software determines when to finalise the measurement.
- **By phase**: Allows accelerating the measurement on transformers greater than 100 MVA

**Environmental conditions**

Temperature: 5º - 35º C / 40º - 95º F
Humidity: 10 - 80% non-condensing

**Storage**

Temperature: 5º - 75ºC / 40º - 165º F
Humidity: 5 - 80% non-condensing

**Physical dimensions**

- Depth: 40 cm / 16” - Width: 45 cm / 18” - Height: 13.5 cm / 5”
- Weight: 11.7 Kg. / 26 lb.

**Test leads**

- Length: 8 m / 26 ft
- Weight: 14.15 Kg. / 32 lb.
Three-phase Short Circuit Impedance and Short Circuit Voltage Meter

The ETP-4 module measures the short-circuit impedance in distribution and power transformers by applying a test voltage on the high voltage winding and measuring the resulting current and phase angle. The reading is automatically compensated by the transformer’s temperature value and normalized to 75º C / 165º F.

The following problems can be detected with the ETP-4 module:

- Shorted turns
- Interrupted winding
- Tap changer dirt or damages
- Magnetic core problems

### SPECIFICATIONS

| Power supply | 230V ac ± 10%, 50Hz ± 5% or 60Hz ± 5%  
| Test signals | 115V ac ± 10%, 50Hz ± 5% or 60Hz ± 5%  
|              | 880 VA max |
| Test signals | Voltage: 12, 24, 48, 108 or 216 Vrms  
|              | Current: 4 Arms max.  
|              | Frequency: supply |
| Measurement modes | Impedance in primary with short-circuited secondary  
| Measurement ranges | Impedance in primary with short-circuited tertiary  
| Measurement ranges | Short-circuit impedance: 2.5 Ω - 4000 Ω in 8 Scales  
| Measurement times | Single-phase: 28 seconds  
| Measurement times | Three-phase: 1 min. 28 seconds  
| Accuracy | Short-circuit impedance: ± 1% ± 2 digits  
|           | Phase angle: ± 25% between 0 and 10º  
|           | ± 2% between 10 and 360º |
| Used parameters | Primary current on each phase  
| Used parameters | Primary & secondary voltage on each phase  
| Used parameters | Phase angle between voltage and current on primary and secondary windings  
| Used parameters | Phase angle between primary and secondary voltages  
| Used parameters | Short-circuit impedance and voltage |
| Environmental conditions | Temperature: 5º - 35º C / 40º - 95º F  
| Environmental conditions | Humidity: 10 - 80% non-condensing  
| Storage | Temperature: 5º - 75ºC / 40º - 165º F  
| Storage | Humidity: 5 - 80% non-condensing |
| Physical dimensions | Depth: 40 cm / 16" - Width: 45 cm / 18" - Height: 13.5 cm / 5"  
| Physical dimensions | Weight: 16 Kg. / 35 lb.  
| Test leads | Length: 8 m / 26 ft  
| Test leads | Weight: 14.15 Kg. / 32 lb. |
Expert analysis software

The DiagHelp and Trends software packages complete the EDA III and ETP systems, facilitating results analysis and subsequent decision-making.

The ETP DiagHelp program makes it possible to perform an initial estimate of the status of the transformer, applying diagnosis criteria to the calculations and measurements carried out by the ETP system. These criteria are based on various standards, theoretical principles and more than 10 years of experience of numerous experts. After entering the transformer’s serial number, DiagHelp will analyze the results from any of the saved tests and will display the transformer’s critical elements on a chart with green, yellow and red indicators, alerts and recommendations as appropriate.

The efficiency and accuracy of DiagHelp diagnostics will be optimum when the four ETP modules are used for testing.

ETP Trends is designed to collect the results from a series of consecutive tests performed on a specific transformer between any two given dates, in order to track the evolution of the machine with time, establishing trends for each of the parameters considered. In this way, it is possible to detect when a transformer enters a risk zone and to schedule the most appropriate maintenance actions. A report including tracking graphics can be generated instantaneously.