Diagnostic testing and monitoring of rotating machines
Reducing the risk of failure in rotating machines

Rotating machines, such as motors and generators, are highly important components in power generation and industrial applications. Machine reliability and availability are therefore in high demand. Premature failure may lead to significant economical losses, due to unexpected outages and possible damage to the asset itself. To plan maintenance effectively, it is essential to have accurate condition information about when components need repairing or replacing.

Negative influences on machine reliability and life expectancy

- **Thermal stress**
  Highest and lowest temperature, overload, hot spots
- **Electrical stress**
  Surges, over voltages, rated voltage, partial discharge (PD)
- **Ambient stress**
  Agressive and reactive chemicals, abrasive particles, contamination
- **Mechanical stress**
  Vibration, oscillation in slot sections and in end winding
A variety of electrical tests can be performed over the complete life cycle of your machines to increase their reliability, prevent premature failures and to extend reliable service life. Off-line diagnostic tests provide you with a snapshot of current condition and detect possible defects. Temporary and permanent on-line monitoring enable continuous condition assessment under normal operating conditions.

Testing and corrective measures to ensure machine reliability and extend life expectancy

- Regular or continuous condition assessments using various electrical diagnostic methods
- Reverse the position of the starpoint
- Partial rewinding of worn parts
- Replace damaged components
### Rotating machine parts and recommended electrical tests

**Detecting faults to prevent failure**

Electrical diagnosis testing can tell you a lot about the condition of a motor or generator. Electrical tests are commonly done after the machine has been manufactured, installed on-site or during periodic maintenance checks.

The electrical tests listed here are diagnostic methods that allow the reliable condition assessment of insulation and other components in rotating machines.

The results of these measurements give you an indication about when you should perform maintenance on affected parts.

<table>
<thead>
<tr>
<th>Machine part tested</th>
<th>What should be checked</th>
<th>Recommended electrical tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stator winding</td>
<td></td>
<td>Partial discharges (PD)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contamination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insulation degradation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Voltage withstand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insulation integrity</td>
</tr>
<tr>
<td>Rotor winding</td>
<td></td>
<td>Inter turn faults</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High contact resistance</td>
</tr>
</tbody>
</table>

![Image of a rotating machine](image-url)
### What should be checked

<table>
<thead>
<tr>
<th>Partial discharges (PD)</th>
<th>Contamination</th>
<th>Insulation degradation</th>
<th>Voltage withstand</th>
<th>Insulation integrity</th>
<th>Connection problems</th>
<th>Inter turn faults</th>
<th>Inter turn faults</th>
<th>High contact resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>■</td>
<td>■</td>
<td>■</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Recommended electrical tests

- Capacitance<br>- Dissipation factor (tan δ)<br>- Power factor measurements<br>- Partial discharge (PD) measurement<br>- On-line PD monitoring<br>- Voltage withstand testing<br>- Partial discharge capacitance and dissipation factor measurements<br>- DC resistance measurement<br>- Insulation resistance measurement<br>- Dielectric absorption ratio measurement<br>- Contact resistance measurement<br>- Pole drop testing<br>- Sweep frequency response analysis<br>- Dielectric response analysis
The ideal solution for your individual machine testing needs

**Recommended diagnostic tools**

For common diagnostic methods on rotating machines, we offer the matching testing or monitoring solution. Together, these solutions allow you to perform a thorough condition assessment of electrical machines in order to quickly identify potential problems and risk of failure.

<table>
<thead>
<tr>
<th>Electrical test</th>
<th>CPC 100</th>
<th>+ CP TD1 + CP CR500</th>
<th>TANDO 700</th>
<th>MPD 600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance, dissipation factor (tan δ)/power factor measurements</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial discharge (PD) measurement</td>
<td>1, 2</td>
<td>1, 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-line PD monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage withstand testing</td>
<td>1, 2</td>
<td>1, 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation resistance, polarization index and dielectric absorption ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC resistance measurements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact resistance measurement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pole drop testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweep frequency response analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dielectric response analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Used as a high-voltage source
2. Also possible with CPC 80 with CP TD1
<table>
<thead>
<tr>
<th>OMS 605</th>
<th>MONGEMO</th>
<th>DIRANA</th>
<th>FRANEO 800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance, dissipation factor ((\tan \delta)) / power factor measurements</td>
<td>Partial discharge (PD) measurement</td>
<td>On-line PD monitoring</td>
<td>Voltage withstand testing</td>
</tr>
<tr>
<td>Insulation resistance, polarization index and dielectric absorption ratio measurements</td>
<td>DC resistance measurements</td>
<td>Contact resistance measurement</td>
<td>Pole drop testing</td>
</tr>
<tr>
<td>Sweep frequency response analysis</td>
<td>Dielectric response analysis</td>
<td>Universal testing set for electrical diagnostics on high-voltage assets</td>
<td>Dielectric testing device with a compensating reactor</td>
</tr>
<tr>
<td>High-precision measurements of capacitance and dissipation factor/power factor for use in test labs</td>
<td>High-end testing device for partial discharge analysis on high-voltage assets</td>
<td>Portable system for temporary on-line PD monitoring of generators and motors</td>
<td>Permanently-installed system for continuous on-line PD monitoring of generators and motors</td>
</tr>
</tbody>
</table>
| Light-weight testing device for dielectric response analysis on high-voltage assets | Sweep frequency response analyzer | | }

The ideal solution for your individual machine testing needs
Capacitance, dissipation factor (tan $\delta$)/power factor measurements

**Why measure?**
Capacitance (C) and dissipation factor (DF/tan $\delta$)/power factor (PF) measurements are conducted to identify defects, which affect the condition of the machine insulation. A healthy insulation is essential for safe operation.

Variations in C and DF/PF over time are often signs of partial discharges (PD) or insulation degradation. The trend data assists in determining the speed of insulation aging and to identify critical changes that may require further inspection.

**How does it work?**
In combination with a high-voltage source, the measurement instrument is connected to the machine’s terminals for either phase-to-ground measurements or a combined three-phase measurement if the star point is not accessible. Phase-to-phase measurements can be performed as well in order to check the end winding capacitance.

The DF/PF is usually measured over a specific voltage ($U/Un$) range during a tip up test. A typical starting voltage and step increment is 0.2 Un. Other steps and starting points, such as 0.1 Un can be chosen. A comparison is made either phase-to-phase or with previous measurements.

C and DF/PF measurements are defined by international standards, such as IEEE 286-2000 and IEC 60034-27-3.
Good to know ...

> A progressive increase of the DF/PF in the curve during the tip up test can be an indication of ongoing PD activity. PD measurement is then recommended to determine the defect type and location.
> OMICRON recommends to test in an upwards and downwards ramp to give an indication of PD activity (inception and extinction voltage).
> DF/PF values can be compared to the manufacturer’s published data or to prior tests to determine insulation condition changes.
> Visual inspections can also identify damage caused by defects.

Why use CPC 100 + CP TD1 + CP CR500?

> Portable high-voltage test source with C and DF/PF measurement capability up to 12 kV and 5A
> Resonant circuit (CP CR500 and test capacitance) for testing at rated frequency
> Fast measurement due to automated test procedures and reporting
> Detailed analysis due to automated voltage and frequency sweeps

Why use TANDO 700?

> High-precision measurements for test labs
> Maximum safety through complete electrical isolation between acquisition units and the control unit
> Measuring of grounded and ungrounded test objects also on high-voltage potential
> Wide measuring input range from 5µA to 1A, and up to 28 A by the use of external shunts
> Customized reporting with selectable measurement parameters and trends

Dielectric losses cause a phase shift.

DF/PF with a fault in phase 1 compared to good results of phase 2 and 3.

The blue line represents a machine with high PD activity (large hysteresis). The red line represents a new machine with low PD activity.
Partial discharge measurement

Why measure?
Partial discharges (PD) occur in the insulation system of rotating machines, where the local electric field stress exceeds the local electrical strength. It causes a progressive erosion of insulation materials that can lead to their failure.

Compared with other dielectric tests on rotating machines, the differentiating character of PD measurements allows single weak points of the insulation system to be clearly identified.

PD in rotating machines (e.g. slot discharges or end winding discharges) causes recognizable patterns. Through the pattern analysis, specific root causes can be identified, such as contamination, voids, cracks, aging, or general deterioration of different insulation components.

How does it work?
Off-line PD measurements are performed when the machine is taken out of service and energized with a high-voltage source. A coupling capacitor is connected to the terminals of the machine, which is connected to the PD measurement device.

Depending on whether the star point is accessible, a single-phase measurement can be done. Otherwise a three-phase measurement in combination with source separation techniques enables you to identify PD activity in a specific phase.

Several measurements over time enable a trending of the insulation condition, which is the most powerful way to recognize a fault in its early stage.

There are a number of relevant international standards that specify how to make PD measurements on rotating machines, such as IEC 60034-27.

Which part can be tested?
- Stator winding
- Rotor winding

MPD 600

- Coupling capacitor
- Coupling capacitor
- Coupling capacitor
- HV Starpoint
- HFCT
- Optional
Good to know ...

> A combined measurement at the star point (when accessible) and at the terminals enables more detailed analysis.
> Low filter frequency measurements enable a larger coverage of the windings.
> Digital, frequency-selective PD measurement systems are robust against external noise and enable advanced diagnostic options.
> Advanced diagnostic tools, such as 3PARD (three-phase amplitude relation diagram) and 3FREQ (synchronous multi-frequency measurements) are used to separate noise and multiple PD sources for more reliable interpretation.
> OMICRON suggests the use of a high-frequency current transformer (HFCT) in the grounded, non-measured phases in order to measure cross-coupled signals and to enable the 3PARD option.

Why use MPD 600?

> Fiber optic transmission of data provides complete galvanic isolation for safe operation and significantly improved signal-to-noise ratio.
> Fully digital filtering results in an exceptionally high degree of reproducibility to perform reliable, calibrated and traceable PD quality control.
> Powerful tools available for separation of different PD sources, such as 3PARD and 3FREQ, enable more effective diagnosis of PD activity.
> Recorded measurement data streams can be selected individually to focus on relevant PD events for customized reporting.

Source separation with 3PARD
On-line partial discharge monitoring

Why measure?
Compared to routine off-line diagnostic tests, on-line partial discharge (PD) monitoring provides asset managers with continuous insulation condition status while motors and generators are in operation and under the influence of deteriorating forces.

Temporary PD monitoring is used to periodically observe changes in PD activity, whereas permanent PD monitoring continuously assesses PD activity over the entire service life of a machine. Based on the collected data, machine operators are able to decide if and when it is necessary to schedule downtime and perform maintenance.

How does it work?
Coupling capacitors are connected to each phase at the terminals when the machine is off-line. A data acquisition unit is then connected to the coupling capacitors. A mobile workstation or central computer is connected via fiber optic cable to the acquisition unit for system setup, administration and data access using the software.

A continuous comparison of measured PD values on each phase is made with user-defined thresholds. Warnings and alarms indicate when such thresholds have been exceeded.

IEC 60034-27-2 is a relevant international standard that specifies how to monitor PD on rotating machines.

Which part can be tested?
- Stator winding
- Rotor winding

OMS 605 temporary PD monitoring system
MONGEMO permanent PD monitoring system

Power grid

\[ U_1 \]
\[ V_1 \]
\[ W_1 \]
Coupling capacitors
HV
Good to know ...

> On-line PD monitoring does not expose insulation to higher voltage stresses than those encountered under normal operating conditions.

> For frequent PD testing and monitoring, it is recommended that the coupling capacitors are permanently installed to avoid having to shut down the machine each time. The use of a terminal box enables convenient plug-and-play connections to the acquisition units.

> Advanced diagnostic tools, such as 3PARD (three-phase amplitude relation diagram) and 3FREQ (synchronous multi-frequency measurements) are used to separate noise and multiple PD sources for reliable interpretation.

> For older machines with increasing PD levels, a permanent continuous monitoring system is recommended to keep a constant eye on the insulation condition state.

Why use OMS 605?

> Portable temporary on-line PD monitoring system for short-term use on machines

> Plug-and-play connections for easy setup while machine is on-line

> Synchronous, multi-channel PD data acquisition for complete PD assessment

> Advanced noise suppression and PD source separation for convenient evaluation

Why use MONGEMO?

> Permanent on-line PD monitoring system for long-term use on single or multiple machines

> Synchronous, multi-channel PD data acquisition for complete PD assessment

> Advanced noise suppression and automatic PD cluster separation for convenient evaluation

> Recording of raw PD data at selected intervals for in-depth post analysis

> Seamless integration with third-party monitoring devices and SCADA systems

Real-time and historical PD data is displayed for each phase.
Voltage withstand testing

Why measure?
To ensure reliable operation, the voltage withstand testing can be used to detect single weak points in the insulation of motors and generators.

The voltage withstand test is a YES or NO investigation. The inherent withstand capability of healthy insulation is well above the usual proof test value. Failure during a test indicates that the insulation was unsuitable for service.

How does it work?
An AC test source is applied to energize the windings with a potential much higher than the rated one in increased, ramped steps or steady increments.

The winding insulation passes the test when a certain overvoltage level is withstood without a breakdown.

Voltage withstand testing is defined by the standard IEC 60034-1. The test is performed only on new machines with the full test voltage according to the standard. For in-service machines, the test is performed at reduced voltage levels.

Which part can be tested?
- Stator winding
- Rotor winding
Good to know ...

> If no suitable AC source is available for testing at the rated frequency, a DC source can be used for testing. In this case, the amplitude of the DC voltage is higher than the RMS AC value according to the applicable standard.

> The potential grading in the winding overhang and the breakdown mechanism are different when using DC instead of AC high voltage excitation.

> An automatic high-voltage power supply (i.e., ramped voltage test set) can be used to linearly increase the applied voltage from zero up to some maximum value at a constant ramp rate, typically 1 to 2 kV per minute.

> A good procedure is to check the polarization index (PI) first in order to see whether larger creepage paths already exist.

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Why use CPC 100 + CP TD1 + CP CR500?

> Detailed analysis due to automated voltage and frequency sweeps

> Maximum test voltage of 12 kV

> Fast measurement due to automated test procedures and reporting

> Modular and mobile system – heaviest component weighs 35 kg

> Potable HV source for testing at rated frequency

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The voltage is increased in a ramp or in steps to the intended test voltage, which is held for at least one minute.

If the voltage is increased in steps, it is recommended by IEC that the sets have to be lower than 5% of the test voltage.
Insulation resistance, polarization index and dielectric absorption ratio measurements

Why measure?
The insulation resistance (IR), polarization index (PI) and dielectric absorption ratio (DAR) measurements are useful for checking machine windings for contamination and insulation deterioration. They are also useful for evaluating insulation integrity to ensure safe operation, as well as to check for moisture in the stator windings after a long standstill period.

How does it work?
For the insulation resistance measurement, a constant DC voltage is applied between the copper conductor and ground.

For determining the PI, the IR measurement is performed for 10 minutes. The PI is the ratio of the 10-minute reading divided by the 1 minute reading of the IR value. The DAR is also a ratio of two withstand values over time. Here one often uses the 60-second to 30-second value.

Compared to other phases or previous measurements, lower IR and PI (or DAR) values indicate possible weaknesses in the high-voltage insulation.

IEEE standard No. 43-2000 defines how these measurements should be performed and provides limits for the assessment of the results.

Which part can be tested?
- Stator winding
- Rotor winding
**Good to know ...**

- This is an integral measurement that delivers an overall statement about the insulation condition of the machine, but is no replacement for high potential AC tests (i.e. C, DF/PF or PD).
- Pre-polarization, resulting for example from previous IR and PI measurements, may affect results. To prevent this, ensure a proper time interval (at least as long as the measurement itself) before subsequent measurements.
- By measuring the dielectric response, the IR, PI and DAR are also determined.

**Why use DIRANA?**

- Automatic measurement of dielectric response, insulation resistance and polarization index
- Simultaneous measurements on two phases
- Connection diagrams help you find the optimal measurement configurations; show you the correct measurement scenarios
- Pre-polarization check enables reliable measurements
- High accuracy and safety by using low test voltages

![Graph](image.png)

IR resistance with a fault in phase U.
DC resistance measurements

Why measure?
DC resistance measurements are performed, to detect possible contact problems in the stator and rotor windings of rotating electrical machines.

Connection problems can occur between single coils or bars of the winding or at the pole connectors in the rotor. They cause local hotspots, which can eventually damage the machine.

The typical origins of these faults include bad soldering contacts, which become weaker through operation, or loose connections as well as oxidized or damaged surfaces on machine pole connectors.

How does it work?
To measure DC resistance, the measuring instrument is connected to the outputs of the machine. The DC current and DC voltage are measured at the same time for each phase and the resistance is calculated.

The data shows a comparison between the phases to previous measurements. A variation indicates a potential contact problem.

For measurement of the contact resistance, e.g. on pole connectors, a high DC current is injected between the contacts. Also in this case, the measurement is compared with other measurements or with previous data.

Which part can be tested?
- Stator winding
- Rotor winding

CPC 100
Good to know ...

> A four-wire measurement enables the most reliable results and minimizes the influence of the test setup.
> As the measurement is a comparative method, the resistance values must be temperature corrected in order to compare the results.
> Inspections with a thermal camera can be used to confirm the results. A high current is applied and a visual inspection with a thermographic camera reveals where the hot spots are located.

Why use CPC 100?

> Multifunctional device applicable for most routine electrical tests on rotating electrical machines
> Up to 400 A DC and 5 kVA for resistance measurements down to the microohm range.
> Easy to transport (29 kg) for on-site testing
> Testing templates, automatically generated testing procedures and test reports

Winding resistance measurement with 100A (phase W with bad soldering contact).
Pole drop testing

**Which part can be tested?**

- Stator winding
- ✓ Rotor winding

**Why measure?**

Mechanical stress in rotor windings cause inter turn faults (short circuits), which can lead to a magnetic imbalance. This causes higher shaft vibrations and, as a result, higher stress and damage to the bearings.

Similar to sweep frequency response analysis, the pole drop test is performed on single-pole rotor windings to detect inter turn faults.

This is a simple comparative test performed during factory acceptance testing, routine maintenance inspections or during refurbishments of rotating machine pole winding.

**How does it work?**

A pole drop test is performed when the generator is in a standstill condition. An AC current is injected into the slip rings to energize the pole windings.

By measuring the voltage drop of every pole between the pole winding connectors, the impedance can be determined. A comparison of the measurement results of each of the poles or with previous measurements identifies possible inter turn faults in the pole winding.

A pole with an inter turn fault shows a significant lower voltage drop (or lower impedance) than the average value of the healthy poles.
Good to know ...

> The impedances of each pole should be compared with one another. Also a comparison with previous measurement results is possible. Based on OMICRON experience, a ±2.5% difference from the average is an indication of a fault and should be investigated.

> The values can change especially for removed rotors depending on their position. This also applies to machines where the upper part of the stator is removed.

> Potential inter turn faults resulting from centrifugal forces cannot be detected as the rotor winding is at standstill during testing.

Why use CPC 100?

> Multifunctional device applicable for most routine electrical tests on rotating electrical machines

> Easy to transport (29 kg) for on-site testing

> Testing templates, automatically generated testing procedures and test reports

The red line indicates average value. Not all measurement values are in the acceptable range within ±2.5% of the average value. This indicates suspected inter turn faults.
Why measure?
Sweep frequency response analysis (SFRA) is performed to detect inter turn faults caused by mechanical stress in the pole windings of machines during factory acceptance testing or during routine maintenance testing. It can also be used for detecting inter turn faults in the stator windings.

How does it work?
The electrical circuit in the stator as well as the rotor can be assumed to be a complex electrical network of capacitance, inductances and resistors with its own frequency response. Any defects in the windings result in a change of the network and the corresponding frequency response. Measuring this frequency response enables the detection of the fault.

A sinusoidal signal is applied at the input of the electrical network. Both the amplitude and the phase shift of the output signal are measured.

The frequency response is determined by comparing the amplitude and phase of the input and output signals. The values deviate between different poles or between previous measurements when inter turn faults change the behavior of the frequency response.

Which part can be tested?
- Stator winding
- Rotor winding

SFRA also allows reliable rotor winding diagnosis for rotating machines.

Sweep frequency response analysis (SFRA) enables inter turn fault detection in stator windings.
Good to know ...

> The SFRA method was developed to detect mechanical deformations of transformer windings and is also used for inter turn fault detection in the windings of rotating machines.

> With surge testing, an injection may be required from both sides of the winding. This is not needed for the SFRA measurement.

> For measurements on poles: As this is a comparative measurement, be aware that if the upper part of the machine is missing, there will be a difference between the upper and lower poles, depending on their position, as well as to previous measurements.

Why use FRANEO 800?

> Highest dynamic range in SFRA testing industry (> 145 dB)

> Higher accuracy (± 0.5 dB down to -100 dB)

> High sensitivity enables reliable results with maximum safety at low voltage levels

> Adjustable output voltage

> Software support for automatic result analysis, comparisons and customized reporting

Measurement principle

The blue line references the healthy pole; the red line indicates pole with inter turn fault, where one turn is bridged.
Dielectric response analysis

Why measure?
Dielectric response analysis of rotating machines assesses the condition of machine insulation, such as contamination, deterioration and insulation integrity. It also detects moisture after a long machine standstill.

How does it work?
The dielectric response analysis determines the dielectric properties of an insulation in a very broad frequency range (µHz to kHz). This makes it very sensitive for detecting a variety of insulation defects.

Usually the phase-to-ground of the stator insulation is measured on rotating machines. The output voltage is applied to the ground, and one or two input channels are connected to the phase(s).

The assessment of the measurement can be performed by using absolute values, such as capacitance or dissipation factor/power factor (DF/PF), etc., or by comparing the dielectric response curves of different phases.

Which part can be tested?
- Stator winding
- Rotor winding

DIRANA
**Good to know ...**

> Dielectric response analysis is performed at relatively low voltages. This allows fast on-site testing. On the other hand, dielectric response analysis does not replace PD measurement. It simply detects certain damages resulting from PD, but it cannot detect PD on its own.

> Creepage paths are easier to detect at lower frequencies. Therefore dielectric response analysis is more sensitive to detect creepage paths compared to DF/PF measurements at line frequency.

> By measuring the dielectric response, the polarization index (PI) and insulation resistance (IR) is also determined.

> Before starting the measurement, it is recommended to check the insulation for pre-polarization as this could influence the measurement results. Pre-polarization can be caused by prior DC tests (like insulation resistance, etc.) or by a previous PDC measurements on other phases.

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**Why use DIRANA?**

> Dielectric response is measured within a wide frequency range

> Automatic measurement of dielectric response, insulation resistance and polarization index

> Simultaneous measurements on two phases

> Connection diagrams help you to find the optimal measurement configurations; show you the correct measurement scenarios

> Pre-polarization check enables reliable measurements

> High accuracy and safety by using low test voltages

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Dielectric response analysis with a fault in phase 3.

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Welcome to the team

At OMICRON you can always depend on an experienced team that actively supports you and an infrastructure that you can rely on. We always listen attentively in order to understand your needs so that we can offer you the best possible solutions. We strive for lasting partnerships and ensure that you can continue to rely on your product long after you’ve purchased it. In order to do this, we focus on quality, the transfer of knowledge and unique customer support.

Charles, Wenyu and René are able to tell you about the services we have available for you and why it pays to be part of the team.

A strong and safe connection

Solutions you can rely on...

... developed with experience, passion and an innovative approach that we use to continually set groundbreaking standards in our industry sector.

We invest more than 15% of the total turnover in research and development so that we can even guarantee the reliable use of the latest technology and methods in the future.

Our comprehensive product care concept also guarantees that your investment in our solutions – like free software updates – pays off in the long term.
We share our knowledge...

... by maintaining a constant dialogue with users and experts. Some examples of this are our customer events and conferences that take place all over the world and our collaboration with numerous standardization committees.

We also make our knowledge available to you in the customer section of our website in the form of application reports, specialized articles and articles in the discussion forum. With the OMICRON Academy, we also provide a wide spectrum of training possibilities and assist you with Start-up training and free webinars.

When rapid assistance is required...

... our excellent level of support is always appreciated. You can reach the highly-qualified and committed technicians in our customer support department 24 hours a day, seven days a week – and it’s completely free. We deal with repair services and service features in a fair and non-bureaucratic manner.

We can help minimize your downtime by lending you equipment from a readily available plant at one of our service centers in your area. A comprehensive offer of services for consulting, testing and diagnostics completes our range of services.
OMICRON is an international company serving the electrical power industry with innovative testing and diagnostic solutions. The application of OMICRON products allows users to assess the condition of the primary and secondary equipment on their systems with complete confidence. Services offered in the area of consulting, commissioning, testing, diagnosis and training make the product range complete.

Customers in more than 150 countries rely on the company’s ability to supply leading-edge technology of excellent quality. Service centers on all continents provide a broad base of knowledge and extraordinary customer support. All of this together with our strong network of sales partners is what has made our company a market leader in the electrical power industry.

For more information, additional literature, and detailed contact information of our worldwide offices please visit our website.