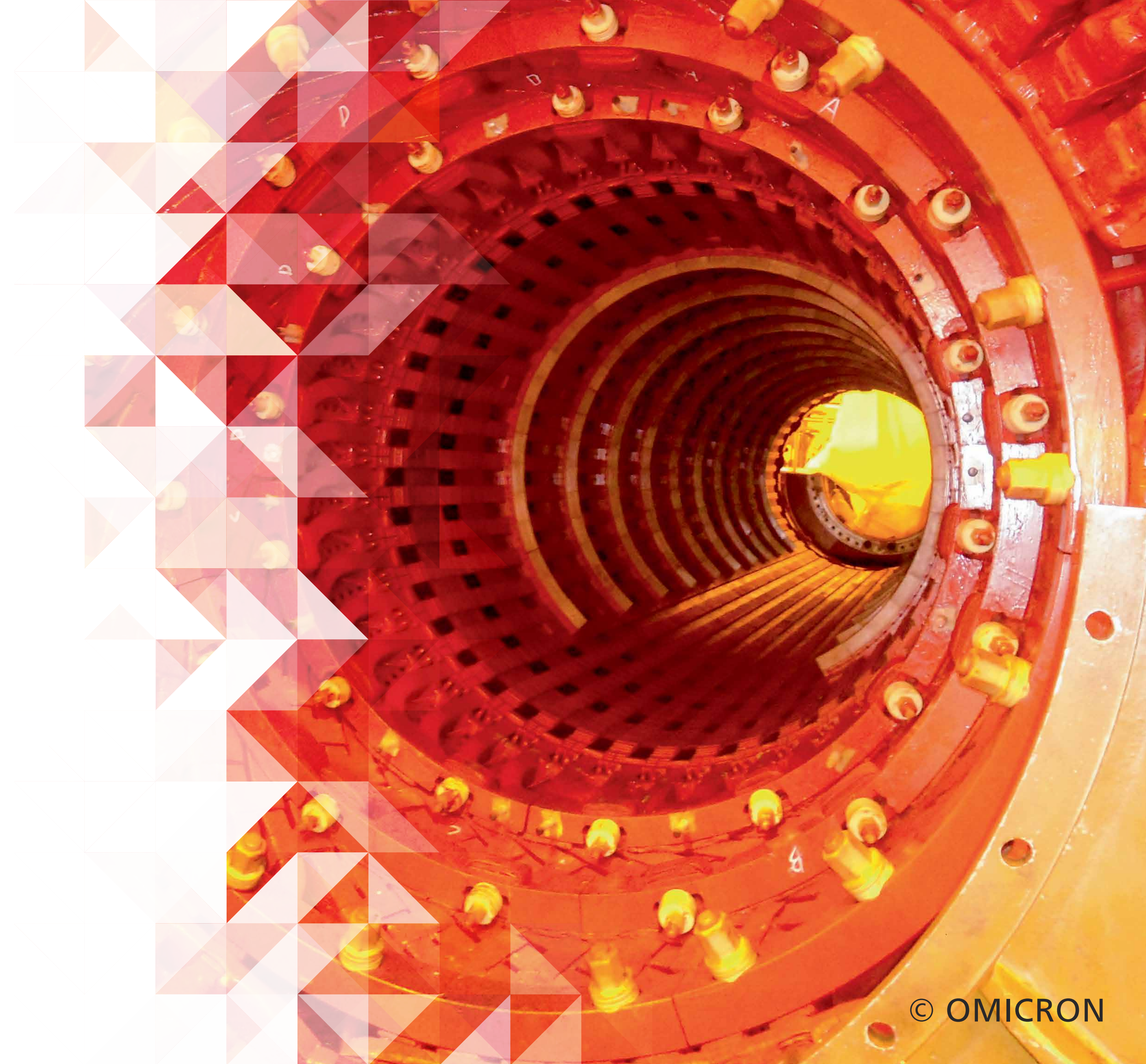
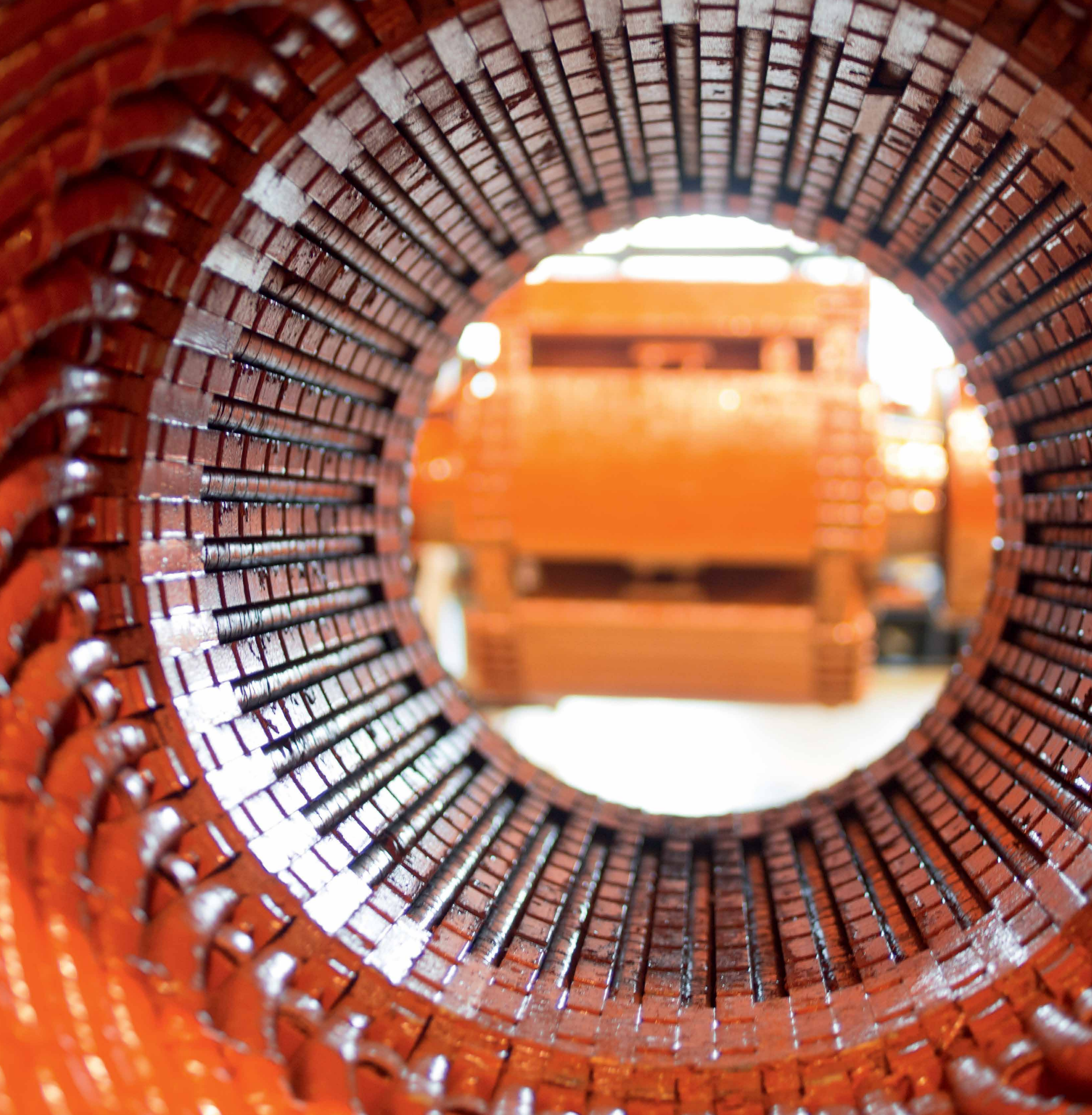


BASICS OF ROTATING MACHINE TESTING

Recommended diagnostic methods for
fast and accurate condition assessments
of generators and motors.





WELCOME

Your guide to motor & generator health

Master the basics of rotating machine testing with this practical guide. Inside, we share our experience with highly recommended tests for the stator cores, stator windings, rotors, and rotor windings of motors and generators. With step-by-step videos to show you how to perform measurements and interpret data, you can use this guide as a reference to help you increase the longevity and reliability of your machines.

Enjoy reading!

PARTS OF A ROTATING MACHINE

In a rotating machine, the stator core and stator windings are located on the outer, stationary frame, with the stator core housing the stator windings in slots. The rotor and rotor windings are located internally, positioned within the center of the stator's bore and mounted on a rotating shaft, separated from the stator by an air gap. In this reference guide, we describe recommended diagnostic tests on the stator core and stator windings as well as the rotor and rotor windings to ensure the reliability of your machines.

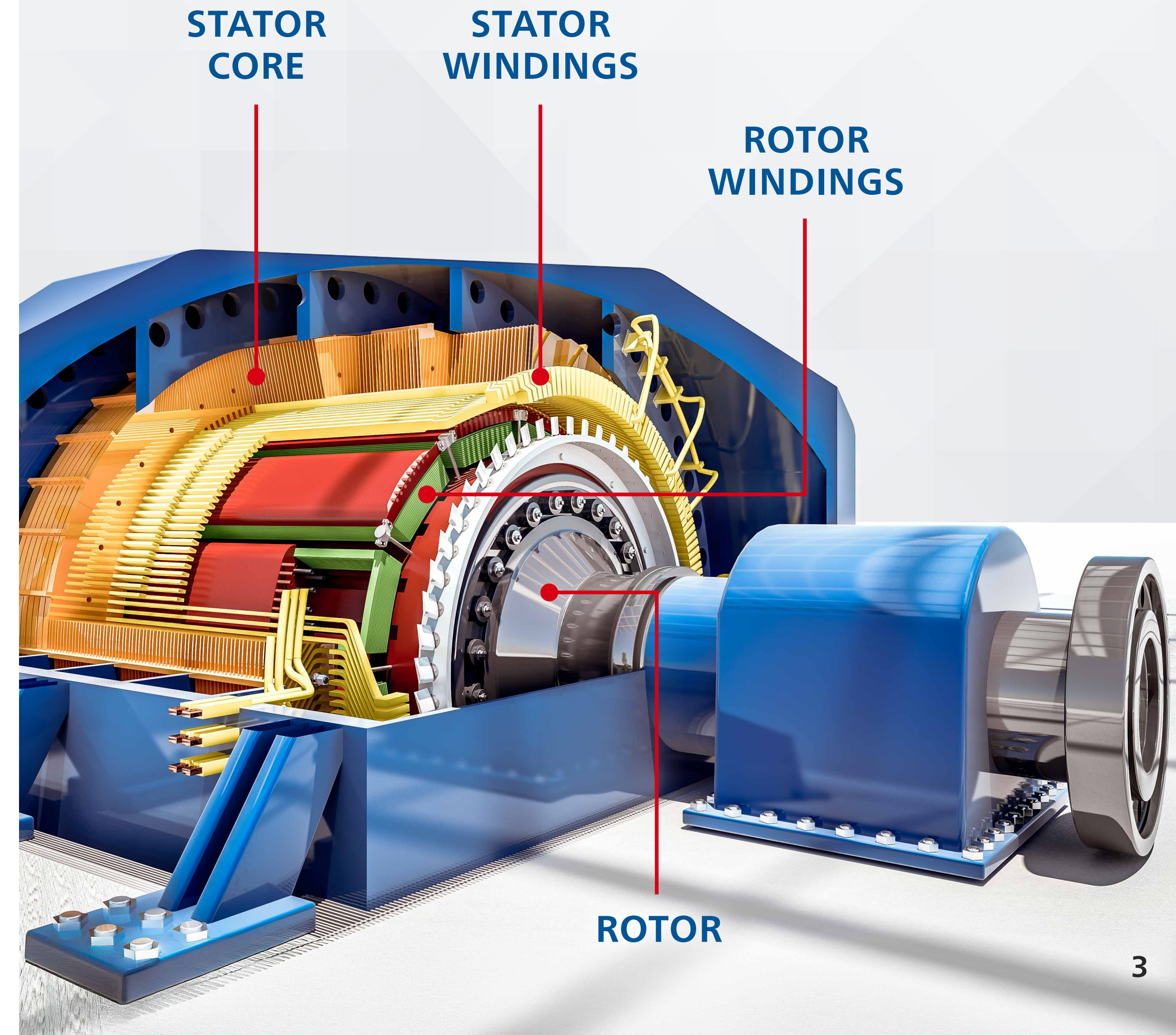


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Disclaimer:

For educational reference only. Electrical testing methodologies and standards change over time. Always follow standard safety protocols and consult professional guidelines before conducting any tests.



INTRODUCTION

These days, keeping rotating electrical machines running smoothly is a major balancing act. Many of the medium- and high-voltage generators and industrial motors that power our infrastructure are now approaching the end of their expected lifespans. This creates a real challenge: how do you maintain reliability when you're also juggling tighter budgets and a shrinking pool of experienced techni-

cians? Whether it's a power plant or a manufacturing line, rotating machines are critical to daily operations. When something goes wrong, the cost isn't just about the physical repair; it's the "standstill" time—the expensive hours when production stops and the grid goes quiet. Because of this, the focus has shifted from just "fixing things" to finding smarter, more sustainable ways to protect long-term machine health.



WHAT CAUSES ROTATING MACHINES TO FAIL?

Several investigative international studies confirm that a major root cause of rotating machine failures is caused by electrical insulation issues. Rotating machines are exposed to periodic and continuous thermal, electrical, atmospheric and mechanical (TEAM) stress factors that cause vital parts, such as the stator winding insulation, to degrade, age and eventually fail.

TEAM STRESS FACTORS

Thermal stress: High / low temperatures, cyclic overloading, and localized “hot spots”. It causes insulation decomposition, and differential expansion leading to mechanical fatigue.

Electrical stress: Voltage surges, continuous overvoltages, partial discharge (PD), and normal operational voltages. It causes aging of insulation and potentially deteriorates field grading layers.

Atmospheric / environmental stress: Contamination, moisture / humidity absorption, abrasive particles, and reactive chemicals. It causes corrosion, surface tracking, and weakened dielectric strength of insulating materials.

Mechanical stress: Vibration, rotor eccentricity/unbalance, oscillation in slots, and end winding movement. It causes abrasion, insulation cracking, and fatigue-induced failure of structural components.



THE MOVE TO CONDITION-BASED MAINTENANCE

Asset managers and maintenance engineers of rotating machines are shifting to condition-based strategies to predict failures, with a focus on the stator winding insulation, a machine's most vulnerable component. Because degradation is often invisible during routine maintenance inspections, specialized electrical testing is required to assess health without costly teardowns. Diagnostic testing and monitoring solutions enable you to accurately identify risks, justify maintenance budgets, and plan interventions to avoid unexpected and expensive critical failures.

THINK ABOUT SAFETY FIRST

Before you begin to test your machines, be sure to take the necessary safety precautions when working around electrical power. A good place to start is by observing the five safety rules as follows:

- 1 **Disconnect completely.**
- 2 **Secure against reconnection.**
- 3 **Verify absence of operating voltage.**
- 4 **Carry out earthing and short-circuiting.**
- 5 **Provide protection against adjacent live parts.**



ESSENTIAL OFFLINE ELECTRICAL TESTS ON STATOR WINDINGS

Four recommended electrical tests to determine the insulation condition of a stator winding

We consider the following tests to be the most important to perform on rotating machines because they provide you with a complete assessment of the stator winding insulation's integrity, aging, and contamination. They are all performed offline during planned maintenance outages.



Test method	Focus area	Primary defect detected	Impact for the engineer
DC insulation resistance & polarization index measurement	Groundwall insulation	Moisture, dirt / oil contamination, and major cracks.	Determines if the machine is “safe to start” or needs cleaning / drying.
Capacitance & dissipation / power factor (tan delta) measurement	Bulk insulation quality	General aging, moisture, contamination, and resin “void” content.	Assesses the overall “health grade” of the entire insulation system.
Voltage withstand (overvoltage or HiPot) measurement	Dielectric strength	Latent weaknesses, pinholes, and severe degradation.	A “stress test” to confirm the insulation can withstand operating voltage.
Partial discharge (PD) measurement	Internal & surface insulation	Voids in resin, loose windings, and “tracking” across end-turns.	The “early warning” system for high-voltage (HV) insulation aging.

DC INSULATION RESISTANCE & POLARIZATION INDEX MEASUREMENT

These combined offline measurements provide you with a quick stator winding integrity check.

- › **Why it's important:** It detects general problems immediately. It is sensitive to surface moisture and contamination which affect insulation integrity.
- › **What it tells you:** If the IR value is low, the insulation is likely damp and/or dirty. The PI is the ratio of insulation resistance over 10 minutes vs. 1 minute. Based on international standards, the PI value should be 2 or higher in modern insulation systems.

- › **The bottom line:** It's the first line of defense for deciding if it's even safe to energize the machine for further testing.
- › **Frequency:** Annually or before startup after a long shutdown period.
- › **Applicable standards:** IEC 60034-27-4 and IEEE 43

DC INSULATION RESISTANCE & POLARIZATION INDEX MEASUREMENT



[Click here to watch the video
“Basics of rotating machine
testing – part 1”](#)

CAPACITANCE & DISSIPATION / POWER FACTOR (TAN DELTA) MEASUREMENT

These offline AC measurements assess overall insulation quality and health.

- › **Why it's important:** As insulation ages, it can become more conductive. Detecting increased insulation losses early supports condition-based maintenance.
- › **What it tells you:** The dissipation factor is the ratio of resistive current to capacitive current (I_R/I_C). The power factor is defined slightly different by using the total instead of the capacitive current. By assessing these dielectric losses in the insulation system, its overall condition and aging or contamination levels can be derived. A phase-to-phase comparison immediately shows you if the winding's parts have problems.
- › **The bottom line:** Dissipation/power factor measurements provide a quantitative indicator of insulation health, enabling early deterioration detection and preventing costly rotating electrical machine failures.
- › **Frequency:** Every 1 to 3 years
- › **Applicable standards:** IEEE 286 and IEC 60034-27-3

CAPACITANCE & DISSIPATION / POWER FACTOR (TAN DELTA) MEASUREMENT



[Click here to watch the video
“Basics of rotating machine
testing – part 2”](#)

VOLTAGE WITHSTAND (OVERVOLTAGE / HiPot) MEASUREMENT

This offline measurement is a more aggressive assessment of the insulation's dielectric strength. The winding is stressed with a specific overvoltage for 1 minute. It can be done in AC or DC, but since the voltage distribution within the insulation is the same during operation, performing the test with AC is recommended.

- › **Why it's important:** The test applies voltages higher than the rated one to see how the insulation behaves under stress.
- › **What it tells you:** It looks for cracks, punctures, or localized weaknesses in the groundwall insulation. It verifies that the insulation can survive voltage stresses beyond normal operating levels without breaking down.
- › **The bottom line:** It confirms that the insulation can withstand its rated operating voltage with a safety margin.
- › **Frequency:** Every 1 to 3 years, combined with dissipation/power factor measurements.
- › **Applicable standards:** IEC 60034-1 and IEEE 95

VOLTAGE WITHSTAND (OVERVOLTAGE / HiPot) MEASUREMENT



[Click here to watch the video
“Basics of rotating machine
testing – part 3”](#)

PARTIAL DISCHARGE (PD) MEASUREMENT

The offline PD measurement is the most advanced and predictive of the four tests. It detects tiny electrical sparks that occur inside the insulation and on its surface, which can damage it over time.

- › **Why it's important:** Most high-voltage failures don't happen instantly; they begin as microscopic voids or bubbles in the resin. PD measurements detect them at an early stage.
- › **What it tells you:** It identifies many different potential problems with the insulation system, including voids, delamination, and loose coils. Although PD degrades the insulation over time, this test can detect internal erosion before it appears in other measurements.
- › **The bottom line:** It's the ultimate early warning system for high-voltage machines (typically 6 kV and above).
- › **Frequency:** Every 1 to 3 years combined with dissipation/power factor measurements and HiPot tests.
- › **Applicable standard:** IEC 60034-27-1 (offline testing)

PARTIAL DISCHARGE (PD) MEASUREMENT



[Click here to watch the video
“Basics of rotating machine
testing – part 4”](#)

BENCHMARKING: TURNING DATA INTO DIAGNOSIS

A single test result is just a data point; a trend is a diagnosis. Comparing current data against Factory Acceptance Tests (FAT) or commissioning benchmarks is essential for reliable assessment. Benchmarking turns data into a financial forecast and gives you the confidence to continue running or repair a machine.

› Establishing the baseline:

Every stator is unique. Without a baseline, naturally high (but safe) readings might be mistaken for “high risk”, causing costly, unnecessary downtime.

› Detecting rate of change:

Insulation aging is rarely linear. While a certain increase in dissipation factor or partial discharge over five years may be normal, the same increase in six months signals imminent failure.

› **Validating repairs:** Comparing post-overhaul results to the original “fingerprint” ensures the machine meets its intended design specifications (IEC / IEEE standards).

› Normalizing data:

Benchmarking helps filter out environmental “noise” like humidity and temperature, ensuring observed changes reflect actual insulation defects.

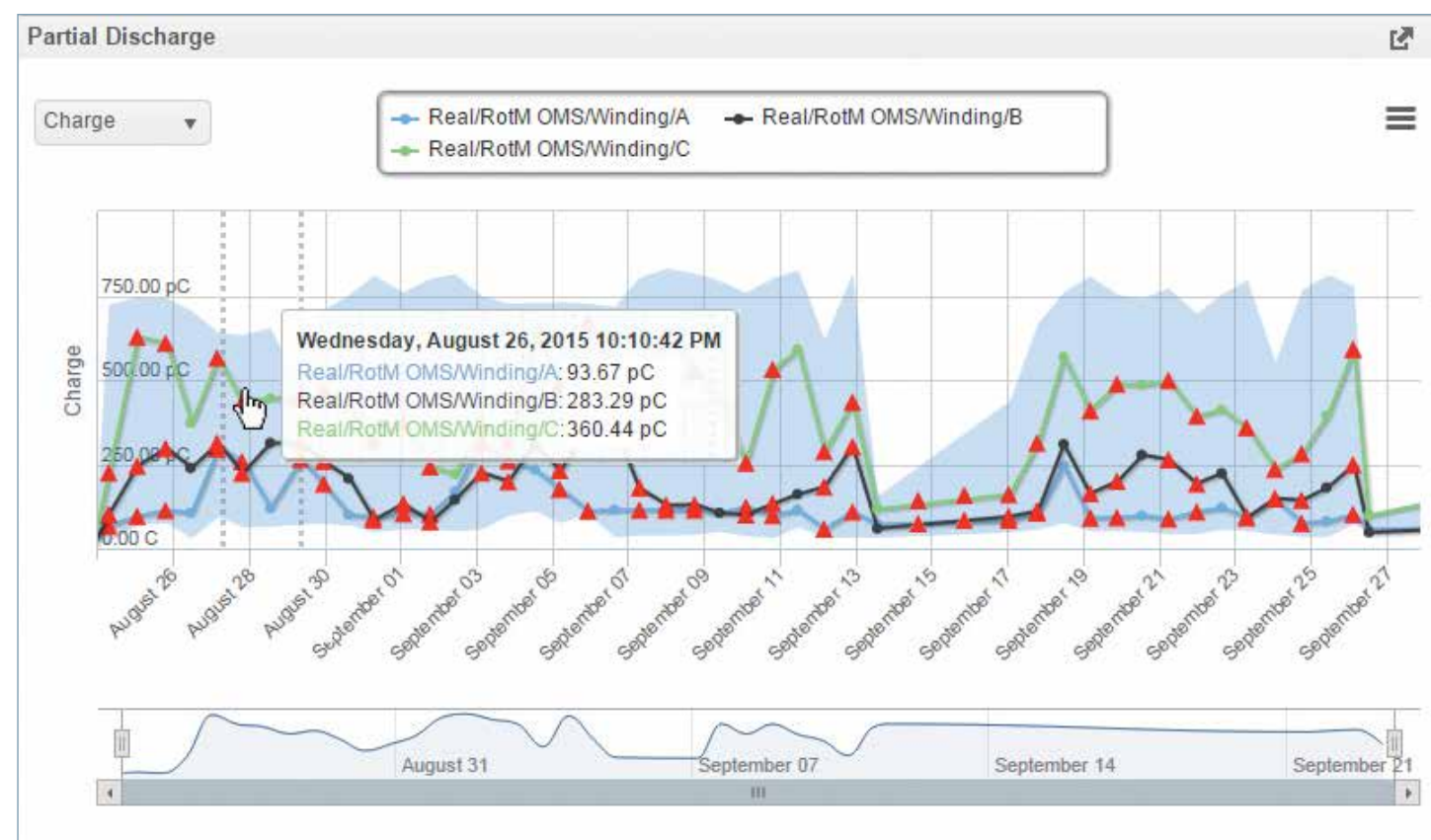
FROM DATA TO ACTION: MITIGATING OPERATIONAL RISK

When test results exceed IEC / IEEE limits or show significant trends, take these steps to mitigate risk:

- 1 Cross-test correlation:** Analyze how results interact. For example, partial discharge with Tan Delta results confirms certain defects, while low PI with increased capacitance suggests moisture or contamination.
- 2 Trend & rate of change analysis:** Compare data to your baseline. A sudden “rate of rise” in leakage current or a rapid drop in Insulation Resistance (IR) is often more critical than the absolute value.
- 3 Operational risk mitigation:** Use a distressed machine only if really needed such as in high demand periods. This is often the case in power plants where two or more similar machines are installed.
- 4 Targeted diagnostic outages:** Use data to focus inspections. Low IR/PI and high Tan Delta points toward oil or dirt, while high PD warrants a visual check for ozone tracking or specific single defects you can identify with PD measurements.
- 5 Data-driven prioritization:** Use condition-based data to define your next maintenance scope. Prioritize specific interventions over general overhauls to address actual degradation.

WHEN TO CONSIDER PD MONITORING

While a standard PD test provides a snapshot in time, PD activity in rotating machines can be highly volatile. Rather than just a snapshot, PD monitoring



PD monitoring trend diagram showing PD activity over a defined time period.

provides you with a continuous view of behavior during the machine's life.

› **Correlation with operational stress:**

PD often occurs in a different way when the machine is at a certain operating point with certain temperature and load condition. PD monitoring allows you to measure the PD activity at different operating conditions.

› **Trend analysis ("rate of rise"):**

In PD analysis, the absolute value is often less important than the trend.

A machine with high but stable PD can run for years (always depending on the failure); a machine with low but rapidly increasing PD is an indication of a developing problem that can lead to insulation failure.

› **Early warning for failures:**

PD monitoring works continuously online while the machine is running. Predefined system alert thresholds can prevent unexpected, forced outages.

TEMPORARY OR PERMANENT PD MONITORING?

The choice between these two approaches depends on the criticality of the machine and the suspected rate of insulation aging.

Temporary PD monitoring

Method: Portable equipment is connected to pre-installed sensors (couplers) for a period of hours or days.

Purpose: Used for periodic health checks or to investigate a specific concern.

Limitation: It only captures data under the specific load and temperature conditions present during the test.



Permanent PD monitoring

Method: Dedicated hardware is hard-wired to the machine sensors, recording data 24/7.

Purpose: For critical high-value assets (e.g., main power generators or essential motors) where any downtime is catastrophic.

Advantage: It provides a complete trend history. It automatically correlates PD activity with fluctuations in load, voltage, and temperature, allowing for a much deeper “root cause” analysis.



WHAT PD MONITORING DATA CAN TELL YOU

Rapid trend increases

If the PD magnitude or pulse count increases significantly (e.g., doubling) within 6–12 months under the same operating conditions, it indicates active insulation erosion.

Load / temperature sensitivity

If PD suddenly becomes highly sensitive to load changes, it often suggests loose windings moving in the slot due to magnetic forces.

Phase-resolved (PRPD) pattern shifts

Changes in where the pulses occur relative to the AC sine wave can indicate e.g. a shift from harmless “surface” PD to dangerous “slot” discharge.

Inception voltage drop

If PD begins to occur at lower and lower voltages during startup, the insulation’s dielectric strength is actively weakening.

ESSENTIAL OFFLINE TESTS ON STATOR CORES AND ROTORS

While our recommended standard electrical tests and PD monitoring described in the last section of this guide assess the condition of the stator winding insulation, other tests described in the following section are also important to perform because they look at the mechanical and magnetic integrity of the stator core and rotor of a machine.



RECOMMENDED TEST TO PERFORM ON STATOR CORES

Test method	Focus area	Primary defect detected	Impact for the engineer
Stator core low energy (EL CID) test	Stator core iron	Shorted laminations and interlaminar insulation failure.	Prevents “core melts” that occur when iron gets too hot.

STATOR CORE LOW ENERGY (EL CID) TEST

The stator core is made of thousands of thin steel laminations coated in varnish to prevent eddy currents. Stator core failure is just as detrimental to a machine as insulation failure.

- › **What it does:** It uses a low-level magnetic flux to scan the surface of the stator core.
- › **Why it's important:** If the varnish between laminations fails, due to vibration, overheating, or physical damage by foreign objects, local hot spots are formed. These hot spots can intensify during operation and result in significant machine damage.
- › **What it tells you:** It is a specialized maintenance test performed during major overhauls for detecting hot spots and assessing any related stator damaged.
- › **Frequency:** Typically, every 5 to 7 years, or whenever the rotor is removed for maintenance.



STATOR CORE LOW ENERGY (EL CID) TEST



[Click here to watch the video
“Basics of rotating machine
testing – part 5”](#)

TESTS TO PERFORM ON ROTORS

Test method	Focus area	Primary defect detected	Impact for the engineer
Sweep frequency response analysis (SFRA) See pages 31–34	Rotor winding	Very sensitive to inter turn short circuits and ground faults in rotor windings.	Identifies winding defects on an early stage, which can cause electrical, thermal and/or mechanical asymmetry.
DC resistance measurement	Rotor winding	Inter turn short circuits, open circuits or poor contacts for example on joints.	Identifies localized heating hazards and imbalances that cause electrical, thermal and/or mechanical asymmetry.
DC insulation resistance measurement	Rotor groundwall insulation	Surface moisture or contamination, insulation degradation, or ground faults.	Determines if the winding is dry and clean enough before putting the machine into operation.
AC or DC overvoltage measurement	Overall insulation system (dielectric strength)	Latent insulation weaknesses, localized voids, cracks, or severe thermal aging.	Validates the safety margin of the rotor insulation to withstand operational stress.

SWEEP FREQUENCY RESPONSE ANALYSIS (SFRA)

SFRA allows you to catch interturn damage in rotor and random wound stator windings.

- › **What it does:** It injects a sinusoidal voltage into the winding across a range of frequencies from Hz to MHz and measures the response.
- › **What it tells you:** It's a sensitive measurement mainly used for rotors and random wound stators that detects short circuits between winding turns. Any changes in the electrical network are detected.
- › **Why it's important:** Interturn short circuits are critical because they create localized circulating currents that generate excessive heat, leading to insulation breakdown and progressive winding damage. If left undetected, they can escalate, resulting in severe machine failure and costly downtime.
- › **Frequency:** Performed as a Factory Acceptance Test (FAT) for windings in smaller machines, such as low voltage motors, and every 1 to 3 years on the rotors of larger machines during their service life.

SFRA test procedure

Preparation

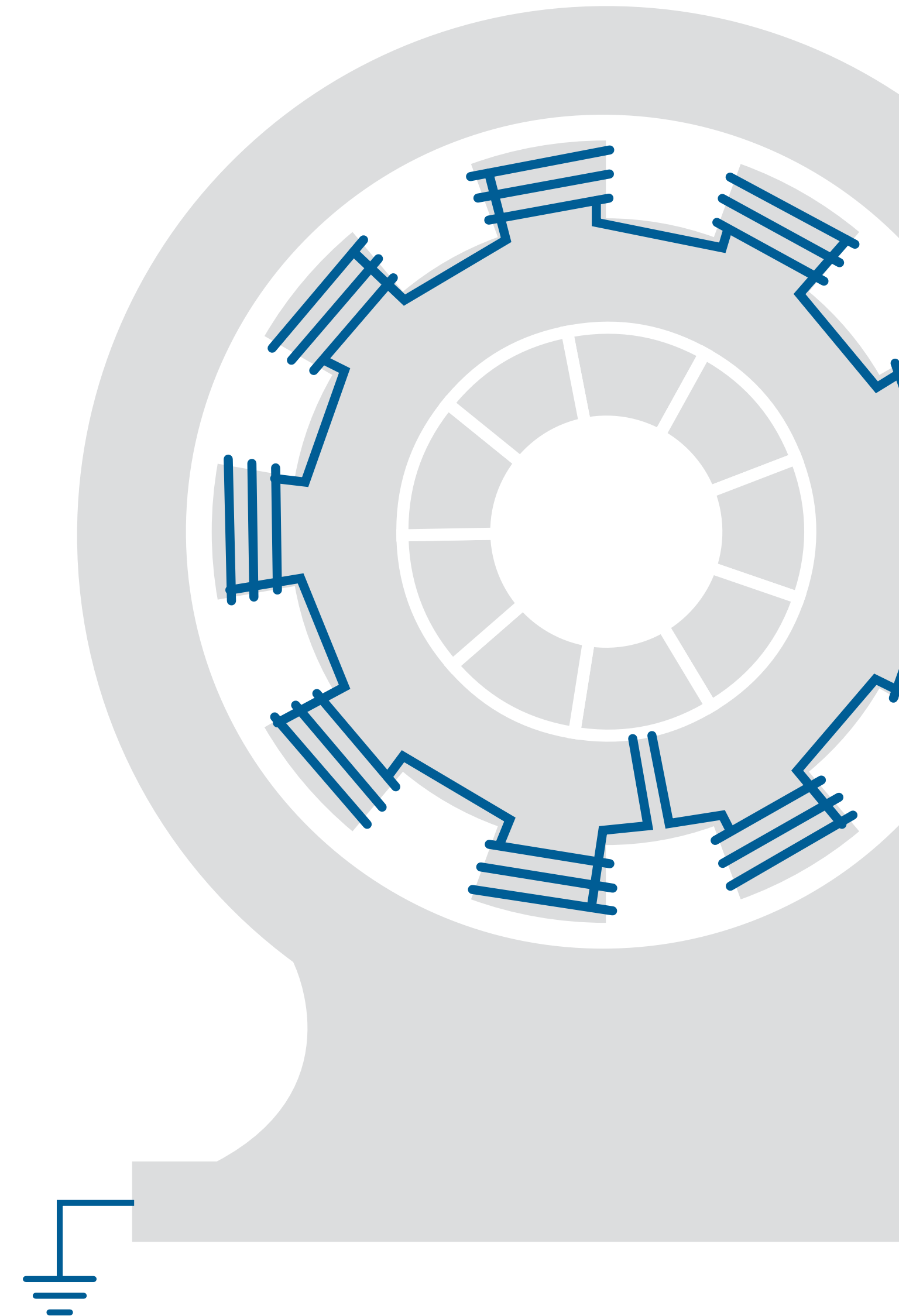
1. Ensure that the machine is de-energized and grounded. Turbo generator rotor windings can be measured entirely, while salient pole windings are measured pole by pole.
2. Connect the source and reference cables to one end of the winding.
3. Connect the measurement (response) cable to the other end of the same winding.

Execution

Inject a low-voltage sinusoidal signal (typically $10 V_{pp}$) starting from 20 Hz up to 2 MHz. The results are compared with other poles or with the swapped measurement in case of full pole rotors.

Frequency

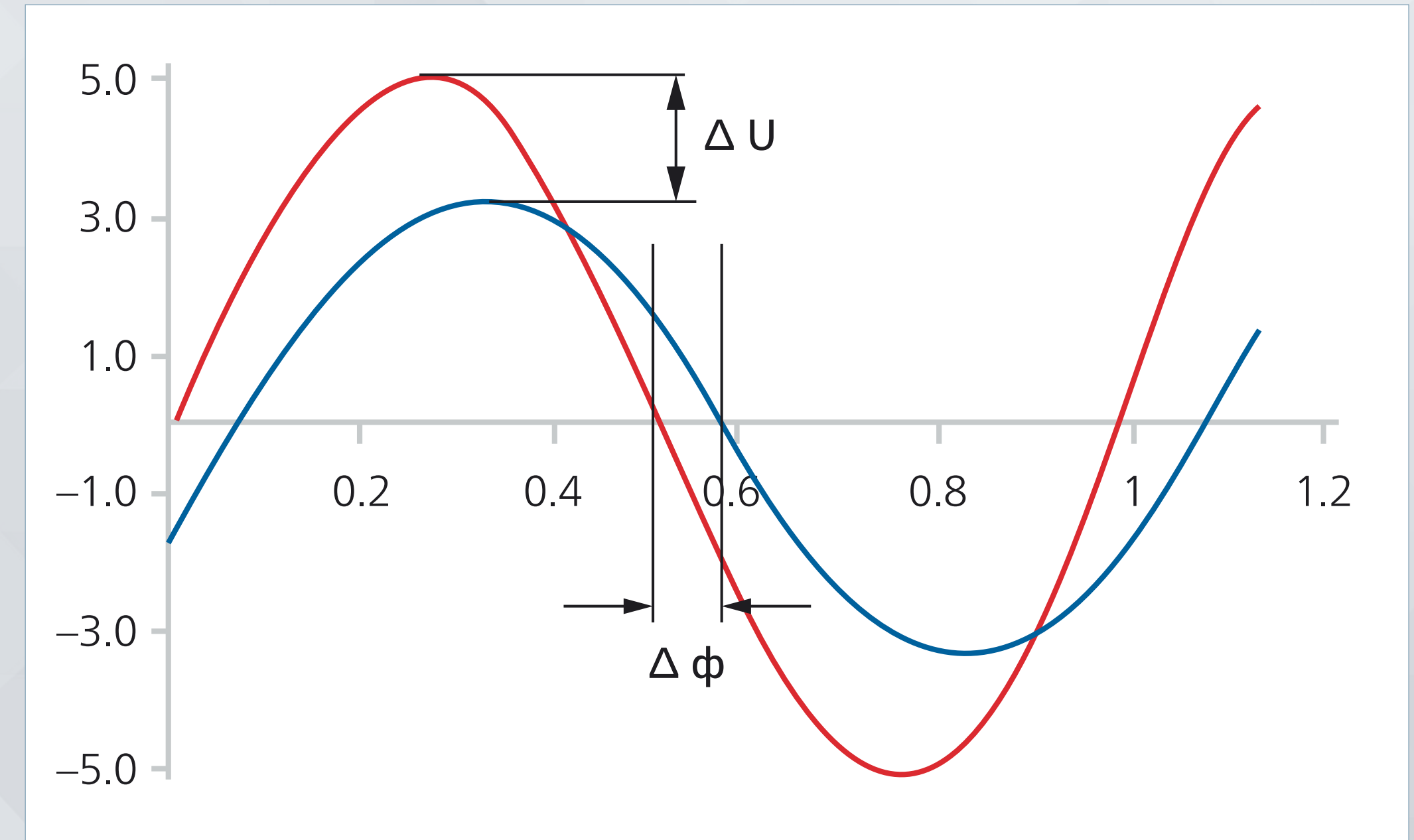
During major overhauls every 5 to 7 years.



SFRA assessment methods

Swapping the connections: In full pole machines two measurements with swapped connections provides you immediately with two curves. Both curves are identical in case of a healthy winding. Any small deviation within the curves indicates a problem.

Pole-to-pole comparison: The salient poles on one rotor are manufactured the same way to be able to compare SFRA curves between poles. Odd and even poles may differ slightly depending on the design, but a deviation caused by a fault can be reliably detected.

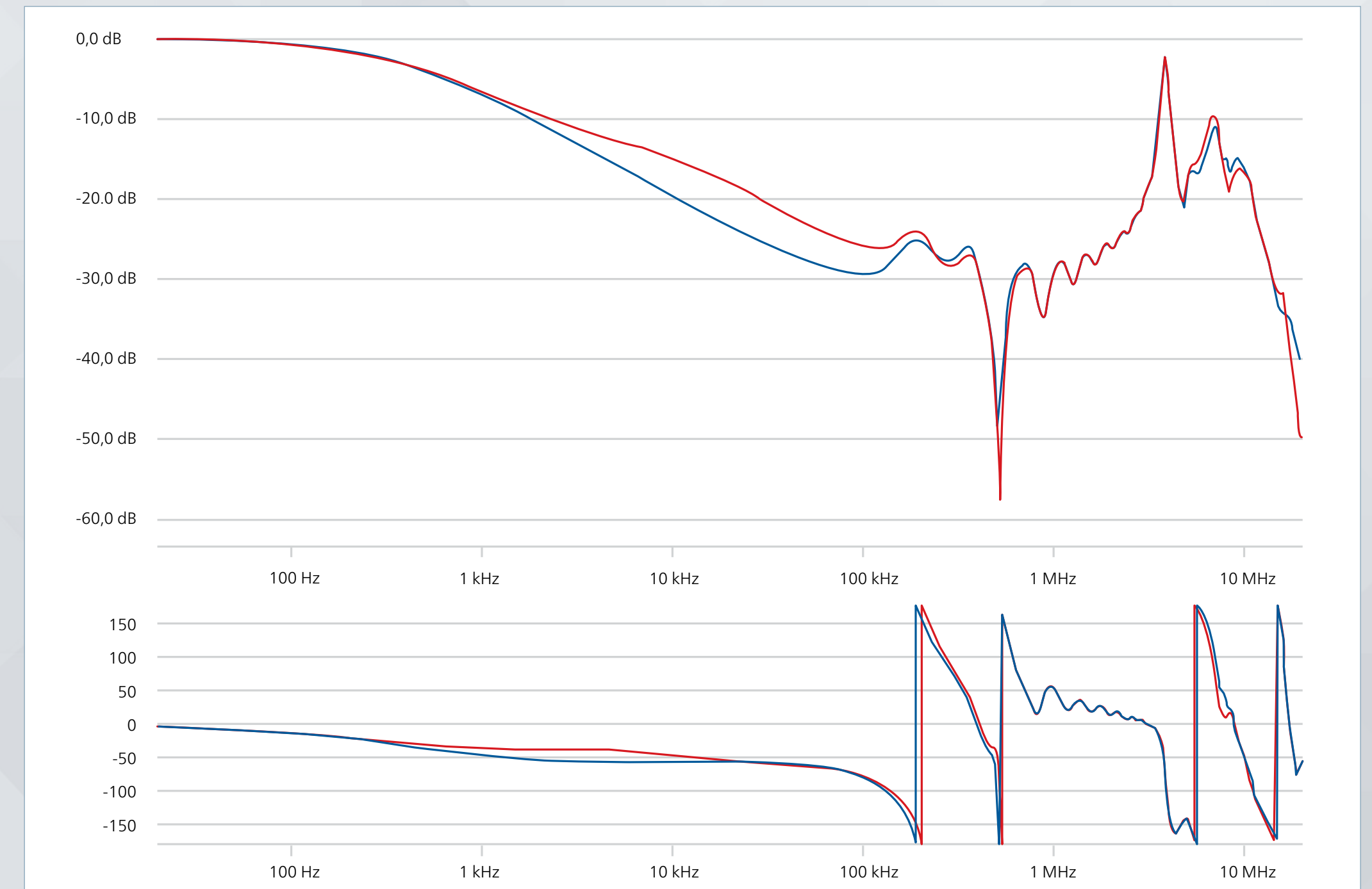


SFRA measurement principle

Time-based comparison: Compare the current trace against a previous “baseline” or “fingerprint” of the same machine. Any shift in resonance peaks or change in the curve shape indicates mechanical movement or insulation changes.

Phase-to-phase comparison: Compare the traces of all three phases. While slight deviations are normal due to the physical layout of the stator, significant mismatches suggest a localized fault (e. g., shorted turns) in one phase

Sister-machine comparison: Compare the results with an identical machine of the same design.



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

CONCLUSION

***Our energy moves your rotating machines –**
We provide you with diagnostic data through
offline testing and online monitoring to assess
machine health. You can rely on our solutions to
help you manage risk, ensure safety, and maintain
the long-term reliability of your machines.*



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