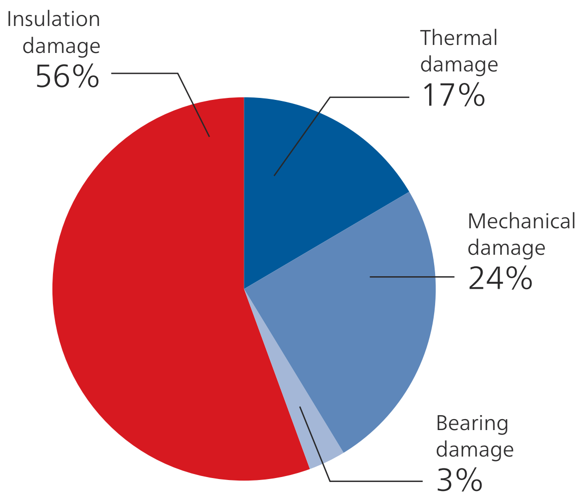
Why Rotating Machines Fail

Rotating machines, such as motors and generators, are key components in power generation and industrial applications. Therefore, machine reliability and availability are highly important. Premature failure may lead to unexpected outages and possible damage to the machine, resulting in significant economic losses.

To plan maintenance effectively, it is essential to have accurate condition information about when machine components need repairing or replacing.

Why rotating machines fail

There are several methods and calculations that exist to evaluate critical components of a machine. The most practical approach is to evaluate surveys about the experience of different machine operators in various segments. An example is the survey regarding hydro generator failures from the A1.10 CIGRE working group. The outcome of the survey is shown in Figure 1a. According to 16 operators with a total fleet of 1,199 hydro generators located all over the world, the most common cause of machine failure is insulation damage. The insulation damage itself has specific root causes, which are indicated in Figure 1b. We will explain how these common issues are measured and detected in rotating electrical machines.



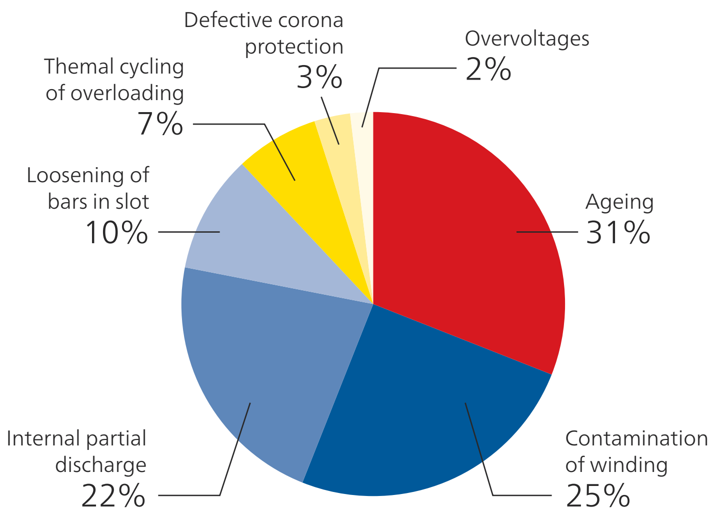


Figure 1a (left): Survey about failure root causes in hydro generators
Figure 1b (right) : Causes of insulation damage
Source: Brütsch et al. "Insulation Failure Mechanisms of Power Generators", DEIS July/August 2008

Insulation combined stresses – TEAM

Rotating machines encounter a lot of periodic and continuous stress factors during their lifetime, such as thermal stress, electrical stress, ambient stress and mechanical stress — abbreviated as TEAM.

> **T**hermal stress: Many temperature shifts lead to premature aging of the insulation.
> **E**lectrical stress: Voltage stress and partial discharge (PD) activity during operation are constantly stressing the insulation.
> **A**mbient stress: Includes moisture, aggressive and reactive chemicals (gas, acids) and foreign particles (metal parts, ash, carbon, lubricants).
> **M**echanical stress: Electrotechnical forces in the slot and the end winding area as well as different thermal expansion levels.

Insulation build up

The insulation of high- and medium-voltage rotating electrical machines is faced with having to compromize between withstanding the electrical field strength, to ensure mechanical stability and to conduct the heat from the copper to the cooling system of the machine. As a result, manufacturers often use a composite insulation system as shown in Figure 2. The main or ground wall insulation is composed of mica in combination with an epoxy resin. This is the area where the most electrical stress occurs. Additionally, the insulation system has some conductive or semi-conductive layers to ensure defined potentials on the interfaces between different materials. An example of this is the outer corona protection to ensure a smooth ground potential on the surface of the insulation. Bigger machines also have an end potential grading and often an inner corona protection.

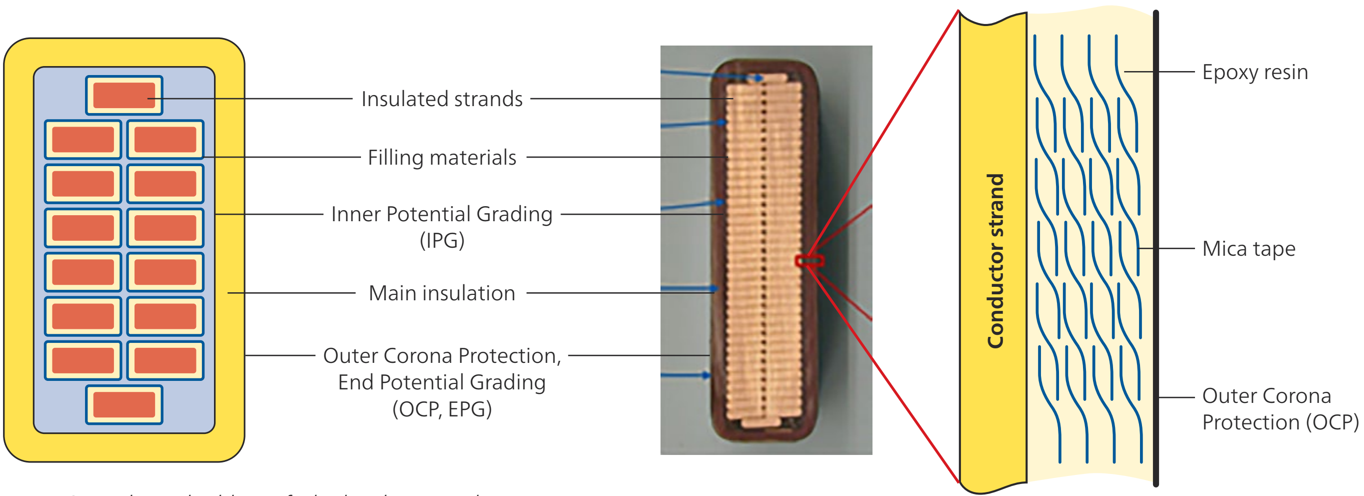


Figure 2: Insulation build-up of a high voltage machine

Most common ground wall insulation defects in stator windings

Voids

Having up to a certain level of voids or cavities in an epoxy/mica insulation results from the manufacturing process and is a normal occurance. As every manufacturer has different production processes, the level of small defects also differs in new machines. Additional cavities will develop over time due to the above-mentioned TEAM stresses.

Withstanding small cavities over time is not a problem for a properly manufactured insulation system. Nevertheless, these small cavities are a source of PD, which can result in a larger insulation defect. The development of such a defect takes a very long time, therefore the status of these partial discharges should be checked over time.

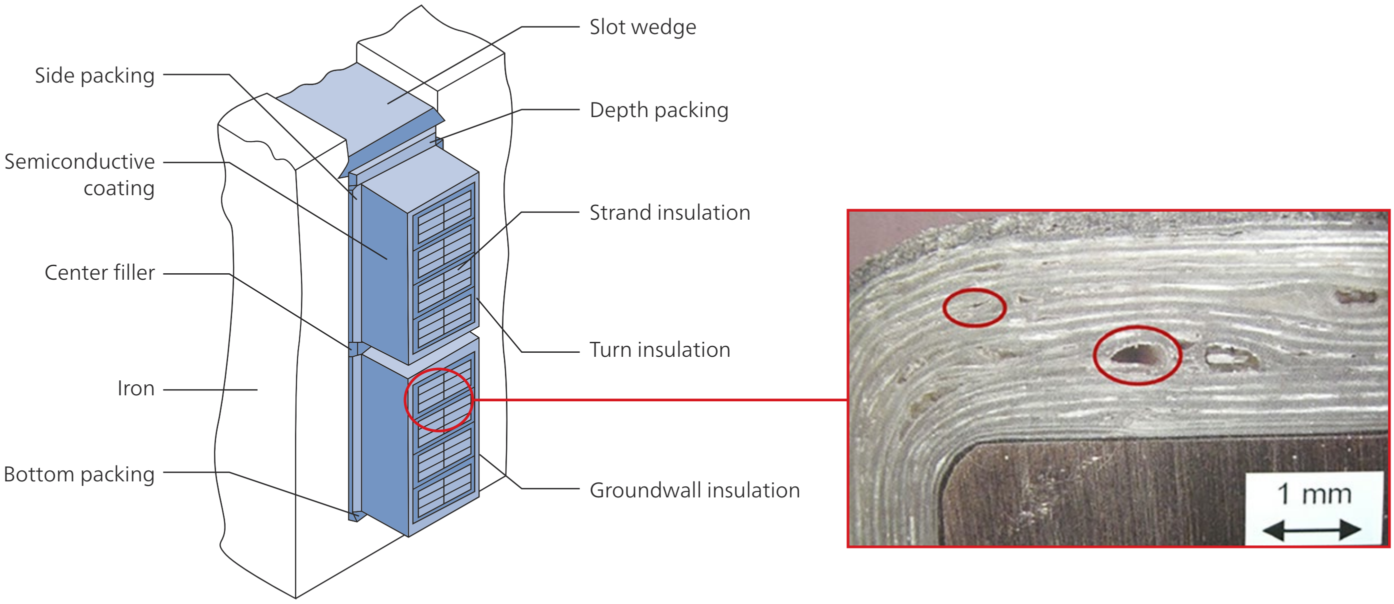


Figure 3: Insulation build-up and microscopic view on large voids in the ground wall insulation
Source: Vogelsang et al. "Performance testing of high voltage generator and motor insulation", Dec 2005

Delamination

Delamination, also known as debonding, within the insulation involves the build up of large cavities between insulation layers. Additionally, delamination can also happen between the copper and the main insulation shell.

Delamination results in a higher PD activity compared to PD activity related to micro voids. The main reasons for this are mechanical tensions caused by the different materials and/or temperature cycles during normal operation.

Loose coils or bars

Electromechanical forces are constantly interacting with the winding. If the winding fixation system becomes defective over time, or was not applied properly, the winding gets loose. Thus, the outer corona protection is attacked and abraded. If the defect is not detected, the vibration also starts to deteriorate the main insulation, which will result in a breakdown of the machine. The defect has a characteristic PD signature and can be identified with PD measurements.

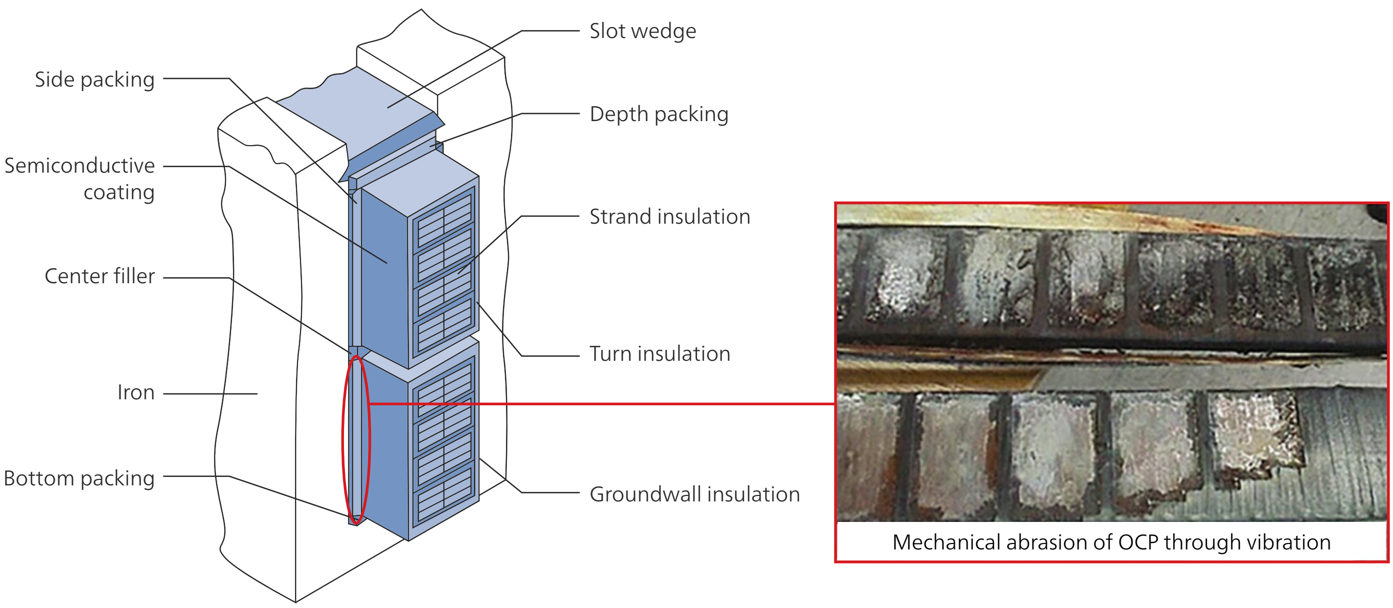


Figure 4: Insulation build-up and typical symptoms of a vibrating bar.

Contamination and imperfect distances at the end-winding area

Constuctional problems, such as imperfect distances (phase separator) or winding contamination, lead to PD activity at the end-winding area. Other common issues in this part of the winding are weak connections between the two gradings, the outer corona protection and the end potential grading. An example of contamination and the PD activity are shown below (Figure 5).

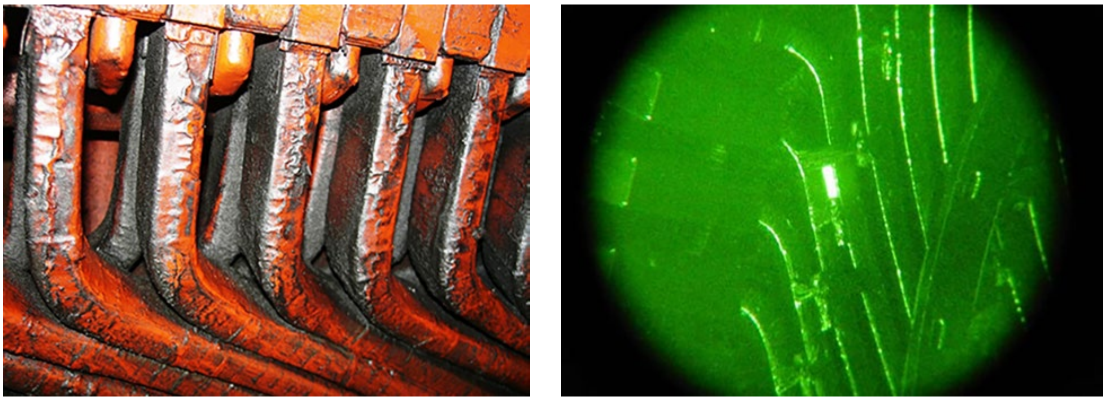


Figure 5: Examples of contamination and PD activity in the end-winding section

The issues discussed above are related to the main insulation. Other components in rotating machines are often affected by different problems as well. Some examples can be:

- > Interturn shorts
- > Connection (contact) problems
- > Interrupted parallel strands
- > Bad soldering of contacts

Extension of expected lifetime

Rotating machines, like every other asset in the electrical network, have a certain expected lifetime. As mentioned, negative influences such as thermal, ambient, mechanical and electrical stress provoke a reduction of the lifetime.

To prevent breakdowns and outages of rotating machines, regular or periodic maintenance is vital. Different diagnostic measurements allow you to assess risk in order to properly plan maintenance based on machine condition.

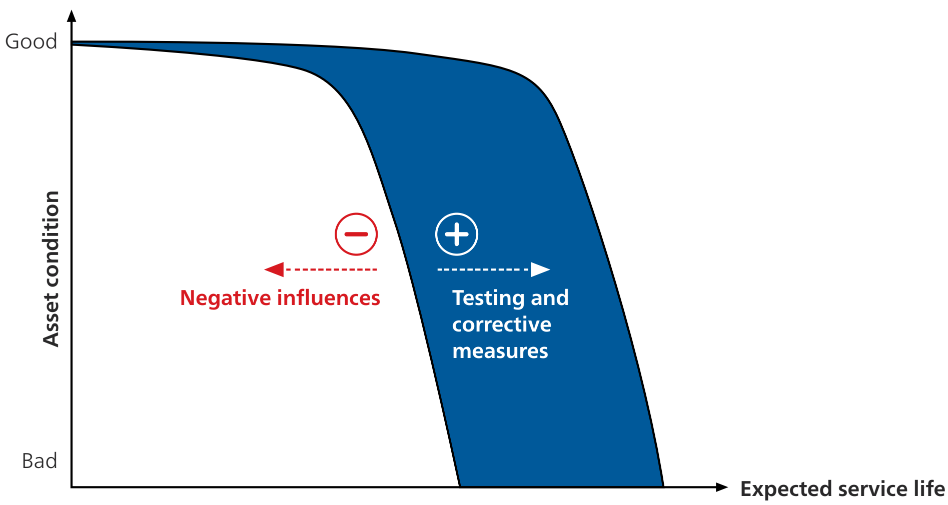


Figure 6: Ideal concept of extending the lifetime with condition-based maintenance

Test overview

The following table provides you with an overview of the most common issues and the electrical test methods used to detect them.

Machine part tested	What should be checked	Capacitance, dissipation factor (tan δ)/ power factor measurements	Partial discharge (PD) measurement	On-line PD monitoring	Voltage withstand testing	Insulation resistance, polarization index and dielectric absorption ratio measurements	DC winding resistance measurement	Contact resistance measurement	Pole drop testing	Sweep frequency response analysis	Dielectric response analysis	Electromagnetic imperfection testing
Stator winding	Partial discharges (PD)	■	■	■								
	Contamination	■	■	■		■					■	
	Insulation degradation	■	■	■		■					■	
	Voltage withstand				■							
	Insulation integrity				■	■					■	
	Connection problems						■					
	Inter turn faults									■		
Rotor winding	Inter turn faults								■	■		
	High contact resistance							■				
Stator core	Core imperfection											■

Table 1: Common issues in rotating electrical machines and the correlating test methods to detect them