WHITE PAPER

# Controlling partial discharge in high voltage motors and generators

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# Introduction – what causes partial discharge?

Partial discharge (PD) occurs in high voltage (HV) electrical equipment like cables, transformers, motors and generators. It is a kind of very small spark that occurs due to a high electrical field. In industrial high voltage motors and generators, electrical stress can reach several kilovolts per millimeter and this can give rise to PD either inside the insulation (internal PD) or on the surface (external PD).

Internal PD generally occurs in microscopic air-filled voids that remain inside the insulation, with the number and size of the voids depending on the procedures followed during manufacturing. Charges build up around the voids and when the local electric field stress across a void exceeds the breakdown field stress, a discharge occurs that short-circuits the void. Special equipment is required to detect and measure internal PD.

External PD occurs on the surface of the insulation, when the local electric field stress exceeds the threshold to ionize the air. Factors behind external PD can include poor air clearances, contamination on the end-windings, and variations or defects in the corona protection in the slots or on the end-windings. External PD is generally easy to detect by visual inspection as it usually results in a deposit of white powder on the surface of the insulation.

PD generates a short-duration plasma burst and emits UV light, both of which stress the insulation. It causes rapid localized temperature spikes and creates chemically aggressive substances such as nitrogen oxides, ozone and nitric acid. These effects impact the surrounding insulation, which should therefore be designed to withstand PD.

# Key roles for design, materials and workmanship

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01 Typical insulation system in high voltage stator winding (image courtesy of Von Roll).

It is not possible to completely avoid PD in high voltage motors and generators. Factors that influence the extent of PD activity include the quality of the design, materials and workmanship. This makes it important to select a reliable manufacturer with a proven track record in these areas.

Ideally the motor or generator should be designed for its specific purpose. A good manufacturer can design the product to match the individual application, taking into consideration all four of the TEAM (i.e. thermal, electrical, ambient and mechanical) stresses that cause aging. For example, the design parameters can be adjusted to strengthen the motor or generator against the effects of high vibration levels, wide ambient temperature ranges, high moisture levels, etc.

Special attention should be paid to the quality of the insulation system, as it naturally plays a key role in minimizing PD. ABB uses the Micadur™ Compact Industry and Enduraseal® systems for the stator windings of high voltage motors and generators, and these systems have been proven in thousands of units manufactured since the mid-1970s. They are based on form-wound technology, built on inorganic mica together with an epoxy-based resin, and undergo a global Vacuum Pressure Impregnation (VPI) process. This makes the insulation resilient to the appearance of microscopic voids and therefore resistant to PD. Under normal operating conditions the insulation system will withstand PD throughout the equipment's entire lifetime, and nothing more than the usual periodic maintenance is needed to manage PD. Of the thousands of ABB motors and generators manufactured with these insulation systems over the years, there have been no known premature failures caused by PD. Image 1 shows a typical insulation system in an high voltage stator winding.

Industrial high voltage motors and generators normally have a design lifetime of 20 years or more. For applications where a very long lifetime is crucial, some manufacturers offer special options. For example, ABB offers the Insulation+ and Lifetime+ product designs. Insulation+ motors and generators have extra layers of insulation – the number depending on the voltage level - to further decrease the electrical stress and therefore reduce the impact of PD. Lifetime+ motors and generators offer the same benefits as Insulation+ together with reduced thermal stress.

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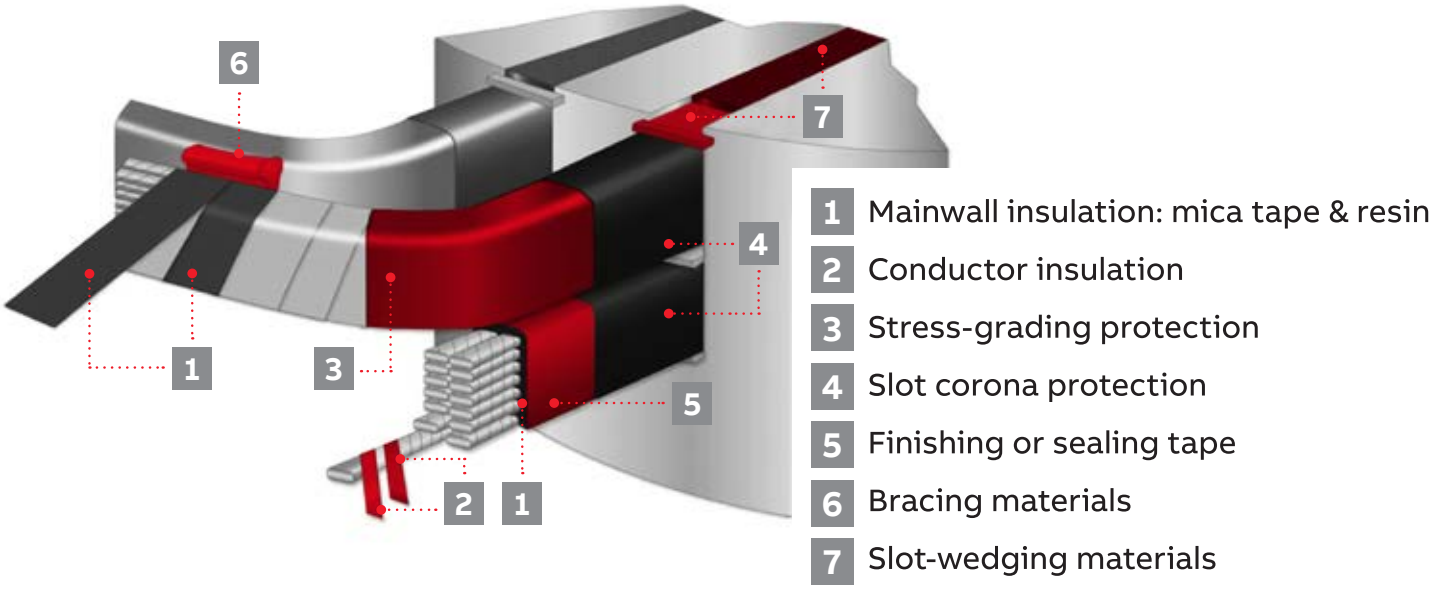

# Detecting and measuring PD

Some plants use PD level tracking as a condition monitoring tool for their high voltage motors and generators. Specialized expertise and equipment are needed to perform the measurements and analyze the results, and plants should decide whether they will train their own personnel to do this work or contract it out to an external service provider. These decisions should preferably be taken as early as possible, before the motor or generator is ordered, because there may be special hardware requirements, for example, that need to be accommodated.

Various methods are available to detect the energy released by PD, typically based on measuring electrical current pulses, ozone levels, sound, light or other high frequency radiation. This article focuses on measurement of electrical current pulses because this is the most commonly used method for motors and generators. Capacitive couplers can be installed in the main terminal box to allow connection of measuring equipment for online PD monitoring on-site.

PD pulses are characterized by their magnitude, polarity, length, and the phase angle at which they occur. PD is analyzed using special software, which may be capable of pinpointing the origin of the PD - especially when used by an experienced operator.

The magnitudes of individual PD measurements do not provide much information. They can be affected by many factors, including the type of sensors and measuring equipment used, the settings (e.g. detection bandwidth) and calibration, the type of software, and the ambient humidity, temperature and noise level. Noise sources that can affect results include welding equipment, overhead cranes and switchgear, to name just a few. Furthermore, PD pulses are attenuated as they are propagated within the stator winding itself. Image 2 is a PD pattern with high background noise, highlighting how noise can make interpretation of PD measurements difficult.

For these reasons the PD magnitudes obtained using different methods or equipment cannot be directly compared. In fact, even if accurate figures for PD magnitudes are obtained, they do not necessarily provide an indication of the remaining lifetime of the insulation. This is because electrical stress is only one of the TEAM stresses which act on the insulation, and for a given motor or generator it may not be the dominant factor in insulation aging. As a result, ABB and many other manufacturers follow IEC and IEEE standards in recommending that trended PD measurements are used rather than absolute magnitudes.

In spite of the limitations, it does make sense to measure PD – especially when this is done periodically to produce trend data. In particular, PD may be a symptom of a more serious issue which would be difficult to detect if PD measurements were not performed. In one case, for example, high PD levels were found when measurements were performed on a 25-year-old high voltage motor with insulation that was not globally vacuum pressure impregnated. See Image 3. Further investigation revealed that the coils were loose in the slots, and this was causing PD. The real problem was that movement of the coils was causing mechanical erosion of the insulation and this – rather than PD - would have eventually resulted in failure of the motor. It should be noted that this type of issue would normally not occur in a modern, high quality motor or generator as most reliable manufacturers now use global VPI for the insulation.

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02 PD pattern (obtained by plotting PD magnitudes as a function of their phase angle). High background noise makes this PD measurement unusable.
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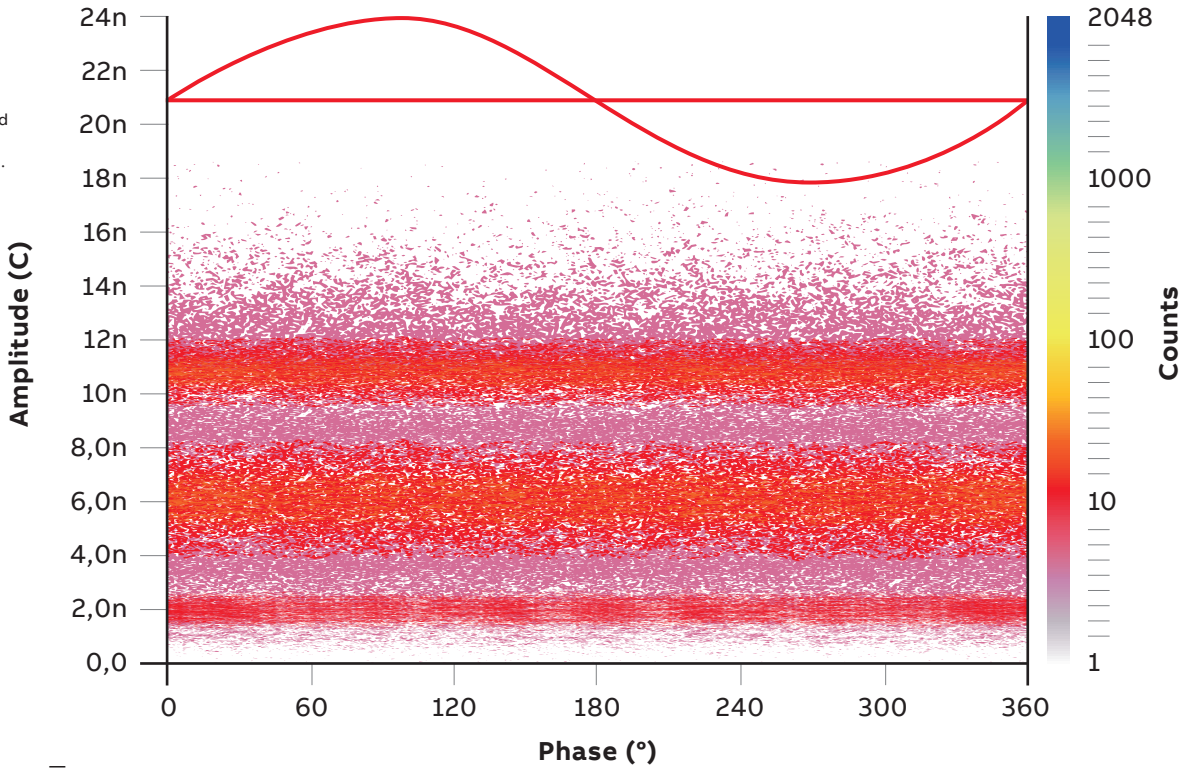
03 PD pattern showing high PD levels on a 25-year-old 13.8 kV motor. In this case the PD was caused by looseness of the coils in the slots.

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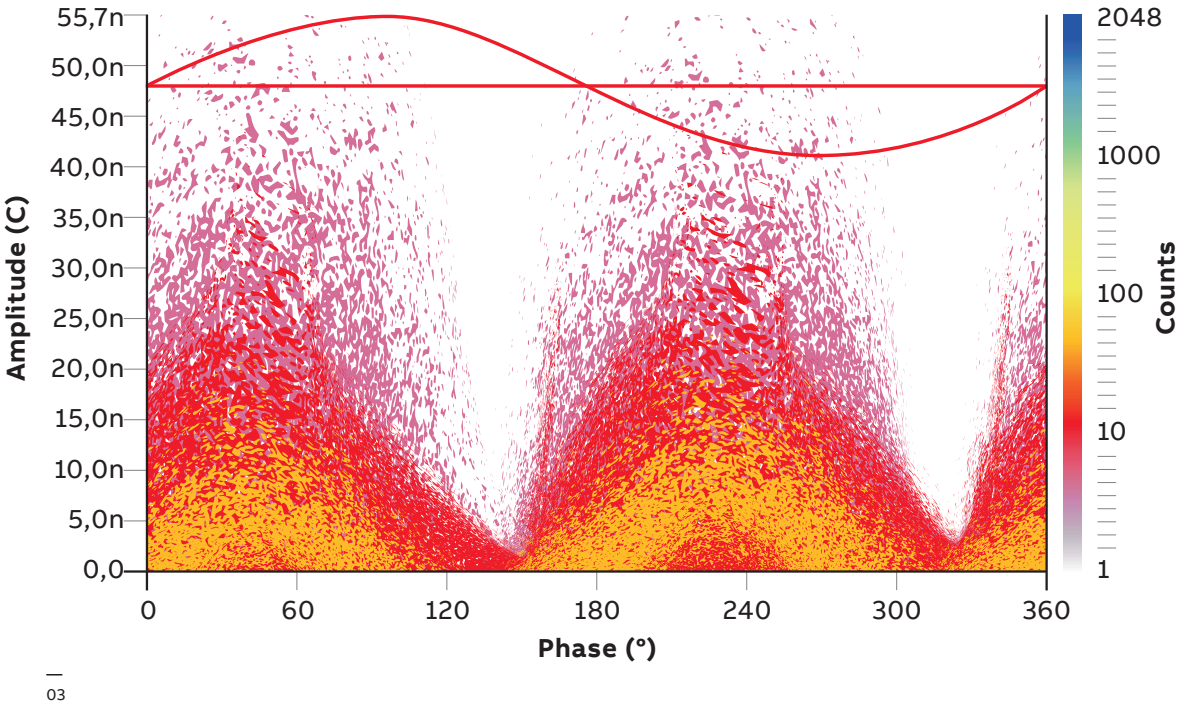


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# Condition monitoring and service

Many manufacturers provide recommendations for condition monitoring of their motors and generators. ABB recommends that the condition of the windings is monitored regularly, for example, and can install coupling capacitors in the main terminal box to enable periodic offline or even online PD measurements.

To establish a basis for trending PD measurements, ABB can perform fingerprint measurements on new motors and generators as part of the factory acceptance testing (FAT). However, it is recommended that a new fingerprint measurement is taken after commissioning because PD activity on-site can vary significantly from the activity level measured during FAT. This is due to the different environmental conditions, noise level, and measuring and calibration equipment on-site.

Measuring PD alone does not provide enough information on the condition of the motor or generator, and visual inspections and other evaluations also need to be done. Services like ABB LEAP (Life Expectancy Analysis Program), which provides regular on-site assessments of the condition of the stator winding insulation and evaluates possible changes in the expected lifetime, can be used for this purpose. ABB LEAP Standard level, for example, includes analysis of polarization–depolarization current, non-linear insulation behavior, tan delta and capacitance, and other assessments, in addition to PD measurements. This can be combined with ABB's standard service program, which mainly focuses on the rotor, bearings and cooler, and includes visual inspections, to realize a broad overall assessment. The data produced by ABB LEAP are more stable than PD measurements alone, as each measurement is enhanced by the others and a large database of earlier tests is used as a basis for ABB LEAP reports.

If monitoring reveals a rising trend in PD levels, this may indicate that a problem exists and action should be taken to identify the source of the PD. If the increase in PD is due to ambient factors – such as a dirty or wet winding – the solution is simply to clean and/or dry the winding. The aging process is highly dependent on temperature, and if high temperatures are causing accelerated aging the cooler can be serviced to bring them back down to normal levels.

# Does it make sense to stipulate low PD levels?

An increasing trend in the high voltage motor and generator markets is for plants to stipulate low PD levels when specifying new equipment. Unfortunately, this will not necessarily ensure a longer lifetime or increased reliability, but it will lead to higher cost and overdesign.

As explained above, reliable manufacturers seek to ensure that the primary high voltage insulation materials in their motors and generators are resistant to PD, i.e. they are designed to operate under varying levels of PD activity. There is also no direct correlation between PD magnitude and insulation lifetime because, for a given motor or generator, electrical stress may not be the dominant TEAM factor behind insulation aging. Furthermore, it is fairly meaningless to state that PD is “low” – absolute PD magnitudes are very difficult to evaluate, which is why trends in PD levels should be used instead.

# Conclusion

This paper highlights a number of ways in which motor and generator users can control PD. The first decision that needs to be made concerns the manufacturer. It makes sense to select a reputable manufacturer with a solid track record, because issues like the quality of the design and workmanship, and selection of materials, play a central part in determining the level of PD activity. At the same time it is worthwhile deciding on PD level tracking - will regular measurements be taken, and if so, who will be responsible? What hardware will be used?

By contrast, specifying low PD levels during the procurement process is not a recommended approach because it will lead to higher costs but will probably not produce the desired results.

Individual measurements of PD magnitude are difficult to evaluate. Therefore periodic measurements should be taken, starting with a fingerprint measurement on the new winding, in order to obtain trend data. A more comprehensive alternative to measuring PD alone is a service like ABB LEAP, which is performed at regular intervals and includes PD along with a number of other measurements. Visual inspections should also be carried out.

While standard high voltage motors and generators from dependable manufacturers are designed and built to withstand PD, enhanced products like ABB's Insulation+ and Lifetime+ will provide even longer service lifetimes and further increased reliability. An investment in this type of extended-lifetime product could be considered as an alternative to an investment in PD monitoring.

# Notes

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For further information please contact
your local ABB representative or visit:

**www.abb.com/motors&generators**



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