TechTalk

Partial Discharge Failure in MV Motors

Compiled by John Sherriff | April 2021 | Rev 1

The scope

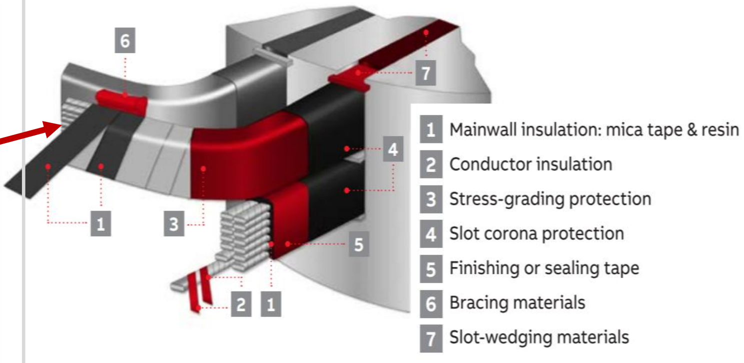
Partial-discharge (PD) measurements have long been used to assess the condition of the electrical insulation in motors and generators rated 3.3 kV and above. There are many ways to measure PD during the normal service of the motor or generator. The drawback with many methods of measuring PD in the stator windings is that measurements are influenced by electrical-interference signals from poor electrical connections, tracking from insulators, discharges from connected terminations and other types of defects. The result can lead to false positives of stator-winding problems, reducing the confidence in PD analysis.

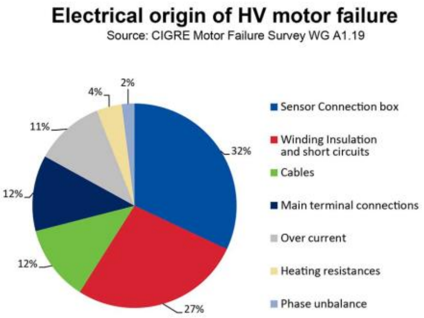
What method is used?

Unconventional PD measuring (IEC 62478) methods and systems can detect PD signals, identifying different physical characteristics and properties of the PD. In general, electrical methods are based on the measurements of electrical signals in the radio frequency (RF) ranges.

Unconventional PD measuring for MV and HV motors

This process is conducted on site during the online condition assessment for the complete energised power circuit and not just the motor stator winding system. This method highlighted high-risk areas within the feeder cable insulation system (joints), terminations, insulators, high resistance connections, overhang (SIWO-KUL) cable and phase connections, current transformer defects, and the complete motor winding insulation system.





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Partial Discharge Failure in MV Generators

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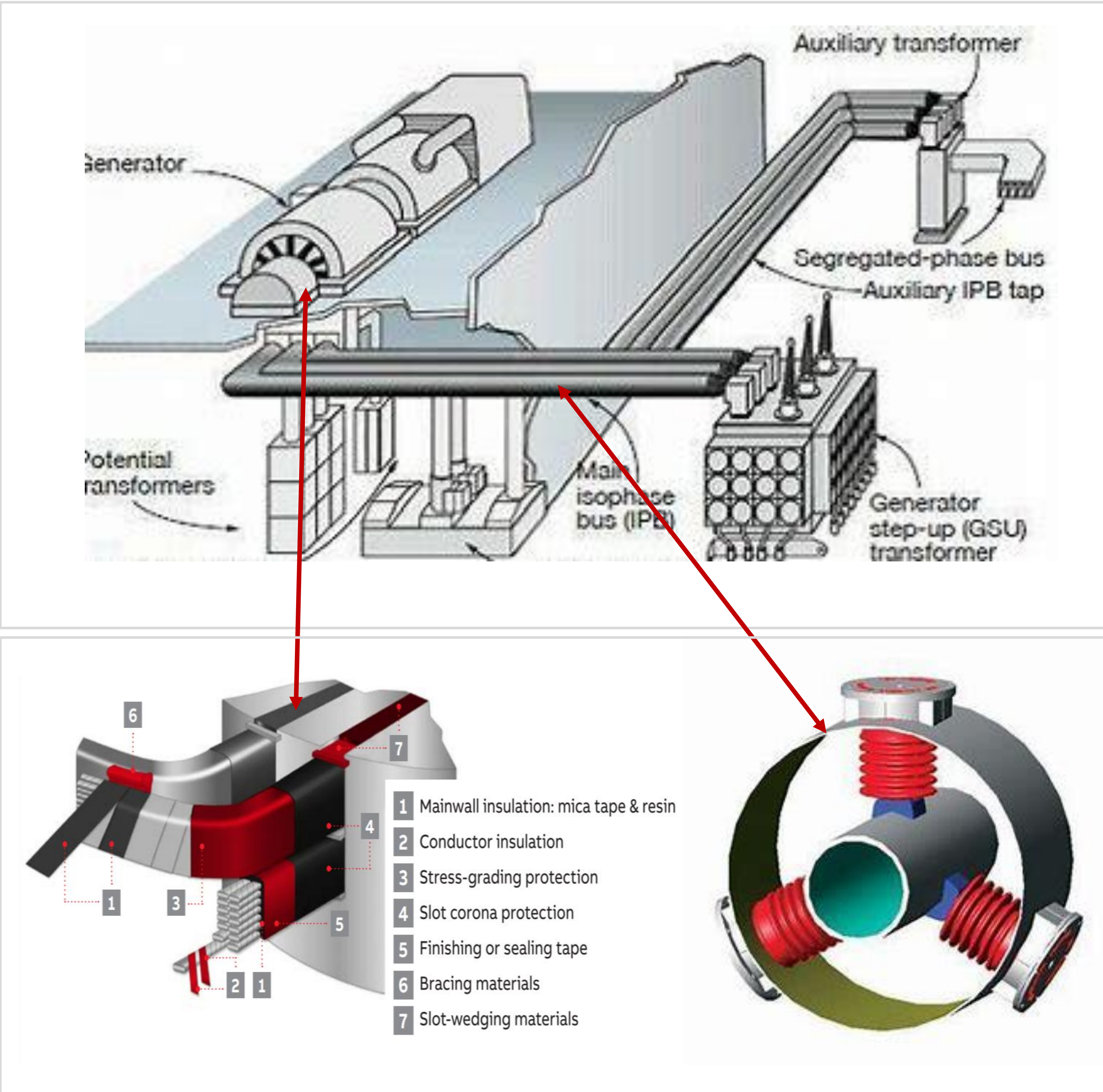
Unconventional PD measuring for air cooled generators

This process is conducted on site during the online condition assessment for the complete energised power circuit and not just the generator stator winding system. This method highlighted high risk areas within the ISO bus duct, insulators, high resistance connections, and the complete generator winding insulation system.



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Partial Discharge Failure in MV Motors

Key Challenge

A key challenge when PD measurements on a motor or generator winding are acquired under normal operating conditions is the presence of noise. Since the machine is connected to the power system, multiple sources of electrical interference (noise) is often present:

- Corona from the power system
- Slip ring/commutator sparking
- Sparking from poor electrical connections
- Tracking from insulators
- PD from the power supply connections

This question should be asked:

Is this harmless noise interference or signs of a defect that can turn into a failure that may result in removal of the MV motor or generator from service?

This electrical noise can mask the PD pulses and may cause an inexperienced technician to conclude that a stator winding has high levels of PD when it is actually due to noise. The consequence is that a good winding is incorrectly assessed as being defective, meaning that a false alarm is given, suggesting that the winding is bad when it is not. Such false alarms reduce the credibility of online PD tests, and even today, many feel that online PD testing is a "**black art**" best left to specialists. This TechTalk briefly describes objective methods that separate PD from the noise in the motor power circuit.

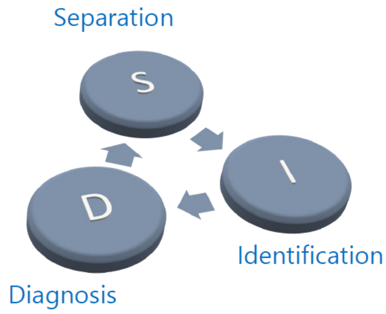
Does a PD assessment provide value added benefits?

When using unconventional methods aquiring wide frequency bands and analysing various frequencies during the on-line assessment , the answer is a definite **YES,** the value added is knowing the defects (all defects within the power circuit). This knowledge can be used by engineers to make good decisions on the highlighted risk areas that can be rectified to avoid premature failures.

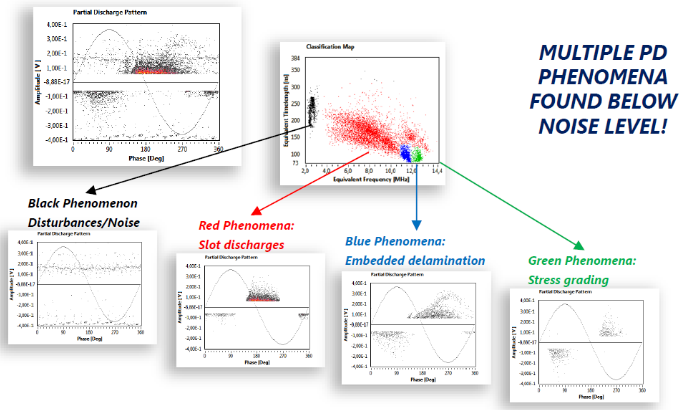
How do "black art" get analysed?

Understanding the power of the on-line technologies, the type of sensors and the TEAM (Thermal, Electrical, Ambient and Mechanical) stresses that can influence the outcome of the analytical process. On-Line condition assessment is not **BLACK ART** and is the best tool to identify deterioration of insulation systems.
These days, software programs give the analyst the power to conduct advanced analytical processes that will eliminate the thought of "analysing is a guessing game". This process must be linked to calculators taking the Qmax (mV), Pulses per cycle and the PDI (mW) intensity into account.

Q_{max} (V)	This is the peak value measured during the entire integration time. This unit should not be used for absolute comparison, but only relative comparison.
$Q_{max95\%}$ (V)	In order to estimate the maximum magnitude of PD (associated with the size of the defect in the insulation), it is not possible to use the highest value detected in an acquisition, because it is not statistically representative. Therefore, the maximum amplitude statistics Qmax 95 % is used, which defines the magnitude of PD below the 95 % of all detected.
N	Repetition Rate (n) - It is the average number of partial discharge pulses per second measured over a selected time. In practice, only pulses above a specified magnitude or within a specified range of magnitudes may be considered.
N_w	Repetition rate as pulses per period of the applied voltage. Additionally, it is very important to know the N_W factor, which is the number of discharges detected per cycle (Cacciari, Contin, & Montanari, 1995). This parameter is directly related to the number of imperfections that can cause PD in the insulation.



- Separation of any multiple PD sources and noise rejection
- Identification of PD Type based on the PD Pattern and resulting harmfulness
- Knowing number and type of defects, the resulting Diagnosis is more accurate and effective



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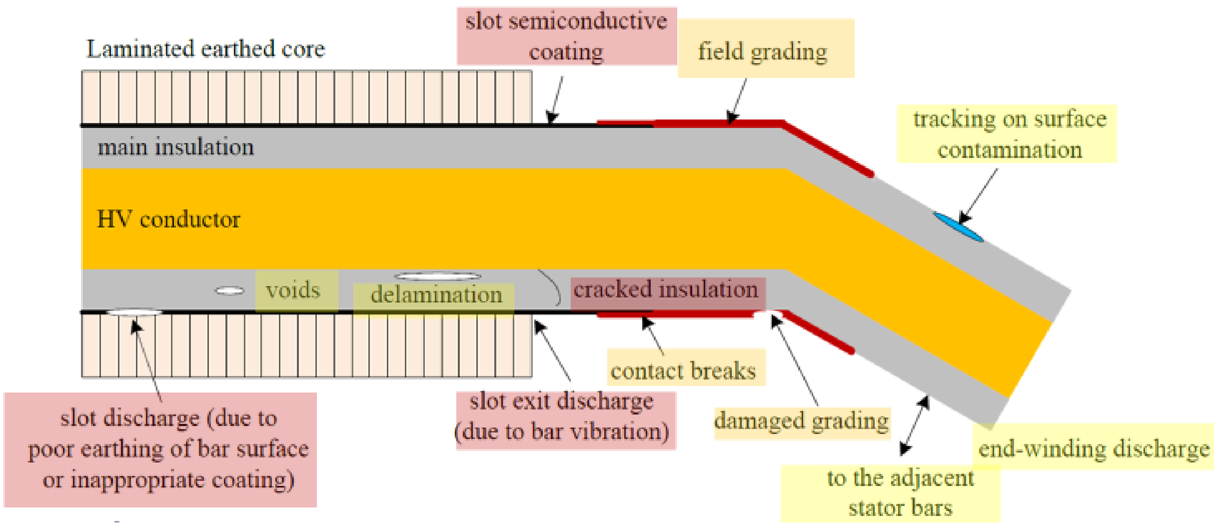
Partial Discharge Failure in MV Motors and Generators

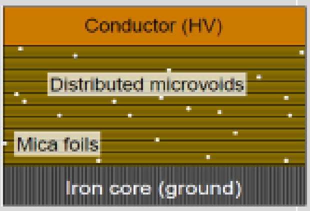
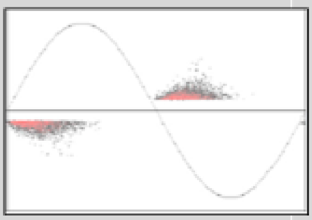
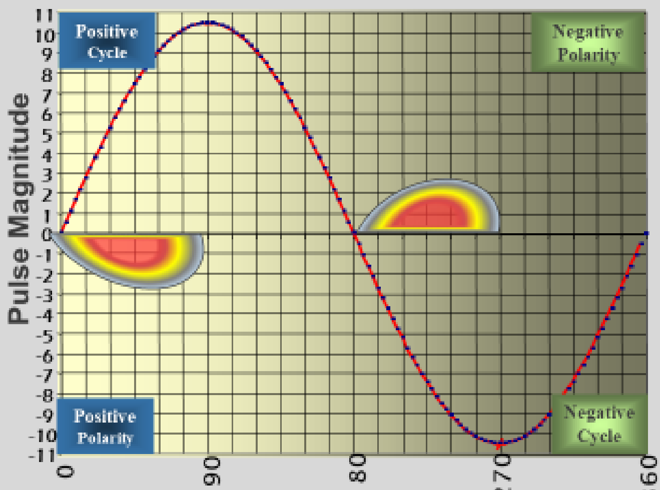
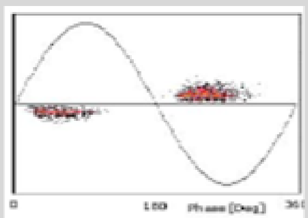
Partial Discharge Phenomena (MV Motors and Generators)

Partial discharge will have different occurrences, i.e. discharges will be different between insulation voids, insulation delamination, contact breaks, crack insulation, end winding, bar to bar, stress grading and slot discharges (highest risk). These partial discharge phenomena's also have different failure rates. Surface tracking is not as destructive as discharges in the slot section, especially with loose wedges that can add to bar bumping and faster deterioration of the stress control systems.

Common areas of PD activities within the stator windings.



Voids in the main wall insulation system

Voids Partial Discharges	Cause	Location	Damage
Void discharges in the insulation system.	These cavities (voids) in the ground wall insulation system is due to unavoidable imperfection in the impregnation process.	Partial discharges in the ground wall insulation section.	The damage caused by partial discharges is a low risk.
Identification of PD	**PD patten**		**Description of the PD patten**
 			Balanced between positive and negative pulses combine with a rounded shape. Typically, negative pulses occur between 0° and 90° and positive pulse occur between 180° and 270° 

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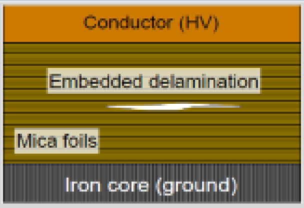
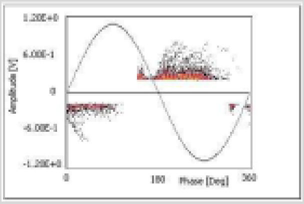
Partial Discharge Failure in MV Motors and Generators

Internal delamination of the insulation system

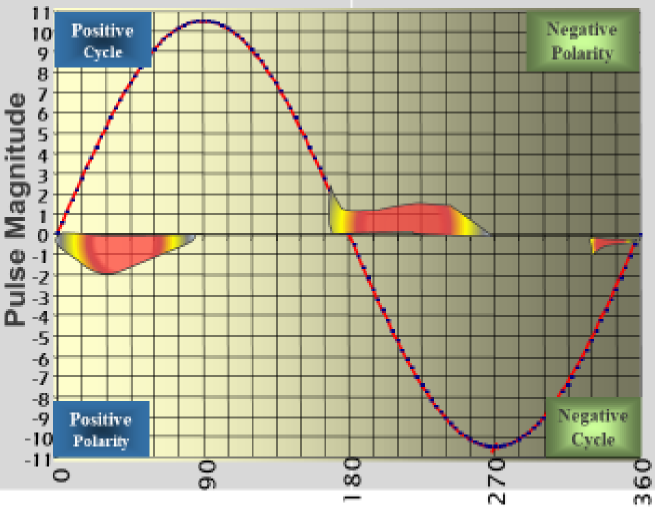
Internal Delamination	Cause	Location	Damage
Internal delamination of the insulation system	Unavoidable imperfection in the impregnation process and delamination of old insulation especially mica type systems	Partial discharges in the ground wall insulation section.	The damage caused by partial discharges is a moderate risk due to overheating and mechanical forces that separate large areas between insulation layers.

Identification of PD





PD patten

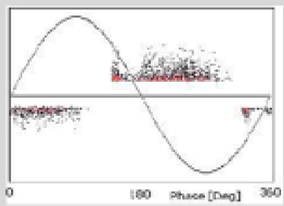


Description of the PD patten

The patten will be symmetric in amplitude and repetition rate.

The patten is similar to internal void discharges, although the repetition rate will be much higher and the shape is less rounded

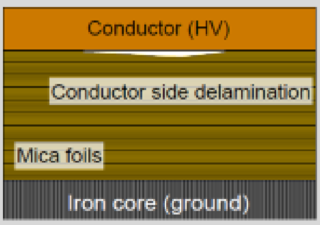
Internal embedded delamination



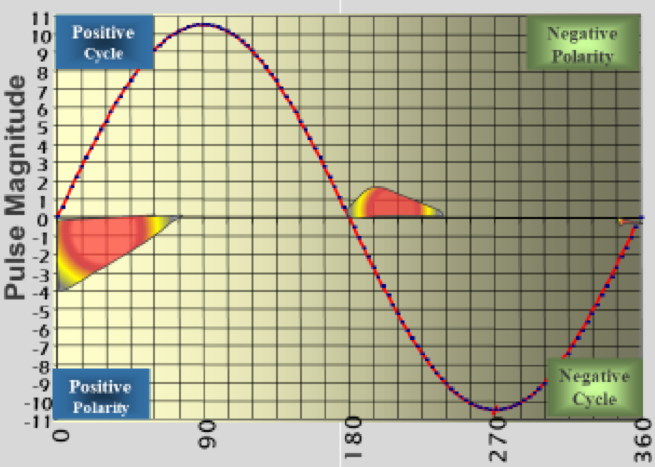
Conductor Side Delamination of the insulation system

Conductor Side Delamination	Cause	Location	Damage
Internal delamination of the insulation system close to the conductor side	Unavoidable imperfection in the impregnation process and delamination of old insulation especially mica type systems.	Partial discharges in the ground wall insulation section.	The damage caused by partial discharges is a moderate to high risk due to overheating and mechanical forces that separate large areas between insulation layers.

Identification of PD



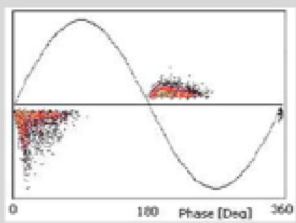
PD patten



Description of the PD patten

The discharge represents an unequal patten with in favor of negative discharges occurring in the positive half cycle (1st quarter)

The positive discharge in the negative half cycle (3rd quarter) intensity is also lower.



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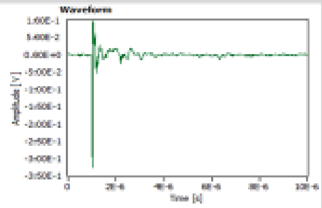
Partial Discharge Failure in MV Motors and Generators

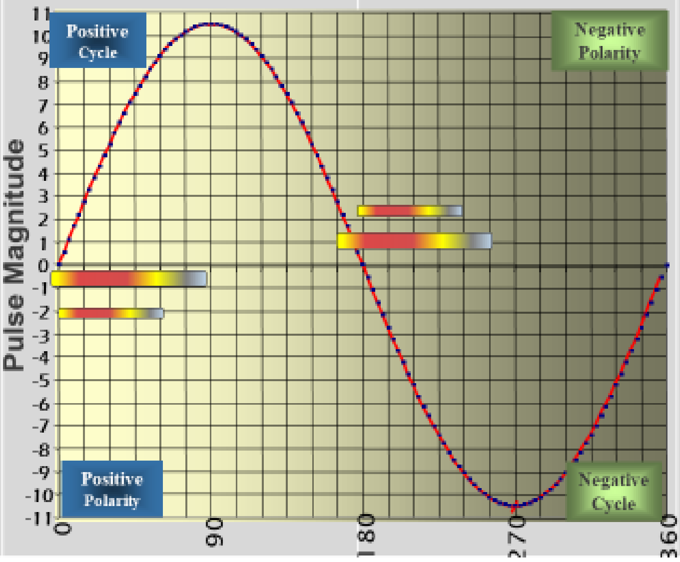
Bar to Bar Partial Discharges (Between top and bottom bars)

Bar to Bar	Cause	Location	Damage
Discharges between two bars in the winding.	Inefficient air gap between top and bottom bars.	This type of discharge will occur between two bars (phases) in the overhang winding	The damage caused by partial discharges are low to moderate deterioration of the insulation system.

Identification of PD



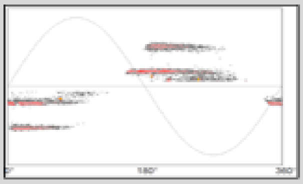
PD patten

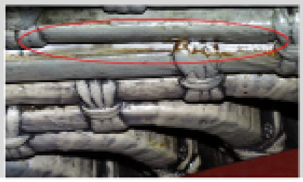


Description of the PD patten

The main characteristic of a gap type discharge activity is a horizontal cloud of PD pulses presented in both polarities and can be found in the 1st and 3rd quarter.

These discharges can be in the cycle from before the zero-crossing due to discharges between bars (Phases)

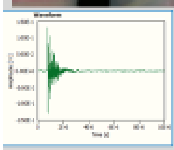


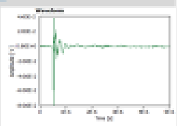


Stress Control Corona Partial Discharges

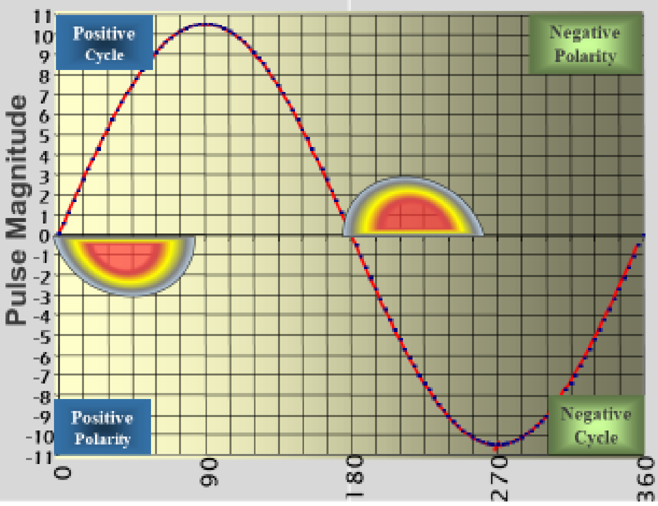
Stress Control PD	Cause	Location	Damage
When the contact resistance between stress-grading and slot-coating is too large or there is no contact at all.	No or limited contact between the stress grading and slot coating	Gas type discharges in the stress control area (Ionization)	The damage caused by partial discharges (corona) in the stress grading system is moderate to high

Identification of PD





PD patten

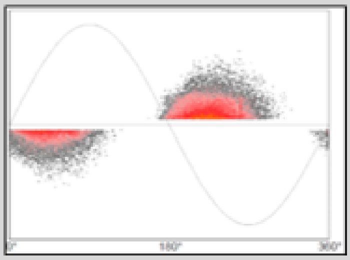


Description of the PD patten

The semi conductive coating discharge is a negative pulse in the positive half cycle and the mV intensity is low as well as the repetition rate.

Discharges start at the zero crossing.

The discharges pulses is in both cycles the same mV intensity.



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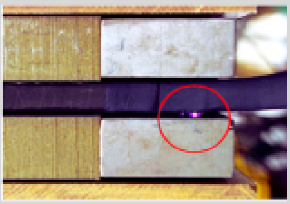
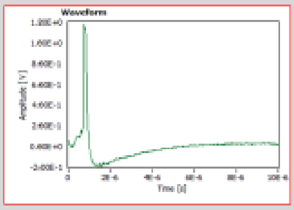
Partial Discharge Failure in MV Motors and Generators

Bar to Core Partial Discharges

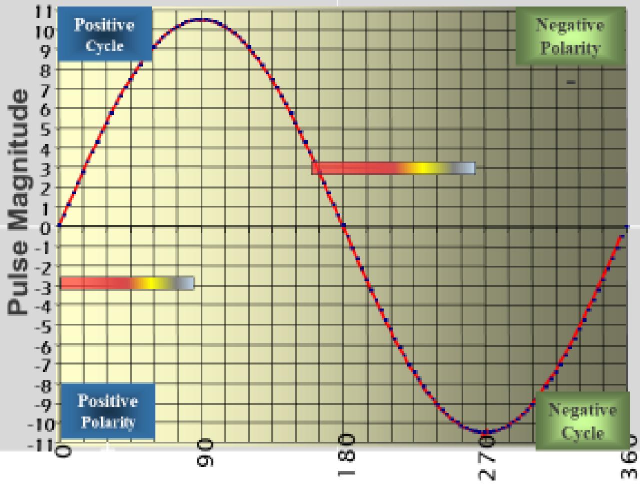
Between Bar and Core Finger	Cause	Location	Damage
Discharges between the core finger and stator bar	Inefficient air gap between top and bottom bars and damage to the stress control system.	This type of discharge will occur between the core finger and stator bar exist.	The damage caused by partial discharges are moderate to high deterioration of the insulation system.

Identification of PD



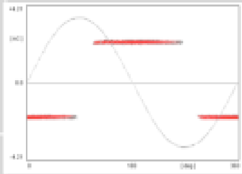


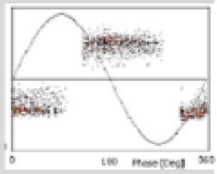
PD patten



Description of the PD patten

The main characteristic of a gap type discharge activity is a horizontal cloud of PD pulses presented in both polarities and can be found in the 1st and 3rd quarter.

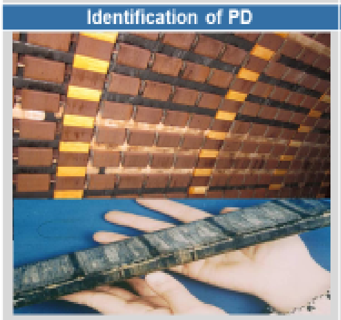


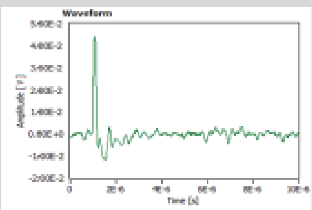


Slot Partial Discharges

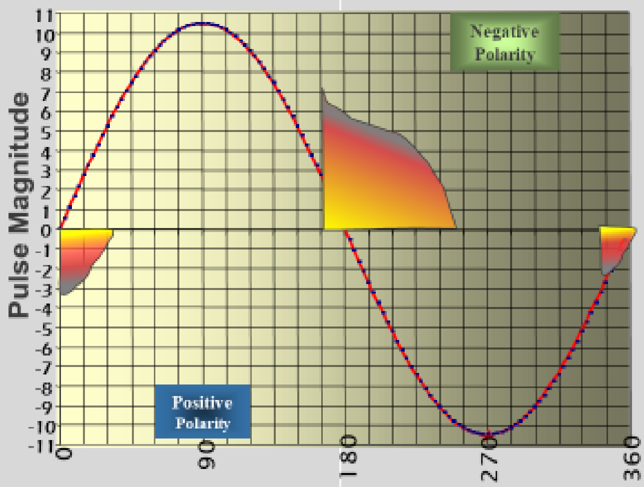
Slot Partial Discharges	Cause	Location	Damage
Slot discharges in rotating machine	Poor design and manufacturing and Lack of maintenance due to loose wedges.	Partial discharges in the slot section between the coil and core	The damage caused by partial discharges of the coil insulation system is a high risk.

Identification of PD





PD patten



Description of the PD patten

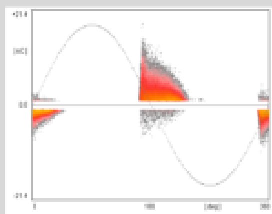
Occur between dielectric (HV, anode) and metal (LV, cathode)

Are observable when slot coating is too resistive or has been abraded by mechanical wear (such as from vibrations.)

Are asymmetric: predominant PD activity occurs during the negative half-cycle of the supply voltage

"Pulse magnitudes on negative half wave is higher than on positive.

Partial Discharge primarily between ground and insulation



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Partial Discharge Failure in MV Motors and Generators

$Q_{max95\%}$ (V) Value for air cooled machines 80 pF couplers

The main purpose of the table below is to give guidance to determine which motors and generators/motors have deteriorating stator insulation, allowing them to plan appropriate maintenance. **For example, for a 13.8-kV stator:**
- 25% of tests had a Qm below 45 mV
- 50% (the median) of the tests had a Qm below 113 mV
- 75% -were below 247 mV
- and 90% of tests yielded a Qm below 510 mV.

Thus, if a Qm of 500 mV is obtained on a 13.8-kV motor, then it is likely that this stator will be deteriorated, since it has PD levels higher than 90% of similar machines.

Information	Rated kV						Remarks
	2-5	6-9	10-12	13-15	16-18	>19	
Martec	9	28	45	55	42	60	25% of the results have Qmax levels below these values
IEEE Transactions on Industry Applications Vol. 42, No. 1,	7	17	35	44	37	N/A	
Dynamic Ratings	5	13	36	37	N/A	N/A	
25% Average – Level 1	**7**	**19**	**39**	**45**	**40**	**60**	
Martec	22	71	100	120	80	106	50% of the results have Qmax levels below these values
IEEE Transactions on Industry Applications Vol. 42, No. 1,	27	42	88	123	195	N/A	
Dynamic Ratings	22	37	83	96	N/A	N/A	
50% Average – Level 2	**24**	**50**	**90**	**113**	**138**	**106**	
Martec	62	159	214	258	175	289	75% of the results have Qmax levels below these values
IEEE Transactions on Industry Applications Vol. 42, No. 1,	100	116	214	246	195	N/A	
Dynamic Ratings	73	112	207	236	N/A	N/A	
75% Average – Level 3	**78**	**129**	**212**	**247**	**273**	**289**	
Martec	216	318	436	507	338	664	90% of the results have Qmax levels below these values
IEEE Transactions on Industry Applications Vol. 42, No. 1,	242	247	454	508	615	N/A	
Dynamic Ratings	155	218	473	514	N/A	N/A	
90% Average – Level 4	**204**	**261**	**454**	**510**	**338**	**664**	
Martec	360	494	679	764	555	971	95% of the results have Qmax levels below these values
95% Average – Level 5	**360**	**494**	**679**	**764**	**555**	**971**	

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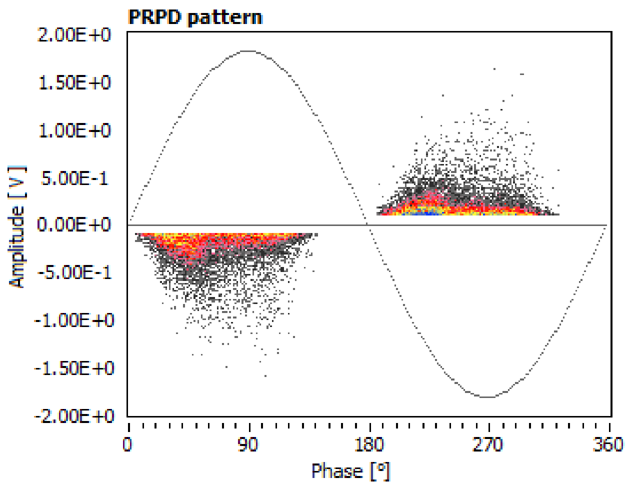
Partial Discharge Failure in MV Motors

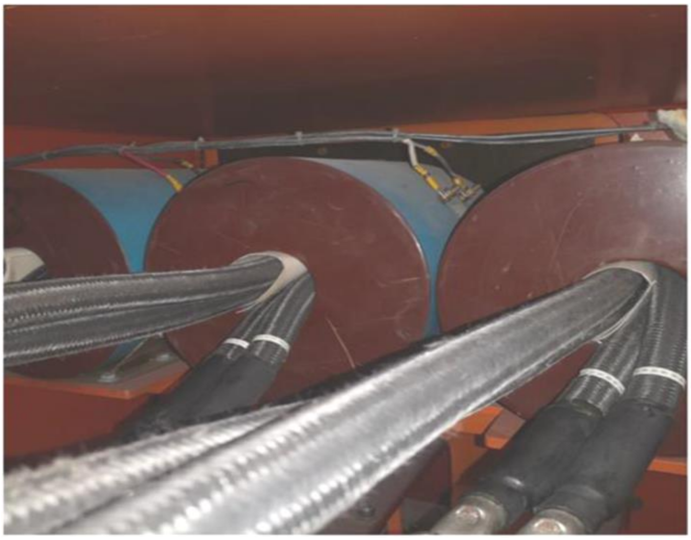
PD in the ring connections and Current Transformers (Siwo-Kul Cable)

The Siwo-Kul cables are part of the MV motor power circuit and if any of these fail, the motor will be out of service for a long time due to contamination and other factors.

Therefore it is important to identify these defects and not look at it as interference noise.

Discharges between two phases were detected during the on-line assessment and identified as Siwo-Kul cable PD.





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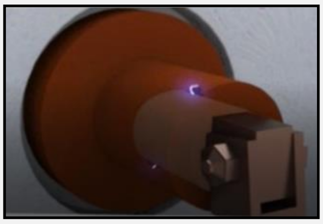
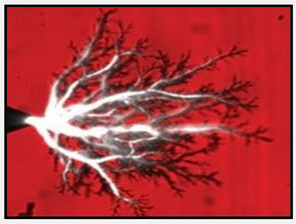
Partial Discharge Failure in MV Motors

PD in the bushings (Surface tracking and Cracked Insulators)

The motor bushings and insulator can have hairline cracks, added moisture, and contamination will create surface type discharges that can turn into premature failures.

Over time, these carbon tracks can spread and form a tree-like shape.

Due to a large number of discharge points and a high number of potential discharge sites in a tree-shaped track, it results in a high discharge rate, often in the range of 8 – 30 pulses per cycle but can be greater.

Component	Defect Type	Progression	End Result
Connections Insulators Cable to VTs	Contamination Cracked / broken Loose connection	Surface tracking Partial discharge Overheating	Erosion Electrical tree Failure
			

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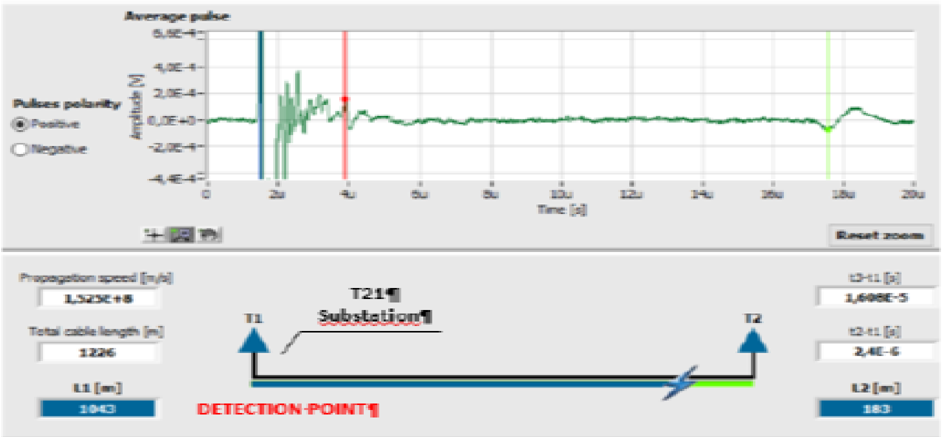
Partial Discharge Failure in MV Motors

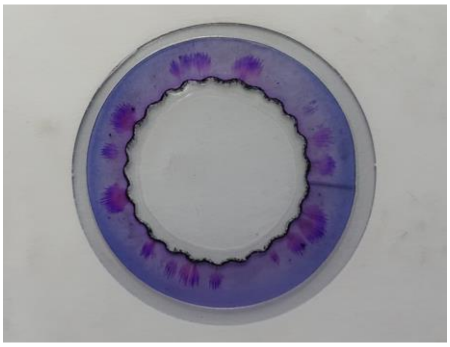
PD in the terminations

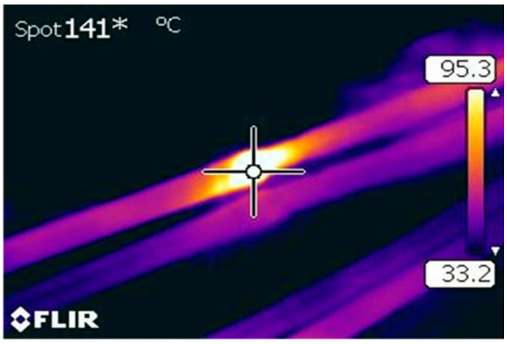
The motor terminations are at the highest risk of failure. This is due to incorrect termination installations, phase leads crossing over in the unshielded area, phase leads touching earth, bad lug connections (High resistant connections) and insulator tracking due to small cracks or contamination.

PD in feeder cables

The feeder cables connected to the motor could be at risk of failure and therefore must be assessed during the on-line condition assessment process. The on-line condition assessment will highlight partial discharge defects within the cable and joint insulation systems at operating temperatures







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Partial Discharge Failure in Generator ISO Bus Duct

PD in ISO Bus Duct System

Partial discharges can lead to failures in the ISO bus duct systems if not identified.

Defect	Possible result	Method of detection
Cracked porcelain	Moisture entry, oil or gas leaks, filler leak out	Visual inspection Power factor test
Deterioration of cement joint		
Gasket leaks		
Voids in compound (porcelain)	Internal corona	Partial discharge
Corona	Internal breakdown, treeing along surface of insulator, ionisation or air due to insulator defects	

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Partial Discharge Failure in MV Motors and Generators

Maintenance and Engineering Decisions

Good maintenance begins with a **proactive approach** to maintain, keep, preserve and protect the equipment.
The most fundamental proactive system to maintain, keep, preserve and protect the equipment is a comprehensive preventive maintenance program.

What does that mean? Preventive maintenance (PM) consists of many parts. Let's break it down into two primary components: **Essential care and Condition monitoring**.

- **Essential Care -** Essential care is preventive maintenance that relates to the prevention of failures. This is analogous to checking the air pressure in the tires on your car or changing the engine oil on a routine basis. In industry, these tasks are generally noted as lubrication, cleaning, adjusting, operating, etc.

- **Condition Monitoring -** Condition monitoring (periodic assessments) is the part of preventive maintenance relating to the detection of failures. It is like checking the wear profile of your car's tires. The tires' wear profile can be how you detect failures (i.e., problems). In industry, these tasks are generally noted as inspection (identify defects), investigation (locate defects), root cause (prevent defects), quality assurance (record findings), monitor (trending).

"But if that's not what the client want, then the client can do whatever to define maintenance and except unwanted premature failures".

Knowledge of the partial discharge phenomena is very important to make the correct engineering decision on the action that should be implemented to avoid premature failures.

Conclusion

Electrical insulation is one of the most important sources of unexpected failures in electrical equipment. It is well known that voltages cannot exceed rated values to avoid electrical breakdown of insulation systems. However, even rated voltages are able to create Partial Discharges (PDs) in power cables and electrical machines. These discharges are low energy electrical breakdown phenomena that take place in highly divergent electrical fields regions and inhomogeneous sites within a solid dielectric.

Partial discharges do not cause immediate failures but contribute to degrade insulation systems by means of chemical and physical attack of the surroundings of the main solid dielectric. This leads to premature failures in electrical equipment, because partial discharges take place several times per power frequency cycle.

Identification of PD phenomena is the key prerequisite to carry out effective maintenance since different partial discharge activities lead to different degradation rates within an insulation system.

As an example, *corona (PD) occurring inside the ISO Bus Duct may not require an immediate action, while an internal partial discharge inside a MV cable termination or in an epoxy bushing can lead to a failure even in a few days. Therefore, ability of detecting, identifying and locating PD events in MV apparatuses is necessary and add value to prevent premature failures.

**It must be noted, that even the corona in the ISO Bus Duct can over time lead to premature failures due to ionization and contamination that can create electrical trees and failure.*