Introduction to Partial Discharge diagnostics on Rotating Machines

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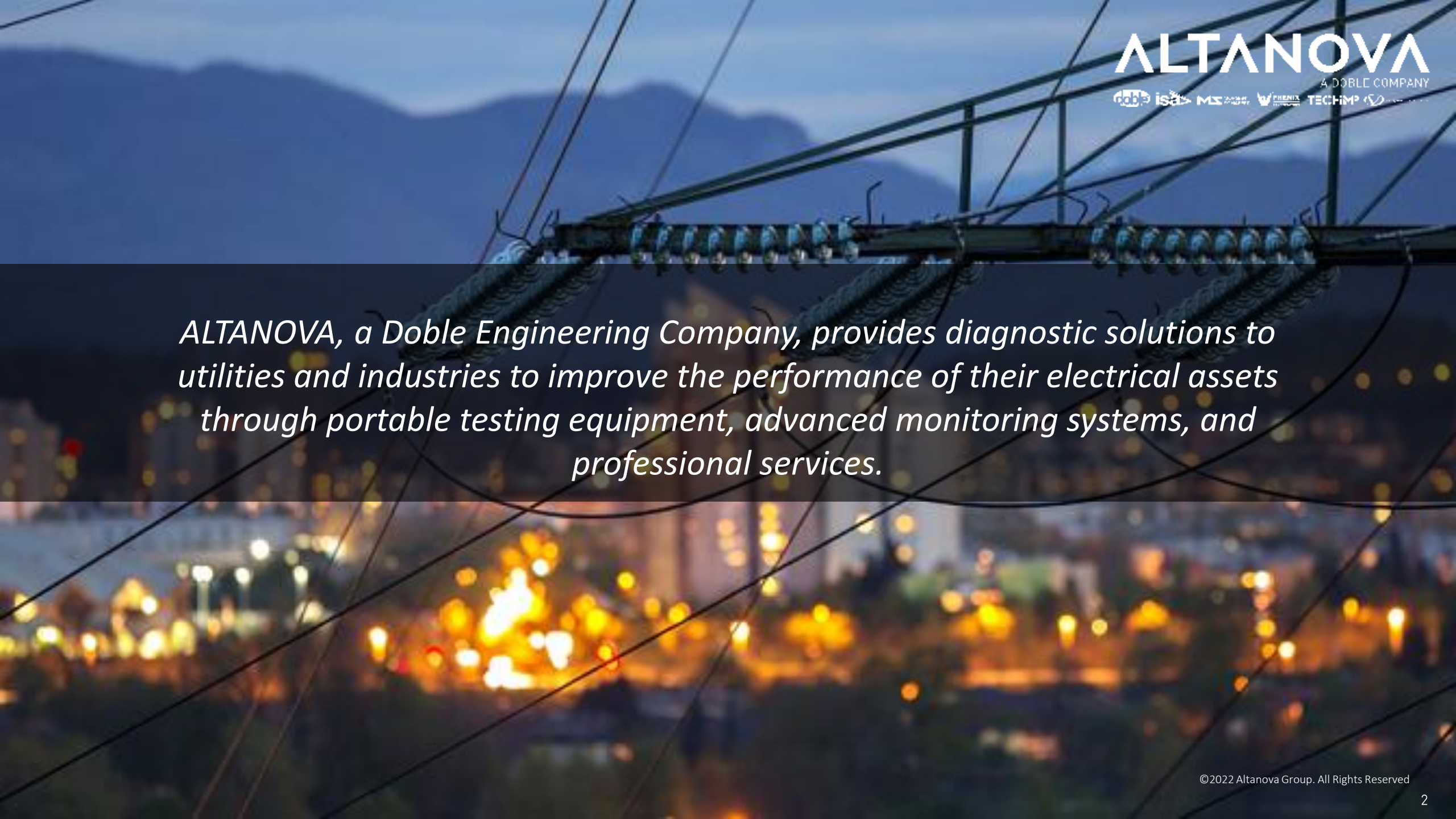

ALTANOVA, a Doble Engineering Company, provides diagnostic solutions to utilities and industries to improve the performance of their electrical assets through portable testing equipment, advanced monitoring systems, and professional services.

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Altanova History

1938 I.S.A. Istrumentazioni Sistemi Automatici S.r.l. is established in Taino ITALY

1999 TECHIMP was born as a spin-off from the University of Bologna ITALY.

2017 I.S.A. and TECHIMP merge giving birth to the ALTANOVA GROUP

2019 INTELLISAW joins ALTANOVA GROUP

2021 ALTANOVA GROUP becomes part of ESCO Technology Group and joins the Doble Engineering Company, as part of the USG division.

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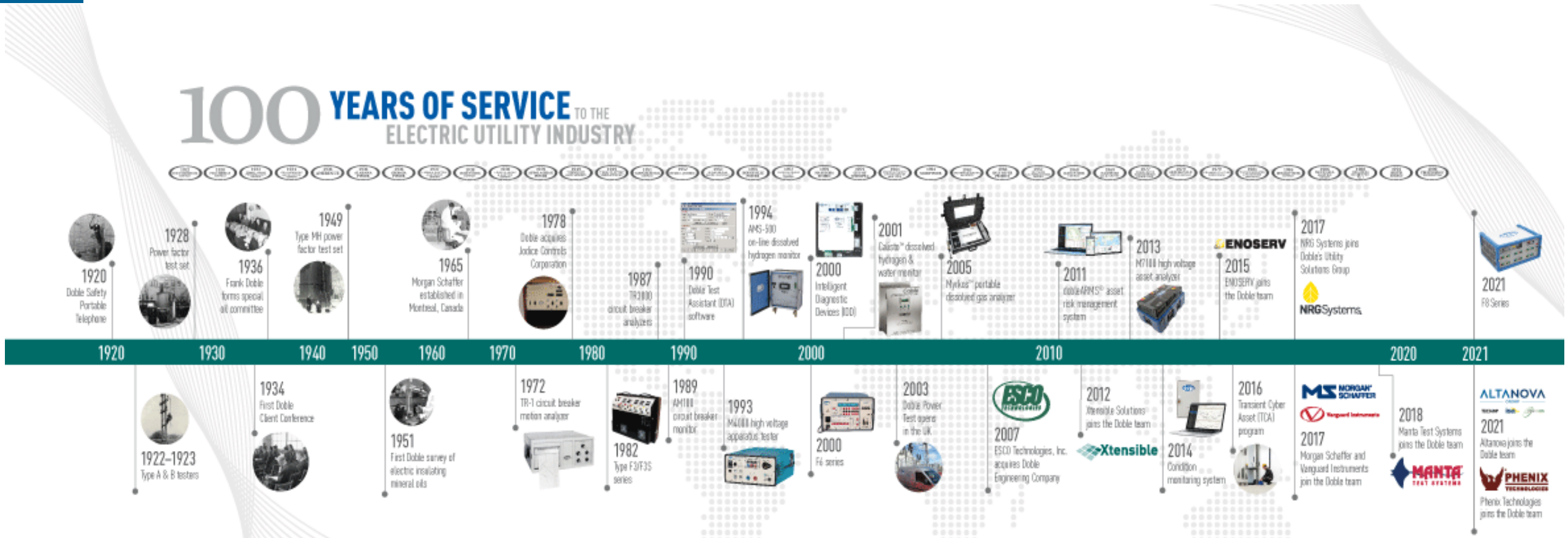
Doble History



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Altanova Today

ALTANOVA
A DOBLE COMPANY

100
COUNTRIES

12
GLOBAL FACILITY LOCATIONS

150+
EMPLOYEES

150+
SALES PARTNERS

5550+
CUSTOMERS GLOBALLY

Part of ESCO Technologies' Utility Solutions Group

PRODUCT BRANDS

doble · isa · MS MORGAN SCHAFFER · PHENIX TECHNOLOGIES · TECHIMP · Vanguard Instruments · ESCO TECHNOLOGIES

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Our Solutions

Electrical Test Equipment

Essential for day-to-day maintenance tests of electrical assets. Useful in specific phases of the asset lifecycle:

- Procure
- Operate
- Maintain
- Decommission.

Professional Services

Diversified offer according to the electrical asset lifecycle:

- Installation and commissioning
- Diagnostic test
- Data analysis
- Consultancy
- Training.

Monitoring Systems

Shift from a time-based maintenance to a condition-based maintenance.

Focus on predictive maintenance and shift in focus from electric asset value cost to network outage costs.

Strong evolution of digitalization trend in the power industry.

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Testing And Monitoring Solutions For:

ALTANOVA
A DOBLE COMPANY

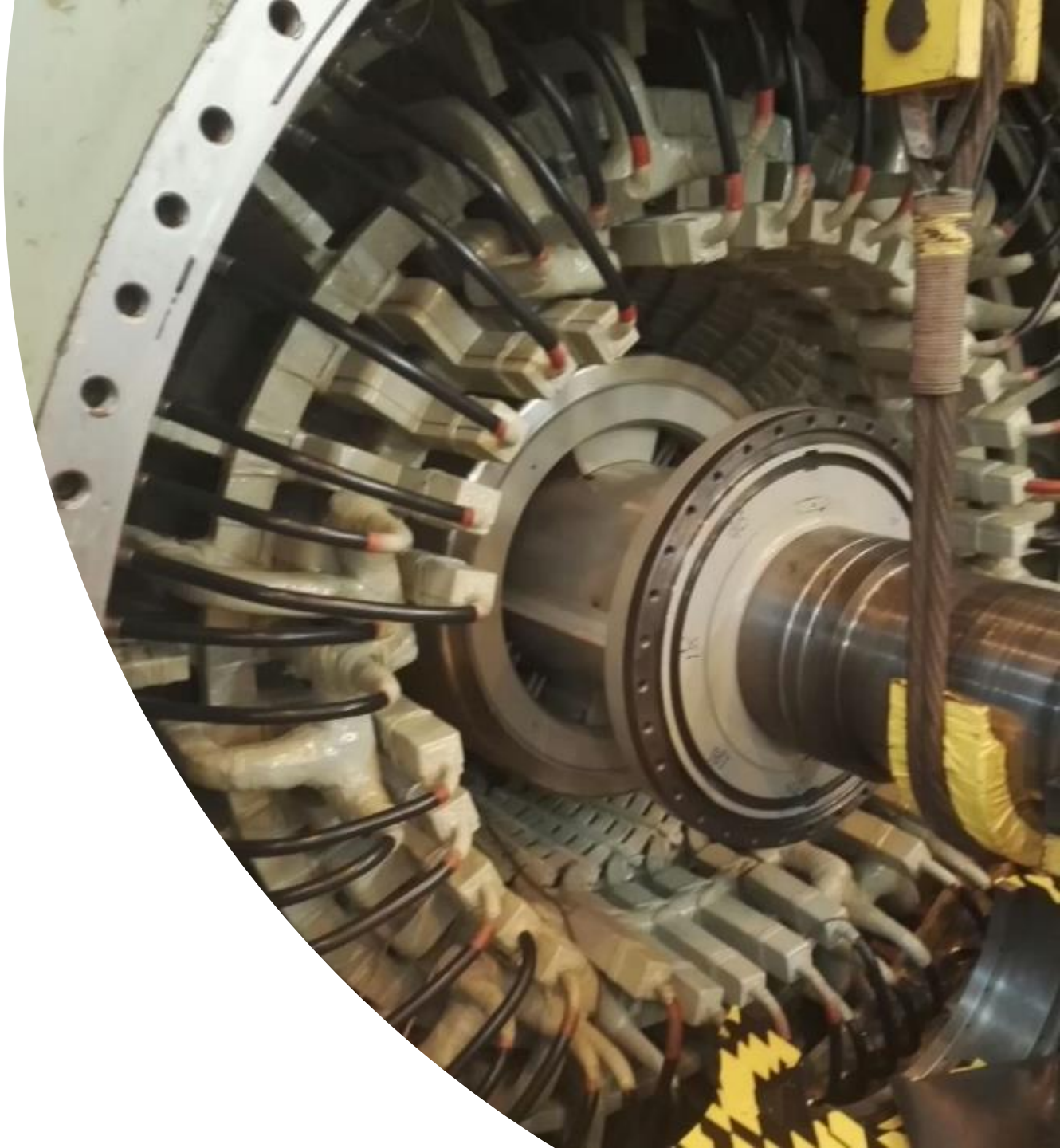
- Power transformers
- Circuit breakers
- HV gas insulated switchgears
- MV/HV/EHV cables
- MV/LV switchgears
- Batteries
- Current & voltage transformers
- Protective relays
- Meters and transducers
- Rotating machines
- Variable speed drives
- Overhead lines






Summary

- Rotating machines diagnostics
- PD & rotating machines
- PD sensors for rotating machines
- On-line vs Off-line
- Typical PD phenomena
- Denoising & Crosstalk
- PD analysis
- Case studies



RM diagnostics

- Resistance and tandelta
- EMI
- PD and rotating machines

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RM diagnostics

Traditional Rotating Machines electrical test

- Insulation Resistance
- Polarization Index
- Winding resistance
- Tandelta
- Capacitance

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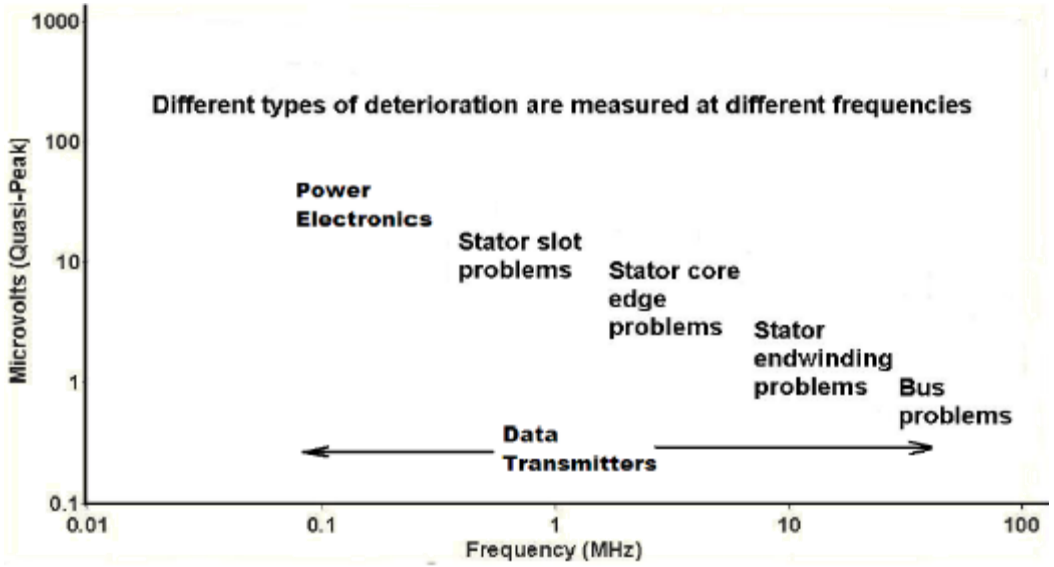
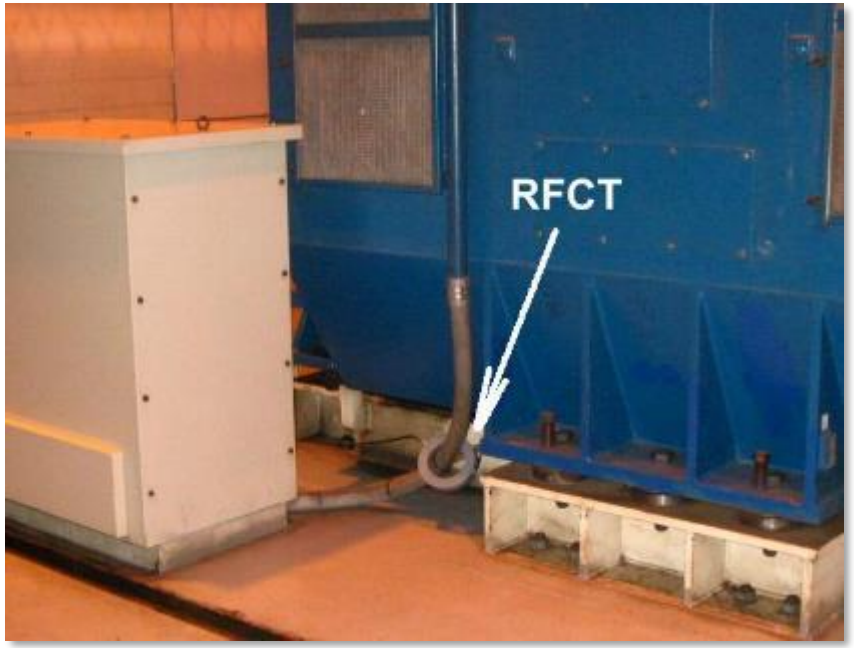
RM diagnostics

Electromagnetic Interference

EMI testing cover a wide range of signals thanks to their signatures.





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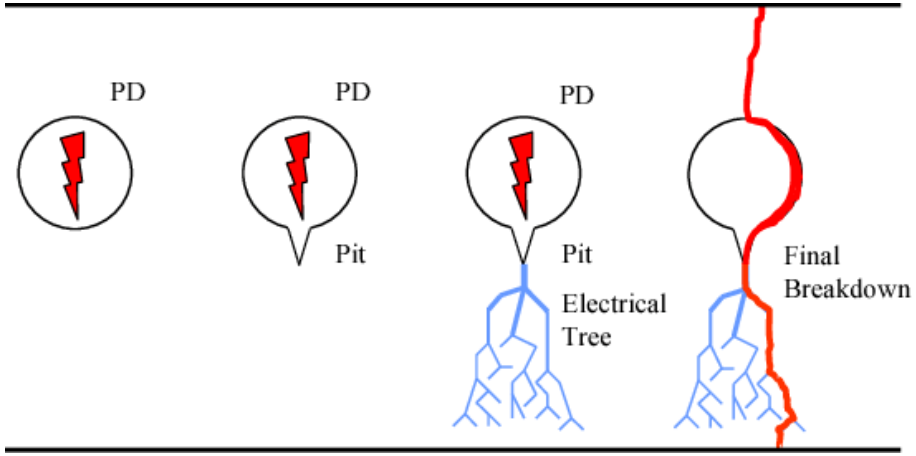
RM diagnostics

PD and rotating machines

Partial Discharge Definition:

IEC: *"Localized electrical discharge that only partially bridges the insulation between conductors and which can or can not occur adjacent to a conductor"*



IEEE: *"Localized electrical discharge that only partially bridges the insulation between conductors"*

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PD and rotating machines

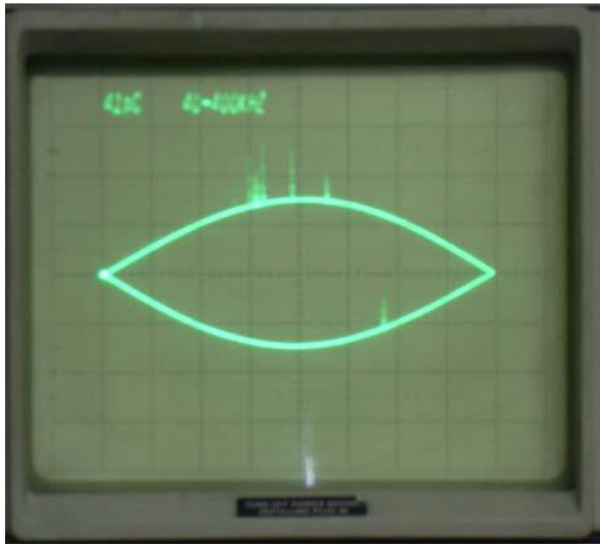
PD and rotating machines

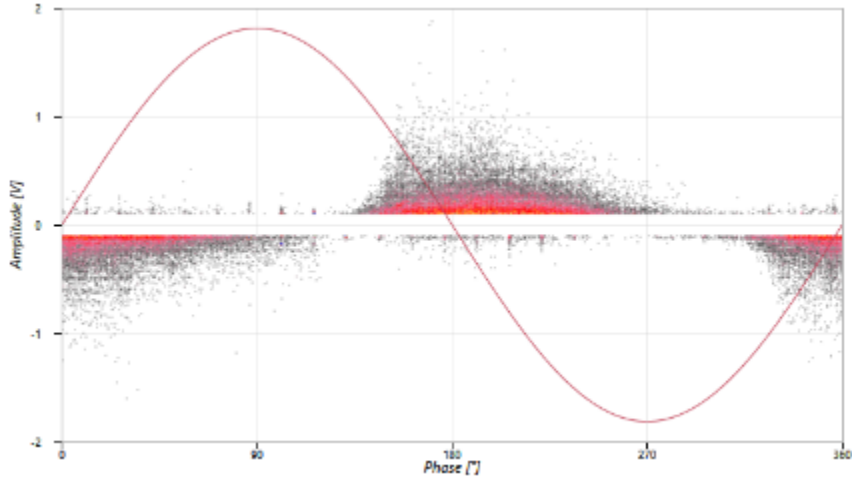
Phase Resolved Partial Discharge Pattern:

Each PD phenomenon generates thousands of PD pulse each second. The common way to visualize them is to plot the pulses' amplitude correlated with the applied voltage.

The correlation is based on the PD physics, the electrical stress due to the applied voltage activates PD.

PRPD pattern recognition is the key for PD diagnostics outside of laboratories.





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PD and rotating machines

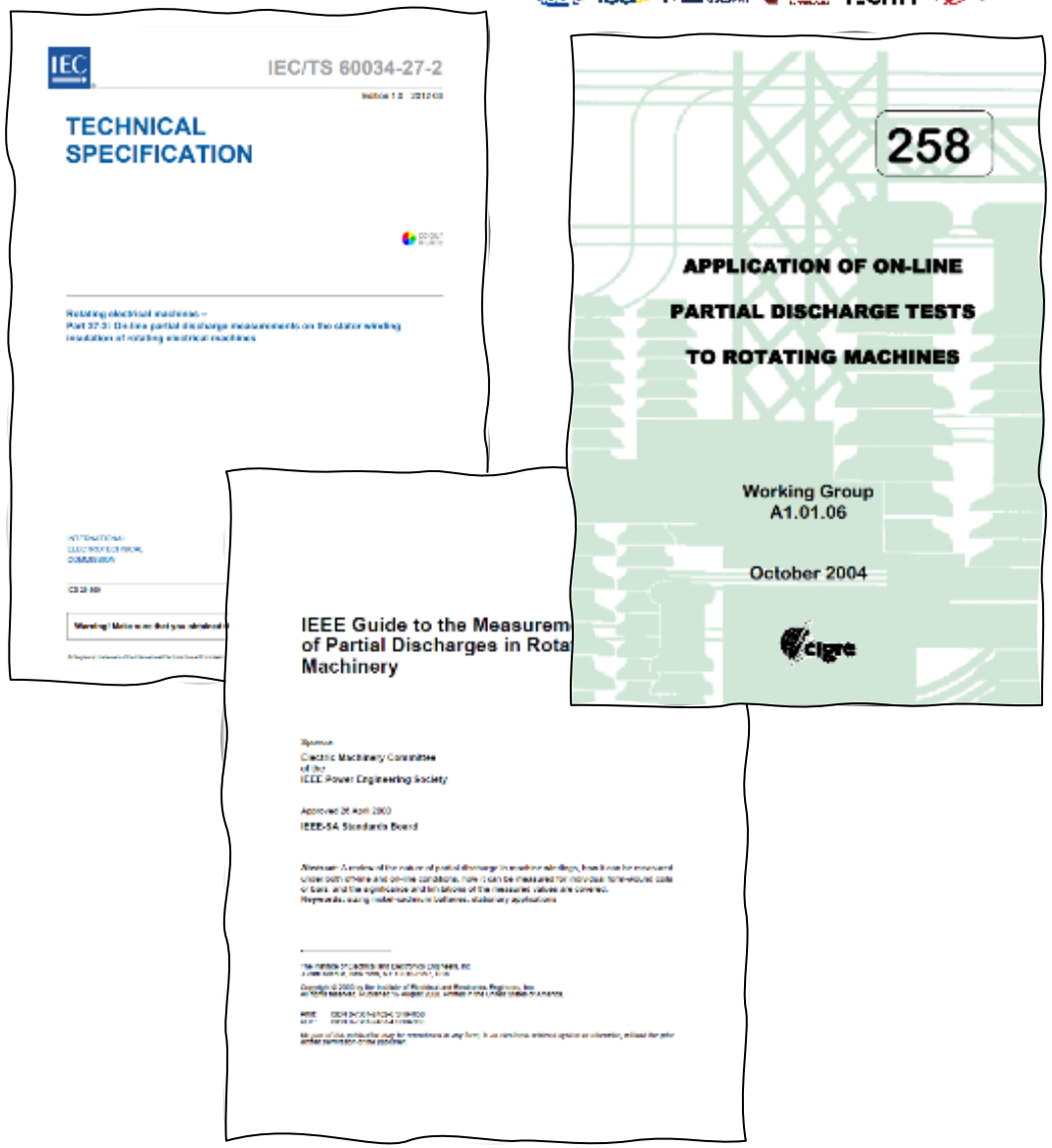
PD and rotating machines

International standards:

IEC 60034-27-2: *On-line partial discharge measurements on the stator winding insulation of rotating electrical machines*

IEEE 1434: *Guide for the Measurement of Partial Discharges in AC Electric Machinery*

CIGRE 258: *Application of on-line partial discharge tests to rotating machines*



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PD sensors

- How to detect the signal
- Sensors typologies
- Sensors Requirements
- Sensors Positioning
- Signal & Safety

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PD sensors

How to detect the signal

Localized insulation defects generate PD signals when subjected to electrical stress: the phenomena is a source of high frequency electromagnetic signals & irradiated signals.

The conducted signal path can be force into a sensor and measured while the irradiated signal is subjected to generator design those can attenuate & affect the sensitivity.

Different sensors:

- Different PD output
- Sensitivity
- Sync signal

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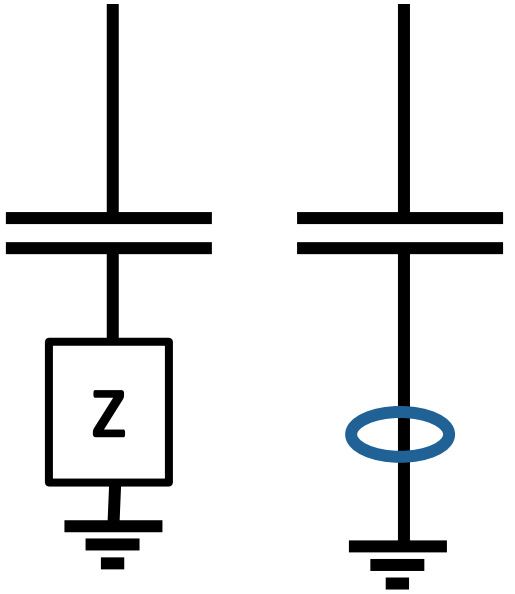
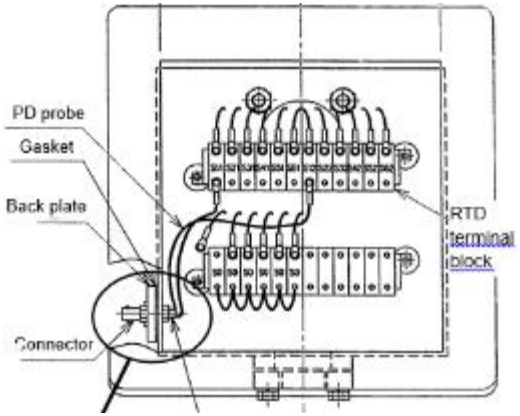
PD Sensors for RM

Sensors Typology

The most popular sensor are capacitive couplers, connected to the machine windings, the PD signal is then measured:

- As voltage drop across and impedance
- By current transformers
- Slot sensors are used as well: installed close to windings to capture irradiated PD signal





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PD Sensors for RM

Sensors Typology

	Capacitive	**Capacitive+ HFCT**	**Slot sensors**
Sensitivity	High	Poor	Very high locally
Installation	Medium Effort	Medium Effort	High effort
Safety	medium	Very high	high
Synch signal	YES	NO	NO
Coupling principle	Conducted signal	Inducted signal	Radiated signal

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PD Sensors for RM

Requirements

Permanent PD sensor will be installed to HV rotating machine

➔ avoid any failure risk for the equipment under monitoring:

- Stressful type testing (impulsive test, thermal, long run HVAC)
- Each sensor subjected to 3x rated voltage withstand test
- Each sensor PD free @rated voltage after pres-stress session
- Capacitance and voltage ratio tested with small tolerance values

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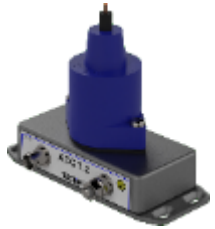
PD Sensors for RM

PD COUPLERS 7KV 1000pF THREE-PHASE KIT



Ideal solution for 6.6 kV motors, limited room required for the installation, light sensor, the permanent installation kit comes with the derivation box (ip 68 selectable), signal cables and HV connection kit.

PD COUPLERS 12/17/24KV 1000pF THREE-PHASE KIT

3 different voltage classes 12kV, 17,5 and 24kV. The voltage classes are influenced by the creepage distances required for the different classes, sensors dimensions depend on such distance

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PD Sensors for RM

Sensors Positioning

PD sensors are installed in hazard zones and the risk of failures shall be minimal.

- Metallic parts shall be nonmagnetic.
- The PD sensor system shall not reduce the insulation capabilities of the stator.
- Temperature and vibration stress to be considered.
- Avoid Corona & surface PD.

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PD Sensors for RM

Signal & Safety

Coaxial cables are used to bring the signal to the derivation box.

Derivation box is required not just to get PD & sync signal from sensors but enhances the safety of the whole system by adding a passive safety on the derivation box side.

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Online vs Offline

- PD offline test
- PD online test
- Technical comparison
- Practical comparison

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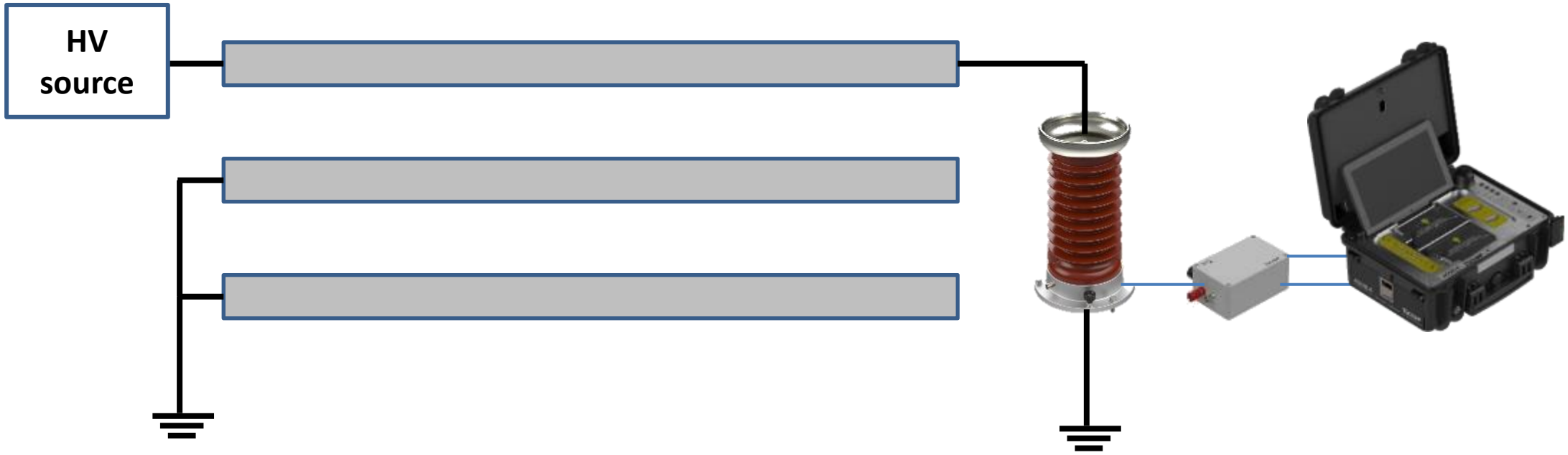
Online vs Offline

Off-line PD test

Off-line PD test refers to a PD measurement performed during machine outages with external voltage source, the PD sensor can be temporary installed and removed after the test.



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Online vs Offline

Off-line PD test

In the offline PD test we have to take into account few technical aspects:

- Phase to ground only, constant along the winding.
- Motionless, no temperature change occurs during the test.
- Steady, the test is not taking into account mechanical behavior.
- Phase by phase test.
- The voltage source shall be free of PD signals.
- PDIV & PDEV evaluation.
- Insulation overstress

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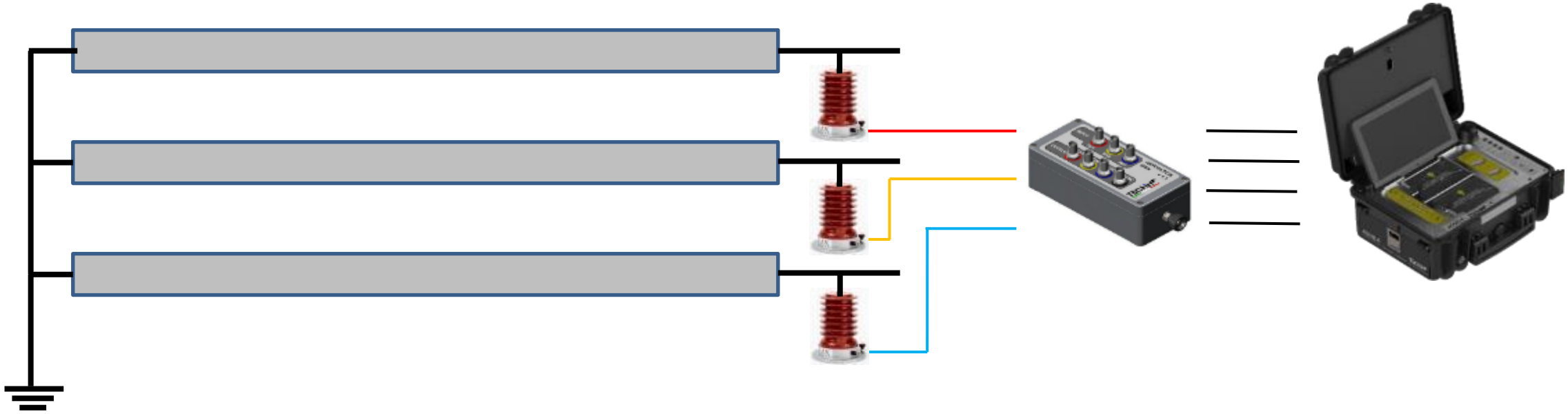
Online vs Offline

Online PD test

Online PD test is performed with running machine in load conditions, permanent sensor are required, it is also possible to temporary install the PD sensors by taking strict precautions and planning an outage.



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Online vs Offline

Online PD test

In the online PD test we have to take into account few technical aspects:

- Routine stress
- Different load and different temperature
- Crosstalk effects
- External disturbances
- 3 phase simultaneous phase
- Permanent sensors
- Safe test

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Online vs Offline

Technical Comparison

	Offline	**Online**
Permanent sensor required	NO	YES
Crosstalk effect	NO	YES
Real electrical stress	NO	YES
Correlation of historic data	Depending from sensor and acquisition unit	Same sensors Depending on acquisition unit
TEAM stress	NO	YES

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Online vs Offline

Practical Comparison

	Offline	**On line**
Price	High	Low
Customer effort	High	High
Outage required	YES	NO
PD Sensor	Brought by service company	Sensors compatibility
Safety	Potential hazards	Safe test
Stress	Different voltage levels applied	Electrical Temperature – Load changes
Operations dept involved	YES	NO
Material Required	HV source, sensor PD acq unit	PD acq unit

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PD phenomena

- PRPD pattern & polarity
- Voids
- Delamination
- Conductor side delamination
- Slot discharges
- Stress Grading discharges
- Bar to bar/bar to ground

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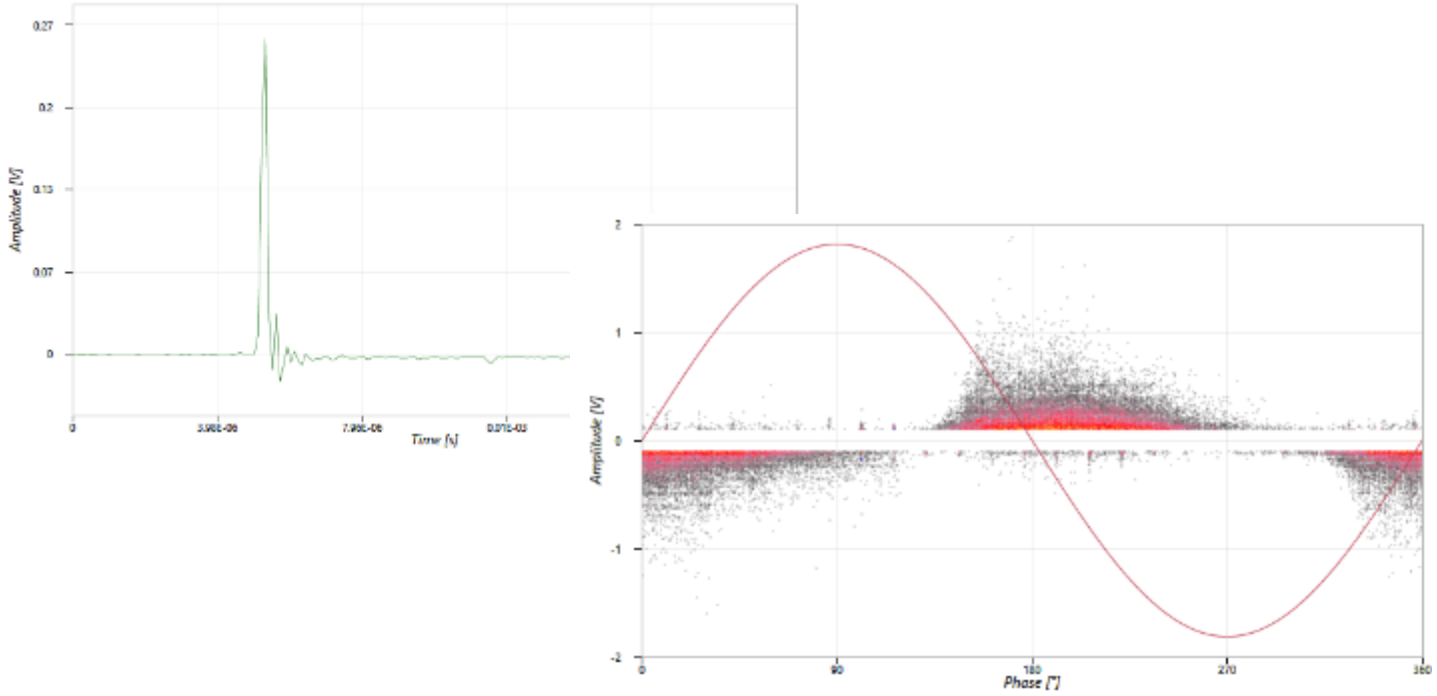
PD phenomena

PRPD pattern and polarity

The PRPD pattern study is the key of advanced PD test diagnostics, knowledge is required to make a proper interpretation, as well as acquire good PD data.

- Pulse Amplitude
- Pulse Polarity
- Phase Angle



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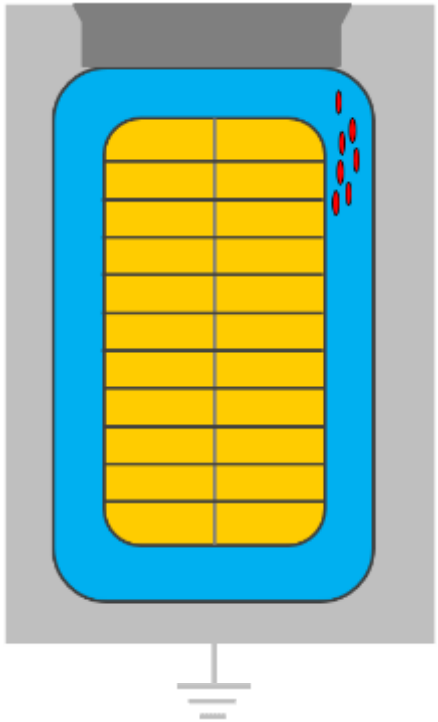
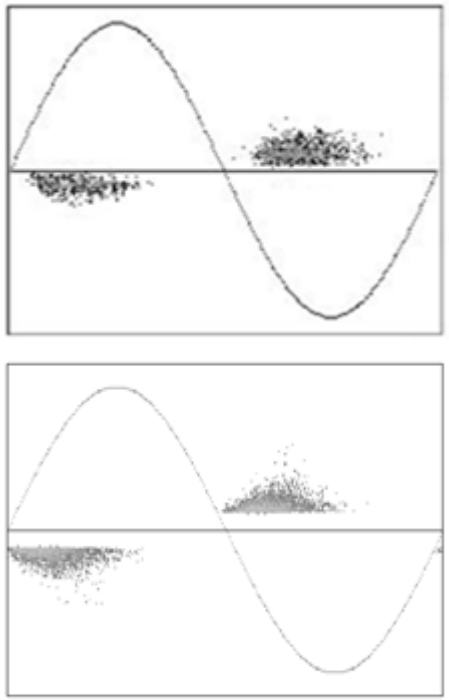
PD phenomena

Voids

Defects internal to the groundwall (mica foils) insulation, consisting of small voids. It is expected that this kind of defect is present in any machine due to unavoidable imperfections in the impregnation process, from the first day of operation until the end of life without reducing the expected life of the machine.





Simmetry PD+ & PD-

Phase angle intervals regular

Magnitude low

Triangular shape

*+/- is referred to pulse amplitude not to applied voltage

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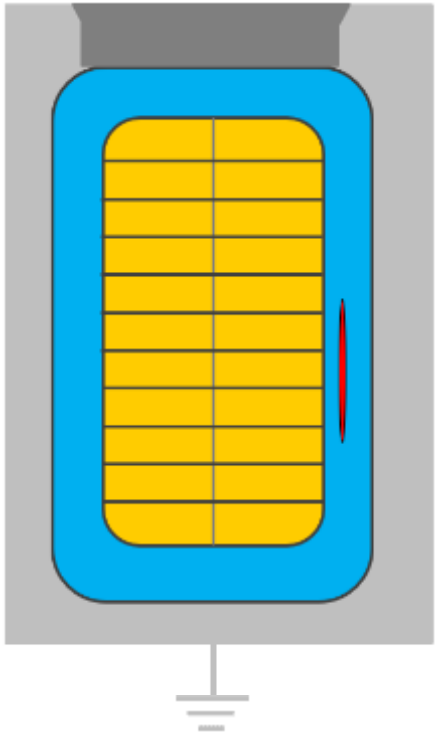
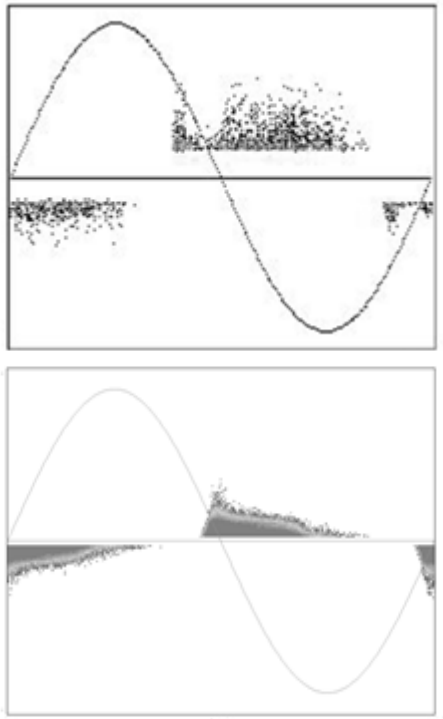
PD phenomena

Embedded Delamination

Detachments between mica foils within the insulation. They are flat voids caused by imperfect curing of the insulation system during manufacturing or by mechanical or thermal over-stressing during operation. These delaminations will reduce the thermal conductivity of the insulation, which might lead to accelerated ageing or thermal runaway.





Simmetry PD+ & PD-

Large phase angle intervals

Shape triangular

Starting before zero crossing

*+/- is referred to pulse amplitude not to applied voltage

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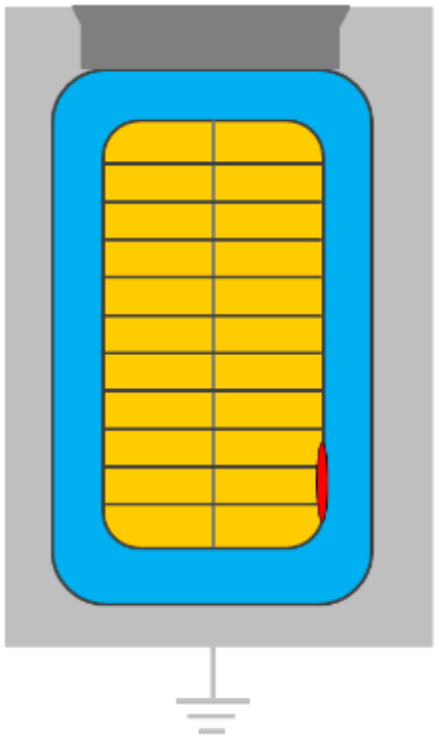
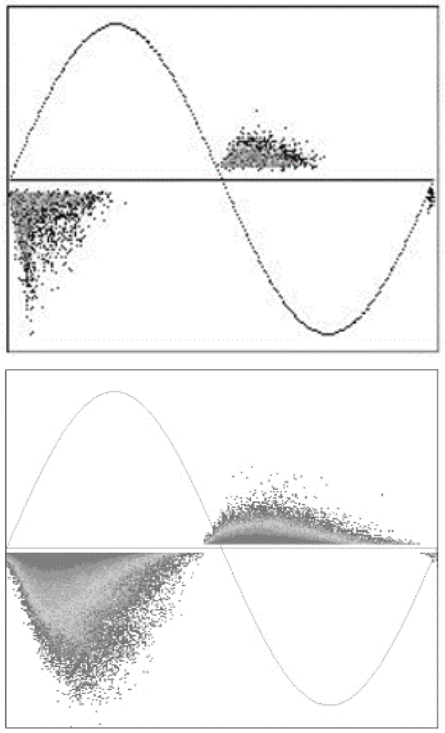
PD phenomena

Conductor side delamination

Detachments of the insulation from HV electrode (copper part of the bar). These defects consist of flat voids placed between HV electrode and insulation. As for embedded, they might lead to overheating (hotspot).





PD- >> PD +*

Phase angle intervals regular

Unbalanced magnitude

Starts before zero crossing

*+/- is referred to pulse amplitude not to applied voltage

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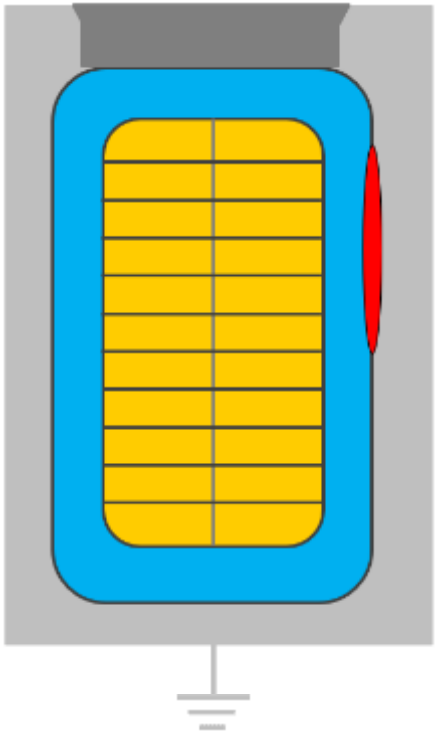
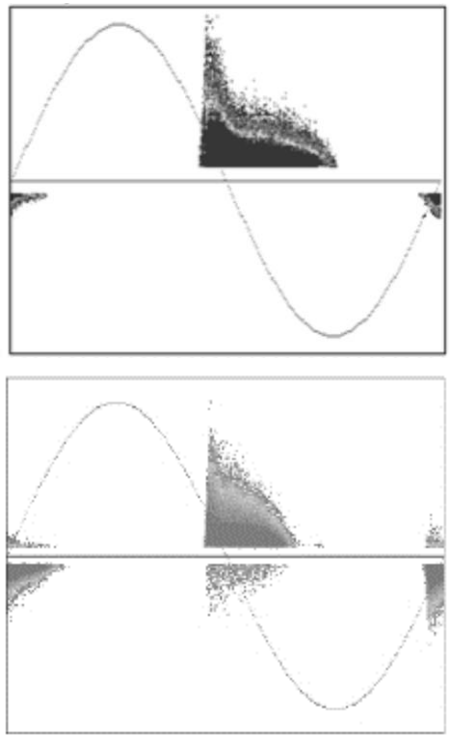
PD phenomena

Slot discharges

Discharges between the semi-conductive slot coating and the stator iron core. They occur when the coating is damaged due to bar/coil movement in the slot, for example by erosion, discontinuities or chemical contamination of the coating. They firstly erode the semi-conductive coating, then the insulation





PD+ >> PD -*

Phase angle intervals regular

Unbalanced magnitude

Starts before zero crossing

PD+ max values ≈ zero crossing

*+/- is referred to pulse amplitude not to applied voltage

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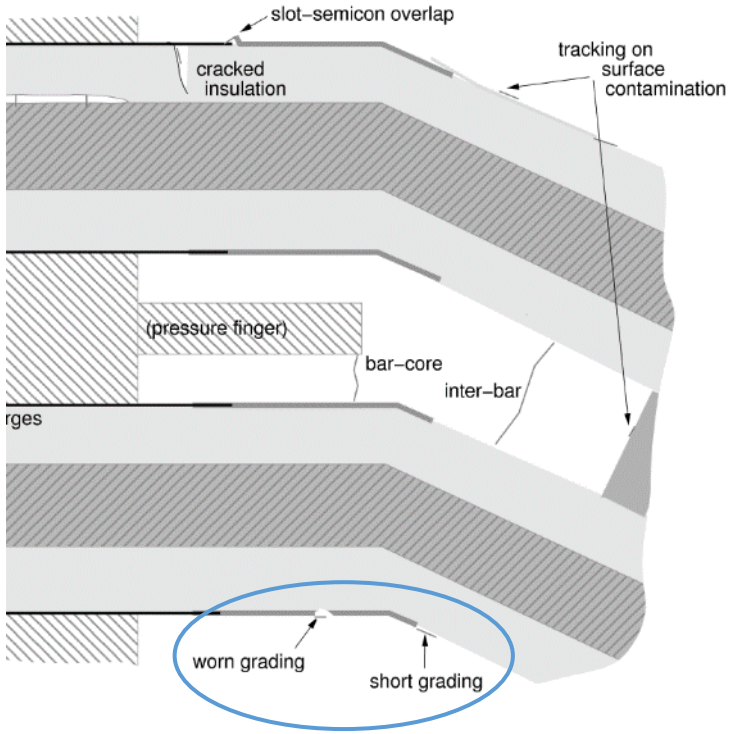
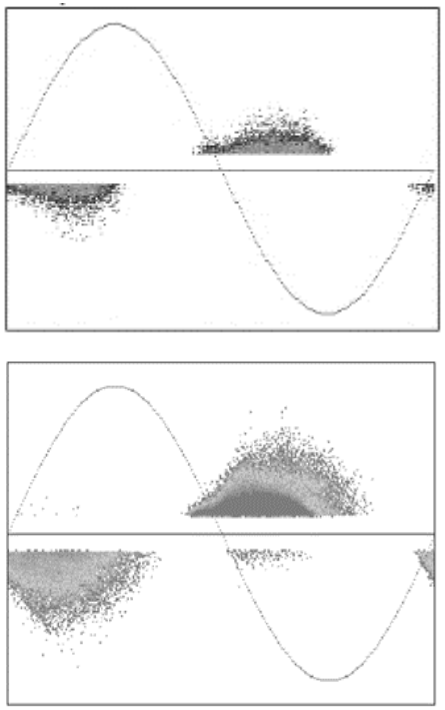
PD phenomena

Stress grading discharges

Discharges occurring at the interface between the semi-conductive slot coating and stress control coating at the slot exit in presence of pollution, contamination or degradation. This is normally a slow failure mechanism even if PD behaviour might change rapidly due to surface effects.





PD+ > PD -*

Phase angle intervals regular

Rounded shape

*+/- is referred to pulse amplitude not to applied voltage

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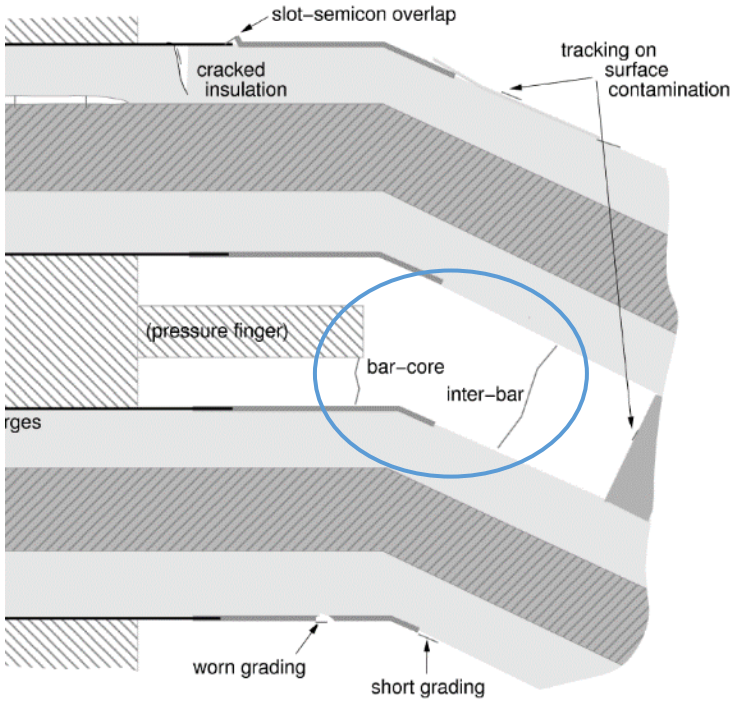
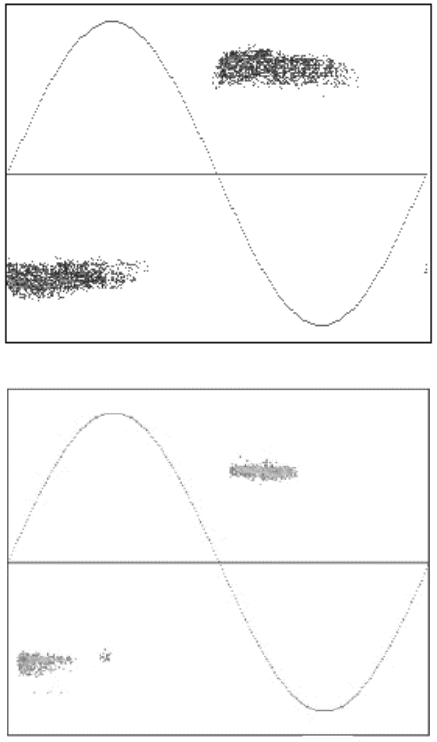
PD phenomena

Bar-to-bar/bar-to-ground

These discharges occur in the air gap between bars of different phases, or between bar and the ground in overhang due to inadequate clearance. They may deteriorate the insulation system faster than corona discharges resulting in phase-to-phase/ground breakdown.





PD+ = PD -*

High repetition rate

Detached from trigger level

“squared” PRPD

*+/- is referred to pulse amplitude not to applied voltage

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Denoising & crosstalks

- RM noise and disturbance issues
- Exciter & electronics
- HW filtering
- Time-Frequency map filtering

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Denoising & crosstalks

RM PD noise & disturbances issues

When testing a generator it is possible to experience many different noise signals affecting the insulation due to the complex electrical system involved, some of the noise disturbances can be considered “classic” and recognized easily: exciter noise, external disturbances and crosstalk.

- Unsynchronized disturbances (crane excitation, power tool operations, etc.)
- Synchronized disturbances (PD sourced in external assets, poor electrical connections, etc

PRPD pattern allows to:

- Recognize voltage correlated signals
- Identify the PD correlation with the proper phases
- Identify crosstalk

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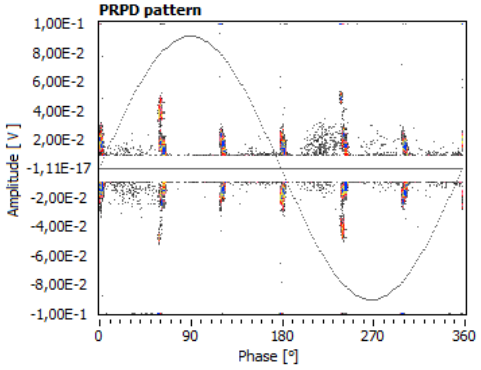
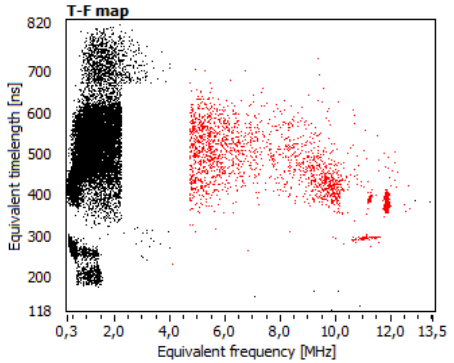
Denoising & crosstalks

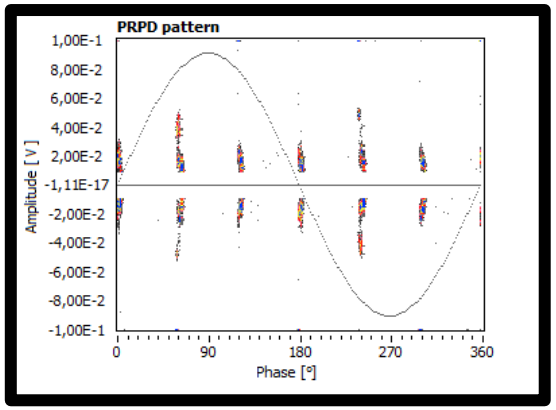
Exciter & Electronics

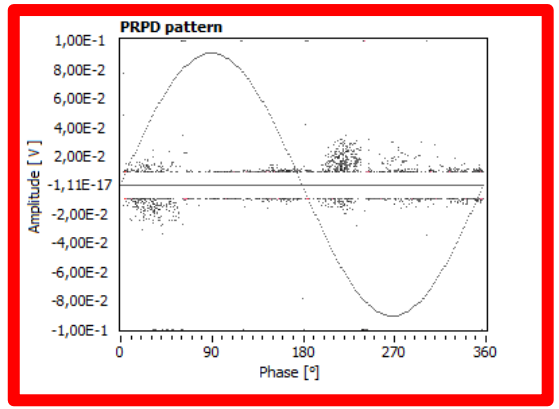
Exciter noise may be very annoying affecting the readings of amplitude and repetition rate of the pulses.

The signal is normally characterized by low frequency component and can be filtered out by the mean of hardware filters or by TF filter tool.









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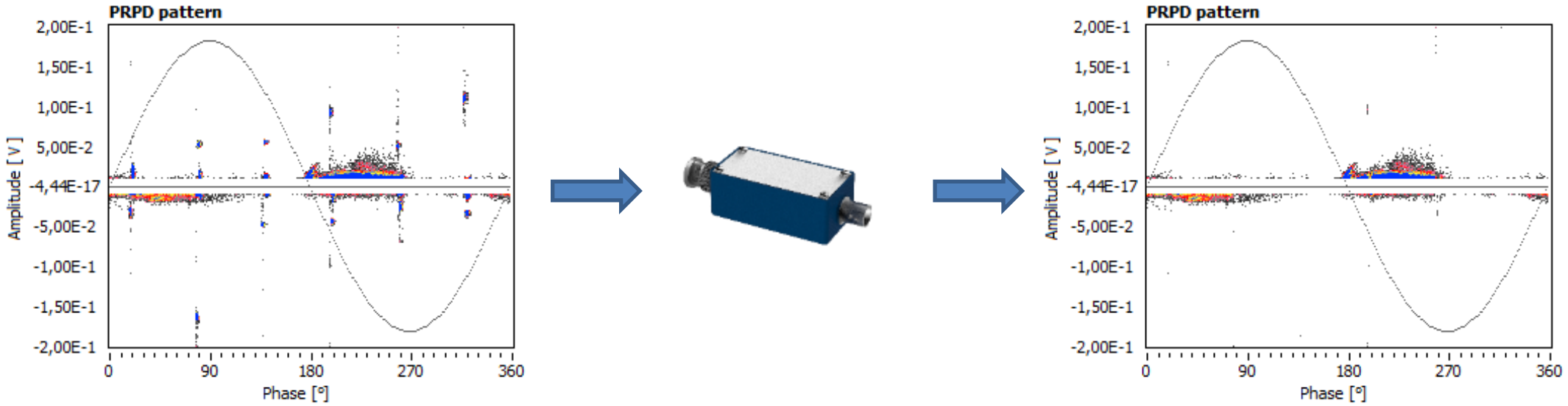
Denoising & crosstalks

HW filtering

It is possible to install signal conditioning devices at the sensor output in order to:

- Remove low frequency disturbances
- Remove high Frequency disturbance
- Create a band pass filter or attenuate the existing signal



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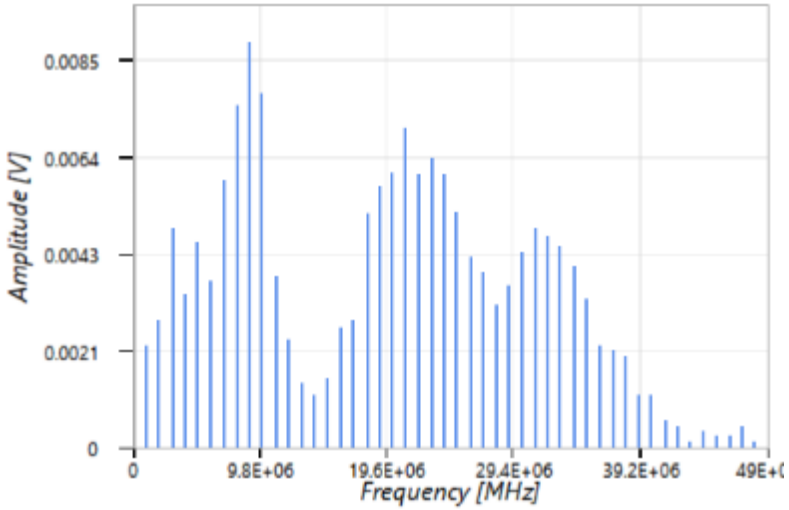
Denoising & crosstalks

Time-Frequency map

Every second the PD instrument acquires thounsands of pulses, it is impossible to visualize and check each single high frequency PD pulse, the only two information saved are amplitude and phase angle.

It is well known that high frequency signals can be studied from the frequency content, each signal can be visualized with its pulse spectrum and such information can be considered as a signal fingerprint.



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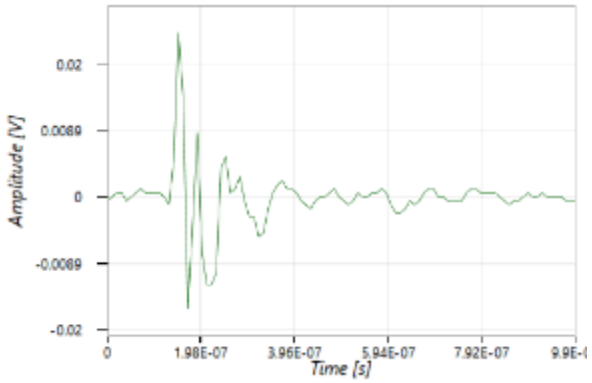
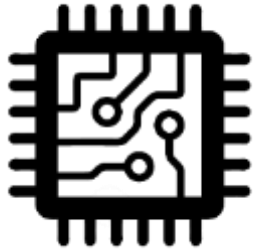
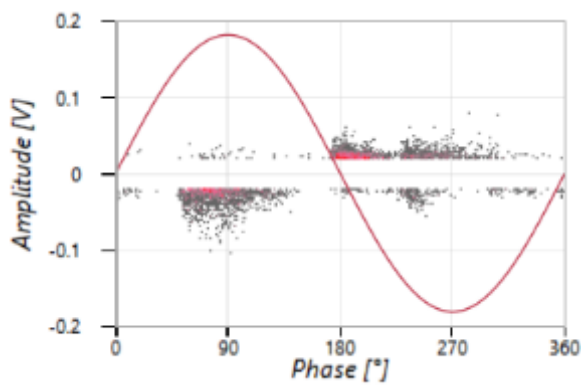
Denoising & crosstalks

Time-Frequency map

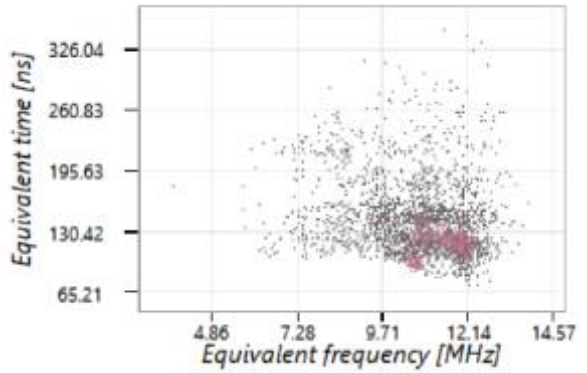






Pulse amplitude & phase angle

➔ Phase resolved PD Pattern



Eq. timelenght & Eq. Frequency

➔ Phase resolved PD Pattern

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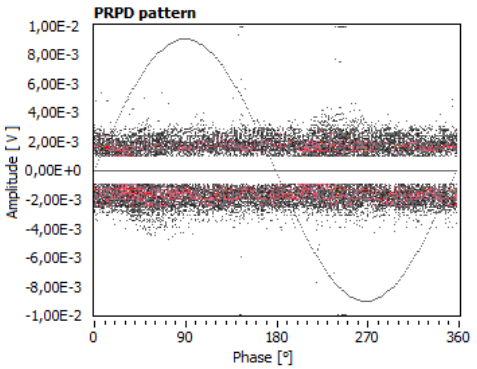
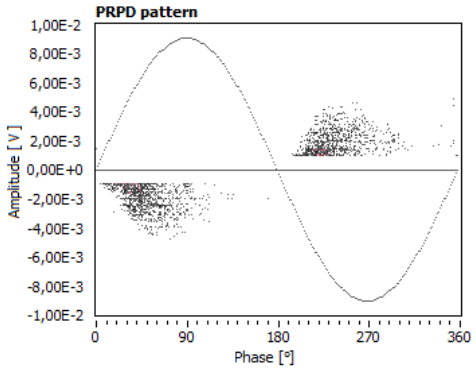
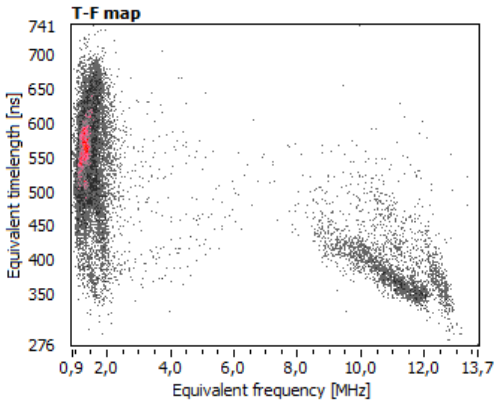
Denoising & crosstalks

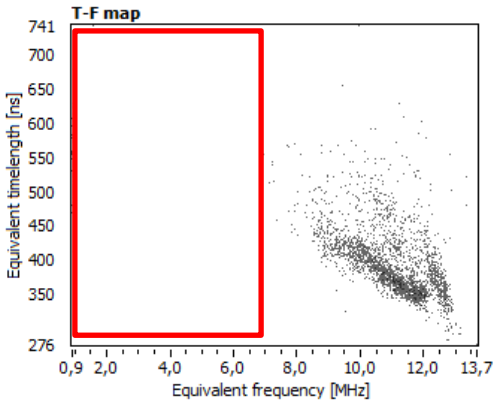
Time-Frequency map

By the mean of the Time Frequency signal footprint we can set areas of the TF map to be filtered out









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PD Analisys

- Acquisition Parameters
- TF map filtering
- Data sets
- TF map Separation
- Single phenomena identification
- Trending

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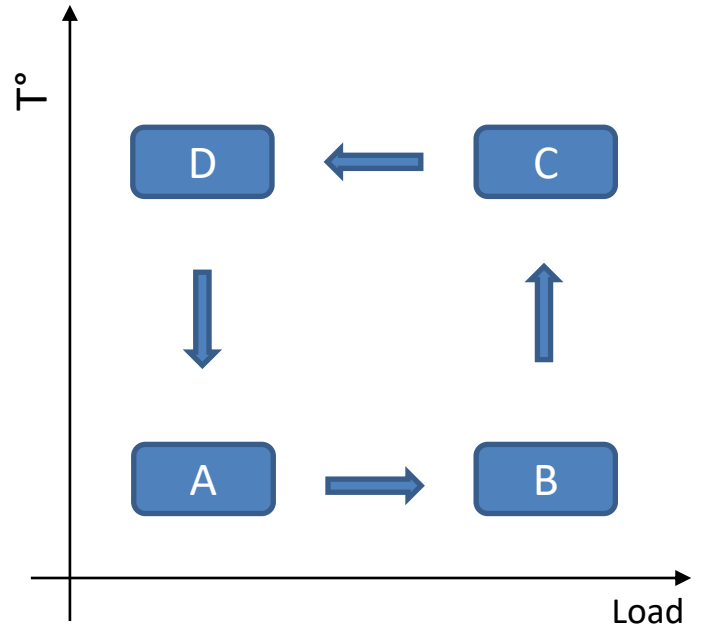
PD Analisys

Acquisition Parameters

PD Analysis starts during the acquisition process, a proper acquisition session shall provide the following data & info to be used during analysis:

- High amplitude PD signals data
- Low amplitude PD signals data
- Machine working parameters (Load & T)



During PD sessions it is also suggested to use:

- Different timelenghts
- Different pre triggers
- HW filtering

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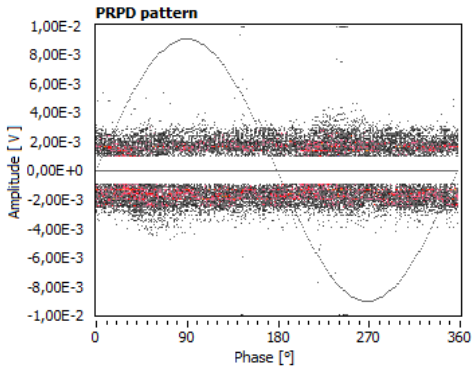
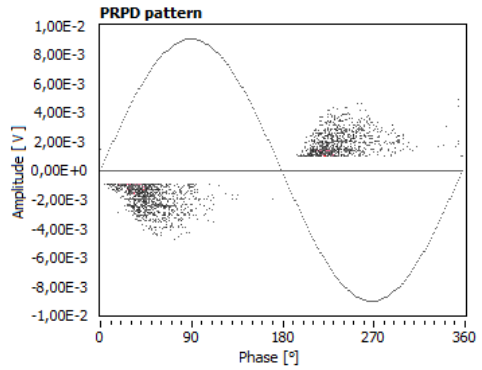
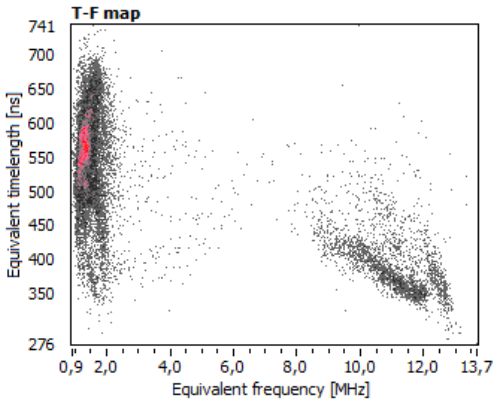
PD Analisys

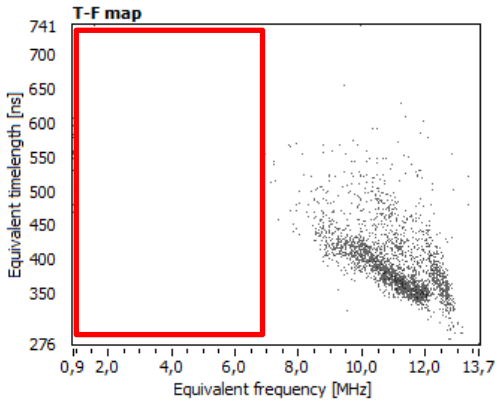
TF map Filtering

PD signals are classically displayed on an amplitude basis, if no further filtering tools are used the PD measurement output will be focused the highest amplitude signals only.









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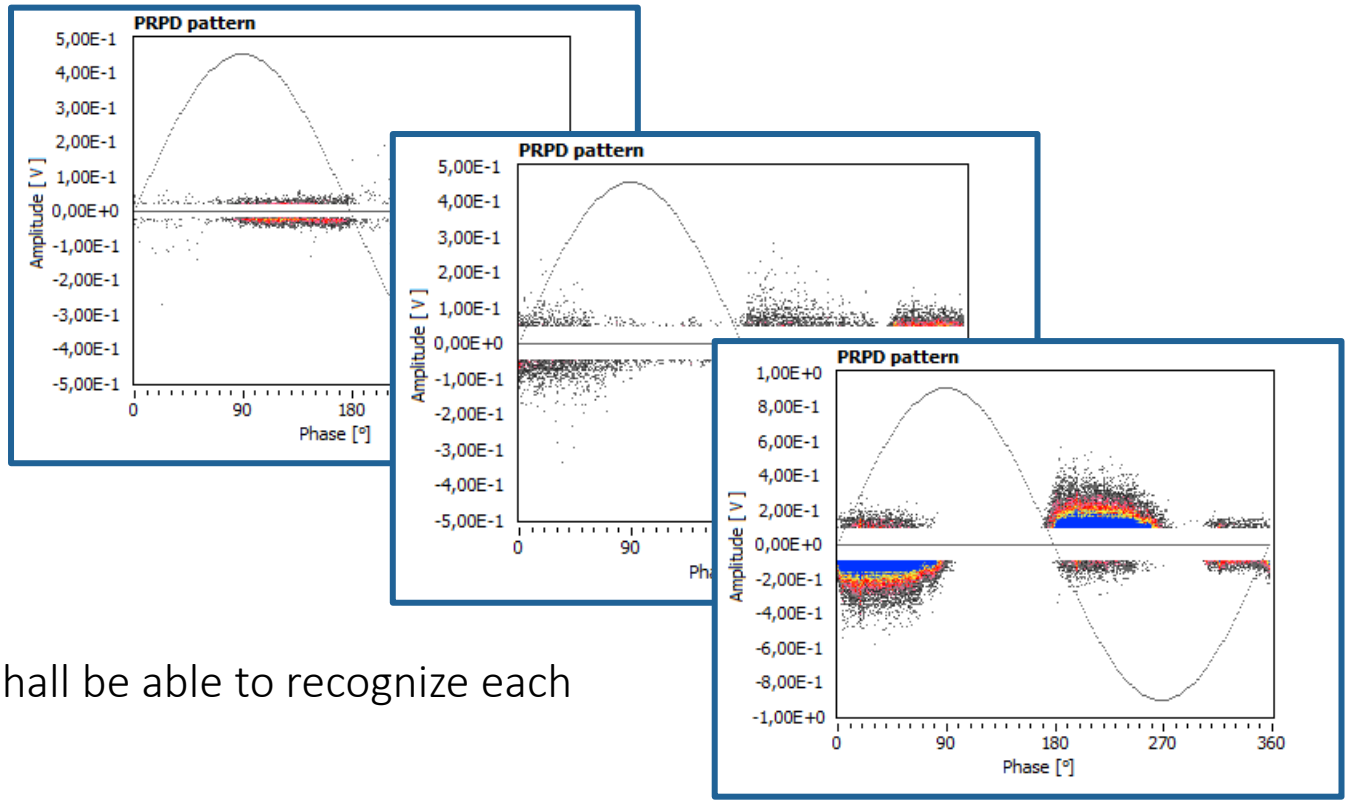
PD Analisys

Data Sets

For each detection point it is strongly suggested to acquire not just 1 PRPD pattern but a full set of data including:

- Different Full scale
- Different Trigger level
- Waveform acquisitions
- With and without HW filters
- With and without SW filters



Ideally when studying the data the data analyst shall be able to recognize each step performed.

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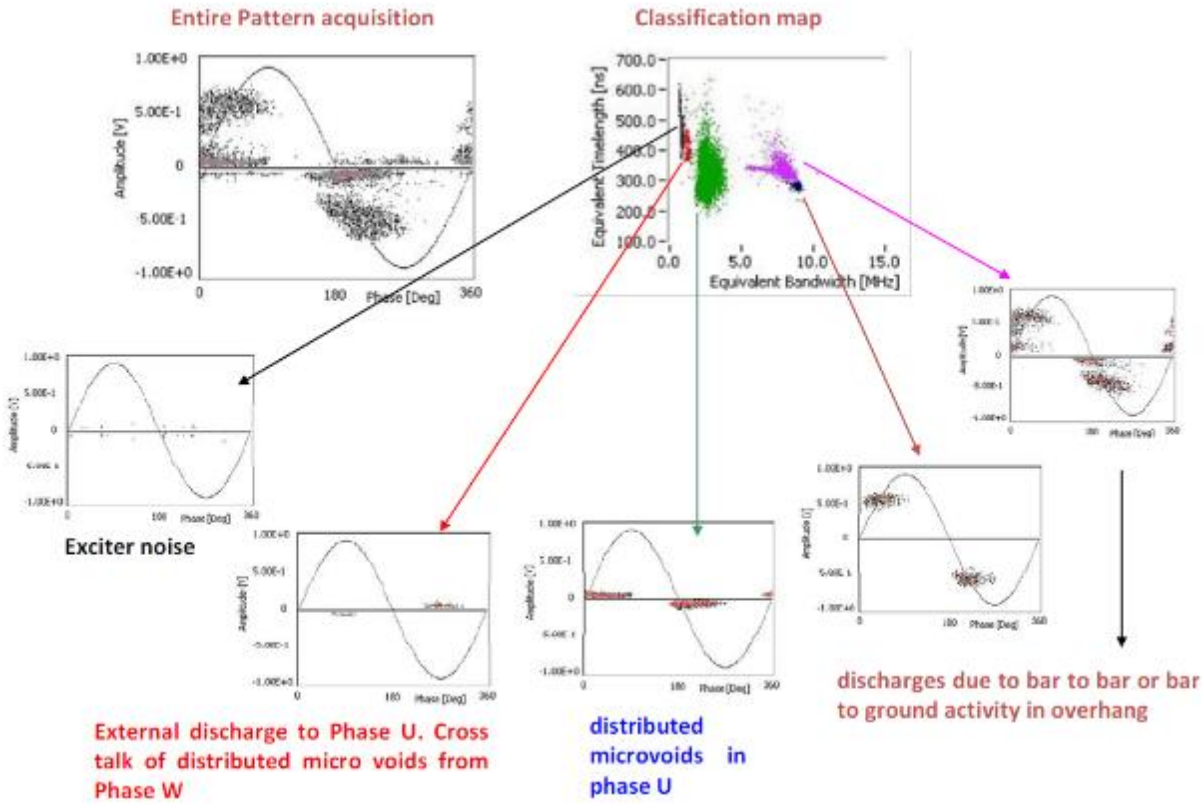
PD Analisys

TF map separation

TF map signals is used during acquisition to remove undesired signals & can be used during the analysis to separate the various PD sources present in the acquisition



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PD Analisys

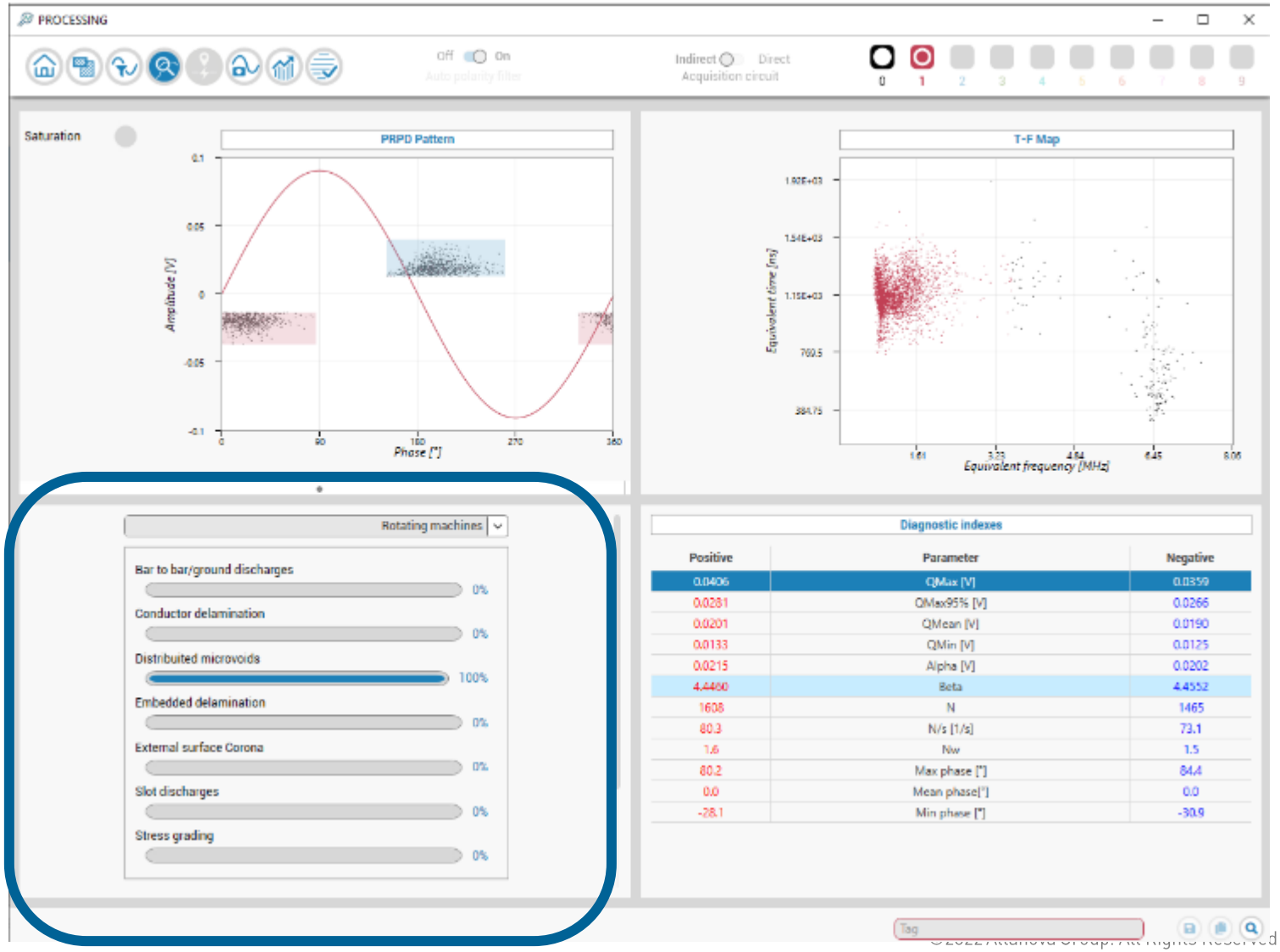
Phenomena identification

The data acquired properly

Noise removed

PD phenomena are separated

The identification of the PD can take place: manual PRPD pattern analysis and PD Pro identification tool



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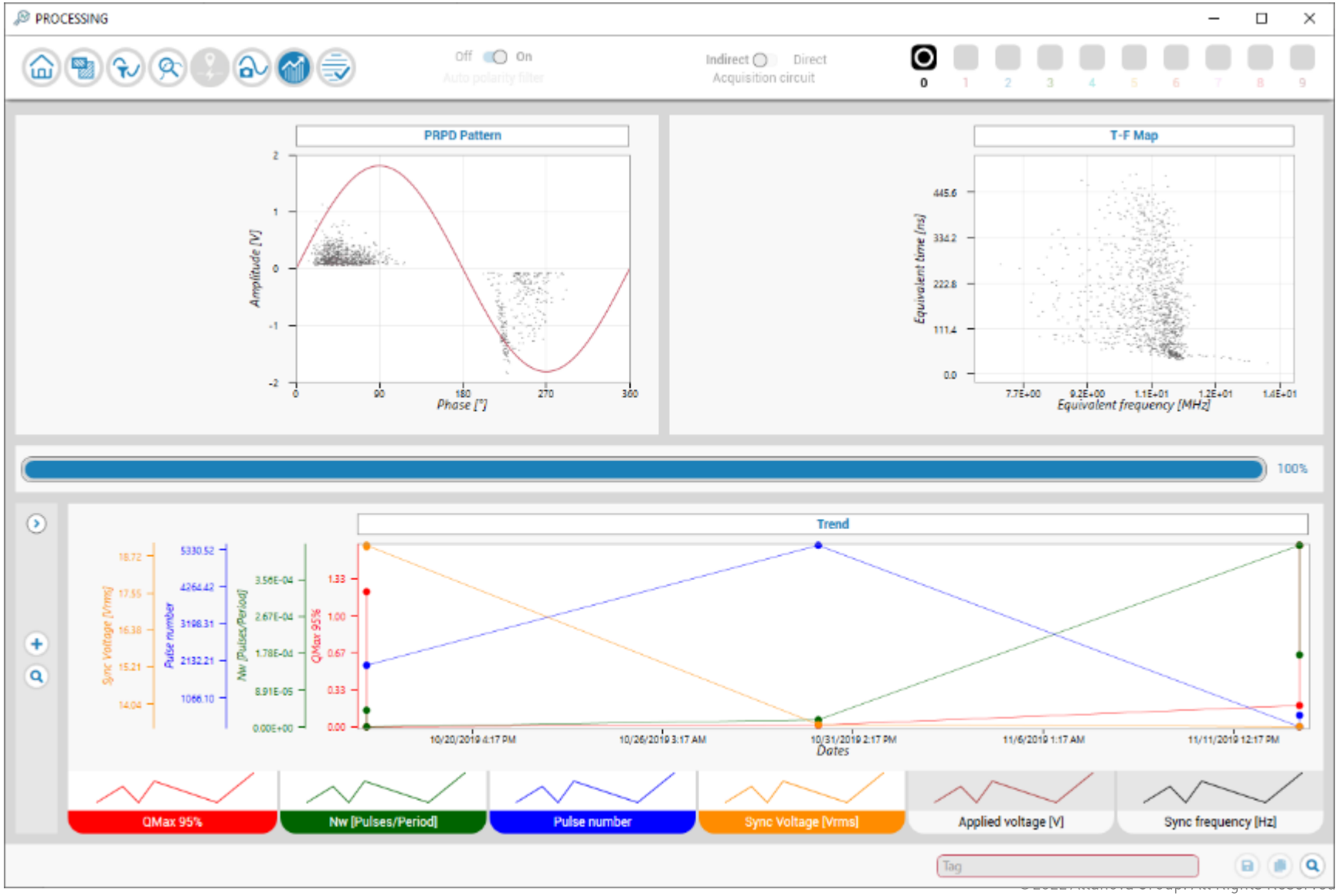
PD Analisys

Trending

Amplitude and repetition rate are markers of the PD evolution: we can have PD lasting for years at the same levels or quickly evolving in amplitude and rep rate.



Case studies

- Motor lab testing
- Noisy drive test
- Slot discharges
- EMI

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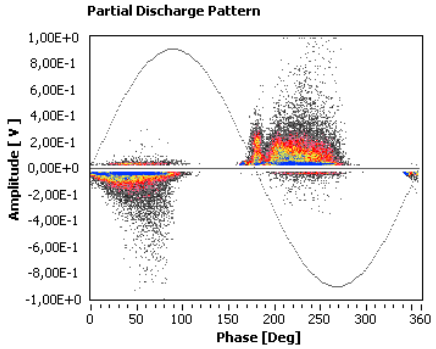
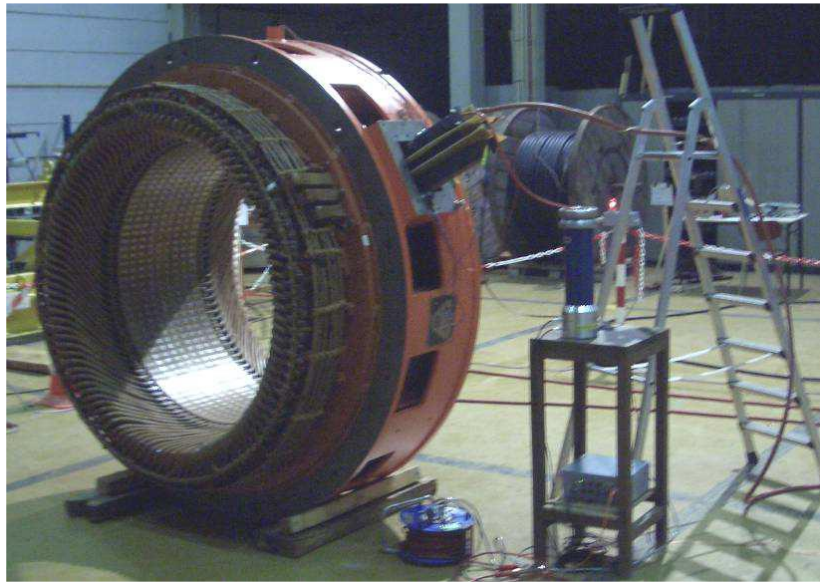
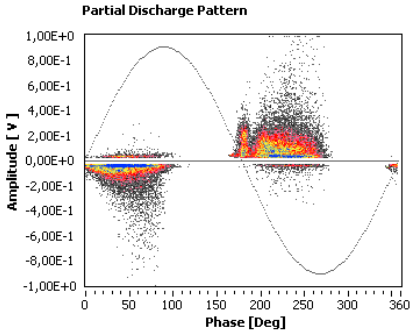
Case study

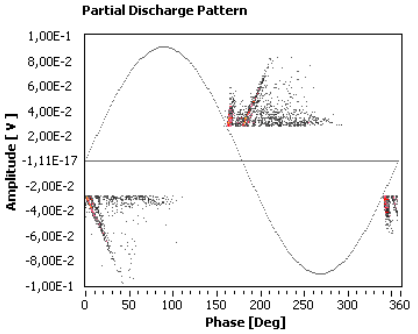
- Lab testing
- Various assets, mainly RM
- Cap Caouplers, HFCTs
- PDBASEII
- Operator: customer





➔ both IEC and UWB test





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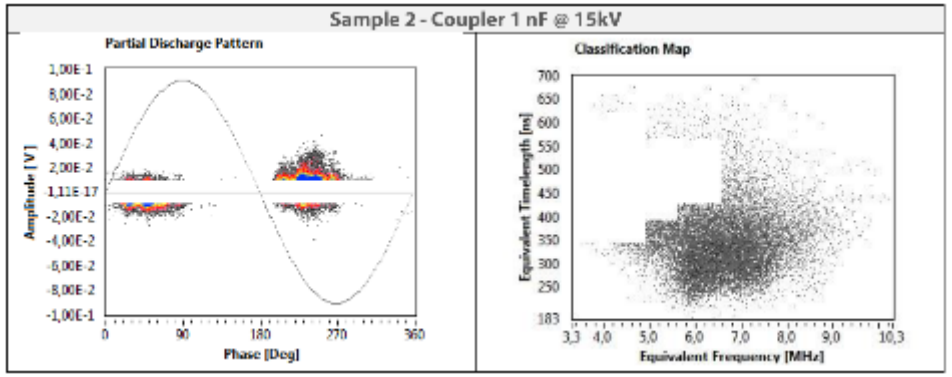
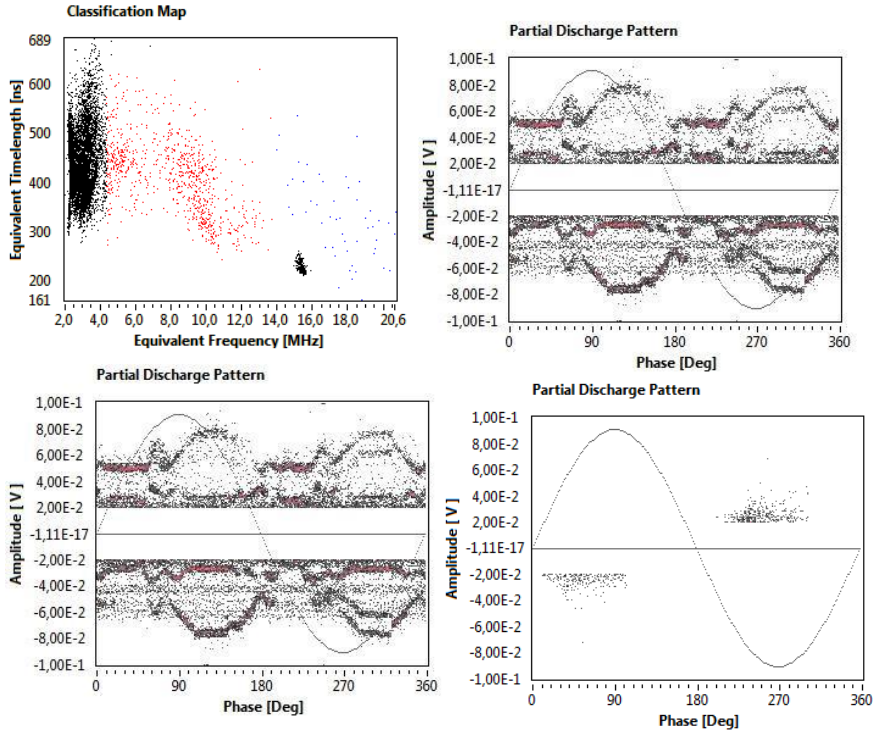
Case study

- Lab testing
- Large Motors only
- Cap Couplers

➔ noise separaiton tool





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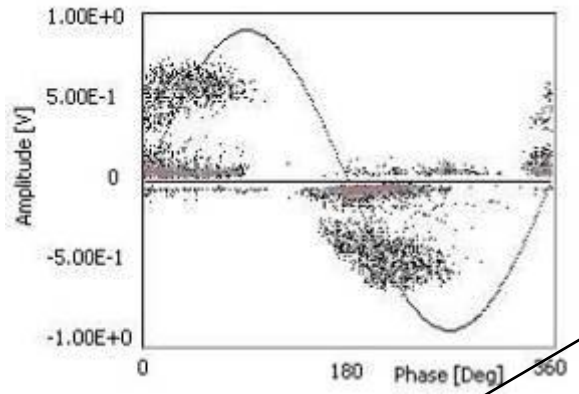
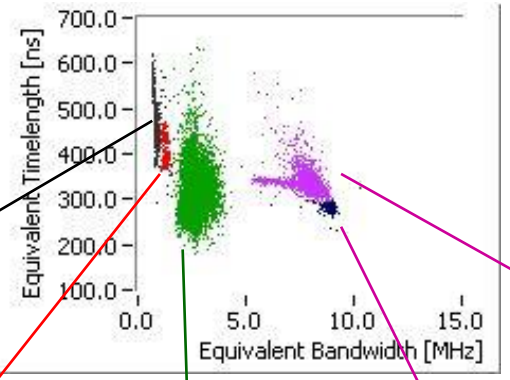
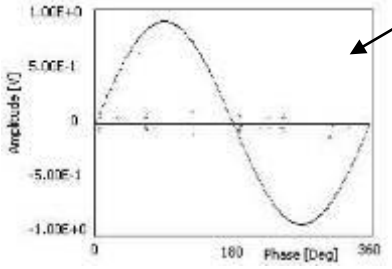
Case study

Entire Pattern acquisition

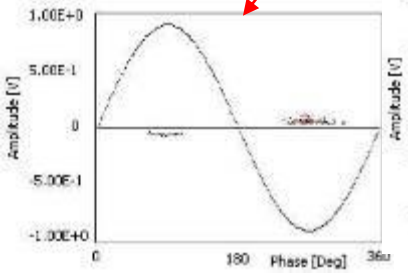




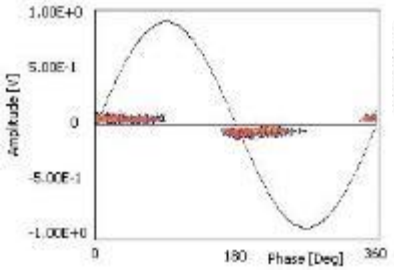
Classification map



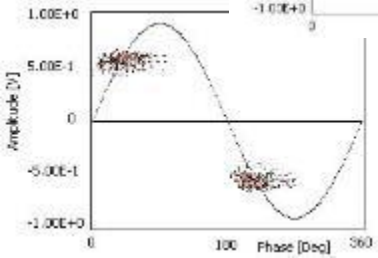
Exciter noise

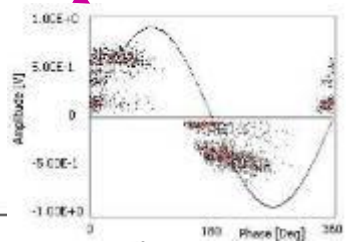


External discharge to Phase U. Cross talk of distributed micro voids from Phase W



Distributed microvoids in phase U





Discharges due to bar to bar or bar to ground activity in overhang

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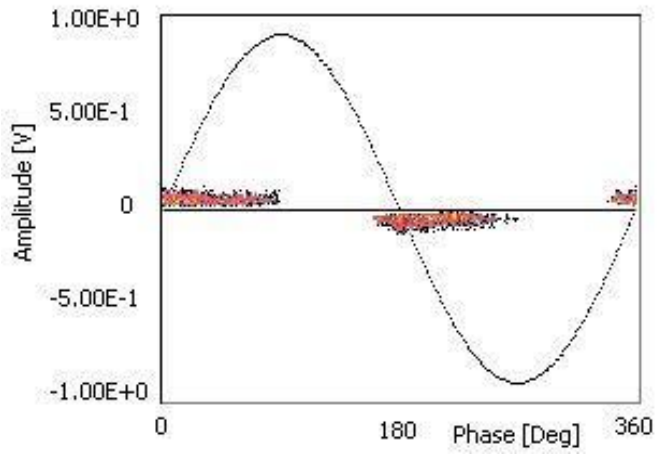
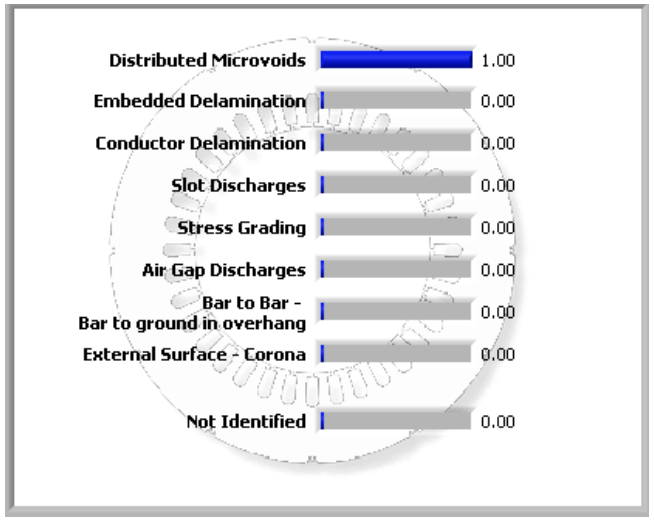
Case study

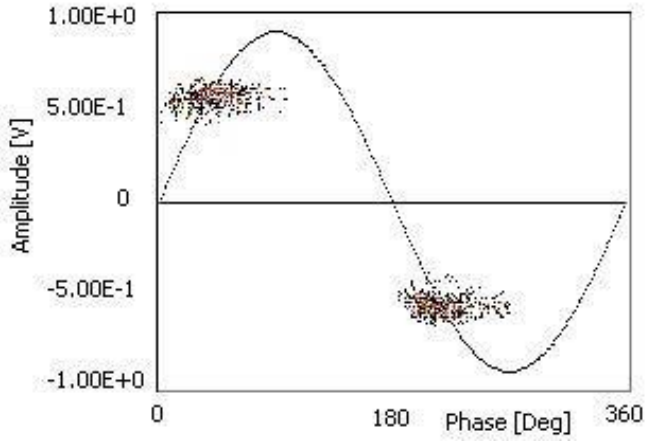
On line PD test on Generator : Phase U

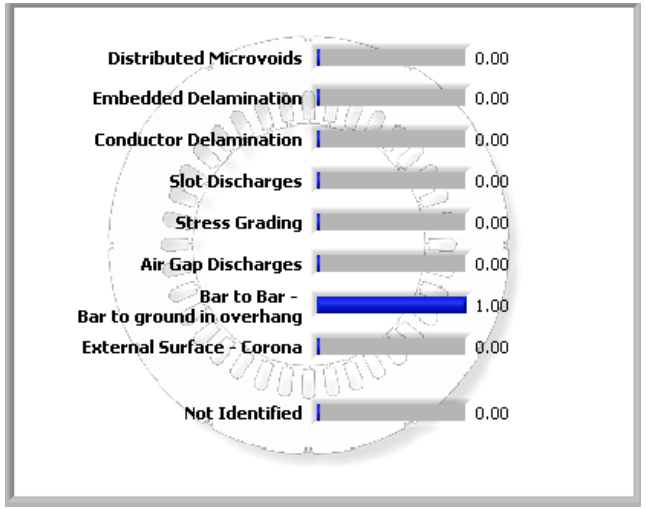
Sub pattern



III Level identification







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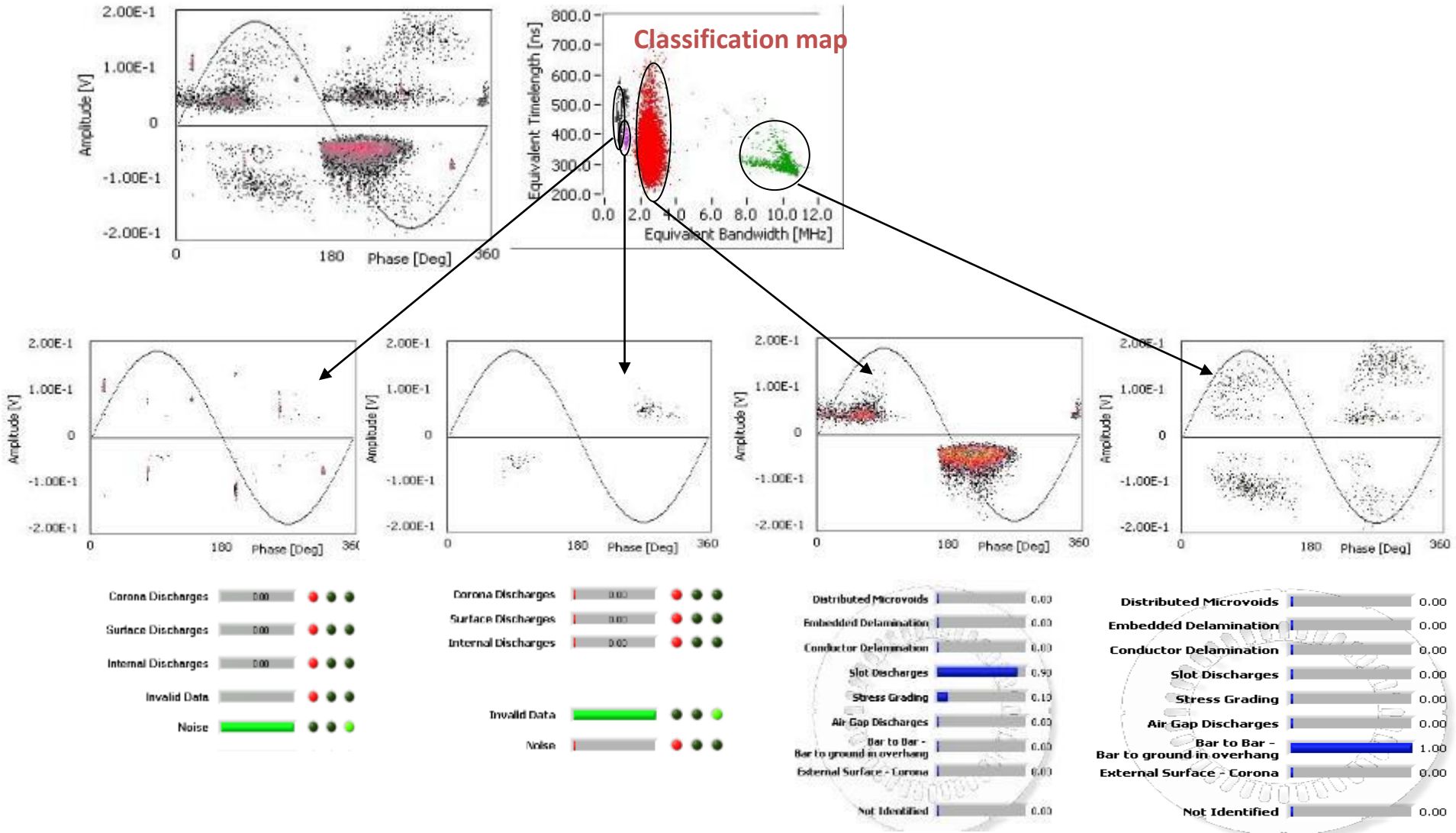
Case study

On line PD test on Generator: Phase V



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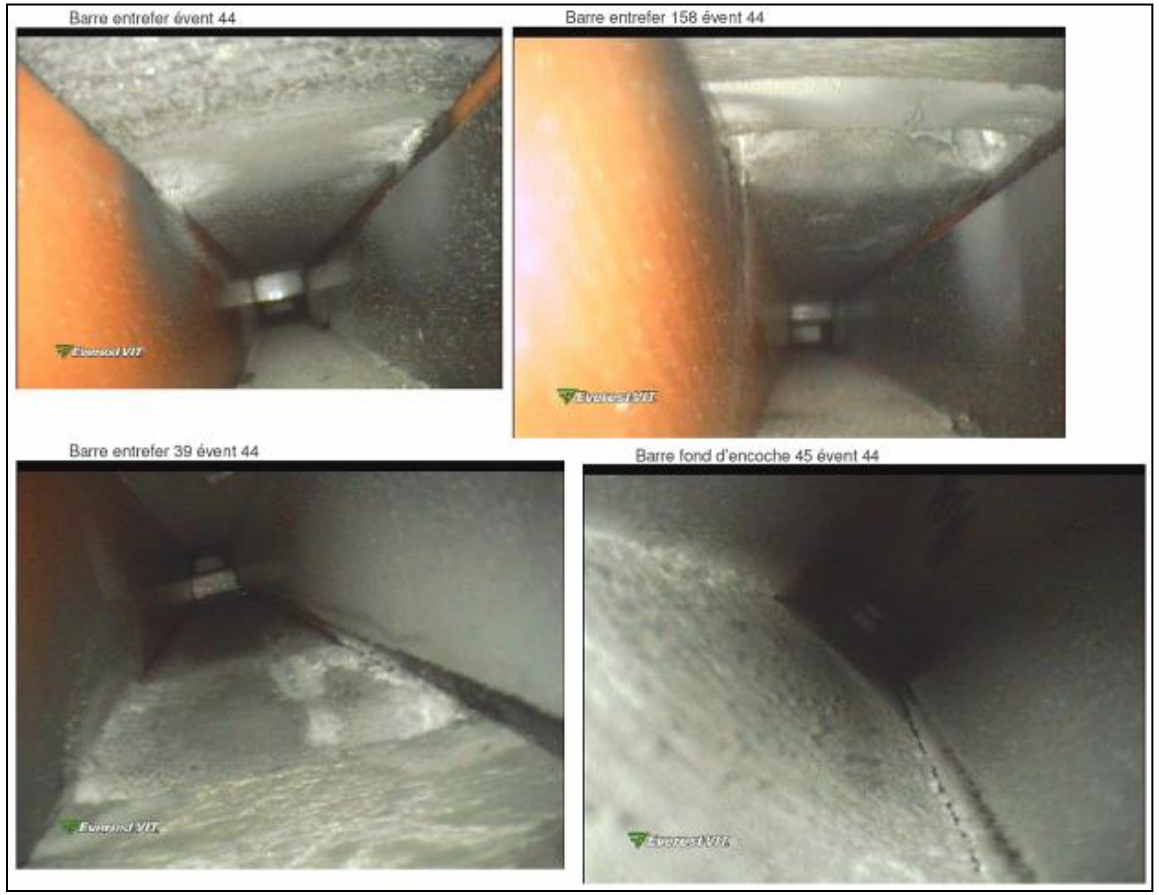
Case study

Results from endoscopic inspection on generator



PD traces found in
12 of the 60 slots
(7 white traces and
8 suspecious traces)

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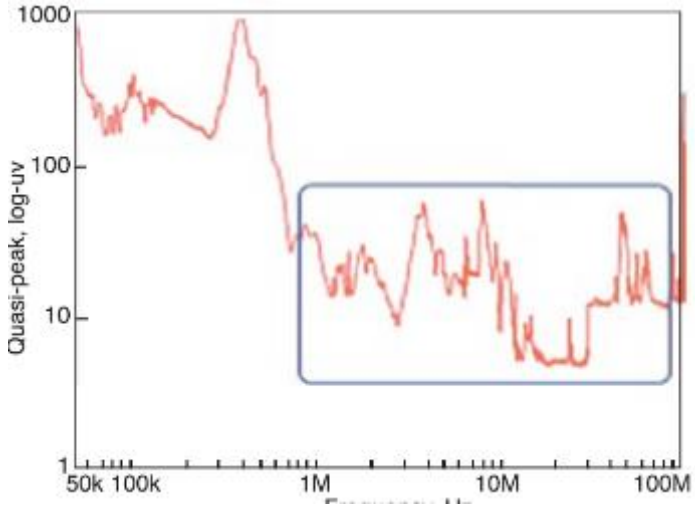
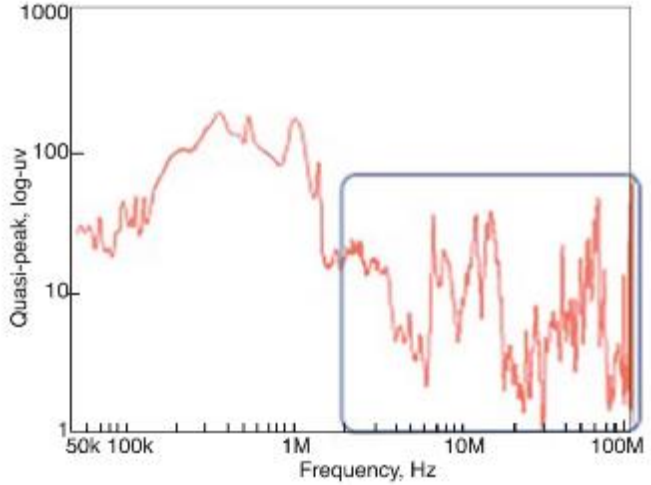
Case Study

EMI testing





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Thank you

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Solution Engineer
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