Megger

Virtual Motor Best Practices Seminar

Day 2: Insulation Assessment of Motors through VLF and PD Testing

Markus Söller

MD, Power Diagnostix Systems GmbH

Todays presenter

- Markus Söller
- Managing Director of Power Diagnostix Systems
- Aachen, Germany

- Working for PDIX by Megger since 1997
- Active in national and international bodies

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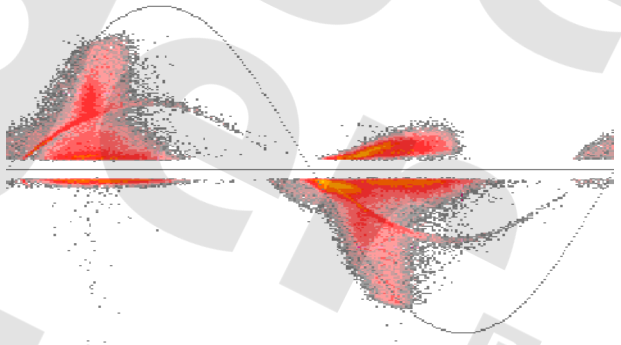
Megger

Insulation Assessment of Motors through PD Testing

Virtual Motor Best Practice Seminar, 23.06.2020

PD Testing on Motors - Agenda

- **Why PD testing on motors?**
- Applicable Standards / Normative References
- PD Measurement Techniques
  - Offline Testing
  - PD Signal Properties
  - PD Calibration & Test Setups
  - Measurement Instruments
- Failure examples



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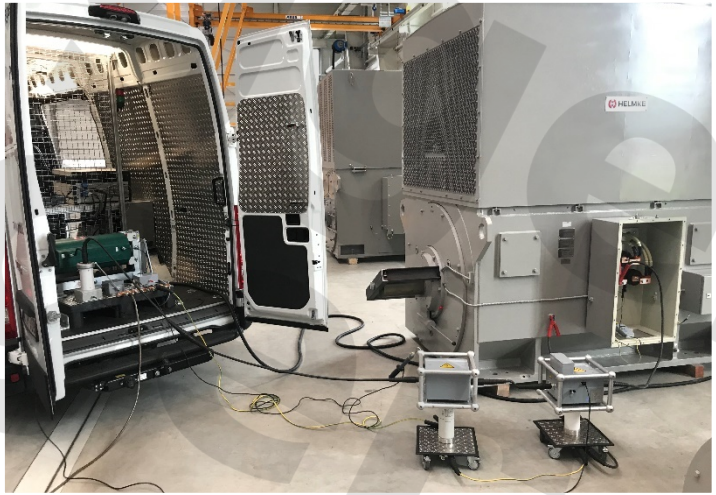
Why PD Measurements on RMs?

- Offline PD Measurements to assess the insulation health of Generators, Motors, or other RMs
- Changing PD Patterns and PD amplitudes indicate incipient failure
- PD Pattern Analysis assists with failure Investigations (Root Cause Analysis)
- Added value if PD Tests are combined with loss factor measurements and other dielectric tests



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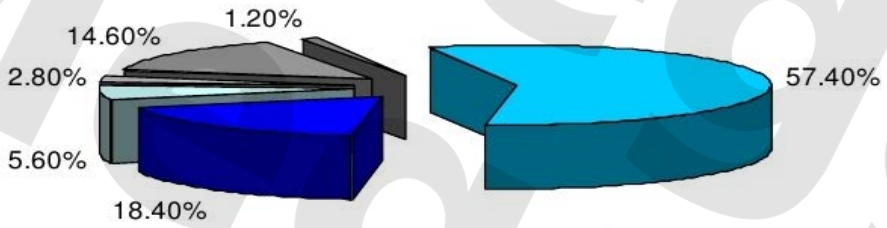
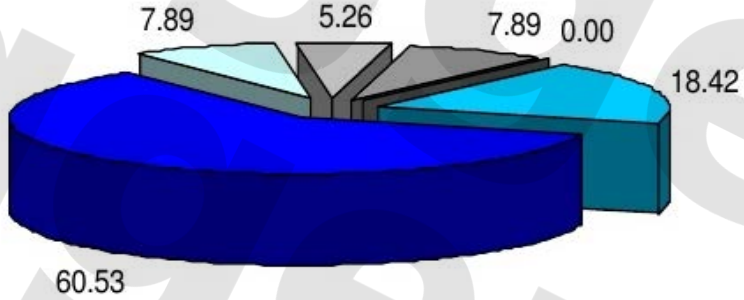
Why PD Measurements on RMs?

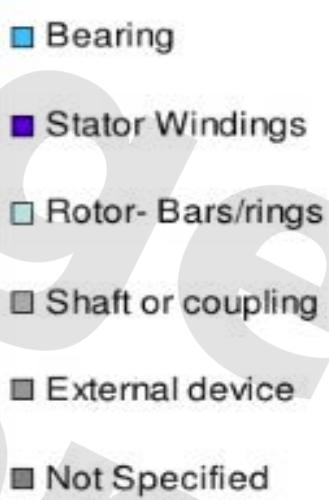
Failure Study : HV motors in the Petrochemical Industry (´99)

HV-Motors < 2MW



HV-Motors > 2MW





Reference: IEEE transactions on industry applications vol.35 N°3

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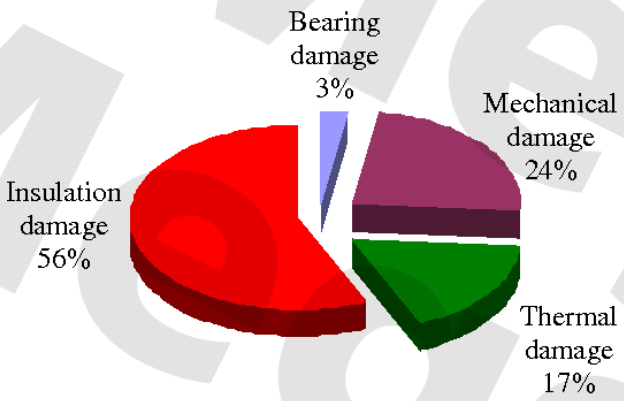
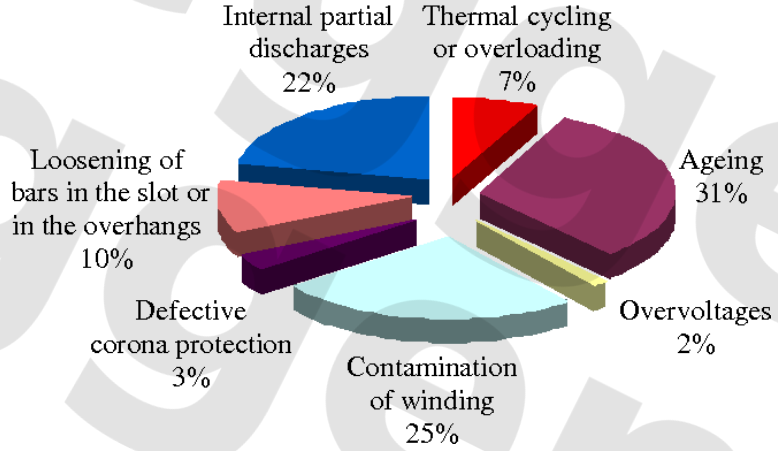
Why PD Measurements on RMs?

IEEE Electrical Insulation Magazine (Vol. 24, Issue 4, 2008)

Stator Winding Insulation Failure Statistics





Damages of hydrogenerators (left) and root causes of insulation damages (right)

Stator Winding Deterioration

- In case of “normal” gradual ageing, the assumed life cycle a stator is up to 20 years
- Manufacturing inefficiencies, poor design and improper processing can enhance the impact of the common operational TEAM-stresses (Thermal, Electrical, Ambient, Mechanical)
- Fast developing PD-behavior reduces life-time of the insulation system
- PD-fault mechanism developing on a critical position within the winding may cause severe problems in a couple of months, only
- PD Testing is an excellent tool to assess the condition of the insulation

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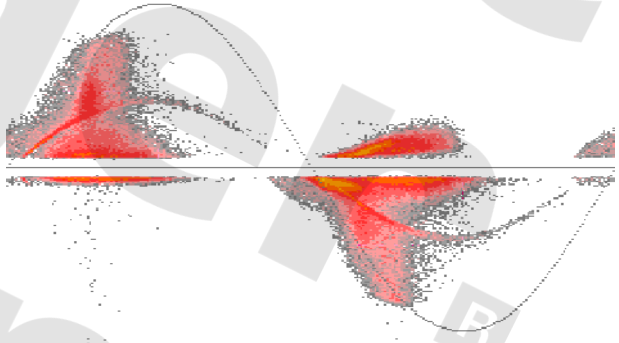
PD Testing on Motors - Agenda

- Why PD testing on motors?
- **Applicable Standards / Normative References**
- PD Measurement Techniques
  - Offline Testing
  - PD Signal Properties
  - PD Calibration & Test Setups
  - Measurement Instruments
- Failure examples



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Applicable Standards

- There are currently no standards defining acceptance criteria for Partial Discharge testing on rotating machinery
- The lack of such criteria often causes endless discussions between owner and manufacturer after submission of test reports, even during factory tests
- An important difference between rotating machines and other applications is property to be PD-resistant versus other PD-free insulation systems
- Frequently asked questions on this subject are:
  - How much PD is now too much PD?
  - Defining acceptance criteria for a PD-resistant insulation systems?

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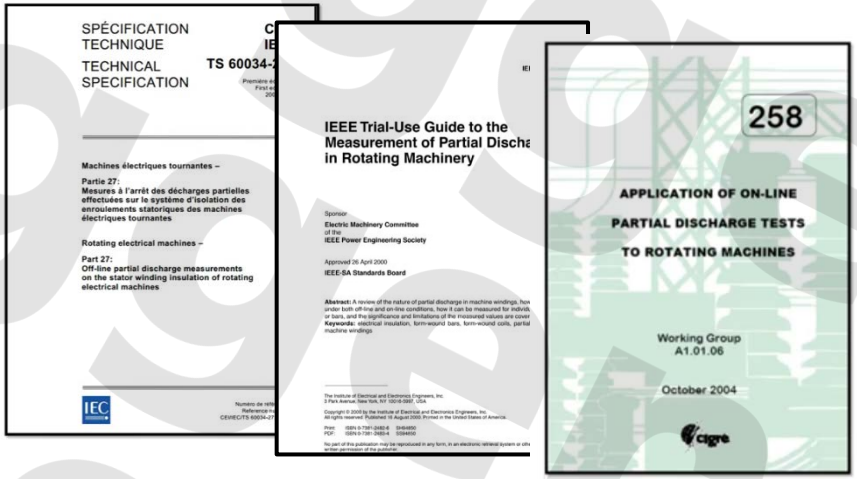
Normative References

- Main “horizontal” standard, i.e. the IEC 60270
- Technical specifications and guides from IEC, IEEE, Cigré, EASA and EPRI
  - Test circuits and procedures
  - Voltage application sequences
  - Test durations
  - PD-detection bandwidths
  - Calibration circuits
  - Typical PD-phenomena



- IEC60034-27, IEEE 1434-2014, Cigré ref.258 and ref.558, etc.

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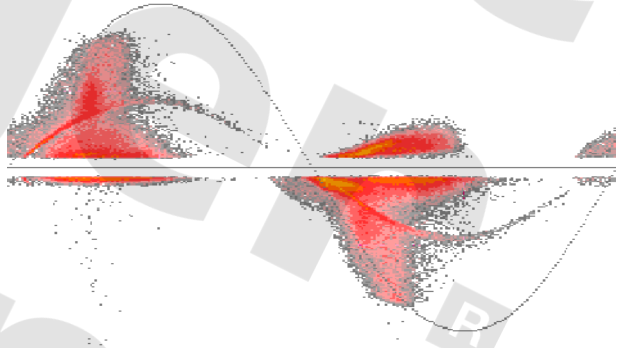

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Offline PD-test : Introduction

- The Motor or Generator is out of service, HV-supply cables or bus-bar system are disconnected and isolated
- Stator windings should be energized using an external „PD-free“ high voltage source
- Measurement condition differ from normal operation
  - Cold conductor (no-load conditions)
  - Influence of environmental conditions (temperature, but mainly relative humidity)
  - Different electrical field distribution
- Reference measurement during factory acceptance test (FAT) and in-depth verification by field testing over time
- Usually combined with visual inspections, loss factor & capacitance measurement and DC-Megger tests
- Excellent guidance for partial repairs

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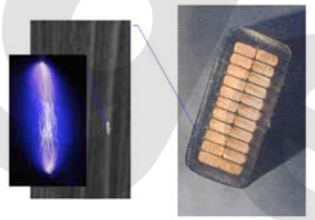
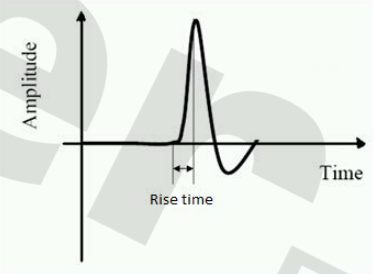
HFPD signal properties

- Internal activities within main insulation generally start as a gas discharge
- The electron avalanche causes a local high frequency current displacement
- At the discharge location, the HF-current impulse has a short rise time
- Under nitrogen (N) conditions, the rise time is typically in range of 1ns, translating into a bandwidth up to 350MHz
- However, a stator winding is a non-ideal high frequency conductor





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HFPD Impulse Properties

- The original PD-pulse properties will be affected by HF-effects such as attenuation, reflections, resonances, dispersion and radiation
- Basic understanding of the pulse propagation and bandwidth selection are essential for the measurement and the analysis
- The lower bandwidths are more prone to HF-noise, but offer the better coverage to detect PD in the entire winding
- Recommended detection bandwidth for offline testing: <1MHz (IEC60270)

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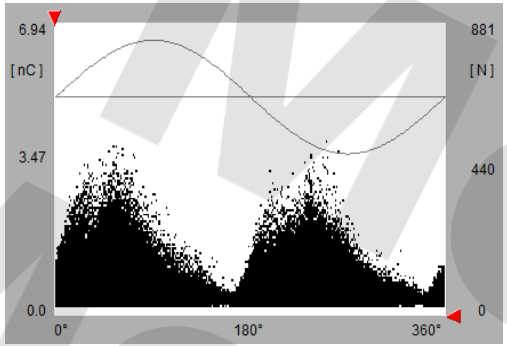
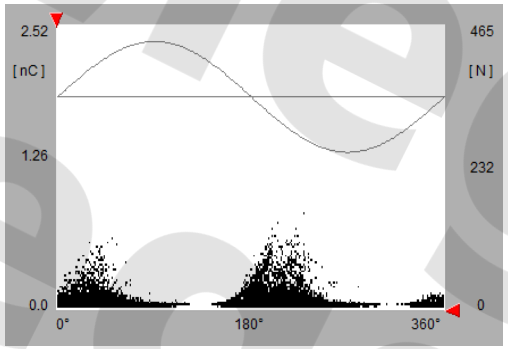
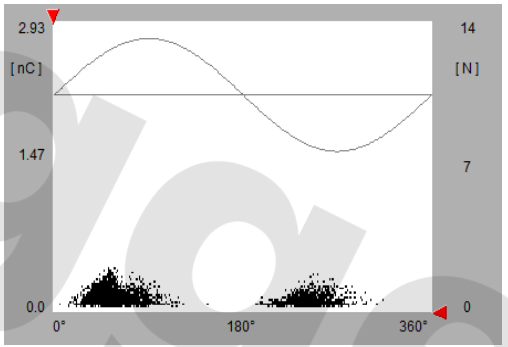
PRPD vs. Detection Bandwidth



40-800kHz (IEC60270)
1215697 Counts



2-20MHz
110843 Counts



20-200MHz
2270 Counts

- 1200kW – 6600V asynchronous motor with internal neutral connection
- New VPI impregnated stator winding
- Offline PD-measurement - 60s PD-pattern acquisition (coupling capacitor)
- Same test object and test voltage - different band pass filters

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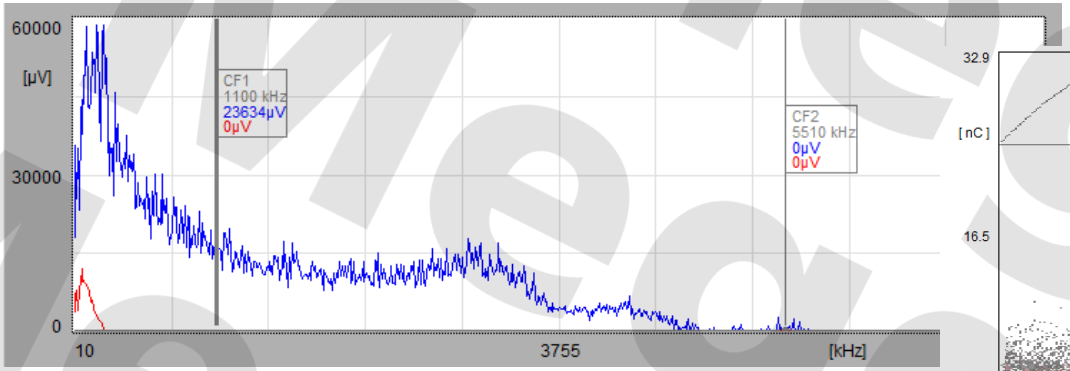
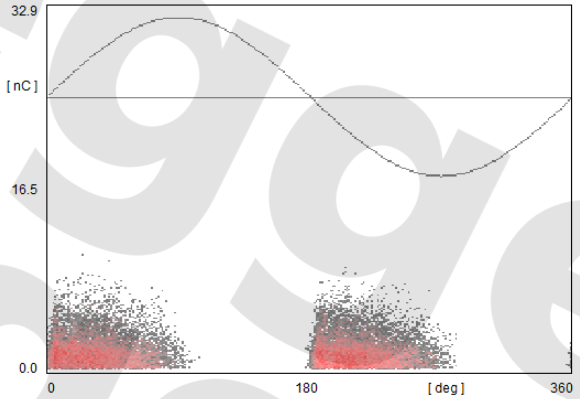
Example of an offline signal spectrum





- 800kW – 6000V asynchronous motor with internal neutral connection
- Internal PD-activity in the main insulation (Ground Wall)
- Offline PD-measurement (conventional circuit acc. IEC60270)
- Available signal up to 5,5 MHz

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PD Calibration

- PD measurements are relative measurements and require a calibration (IEC60270)
- Compensation of the test circuit´s overall attenuation
- Injection of a calibration pulse with defined magnitude & magnitude adjustment of the signal response
- Strictly following the IEC60270, a calibration is valid only when using a bandpass filter

$30kHz \leq f1 \leq 100kHz$ $f2 \leq 1MHz$ $100kHz \leq \Delta f \leq 900kHz$

- However, PDIX instruments support the principle of the so called quasi integration at higher frequencies as well

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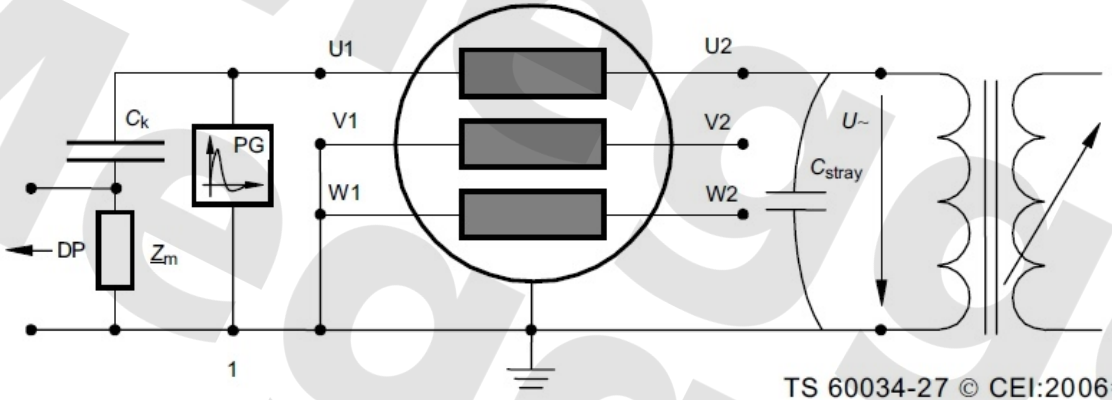
Offline Calibration Circuit



- Typical calibration levels for rotating machines (in IEC range /off-line): 500pC-10nC
  - Depending from winding to winding (slot length – capacitance)
  - Signal-to-noise ratio (SNR)
- Valid for the test setup in final arrangement, at a specific detection bandwidth and calibration magnitude

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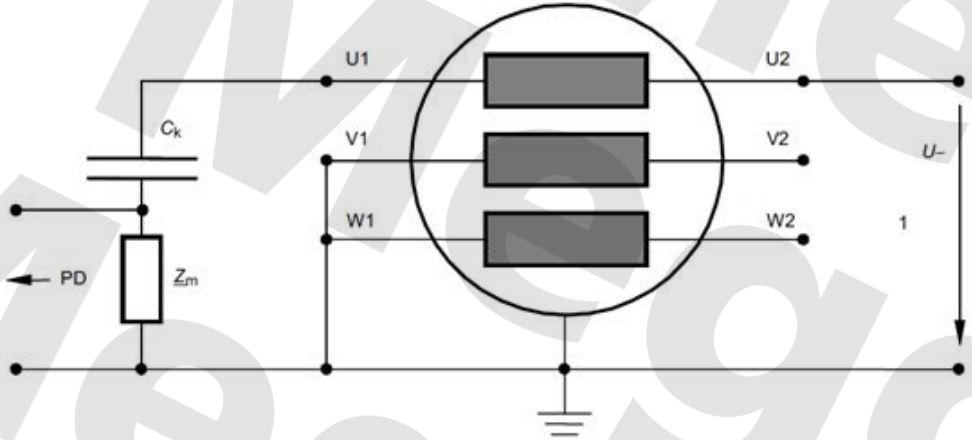
Recommended Off-line PD-Test Circuits (1/2)



ID number	HV	Ground	C_K
S1.1	U2	V1W1	U1
S1.2	V2	U1W1	V1
S1.3	W2	U1V1	W1
S1.4	U2V2W2	-	U1V1W1

According to IEC TS 60034-27

- Motor or Generator windings with accessible neutral connection allow energizing of complete winding to ground and the individual phases to ground

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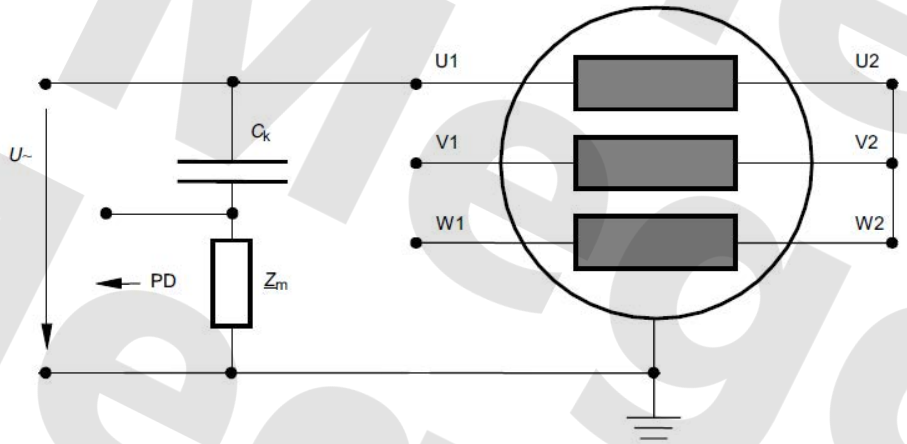
Recommended Off-line Test Circuits (2/2)



According to IEC TS 60034-27

ID number	HV	Ground	C_K
Accessible star point			
E2.1	U2V2W2	-	U1
E2.2	U2V2W2	-	V1
E2.3	U2V2W2	-	W1
E2.4	U1V1W1	-	U2V2W2
Inaccessible star point			
E2.5	V1	-	U1
E2.6	W1	-	V1
E2.7	U1	-	W1

- Stator windings with internal star point (neutral) connection allow energization of the complete winding, only (phase-to-ground)

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  - PD Signal Properties
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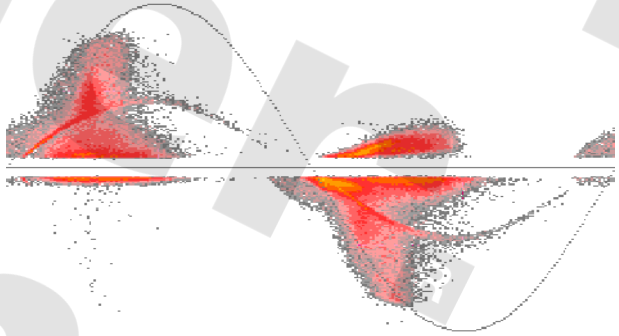
  - **Measurement Instruments**
- Failure examples



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ICM*system* : configuration for rotating machines

Decoupling

Capacitive couplers (CC7B, C14B,CC25B/V)

HFCT (e.g CT100)

Pre-processing

- <1MHz (IEC-60270) RPA1e
- Wideband (20MHz) RPA1H

Acquisition

- ½ 19inch ICM*system* (2ch)
- ½ 19inch ICM*system* *(4ch)*

ICM*system* (Generation 5)

- Advanced PD-detection system and analysis tool
- Simultaneous real time acquisition on up to 10ch (typ. 4 ch. with RM testing)
- Integrated spectrum analysis up to 10MHz (BW: 9kHz/300kHz)
- Time domain analysis using the built-in 100MS DSO
- Measurements with AC and DC voltages
- Advanced (SC/MC) control software
- High Resolution PRPD-Pattern (16-bit)
- Powerful Suppression Tools
- Input sensitivity <0,02pC
- IEC 60270 compliant
- Field and factory environment

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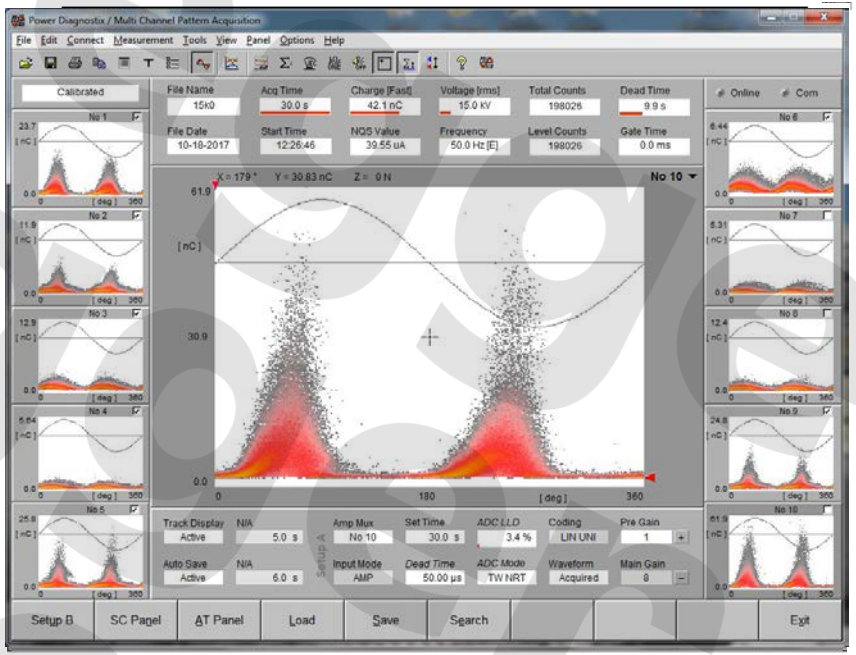
ICM*system* : software

Misc. Panels and Visualizations

- Single Channel Acquisition (SC)
- Multi channel Panel (MC)
- Spectrum Analysis
- Trending Functionality
- 16-bit PD-pattern
- Statistic Analysis Panel
- Time Domain (DSO)



ICM*system:* Setup Impressions

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ICM*flex*

- Measurement System for Partial Discharge (PD), Dielectric Loss Factor (Tan δ) and capacitance
- Unique design with Acquisition box on HV-potential
- Power frequency synchronization (20-510Hz) & VLF
- Plug and play setup incl. high voltage line filter
- User friendly control software with reporting functionality
- Optional step-by-step guide
- Bluetooth or Fiber optic communication
- Battery operated (up to 12h)
- IEC 60270 compliant
- Ultimately suited for Routine field and factory testing

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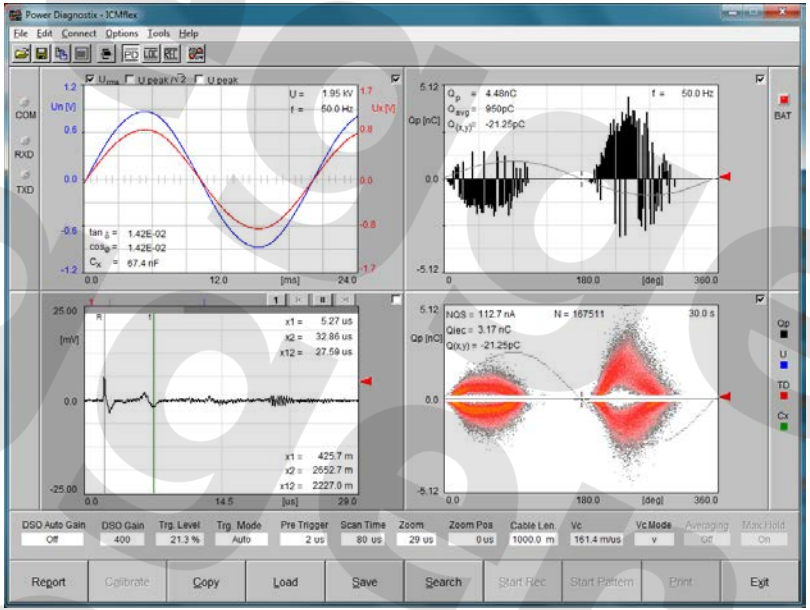
ICMflex – Software

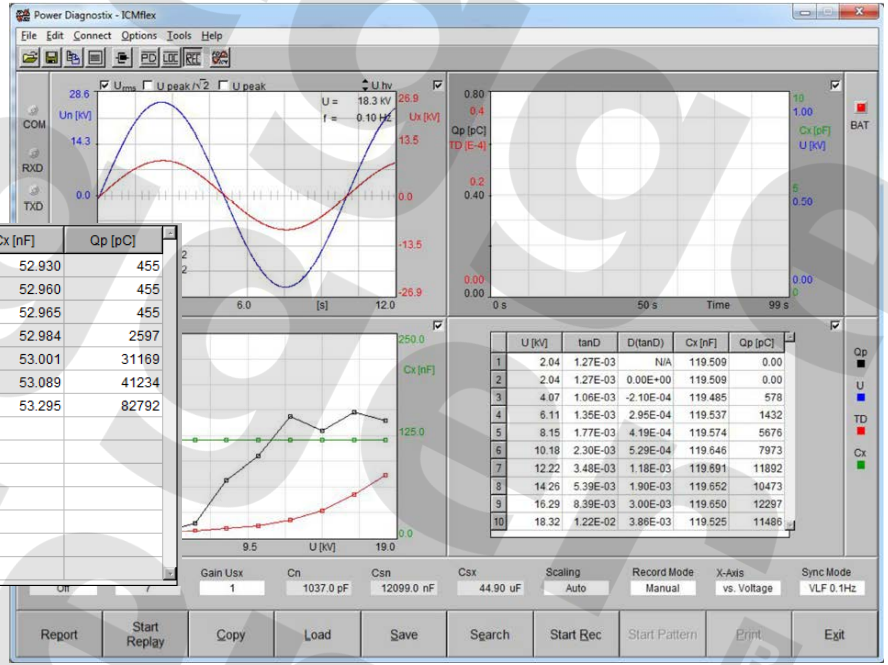
- All-in-one operation panel
- Direct access to all relevant instrument settings
- Multiple graphs updated simultaneously
- Data recording vs. time and vs. voltage
- Test automation
- Export data format .xls, .xlsx, .html



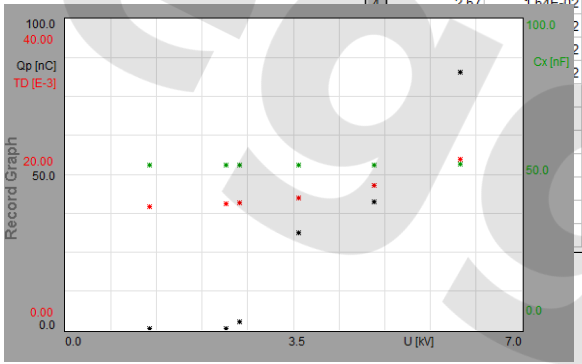
ICM*flex* – Software

PD & TD Recording

- Trending graphs of triggered data
- Auto and manual trigger
- Guided power factor tip-up test acc. IEEE286

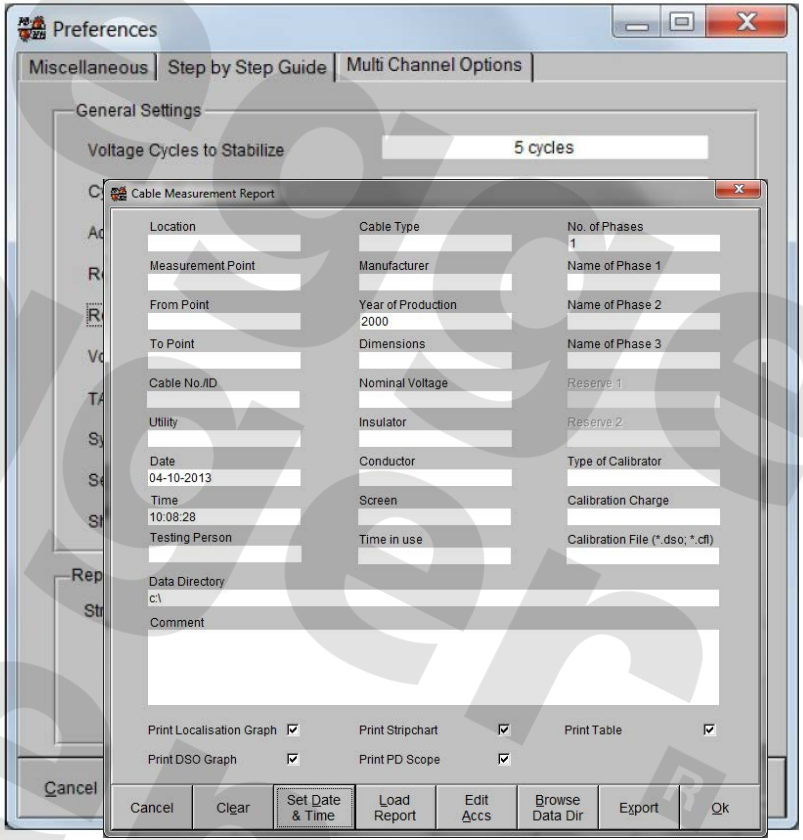


	U [kV]	tanD	D(tanD)	Cx [nF]	Qp [pC]
1	1.29	1.58E-02	N/A	52.930	455
2	2.47	1.62E-02	3.93E-04	52.960	455
3	2.47	1.63E-02	1.39E-05	52.965	455
4	2.67	1.64E-02	1.13E-04	52.984	2597
5	4.07	1.66E-02	5.83E-04	53.001	31169
6	6.11	1.68E-02	1.60E-03	53.089	41234
7	8.15	1.70E-02	3.37E-03	53.295	82792



ICM*flex* – Step by Step Guide

- Implemented into the ICM*flex* standard software
- Simplifies measurements
- Guided steps prior and during measurements
- Customized reporting tool



ICM*flex* – Step by Step Guide Report

PD

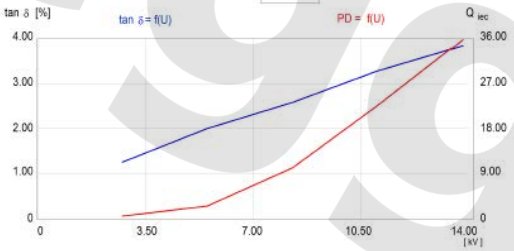
Date 05/15/14

Tan δ Loss factor and PD measurement

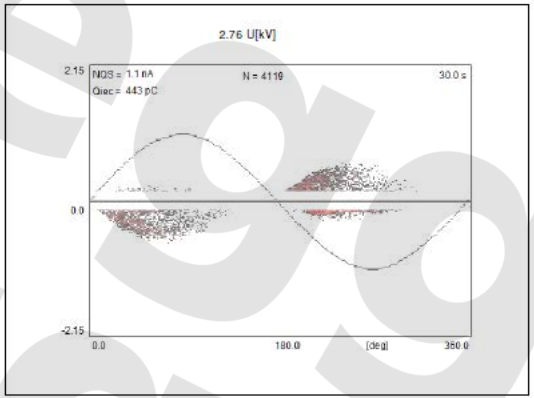
Work No.	12BP1005	Serial No.	12BP1005
Machine Type	G16m-10	Phase(s)	V
Measured by	Goedertier/Milcher	Approved by	Goedertier
Nominal Voltage	13.8		
Max Voltage	1.0 * U_n		
Device	ICMflex Ser No. 74 - FW Version 1.28		

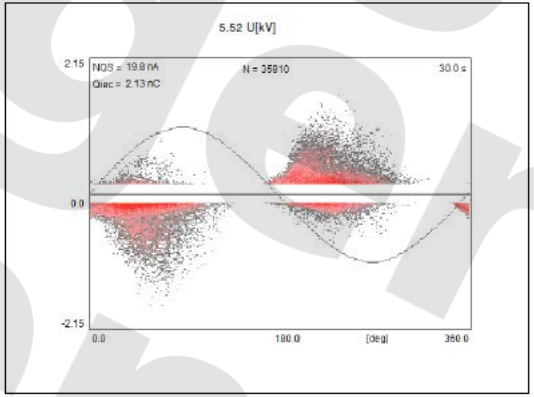
U [kV]	Tanδ / %	Δ (Tanδ) /‰	Cx [nF]	Qiec [nC]
2.76	1.254		146.876	0.480
5.52	2.001	7.477	148.514	2.49
8.28	2.580	5.788	150.293	10.1
11.04	3.273	6.926	152.452	22.5
13.80	3.839	5.665	154.283	35.7

Max. Δ tan δ / ‰ 7.477



1 of 2 PD





2 of 4 PD

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ICMflex – How to connect

HV*control* and HV transformer

ICMflex connected to a motor terminal box

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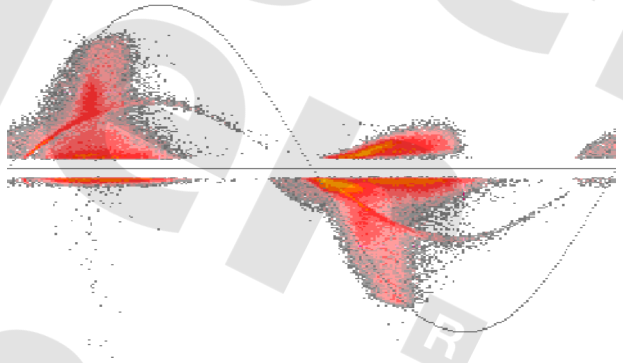

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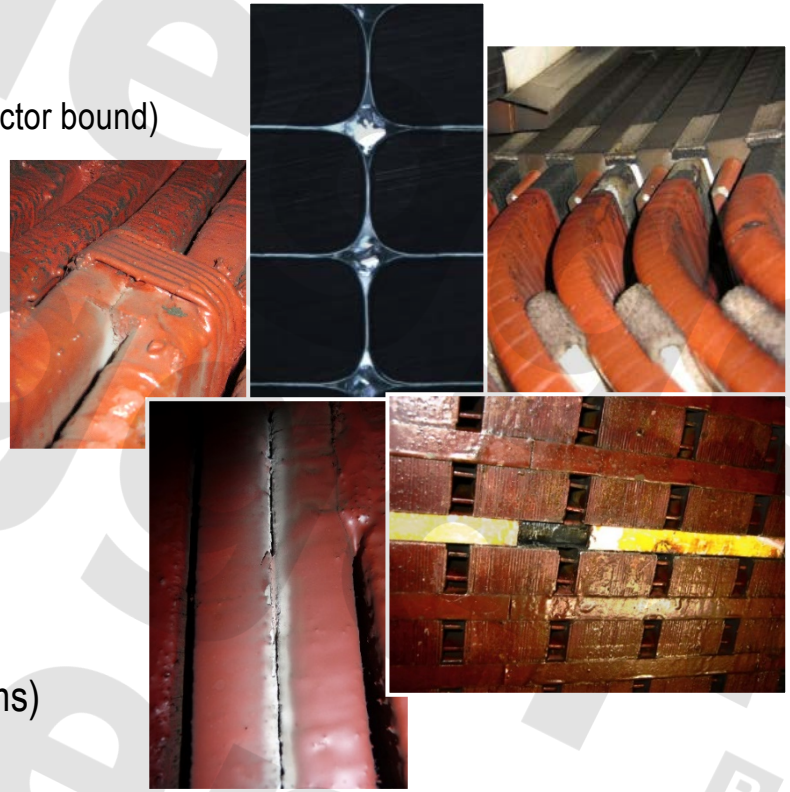
Classification of Rotating Machine PD

- Internal Discharge Activities
  - Delamination's (main insulation or conductor bound)
  - Micro Voids
  - Thermal ageing
- End Winding (overhang) Discharges
  - Surface Discharges by contamination
  - Bar-to-Bar activity
  - Vibrations
- Slot Discharges
  - Wedge problems
  - Inadequate impregnation
- Slot-exit Discharges (Field grading problems)
- External high frequency disturbances



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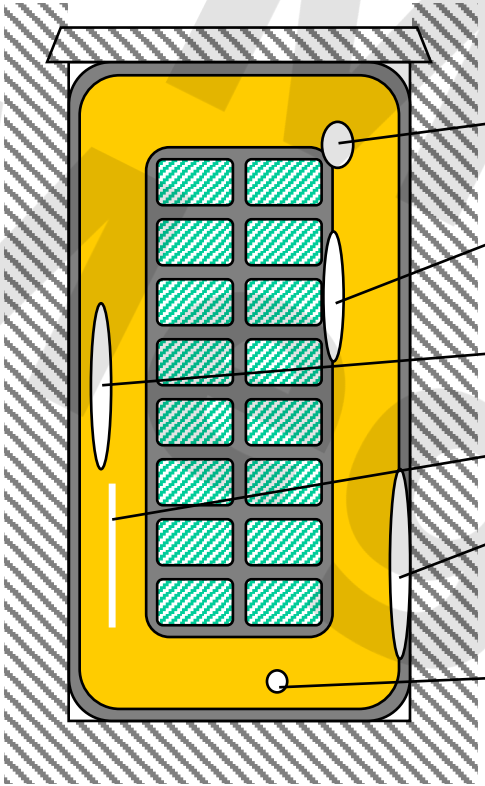
Defect Locations in the Stator Bar



A: Strongest electrical Field

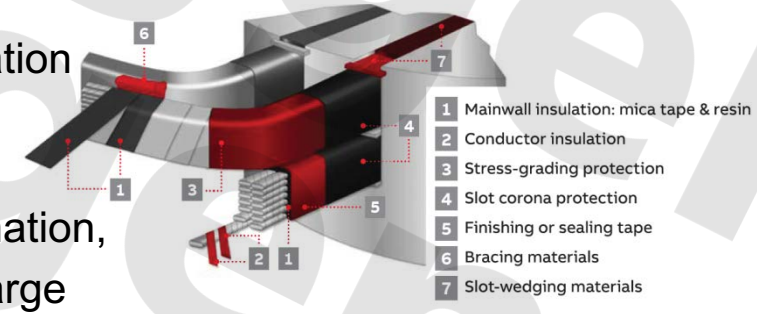
B: Delamination of the Main Insulation from the Winding

C: Tape Layer Delamination

D: Treeing in Layers

E: Ground Wall Delamination, so-called Slot Discharge

F: Internal Voids



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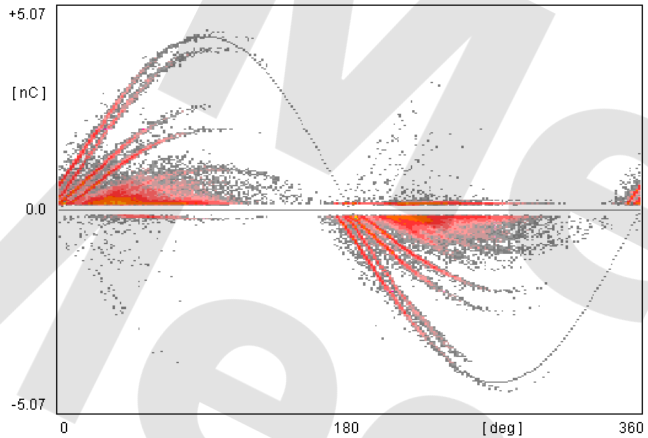
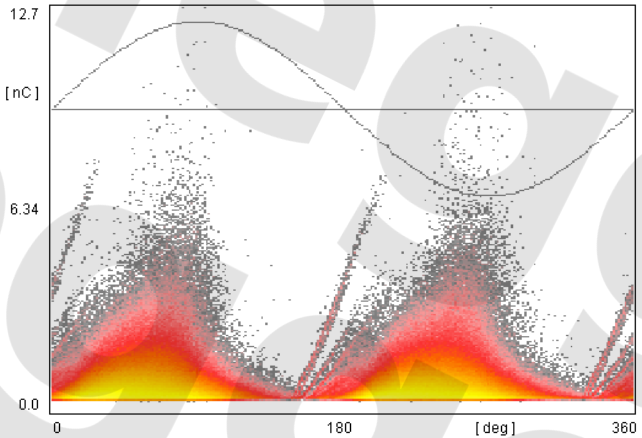
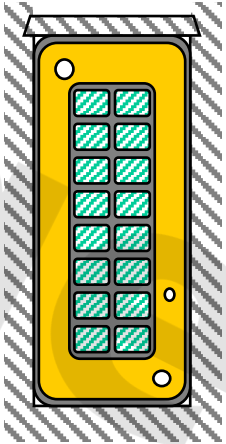
Void Discharges

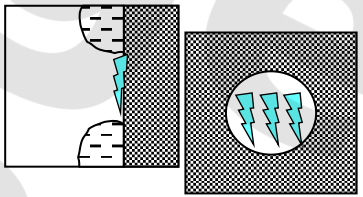






Symmetrical Electrode Configuration

- Multiple Voids of different Sizes
- Increased Test Voltage
- Voltage shaped clusters (line type pattern)
- Void and Surface Discharge



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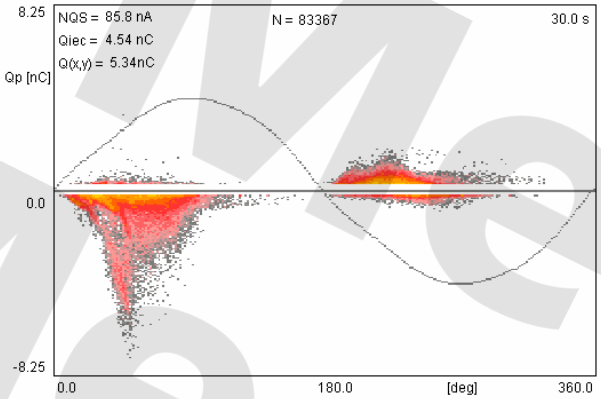
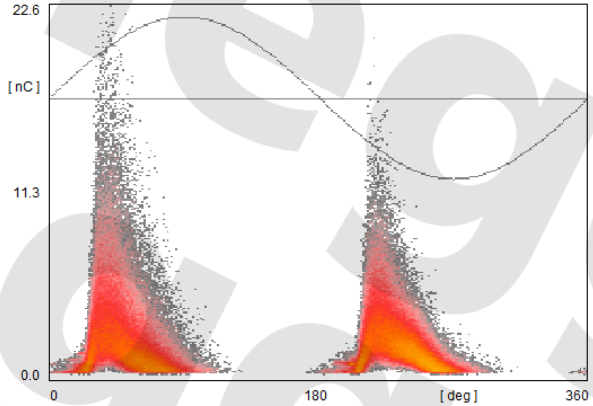
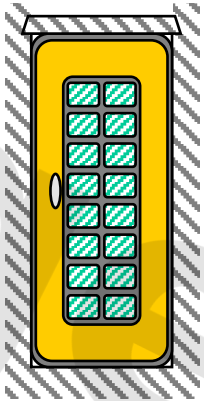
Conductor-bound delamination

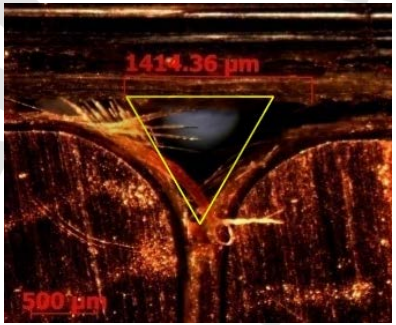






Main Pattern Properties:

- Asymmetrical pulse distribution for both cycles
- Dominant positive cycle
- Delamination at inner conductor circuit
- Normal Ageing : frequent load cycling (e.g. pump storage stations)



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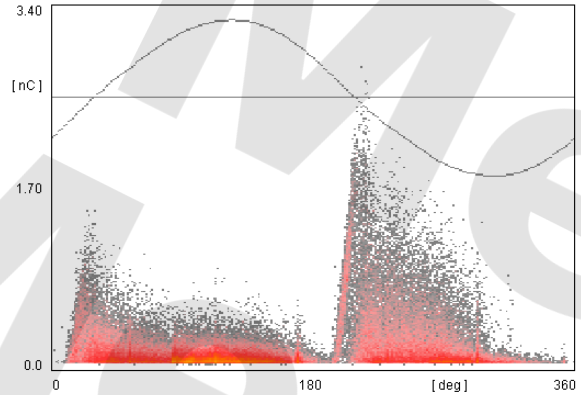
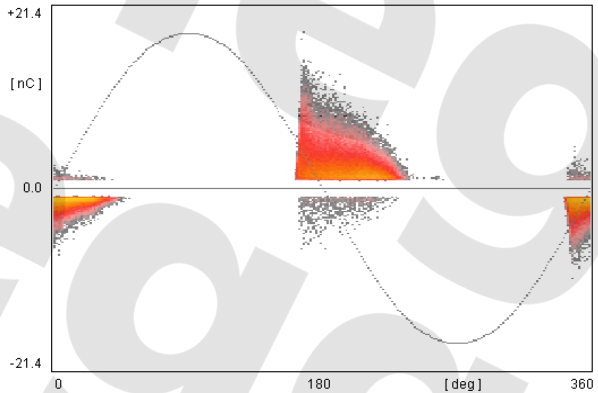
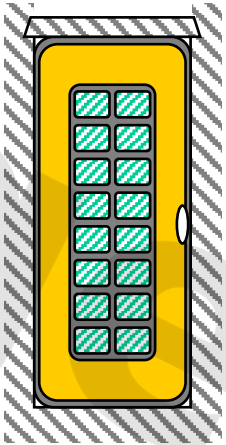
Slot Discharges with Machine Bars



Unipolar Pattern

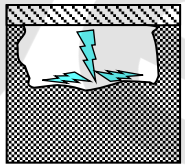


Bipolar Pattern



Asymmetrical Electrode Configuration

- Predominantly in the negative Half Cycle
- Often typical triangular Pattern
- Strongly Load Dependent due to Magnetic Forces
- Delamination at the slot corona prevention layer
- Consequent high Ozone (O3) generation causing “collateral damage”



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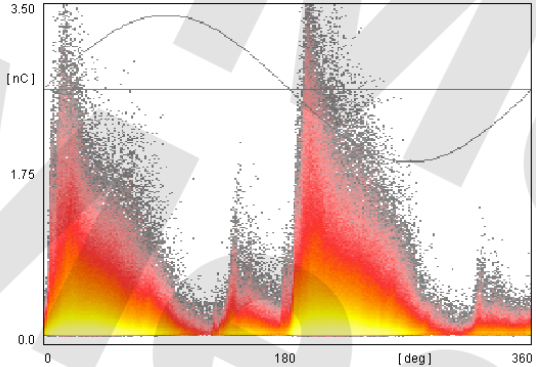
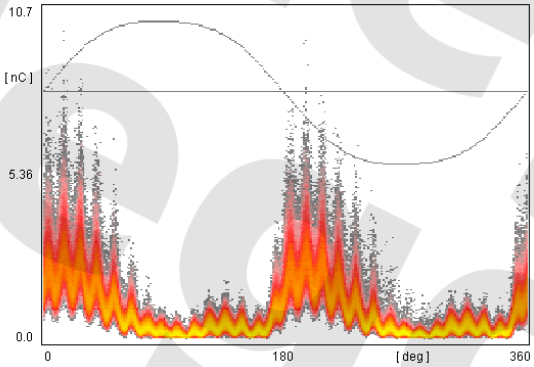
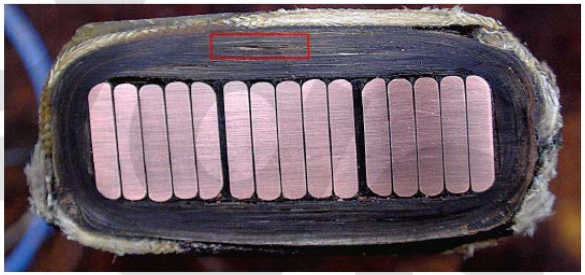
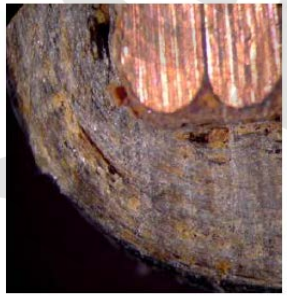
Discharges of thermally aged main Insulation



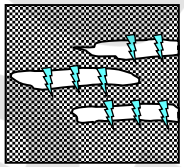






Symmetrical Electrode Configuration

- Similar Pattern for both Half Cycles
- Equal Polarities and Amplitudes
- Often typical triangular Pattern
- Cross-coupling of adjacent Phase
- Main Insulation Delaminations/Voids



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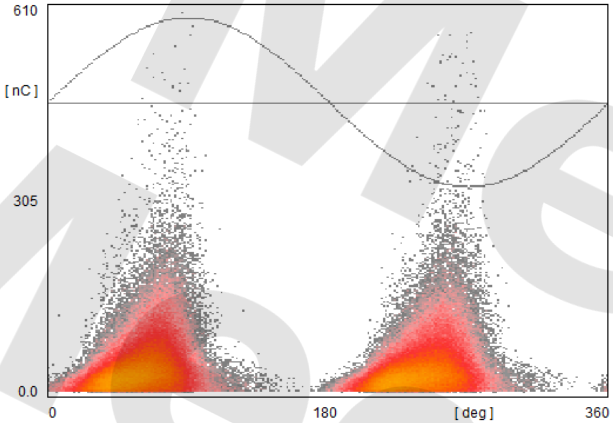
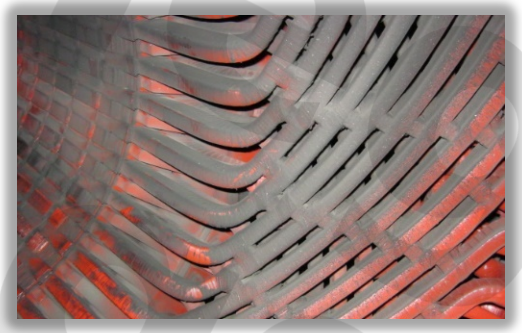
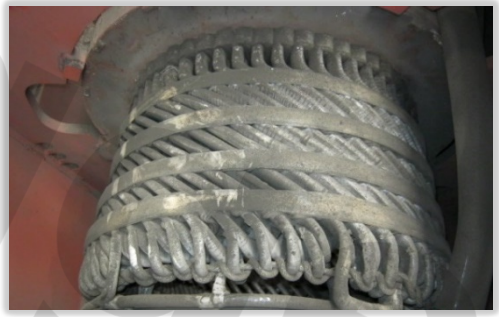
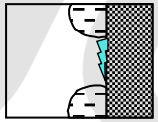
End Winding Surface Discharges









Contaminated Overhang

- Similar, often triangular, PD Pattern for both half cycles (90° / 270°)
- Strongly voltage dependent discharge magnitude
- Contaminated or Moisty Insulation Surface
- Insufficient Spacing between inter phases
- Insufficient Grading by the Semi-Conductive layer

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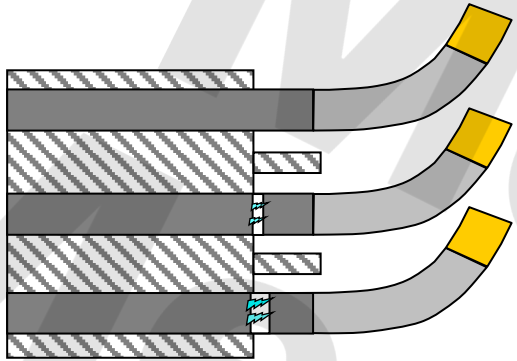
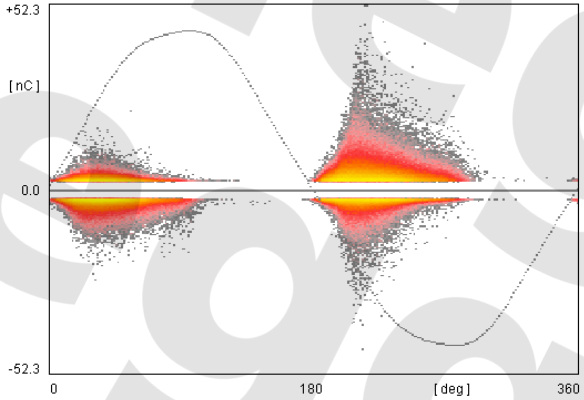
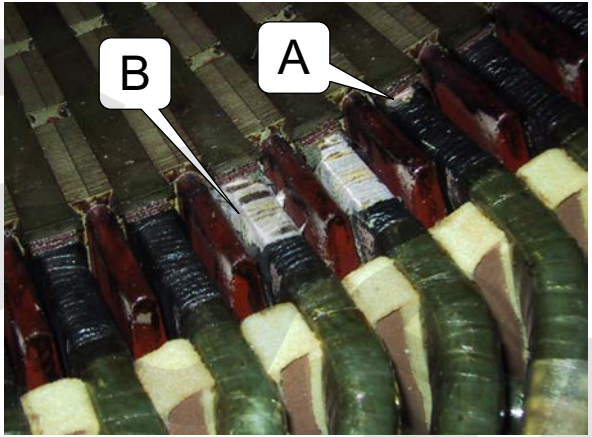
Slot-Exit PD-activity: Initially

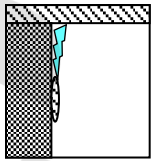






Defect Mechanism with Vacuum Impregnation Systems

- Thermal Stress causes Surface Cracks
- Initial State: Surface Discharge
- Discharge Level: 10-50nC
- Gap Grows due to the PD “consumes” insulation



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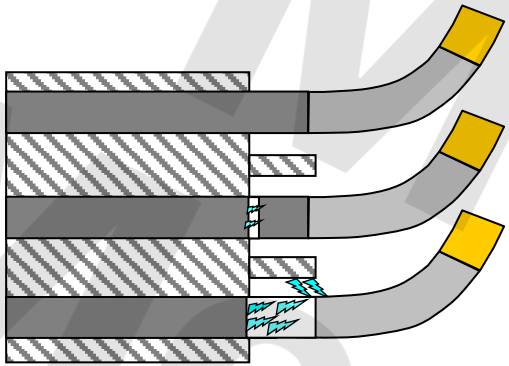
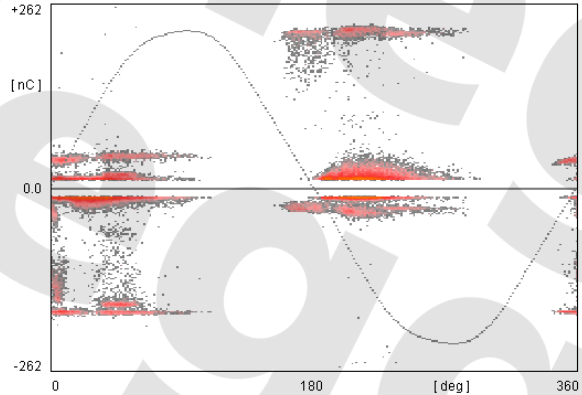
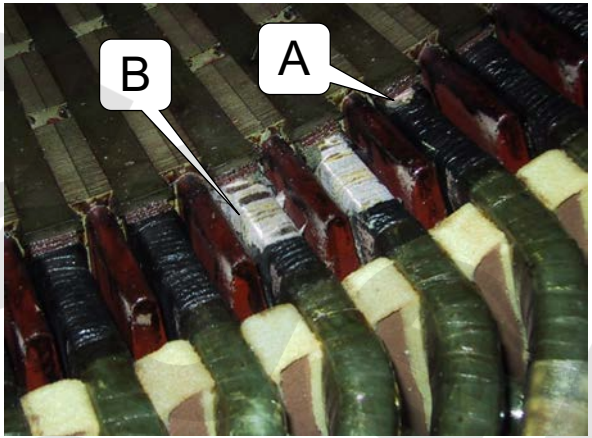
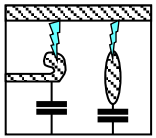
Slot-Exit PD-activity: Final Stage



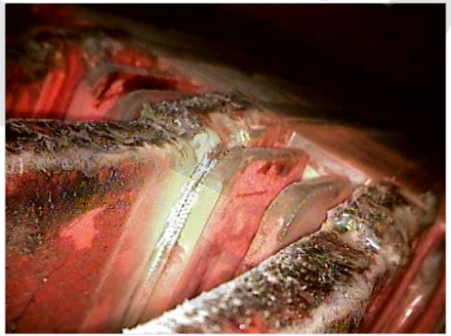




Defect Mechanism with global Vacuum Impregnation



- Loss of dielectrical strength to Ground Potential
- Discharge to the Pressure Finger, Plate or stator core
- Final Stage: Floating Potential Discharge
- Strong Discharge Amplitude Qp > 100nC



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Summary

- Stator winding insulation system are PD-resistant and widely tolerate PD-activity for several years of operation without being the root-cause of failure
- Dielectric measurements are as important as monitoring of vibrations
- Partial detection on rotating machinery is a matter of trending and comparing actual results with available reference data – there are currently no acceptance criteria defined
- Sufficient care must be taken with the bandwidth selection, calibration procedure and correct selection of recommended measurement circuits
- Analysis of the phase resolved partial discharge pattern (PRPD) provides essential information about the ongoing type of partial discharge and the concerned location
- Off-line measurements serve as an in-depth verification after manufacturing, during the first months of operation and during major maintenance outages. Moreover, they are an excellent tool to be used for partial repairs

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PD Testing of Rotating Machines

Insulation Failures are costly and can be disastrous...

Thank You for Your Attention!

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Survey and Contact Information

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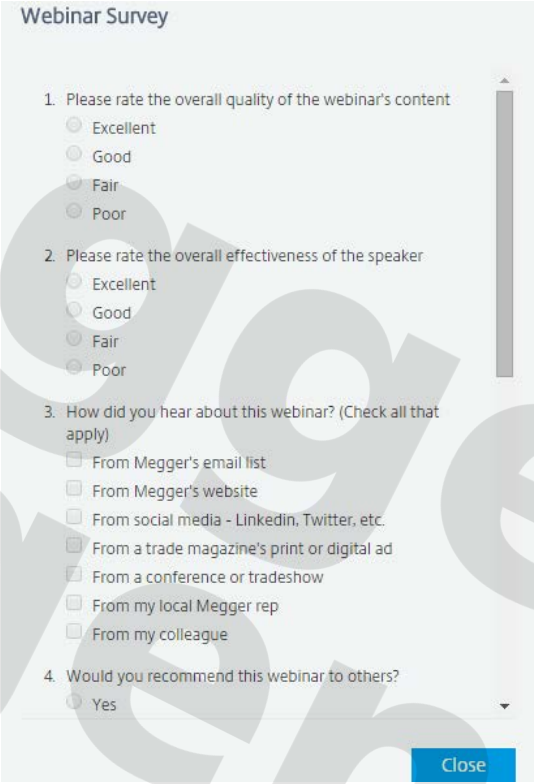

Please help us improve by filling out the survey after the webinar ends

Megger

Megger

Questions ???