# Electrical Testing of Rotating Machines

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# Electrical Testing

- Commissioning or acceptance test
- Maintenance test

- ❑ Destructive test (go-no go test)
- ❑ Diagnostic test

# Resistance/ PI

INSULATION RESISTANCE AND POLARIZATION INDEX - *Megger™ test*

Most widely used diagnostic test

IR is strongly dependent on temperature. A 10 ◦C increase in temperature can reduce $R_1$ by 5–10 times

“temperature correction” graphs and formulae are available to enable users to “correct” $R_1$ to a common 40 ◦C temperature but most of them are unreliable

If a very high $R_1$ is measured (say >5 GΩ), PI is not likely to indicate anything

Modern instruments can apply voltages up to 10 kV DC, and measure resistances higher than 100 GΩ (100,000 MΩ)

# Resistance/ PI

PI is the ratio of the IR measured after voltage has been applied for 10 min ($R_{10}$) to the IR measured after just 1 min ($R_1$)

$$\mathrm{PI} = \frac{R_{10}}{R_1}$$

PI is less sensitive to temperature

Generally, if the PI is about 1 for form-wound stator windings, the winding is wet or contaminated. If PI is greater than 2, it is clean and dry

*IEC* ***60034-27-4:2018****:*

Measurement of insulation resistance and polarization index of winding insulation of rotating electrical machines

# CAPACITANCE/PF

Capacitance tip-up -> indirect partial discharge test

Silicon carbide coatings can be guarded out

Increase in capacitance due to PD activity

Only relevant for form-wound stator windings rated 2300 V and above

The low voltage capacitance ($C_{lv}$) measured, at about 0.2*E*

The high voltage capacitance ($C_{hv}$) measured, at about 0.6*E*

$$\Delta C = \frac{C_{hv} - C_{lv}}{C_{lv}}$$

*E* is the rated phase-to-phase voltage

# CAPACITANCE/PF

Typical DFs are about 0.5% or less for modern epoxy

A significant amount of deterioration has occurred if the DF

has increased by 1% or more from the initial value

A process monitor for the impregnation process.

As the groundwall is impregnated, the DF will increase.

As the coil cures, the DF will decrease to its steady final level

DF tip-up test

DF from 0.2E to 1.0E, in 0.2E increments

*IEC **60034-27-3:2015**:*

Dielectric dissipation factor measurement on stator winding insulation of rotating electrical machines

# HiPot

Sensitive to **major flaws** in the groundwall insulation

Commissioning or acceptance hipot

Maintenance hipot

Destructive test -> if fail rewound or a major overhaul

No diagnostic information

Perform an IR/PI test prior to a maintenance hipot test

Not perform hipot test until the winding is **dried and/or cleaned**

Reduce test voltage for unimpregnated windings (60~80%)

*IEC **60034-15:2009**:*

Impulse voltage withstand levels of form-wound stator coils for rotating a.c. machines

# HiPot

## AC HIPOT TEST

AC hipot acceptance level of **(2*E* + 1) kV**

AC hipot will age the insulation

*E* is the rated rms phase-to-phase voltage

AC maintenance hipot for stator windings should be **1.25 to 1.5*E***

A 13.8 kV generator stator winding with a capacitance of **1 μF** requires a charging

current of **8 A** at 60 Hz for a 1.5*E* maintenance hipot test 21 kV at 8 A or about

170 kVA

For rotor windings rated less than 500 $V_{dc}$, the AC hipot is 10 times the rated DC voltage

For rotors rated >500 V, the AC hipot is two times the rated voltage plus 4000 $V_{rms}$

# HiPot

## DC HIPOT TEST

Much lower charging current

DC acceptance hipot should be **1.7 times the AC hipot** acceptance level

Maintenance hipot should be as high as 75% of the acceptance hipot level

Many users have adopted a DC maintenance hipot level of about ***2E***

# HiPot

## Impulse HIPOT TEST

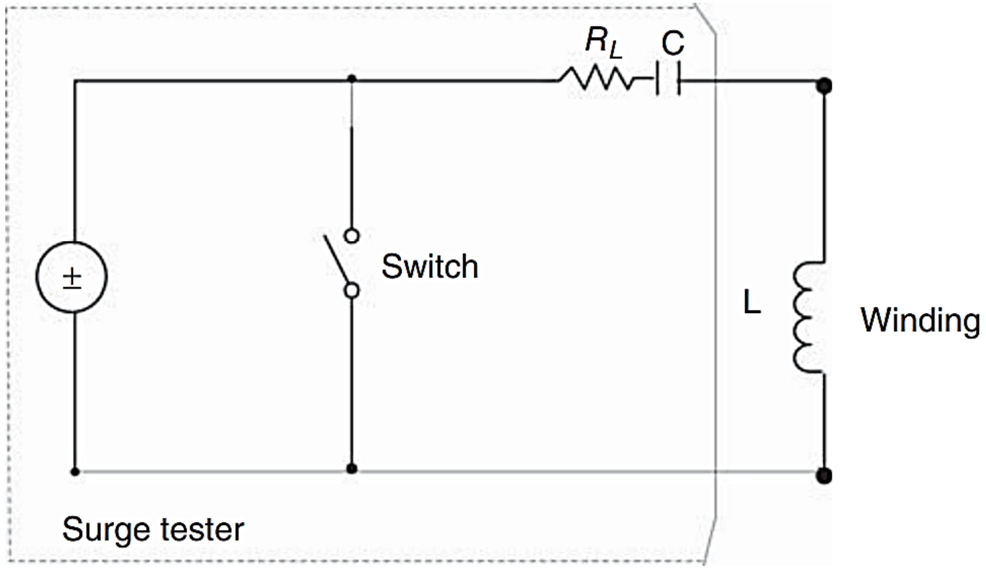
Measures the integrity of the **turn insulation**

A turn-to-turn puncture in a winding does not cause a huge increase in current from the power supply

Detected by means of the change in resonant frequency caused by shorting out one turn

Rise-time of 100–200 ns and a maximum magnitude 2.8 E

Maintenance test -2 E



# Voltage Endurance

Long life aging (for 13.8 kV machine)

- ➢ 400 hrs. at 30 kV and 120 ˚C
- ➢ 250 hrs. at 35 kV and 120 ˚C
- ➢ 50 hrs. at 40 kV and 120 ˚C
- ➢ Equivalent to 40 + 4 years continuous service

# PARTIAL DISCHARGE

**OFF-LINE**

Discharge inception voltage (DIV)
Discharge extinction voltage (DEV)

DEV above about 75% of the rated line-to-ground voltage.

*IEC* ***60034-27-1:2017****:*
Off-line partial discharge measurements on the winding insulation

Peak magnitudes (Qm)

Fully manufactured (i.e., impregnated and cured) bars and coils should have a PD level below **100 pC** when tested at rated line-to-ground voltage

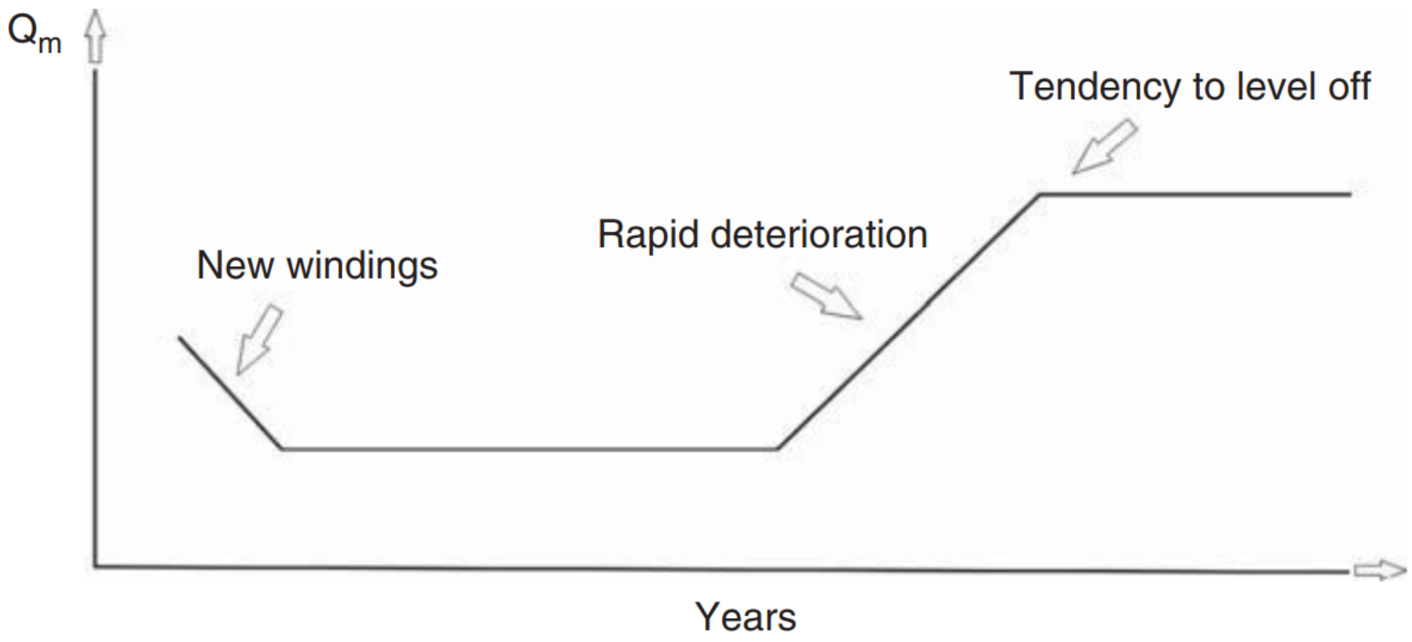
# PARTIAL DISCHARGE

## ON-LINE

- ***Trend***
- ***PRPD***

*IEC TS* ***60034-27-2:2012***:

On-line partial discharge measurements on the stator winding insulation of rotating electrical machines



# Rotating Machine Testing

Different Testing stage

1) Coil/bar testing
2) Commissioning
3) Maintenance
4) Online Monitoring

Source of problems

- Design
- Material selection
- <u>**Manufacturing**</u>
- Various operating stresses

# Coil/bar testing

**Inadequate resin impregnation**

Failure due to PD in the groundwall voids can occur in as short a time as 2 years in stators rated 6 kV or more

Should be **PD-free** when manufactured

- ➢ resin/varnish viscosity that is too thin or too thick
- ➢ Improperly stored tapes
- ➢ Poor taping
- ➢ Taking too long a time from the impregnation tank to the curing oven

Dissipation factor **tip-up or off-line PD** tests are done on every coil, bar and stator (in the case of GVPI stators)

For machines rated 3 kV or above, the PD test is the best way to detect poor impregnation

# Coil/bar testing

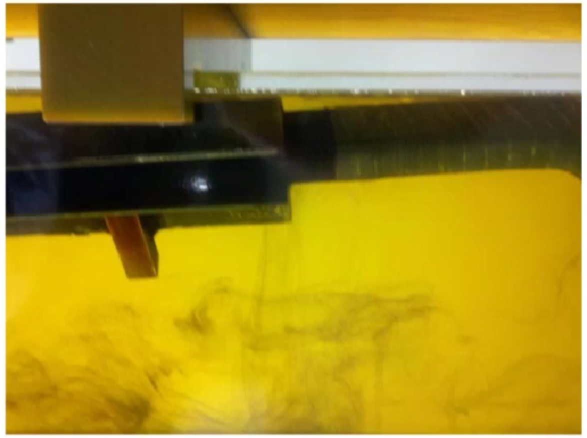
Sacrifice coil

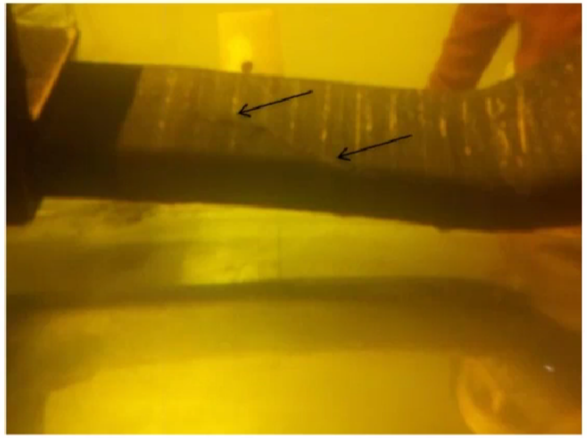
Consider at least two or three coils as **sacrifice coils**

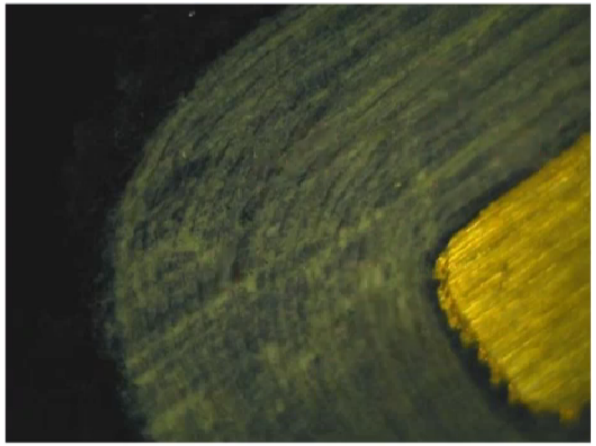
Cut open and verify resin penetration down to the conductor

use for withstand capability and PD test up to breakdown voltage

Coil failed in gradient tape (in oil) at 87 kV (AC) for 13.8 kV coil







# Commissioning/ maintenance Testing

**Loose coils in the slot**

Initial looseness can be prevented using ripple springs under the wedges or as side

If the coils are loose, the PD activity will increase dramatically with load

A significant amount of ozone

**High intensity slot discharge**

Semiconductive coating becoming isolated from the stator

core for the entire length of the slot

# Commissioning/ maintenance Testing

**Vibration sparking**

if the semiconductive coating at some point loses contact with the core, an arc (or spark) will form if the interrupted current is large enough

VS seems to involve a high intensity spark that has sufficient power to relatively rapidly fail bars in as short a time as 4 or 5 years.

# Commissioning/ maintenance Testing

**Semiconductive/grading coating overlap failure**

It is unlikely for this process alone to directly lead to groundwall failure, at least in less than **20 years** or so, despite the large discharge magnitude.

Poor stress control design and/or poor manufacture

White band

There seems to be less chance of this problem in tape based rather than paint based

# Commissioning/ maintenance Testing

Semiconductive coating deterioration caused by poor
manufacture and/or high temperature operation,
which leads to PD, creating ozone that
chemically attacks the insulation

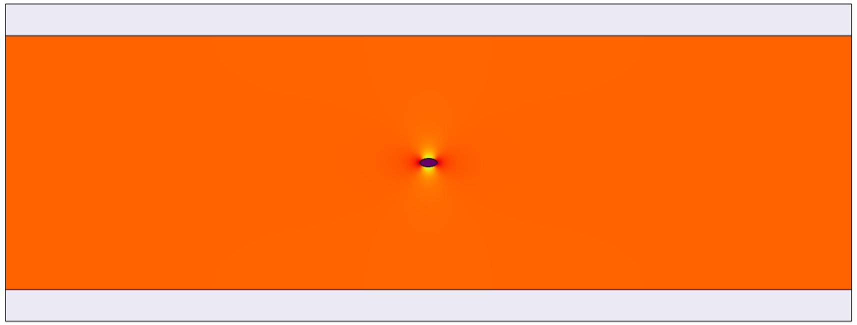
Internal coronal protection (IGS) – In the conductor stack

External corona protection (AGS) – within the slot

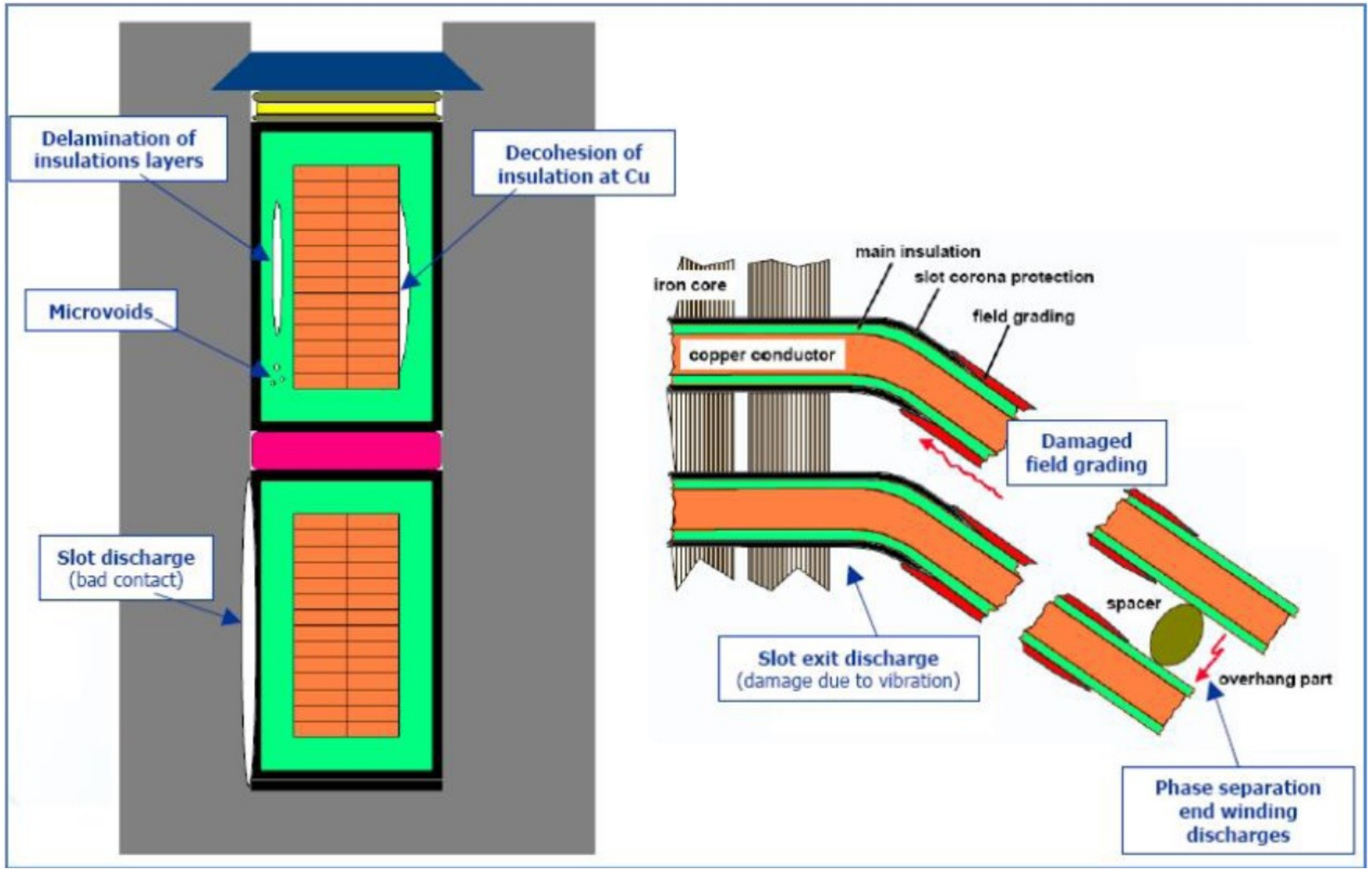
End corona protection (EGS) – at the slot end

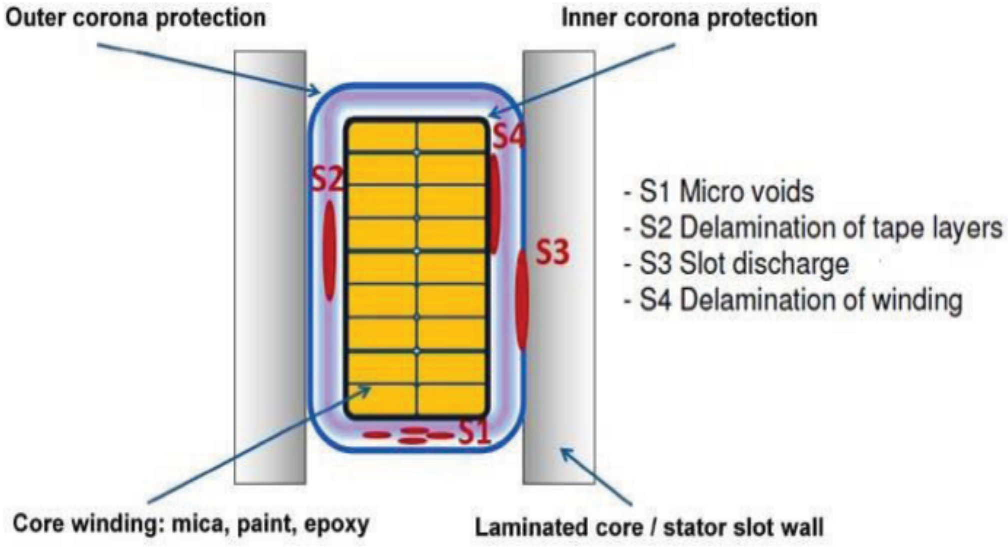
# Commissioning/ maintenance Testing

- Thermal deterioration creates **delamination**, allowing PDs that ultimately erode a hole through the insulation
- Failure due to PD in the groundwall **voids** can occur in as short a time as 2 years in stators rated 6 kV or more



# Rotating Machine Online Monitoring



# Rotating Machine Online Monitoring

| Type [9,20] | | Cause [1,9,18–21] | Location [9,20] | Frequency/MHz [23–25] | Time to Failure/Years [20,21] | Damage [9,29,32] |
|---|---|---|---|---|---|---|
| Internal PD | Internal voids | poor manufacturing | HV winding | 50 | >30 | Low |
| | Internal delamination | poor design & manufacturing | | | <10 | High |
| | Delamination between conductor and insulation | poor design & manufacturing | | | <10 | High |
| Slot PD | Mechanically induced slot PD | poor design & manufacturing, improper maintenance | HV slot winding | 100 | <2 | High |
| | Electrical slot PD | poor manufacturing | | | >30 | |
| | High intensity slot PD | poor design & manufacturing | | | <1 | |
| End-winding PD | End-winding corona | poor design, installation defect | HV overhang winding | 500 | >20 | Normal |
| | Surface tracking | lack of maintenance | | 250 | >10 | |
| | Phase to phase discharge | poor design, installation defect | | 250~500 | >5 | |
| Arcing | Broken conductor | poor design, installation defect | Slot exit | >30 | <1 | Very high |
| | Welding crack | | End cap | | | |
| VS | | poor design | Slot winding | >6.7 | <4 | High |

# Rotating Machine Online Monitoring

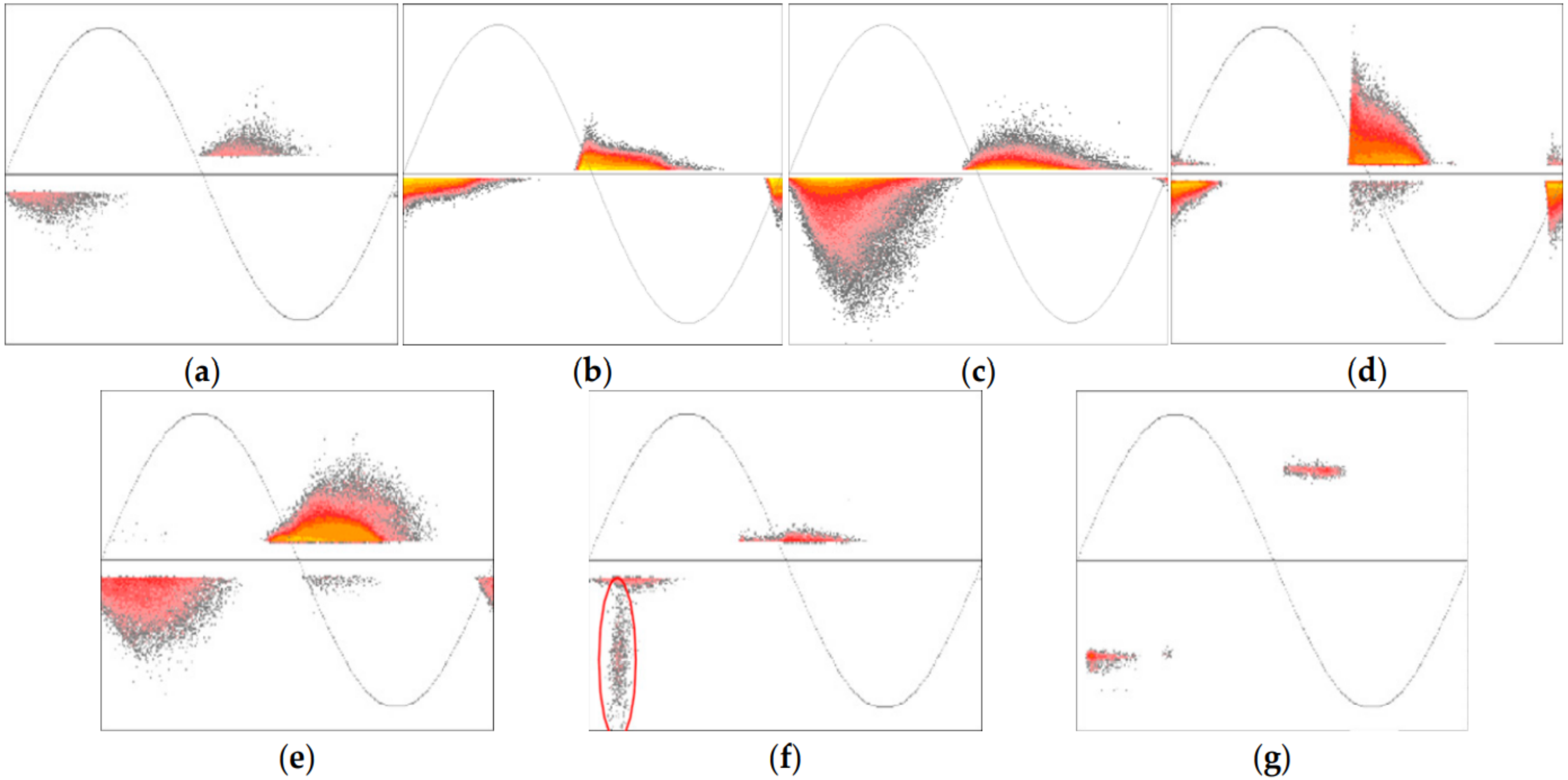
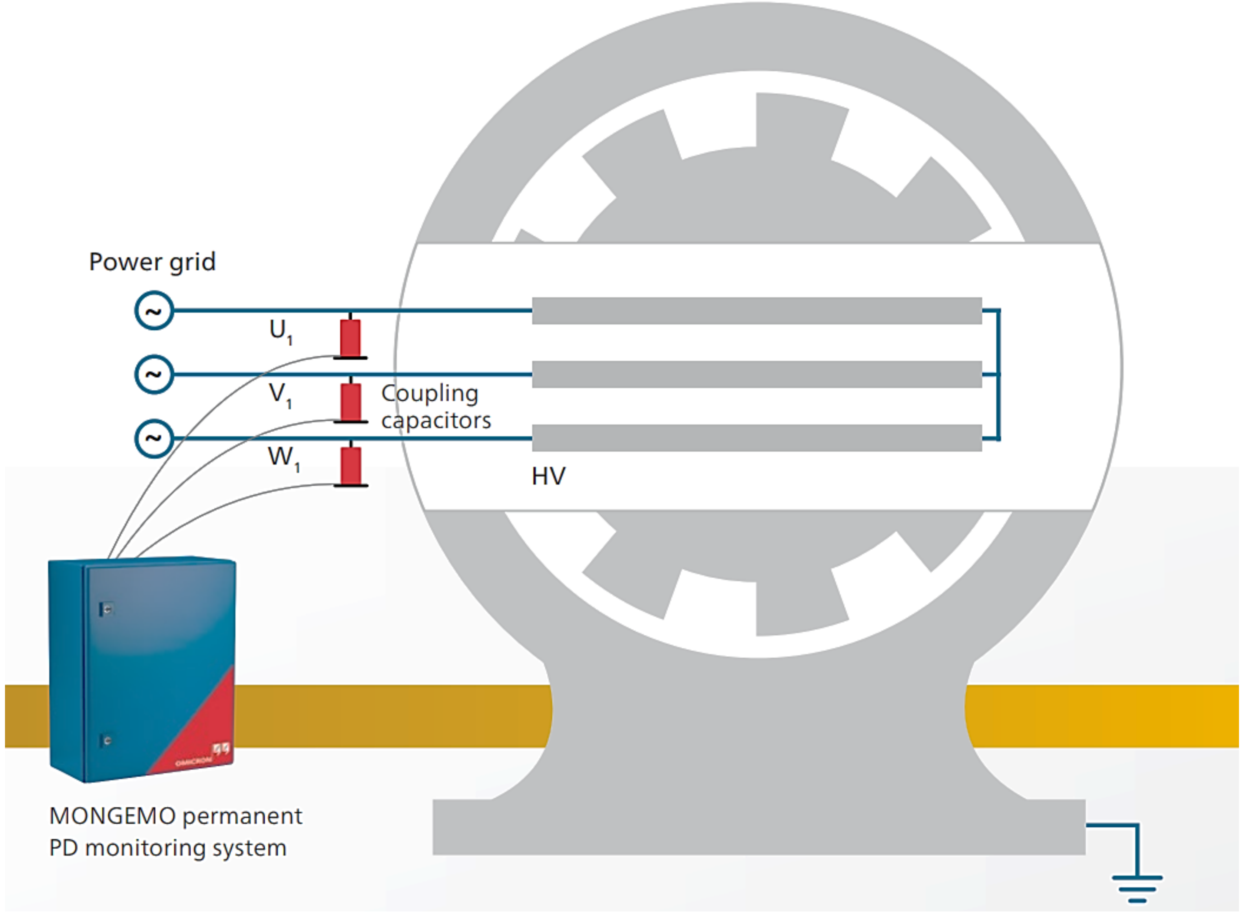



**Figure 3.** PD patterns in [9,23] (**a**) Internal voids; (**b**) Internal delamination; (**c**) Delamination between conductor and insulation; (**d**) Slot discharge; (**e**) End-winding corona; (**f**) Surface tracking; (**g**) Phase to phase discharge.

# Rotating Machine Online Monitoring

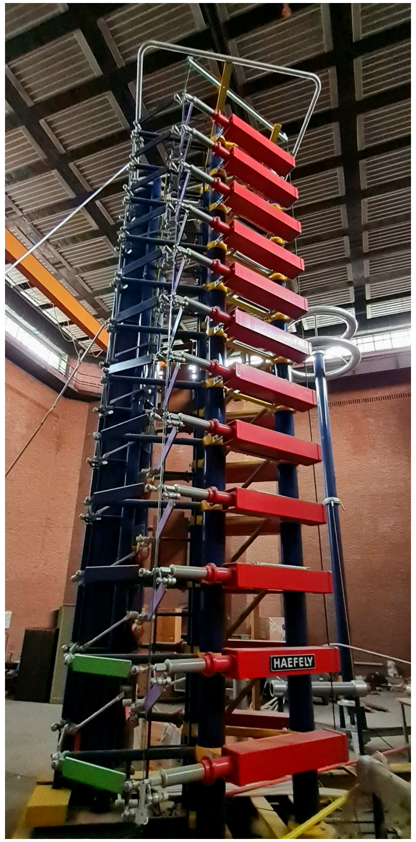
Coupling Capacitor



# ODTÜ HV Laboratory

- Sacrifice coil testing
- On site PD measurement

MPD 800




2.4 MV Impulse Generator

200 kV Transformer