Hydro-generator condition-based monitoring system modernisation for maintenance optimisation

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Agenda

1. Modernisation
2. Monitoring Overview
3. Vibration
4. Airgap
5. Partial Discharge
6. Rotor Flux
7. Application Example

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Why Hydro Modernisation is Important

- Plant estimated maximum useful life 100-125 years
- Generator design life ~25-50 years (electrical insulation)
- Average US Hydro Power Plant (HPP) age is 64 years (stats as of 2016); today being 73 years
- Average EU HPP age of 46 years (stats as of 2018)
- HPPs account for 99% of all currently operating capacity in US built before 1930
- 50 oldest electric generating plants in the US are all hydroelectric generators; each has been in service since 1908
- 50% of all HPPs worldwide were originally commissioned more than 40 years ago

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Modernisation Options

- Retirement
  - decommissioning assets from service
- Redevelopment
  - developing new assets to replace existing ones
  - E.g. new reservoir tunnel built to substitute an original, 65-year+, old single tunnel
- Life Extension
  - repairing or replacing equipment to maintain or restore output and reliability
  - rewinding the generator stator to re-establish insulation systems
- Modernisation
  - upgrading or uprating equipment to increase output and/or reliability
  - replacing the turbine runner to improve overall efficiency

Monitoring Technologies

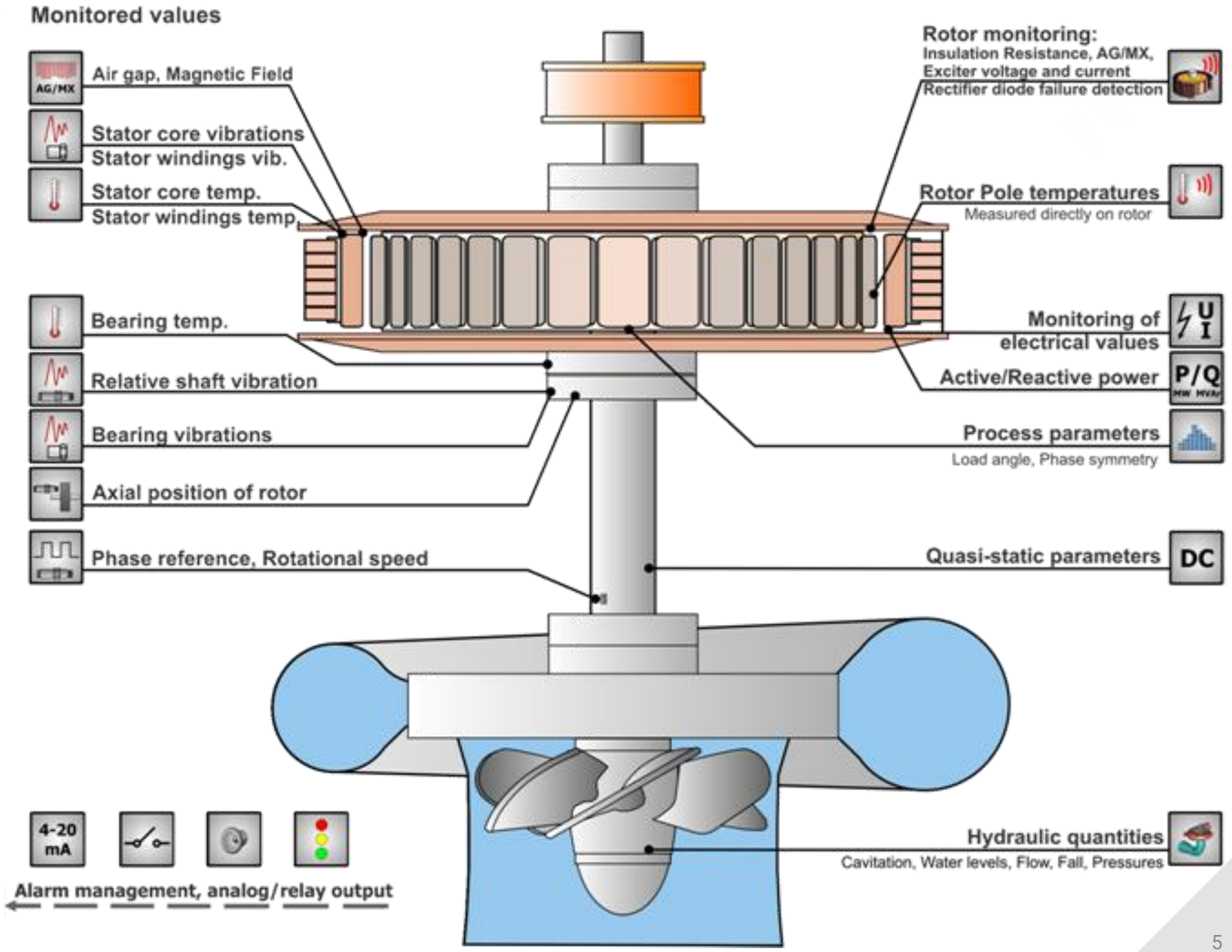
Mechanical

- Shaft Relative Vibration
- Bearing Absolute Vibration
- Air Gap

Electrical

- Partial Discharge
- Magnetic Field (flux)

Temperature, Process, Hydraulic, etc…



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Fault Detection by Technology

Combination of “conventional” vibration monitoring, combined with air gap, PD, and flux covers the widest range of potential faults

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Faults / Measurement	Bearing vibrations	Relative shaft vibrations	Bearing temperatures	Turbine cover vibrations	Air gap	Magnetic field	Stator core vibrations	Stator frame vibrations	Generator temperatures	Process quantities	Cavitation	Electrical quantities	Partial discharge	Hydraulic quantities
VESKi Fault detection and Corresponding measurements														
Mechanical Unbalance	1x •	1x •												
Electrical unbalance	1x •	1x •			•	•								
Hydraulic unbalance	1x,nx •	•		•										•
Misalignment	1x, 2x •	1x, 2x •												
Eccentricity of stator and rotor		DC •			•	•								
Bearing wear	•		•											
Stator windings vibrations							100Hz 200Hz •	100Hz 200Hz •						
Insulation wear													•	
Rotor shape		•			•	•								
Overheated stator coils									•	•			•	
Phase symmetry							•	•				•		
Bearing stiffness	•	•												
Excitation problems						•						•		
Load angle detection					•	•						•		
Pressure pulsation											•			•

Vibration – Overview

Widely adopted, good for many mechanical failure modes:

- *unbalance, misalignment, looseness, bearing degradation*

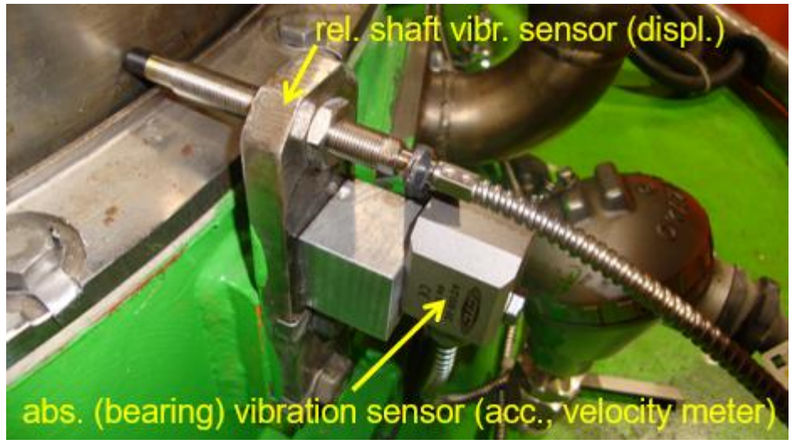
Data plots include trends, waveform/orbit, spectra, polar/bode, and shaft centerline

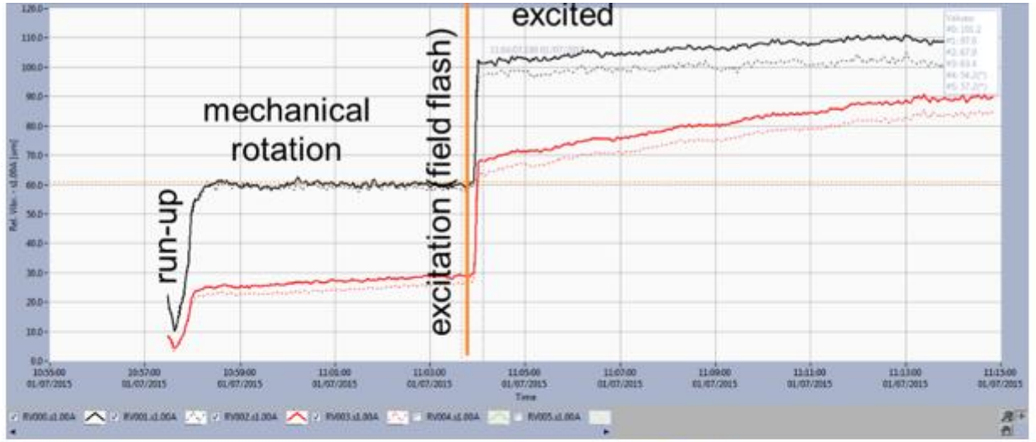
Typical measurements include:

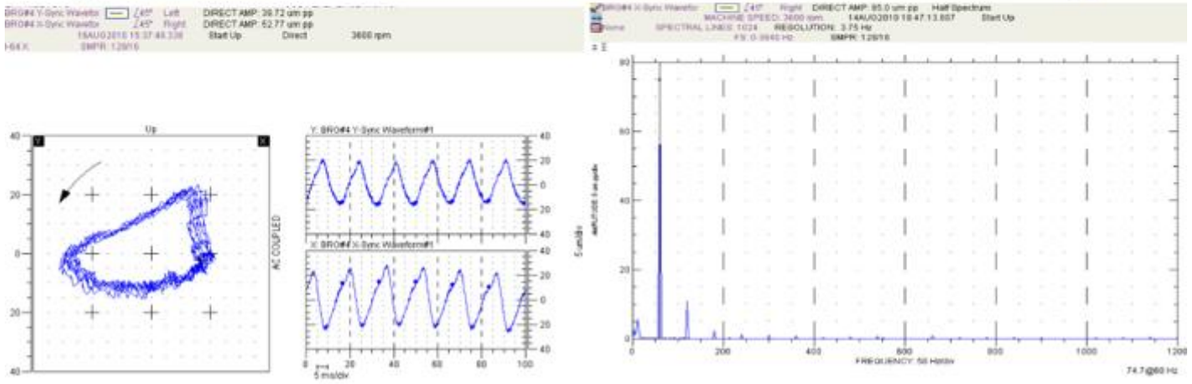
- Shaft Relative Vibration– Proximity Probes
- Bearing Absolute Vibration – Accelerometers

Supplementary measurements:

- Frame/Core Vibration, Endwinding Vibration (Fiberoptic Accelerometers), Turbine specific, and Auxiliaries







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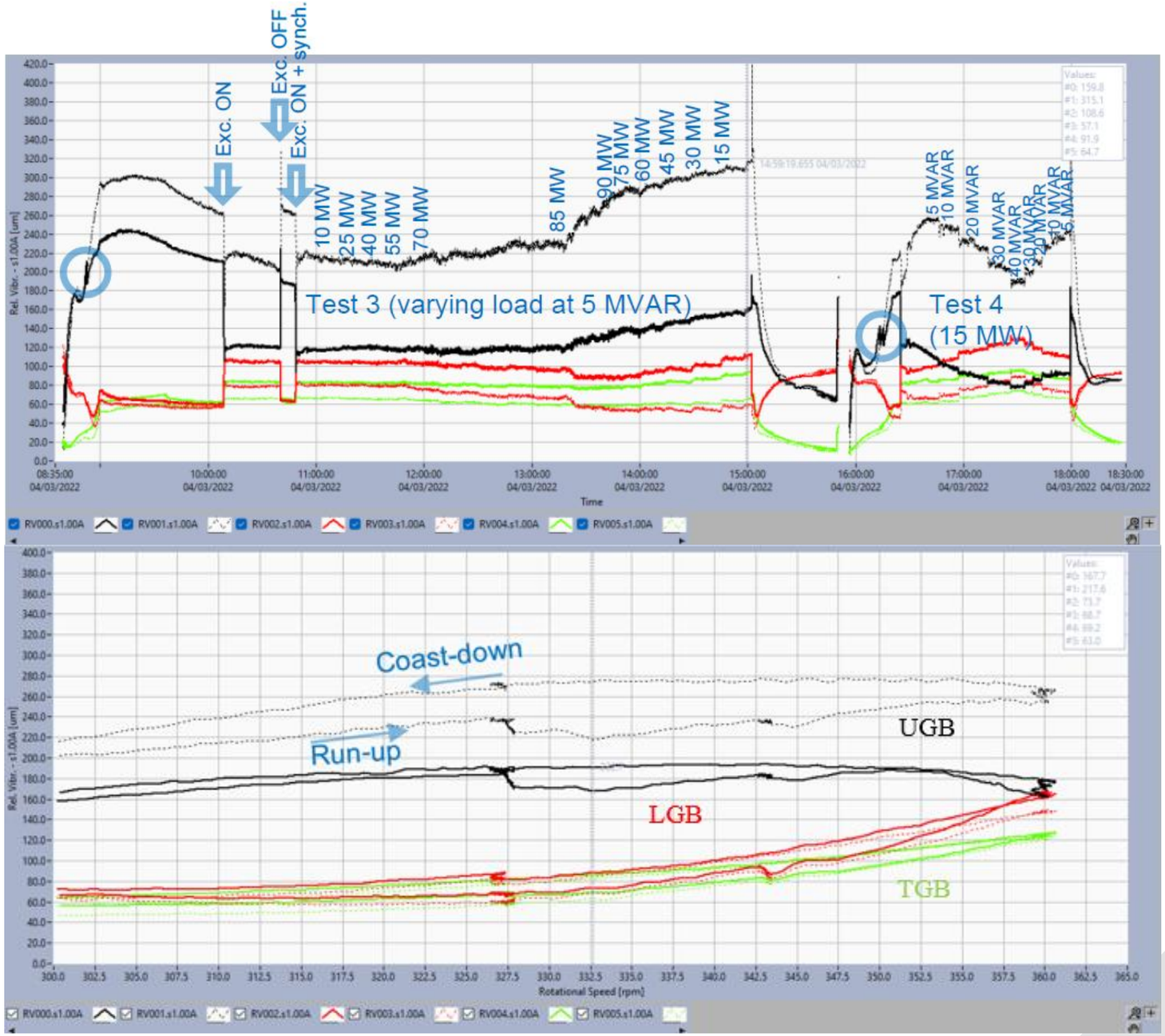
Vibration – Case Study

120MW, 22 pole unit in North America

Upper Guide Bearing (UGB) vibration **(black lines)**

- On startup at 240-255 RPM UGB vibration would decrease –mechanical unbalance changing
- Non-repeatable under load – increasing above ~85MW, continuing after load reduced
- Following overspeed test at 110% of nominal speed UGB vibration changed

Temporarily reduced vibration by balancing, but problem re-occurring – ***root cause suspected to be rim to spider fit***



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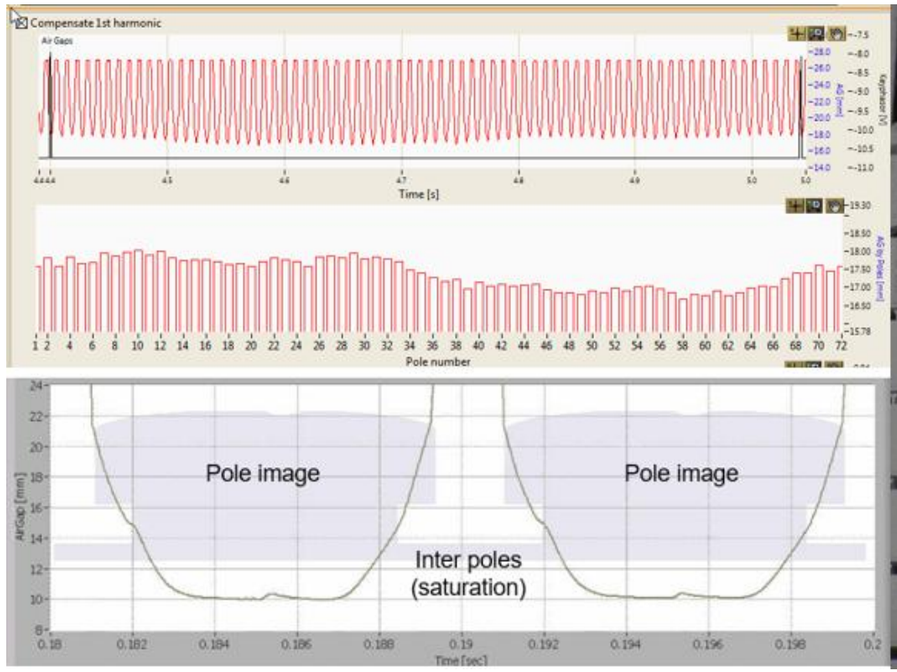
Airgap – Overview

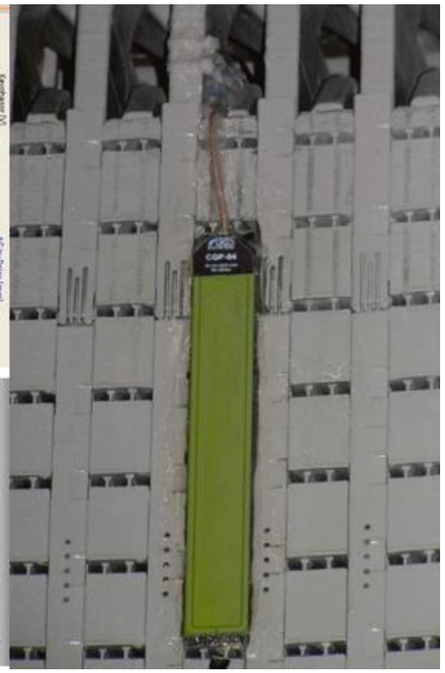
Specific to salient pole rotors – large low speed hydro's

- Rotor rim – floating vs shrink fit
- Identifies rim looseness, spider deformation, foundation and frame weakness

Application:- 4+ probes mounted on stator tooth – directly measure air gap

Measured:- Rotor/stator concentricity/circularity, min/max/average air gap (by pole), dynamic eccentricity (precession) of rotor in air gap





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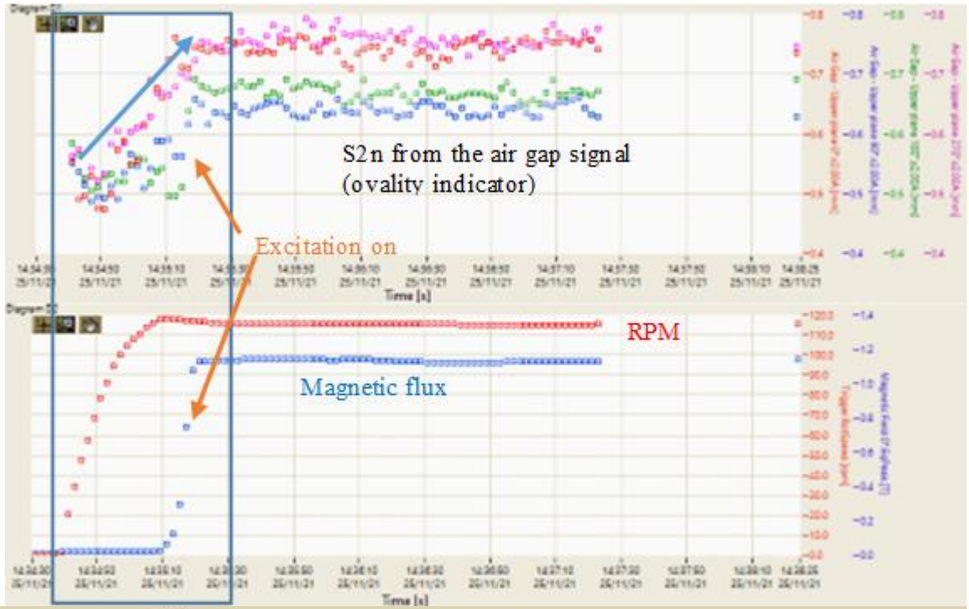
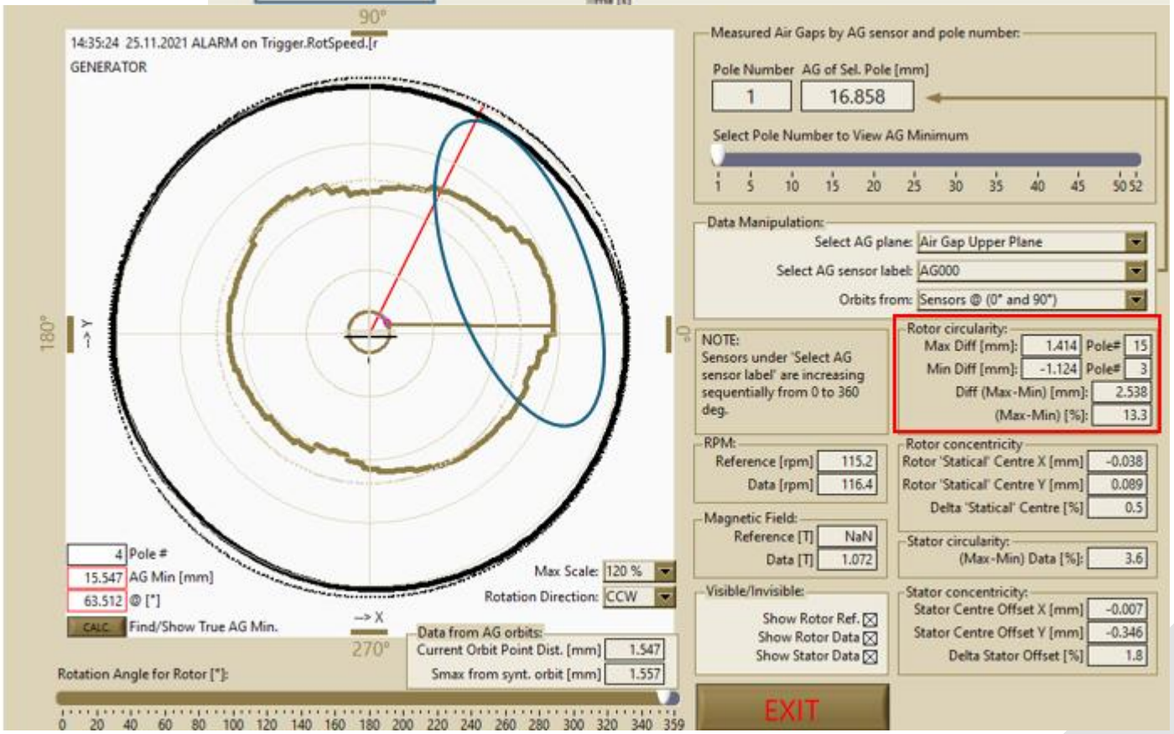
Airgap – Case Study

125 MW, 52 pole unit in Europe

- During startup, twice turning speed frequency component observed in the airgap vibration data – rim ovality
- At nominal speed, with field excitation applied, elliptical shaped and poor circularity confirmed

- Root Cause – Relaxation of the rim's shrink fit due to high centrifugal forces & thermal cycling over time





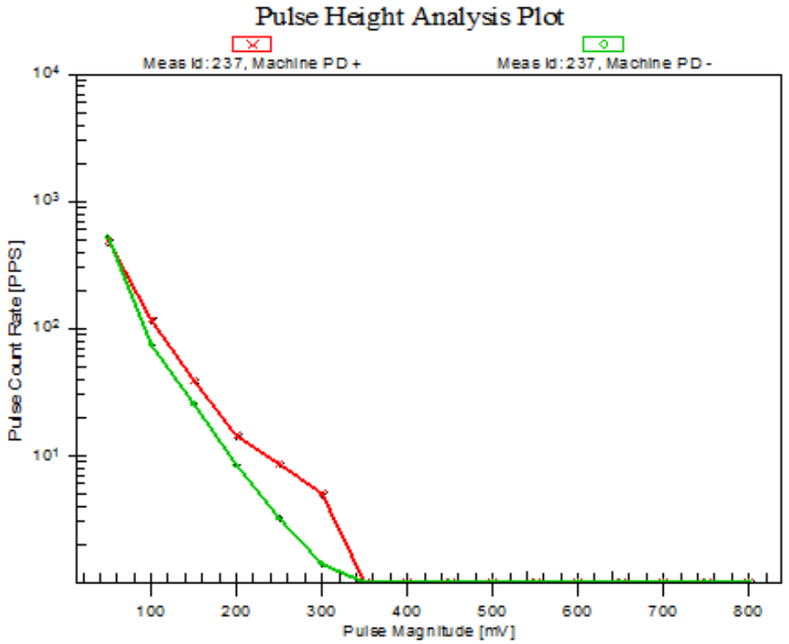
Partial Discharge – Overview

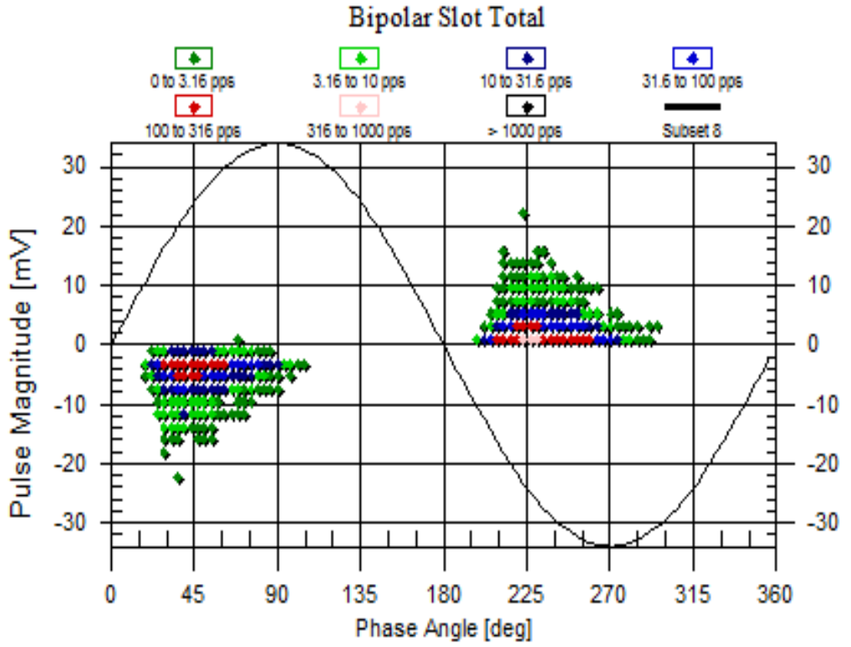
Specialised monitoring for stator winding insulation

- Long history and widely adopted in both hydro and turbo generators
- Used to identify insulation abrasion due to loose coils/bars in the slot, insulation delamination due to thermal deterioration or load cycling, electrical tracking caused by contamination, poor epoxy impregnation, and insufficient coil/bar clearances in the endwindings

Sensors measure very small current/voltage pulses – high frequency current transformer at the neutral point, high voltage capacitors at the phase terminals, or radio frequency antennae

- 2D analysis – number of PD pulses versus PD magnitude
- 3D analysis – phase resolved PD (PRPD) shows number and magnitude of PD pulses versus ac phase angle

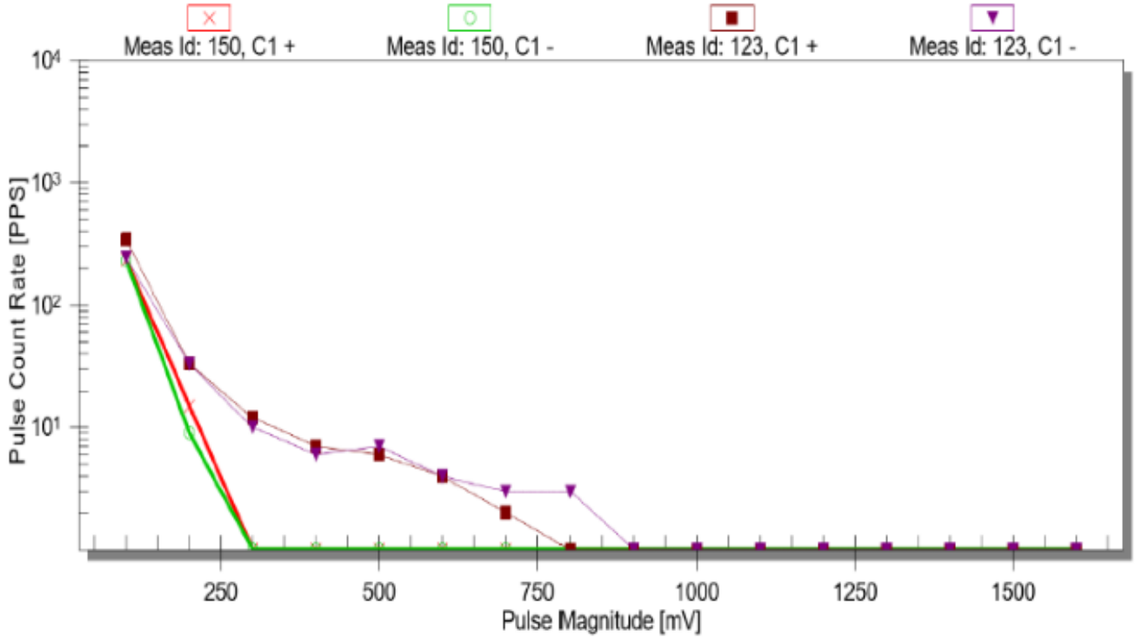


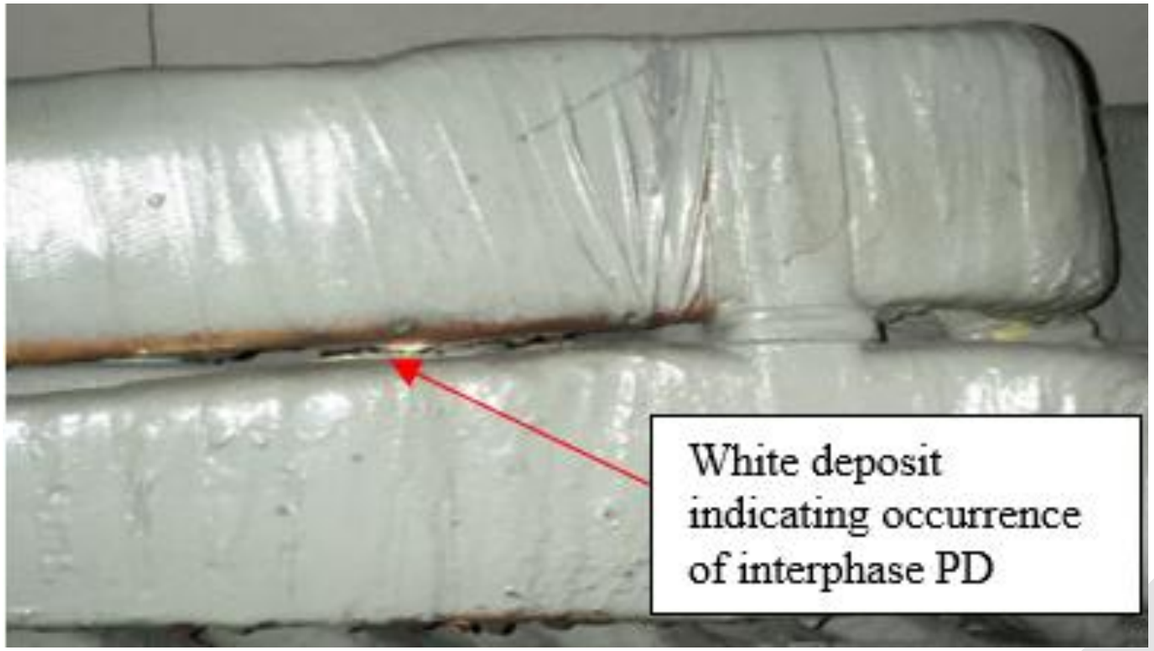


Partial Discharge – Case Study

125 MVA, 14.7 kV, 300 rpm machine in Europe

- PD testing was performed in November 2018 indicating high levels of PD, exceeding 90% of similar machines
- Analysis of PRPD plots identified phase-to-phase PD requiring intervention to avoid further damage and insulation degradation
- Comparing PD with stator winding diagram, a 2-hour shutdown was sufficient to visually locate the problem
- During the next scheduled outage in summer 2019, corrective action was implemented
- Testing was repeated under similar operating conditions confirming that the intervention reduced the PD





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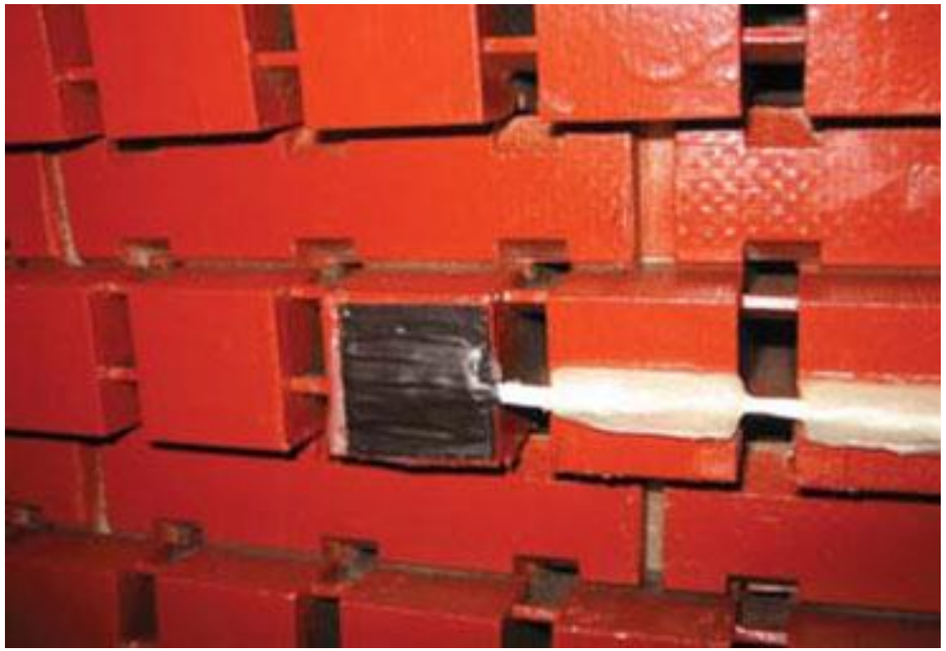
Rotor Flux – Overview

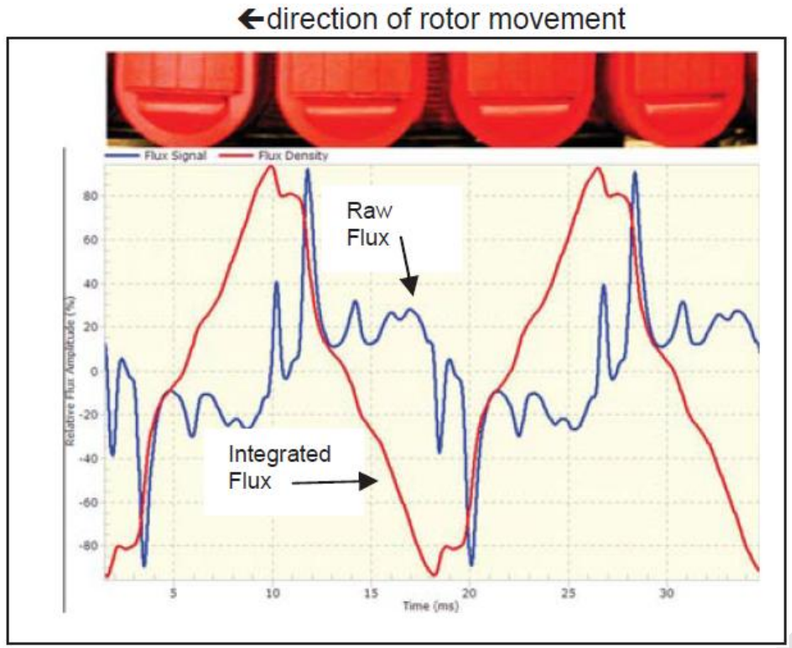
- First developed for cylindrical rotors in turbo generators
- Originally proposed as online replacement for pole drop test in salient pole rotors

Identifies shorted turns in the field pole windings

- Measures magnetic flux with a probe (coil) installed in the airgap
- Voltage is induced in the probe as rotating field poles pass the coil – pole with shorted turns has reduced flux due to reduced ampere-turns allowing detection

Rotor geometry (circularity and dynamic eccentricity) must also be considered





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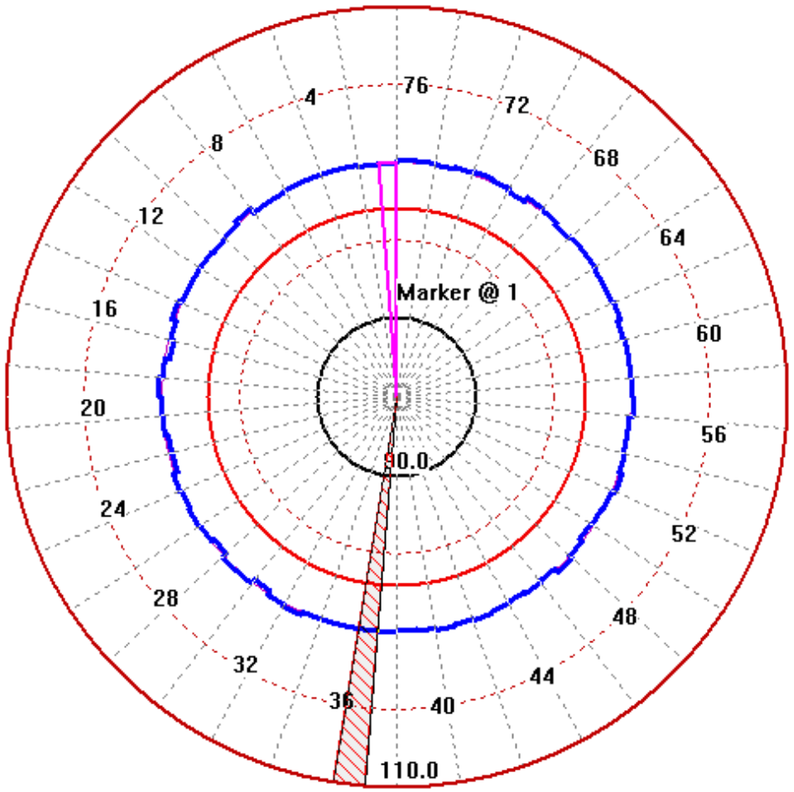
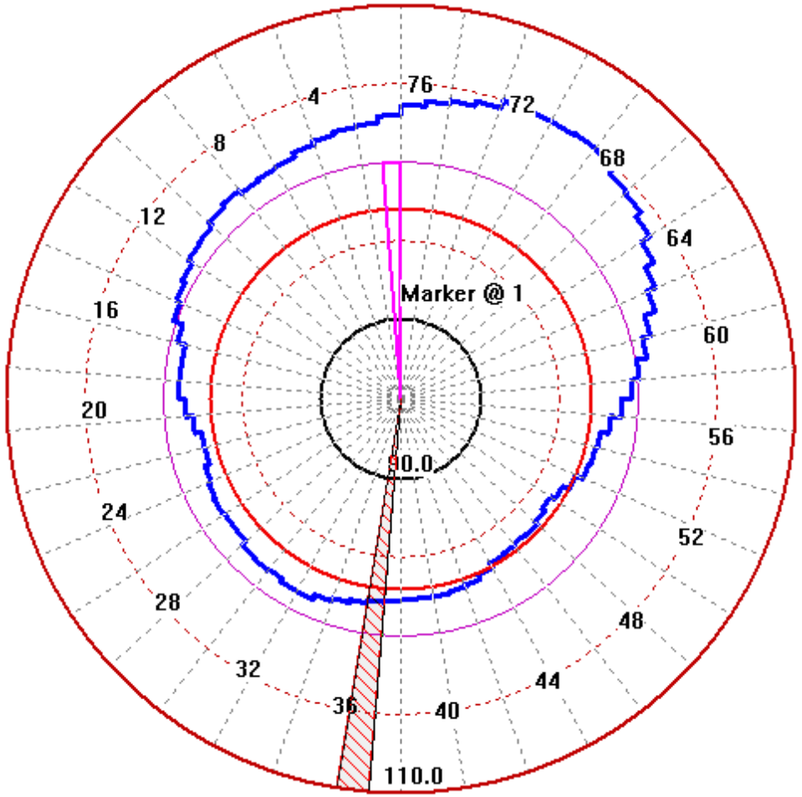
Rotor Flux – Case Study 1

60 MW, 76 pole unit in North America

- LEFT plot – comparison of pole to adjacent pole
  - No indications of shorted turns
- RIGHT plot – comparison of pole to average
  - Minor circularity/eccentricity issues





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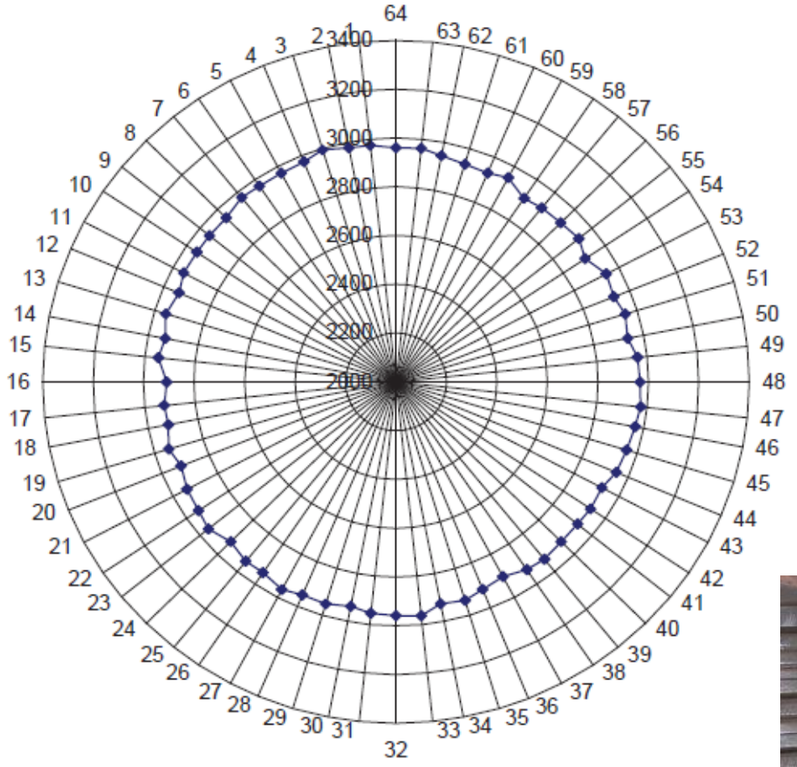
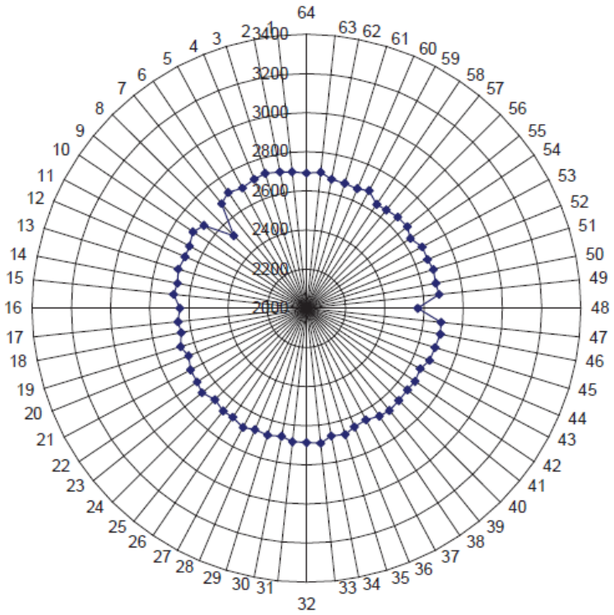
Rotor Flux – Case Study 2

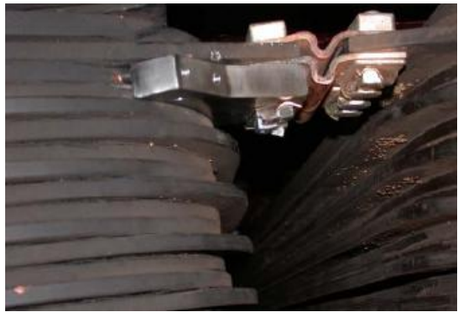
330 MW, 64 pole unit in North America

- LEFT plot – comparison of pole to adjacent pole
  - No indications of shorted turns
- RIGHT plot – comparison of pole to adjacent pole
  - Shorted turns temporarily installed on poles 8 and 48
- Detects as few as 1-3 turns shorted (out of 21 per pole)





3 shorted turns

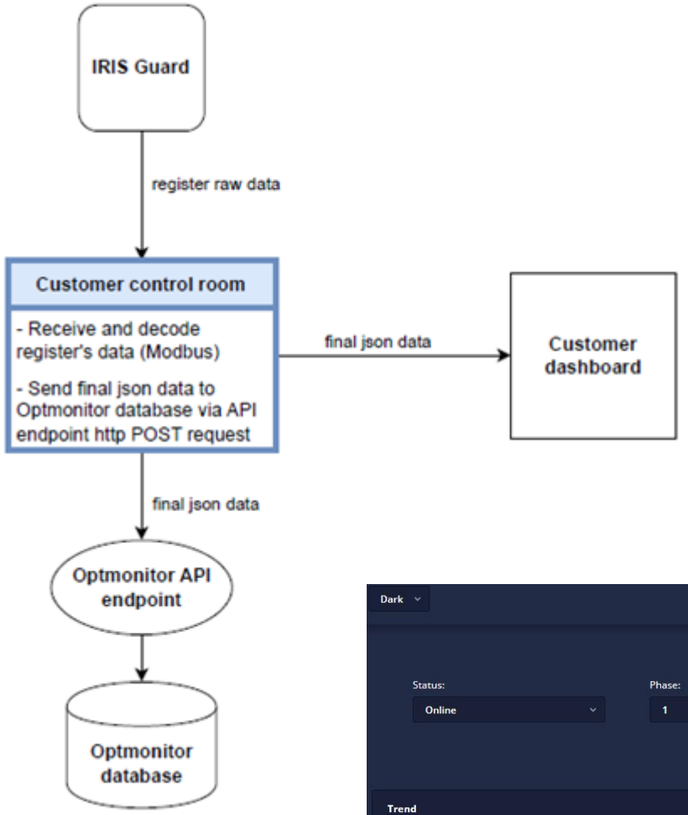


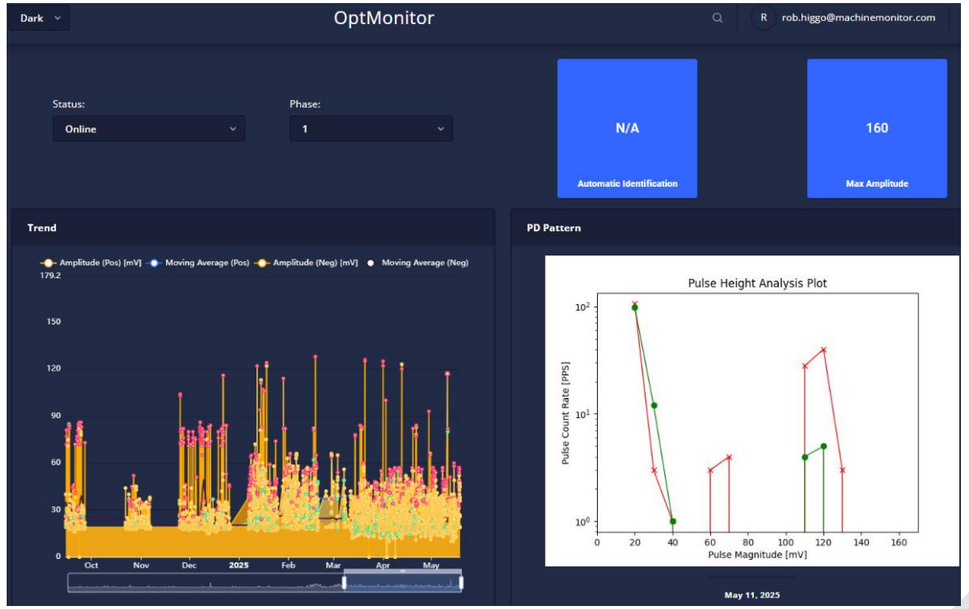
1 shorted turn

Application Example - QLD

Continuous online Partial Discharge and Rotor Flux monitoring on two large pumped storage hydro units (312MVA, 13.8kV, manufactured 1984).

Data transmitted 24/7 to operators SCADA, and to machinemonitor®'s AI assisted monitoring system where web-access is provided, and alarms established for both increasing average values, as well as instantaneous excursions.





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Questions?

Thank you

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