Integrated On-Line Monitoring of High Voltage Motors and Generators

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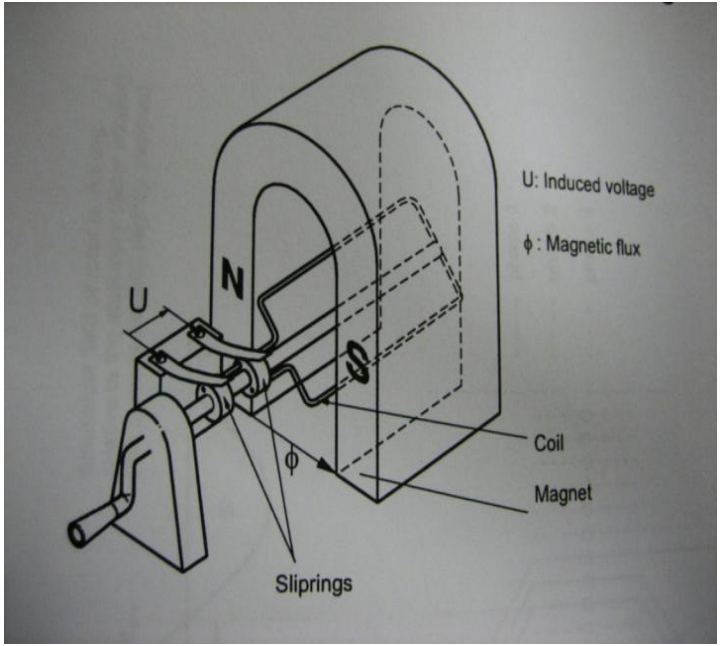
WHAT ARE THE TOPICS?

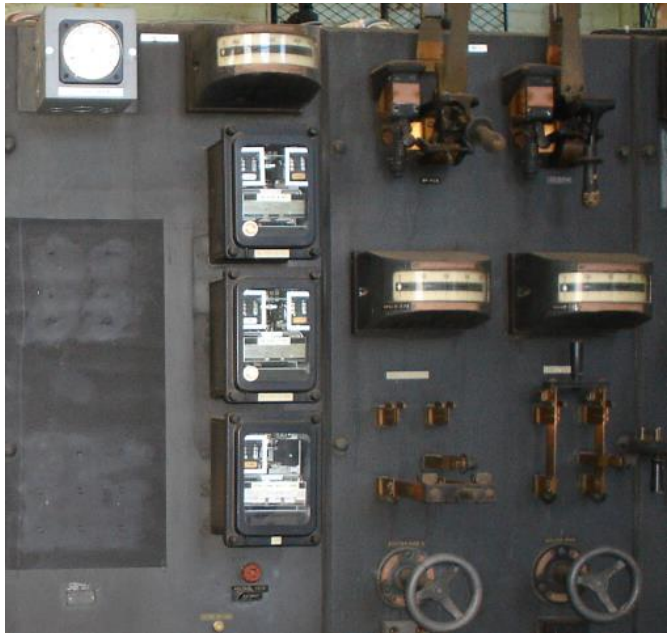
- What is Condition Based Maintenance (CBM)?
  - focus is on rotor and stator windings
- On-line Monitoring tools for machines:
  - Stator winding partial discharge
  - Stator winding endwinding vibration
  - Rotor winding shorted turns detection using magnetic flux
  - Shaft ground brush voltage and current
- GuardII+ - an integrated on-line monitor to implement machine winding CBM
- Live Q&A



General principles of Testing, Monitoring and Maintenance

Maintenance strategies:

1. Breakdown or corrective only
   - uses protective relaying
2. Time-based or preventive
   - based on past experience for outage intervals, off-line tests, visual inspections
3. Condition based or predictive
   - uses on-line monitoring to plan when off-line tests, inspections advisable



Protection
Metering
Monitoring
Testing

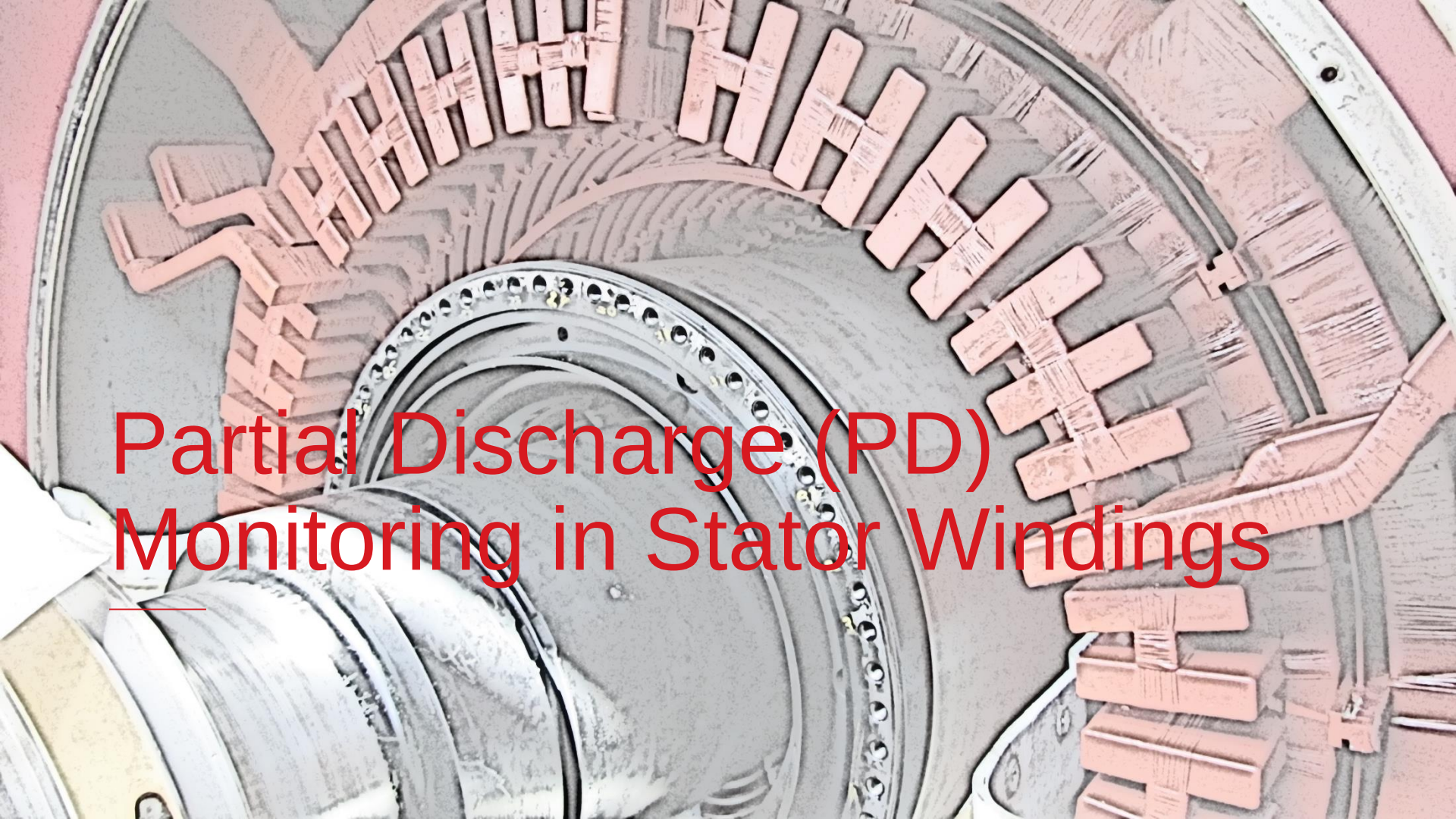
CONDITION BASED MAINTENANCE (CBM)

The goal of CBM is:

- Prioritize which machines in a fleet need maintenance
- Extend time between outages for testing/inspections
- Reduce risk of an in-service failure

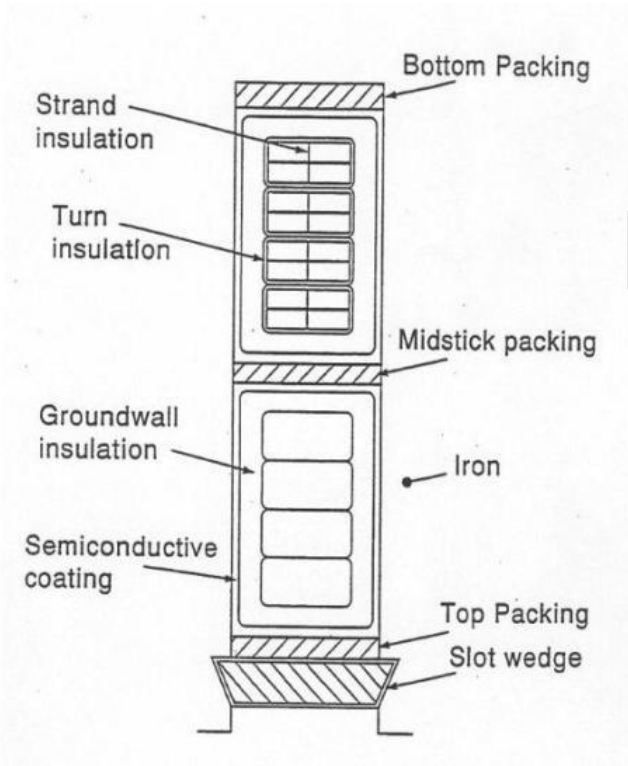
CBM requires continuous or periodic on-line monitoring to detect the most likely causes of failure

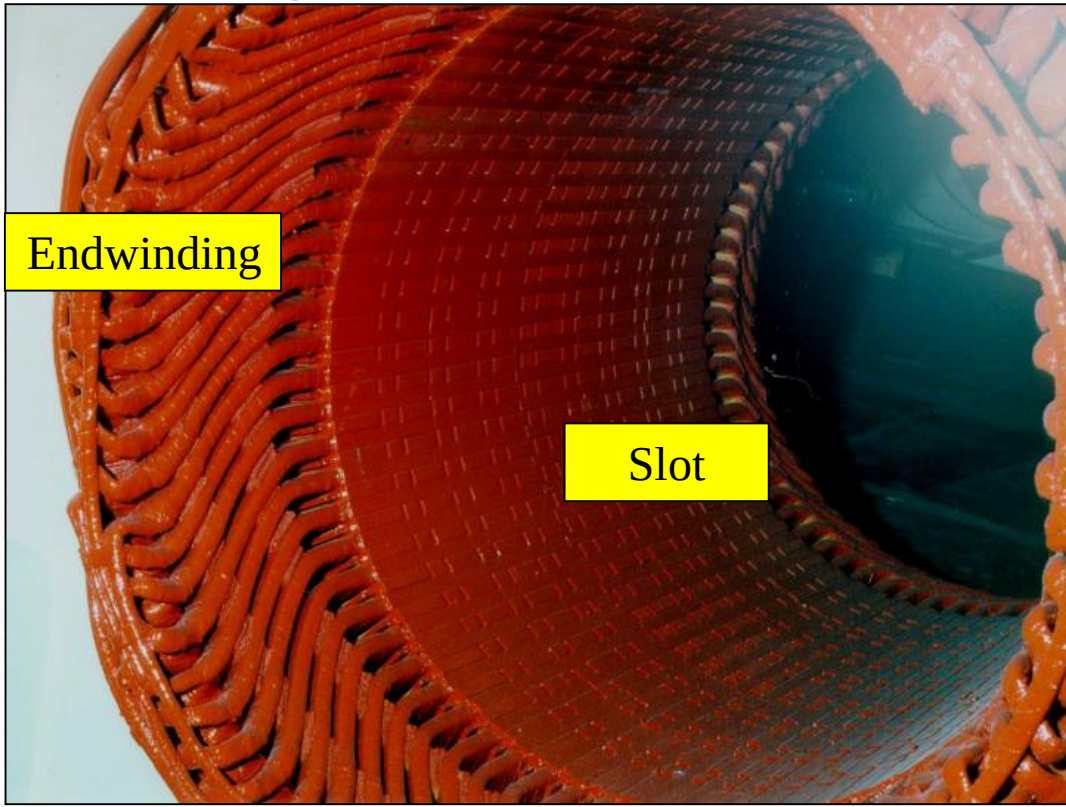
CBM can detect aging related problems (not failures caused by operating errors or power system transients)



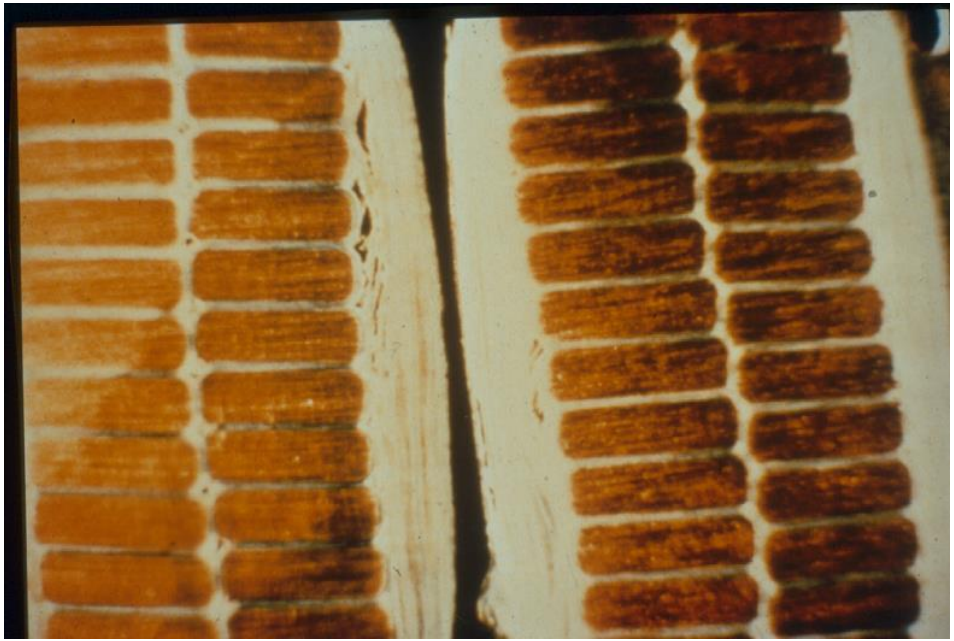
Partial Discharge (PD) Monitoring in Stator Windings

What are the parts of stator winding?



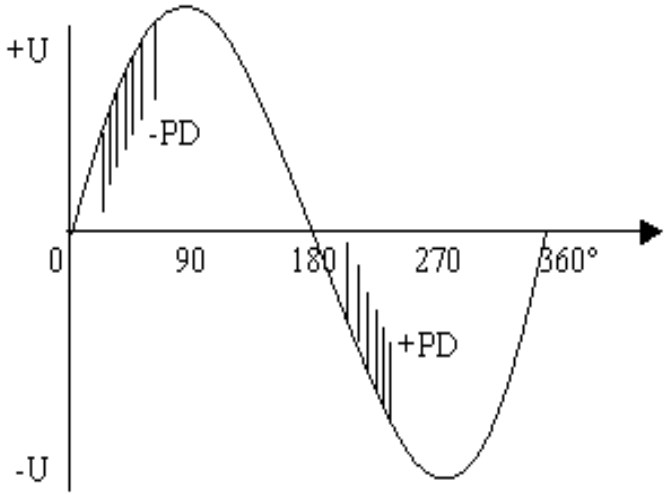


What are the common problems – mainly with the insulation



What is Partial Discharge?

- Partial Discharges are “sparks”, or pulses of electrons and ions, occurring in voids and gaps in high voltage insulation.
- They occur because breakdown strength of the gas in the void is much lower than that of the solid insulation around it.
- PD is normally a **symptom** of thermal or mechanical insulation aging that leads to “voids”
- Sometimes PD alone causes failure



When voltage is not high enough, PD WILL NOT occur.

Why PD testing/monitoring?

- In equipment using purely organic insulation (power transformers, gas insulated switchgear (GIS), power cable) PD is an important **cause** of failure
  - PD testing therefore used as QA test to ensure no PD in operation, as well as an off-line or on-line test to warn of near-term failure.
- For High Voltage stator winding insulation, where PD resistant mica is the insulation – PD is mainly a **symptom** of insulation failure by other causes.
  - QA PD test on new stators relatively rare – instead it is mainly used as off-line or on-line test.

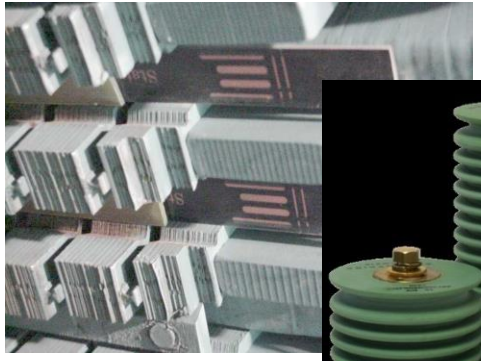
Separating PD and Noise

- The key to reliable insulation condition information-the task is not simple.
- ‘Noise sources’ such as transmission line corona, sparking electrical connections, slip ring sparking, etc. could be seen as a false indication (IEEE 1434 or IEC 60034-27-2)
- Sensors and instruments need to separate electrical noise from PD.
- Separation techniques used are different for different applications (GIS, transformers, rotating machines) and depend on PD detection frequency range.

Components of IRIS PD System are:

- Sensors (80 pF EMC, SSC)

More than 80,000 PD sensors installed



- Termination Box

On more than 18,000 machines

- Instrumentation

Portable or Permanently Installed

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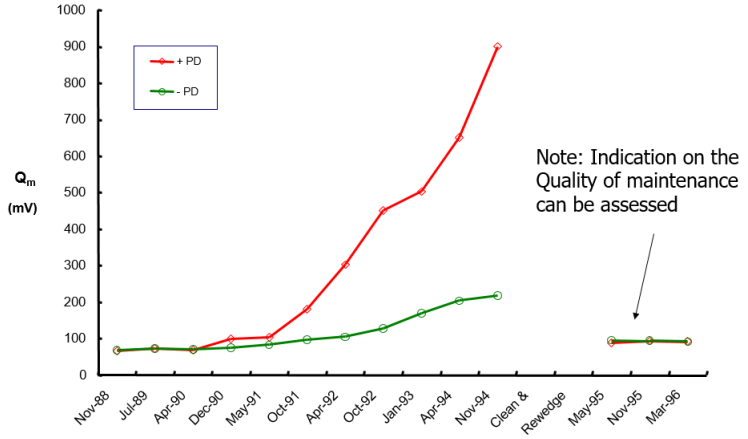
Interpretation: IRIS PD Database to set “Alert” levels for high PD

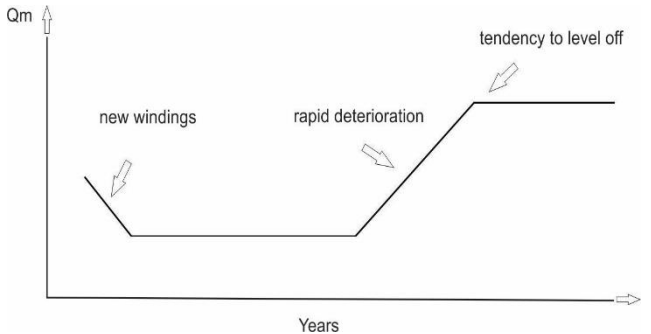
- Over 680,000 periodic test results from thousands of machines https://irispower.com/online-partial-discharge-severity-tables/
- Each year Iris publishes the statistical range of Qm (peak PD in mV) for each type of stator (voltage rating, air or hydrogen cooling, and PD sensor type)
- If a stator has a Qm that exceeds 90% of readings from similar machines, then the winding is deteriorated.
- Table for air cooled machines with 80 pF sensors

	2-4 kV	6-8 kV	10-12 kV	13-15 kV
<25%	5	13	36	37
<50%	22	37	83	96
<75%	73	112	207	236
<90%	155 mV	218 mV	473 mV	514 mV

Interpretation: Trend in PD Over Time

- Doubling of PD in 6 months – stator needs attention
- A reliable trend requires machine operating info – kV, HP/MW, stator T – since all can affect the PD
- Best trends and most warning of a developing problem require continuous on-line monitoring





IRIS PD Monitoring Summary

- Well established method for ON-LINE monitoring of stator winding insulation
- Applicable for all rotating machines rated higher than 3.3 kV
- Different sensors and instruments (portable and continuous) available

Endwinding Vibration Monitoring

Monitoring of Endwinding Vibration

OBJECTIVES OF STATOR WINDING SUPPORT SYSTEM:

- Keep stator coils in stator slots
- Keep together stator coils outside slots
- Provide support against steady and sudden mechanical forces
- Provide flexibility for thermal expansion

Why Monitor Stator Endwinding Vibration?

1. Aging fleet
   - As machines get older blocking and bracing material shrink, loosening endwinding support resulting in excessive movement
2. In the past decade, many OEMs have reduced cost by providing less robust endwinding support
   - Result is a dramatic increase in EW vibration problems, commonly in large (> 100 MW) 2 pole turbo generators

Table 4.1 Comparison between Old and New Generator

		Existing generator	New generator
Rating	Turbine output	350 MW	400MW
	Generator output	389MVA	445MVA
	Power factor	0.9	
	Frequency	50Hz	
	Rotating speed	3000rpm	
	Voltage	15kV	
	Cooling system	Rotor:H_2-cooled/Stator:Wator cooled	H_2-cooled
	Hydrogen pressure	310kPa	410kPa
Weight	Stator	333ton	287ton
	Rotor	52ton	54ton
	Total	385ton	341ton

Detecting Endwinding Vibration Problems

1. Periodic visual inspection
   - Look for evidence of vibration (dusting, fretting, greasing)
2. Periodic impact testing
   - Make sure natural frequencies have not shifted towards 60 and/or 120 Hz (50 and/or 100 Hz) resulting in a resonance

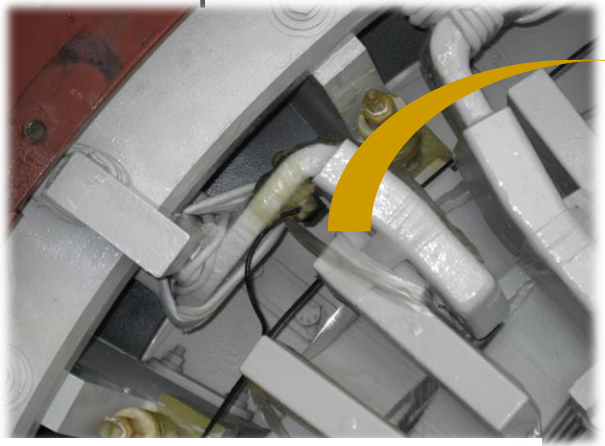
These require an outage and at least the removal of end shields

BEST ALTERNATIVE:

3. On-line continuous monitoring of EW vibration using fiber optic accelerometers

Typical Endwinding Installation

Fibreoptic Sensor



Electro-optical Converter

GuardII+ Monitor

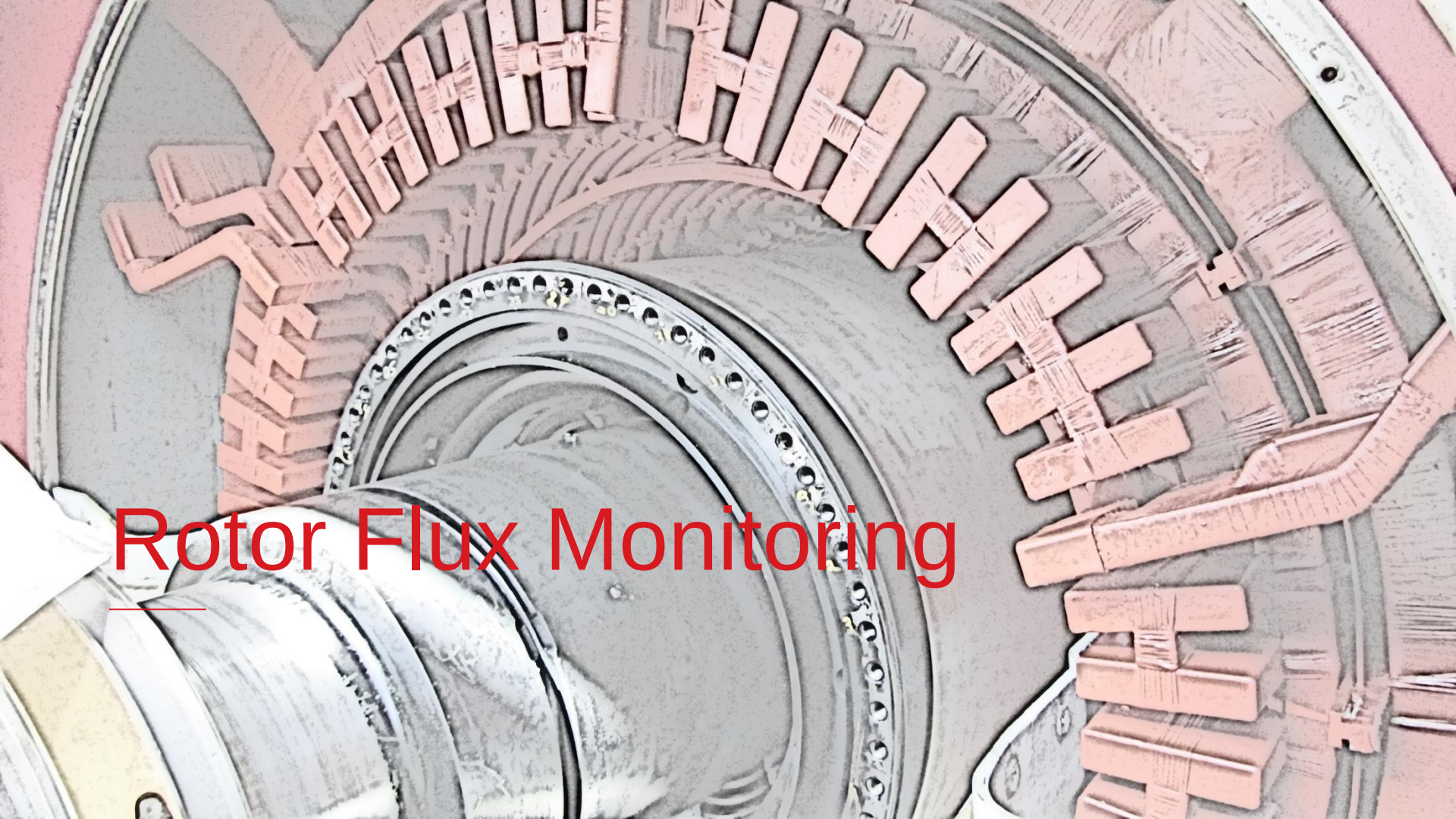
Hydrogen Penetration and Junction Box

Penetration and feedthrough for Hydrogen Cooled machines

- Multichannel feedthrough with spare fiber optic cables
- Feedthrough accelerated life tested
- Penetration and feedthrough pressure tested to 400 psi
- Operating temperature: -20 to 80°C

Endwinding Monitoring Summary

- Past published levels may have been erroneous due to poor probe location and/or vibrating fiber optic probe leads.
- Industry recommendations are:
  - < 4 mil (100 micron) peak to peak is considered acceptable
  - >10 mil (250 micron) peak to peak is cause for some concern
- Off line testing provides limited diagnostics.
- Better to monitor continuously and use vibration trending capabilities and correlation to machine operating parameters.
- IEC 60034-32



Rotor Flux Monitoring

Why Monitor Rotor Flux?

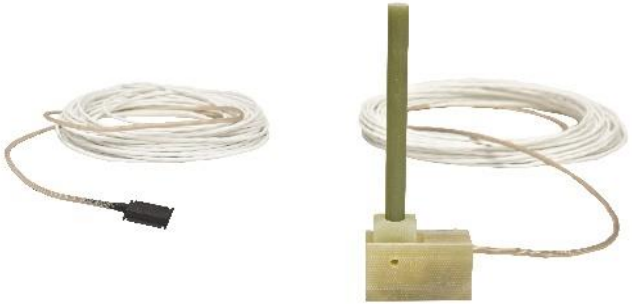
- Little on-line monitoring is available for machine rotor windings
- Air gap magnetic flux monitoring is a proven tool to provide information on the integrity of the rotor winding inter-turn insulation.
- This information is critical in planning maintenance, explaining abnormal vibrations, and verifying new and rewound rotor integrity.

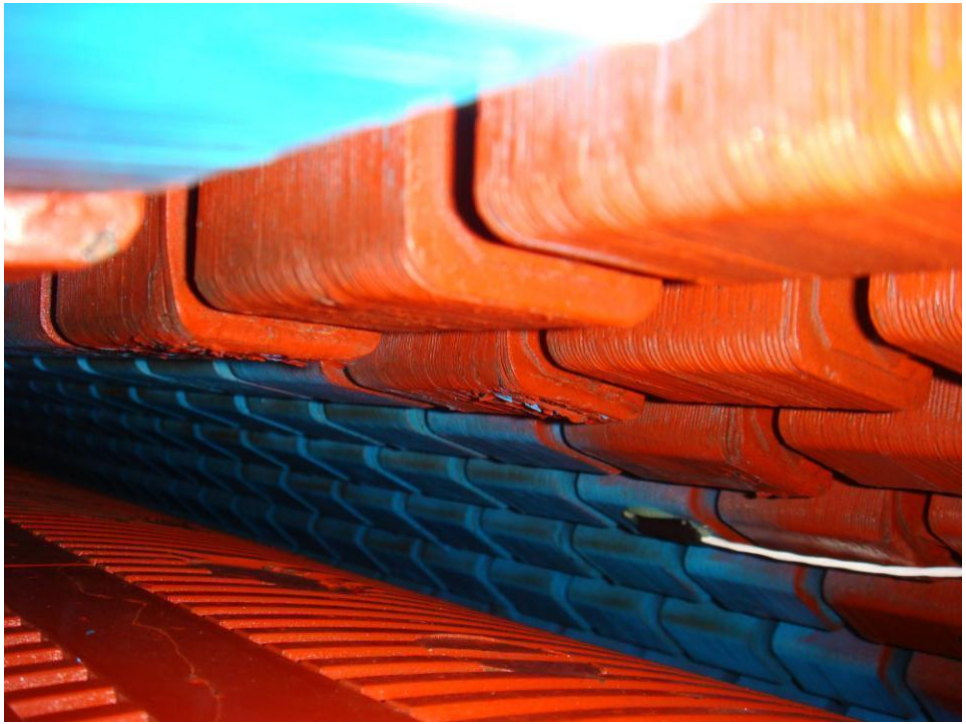
- Shorted turns indicate insulation failure in the rotor, but does not directly cause a generator failure
- Shorted turns may result in less MVAr output, and increased bearing vibration
- If the number and severity of shorted turns increases over time – aging occurring and there is a greater risk of a rotor ground fault

Flux Sensors

Two types of Flux Probes

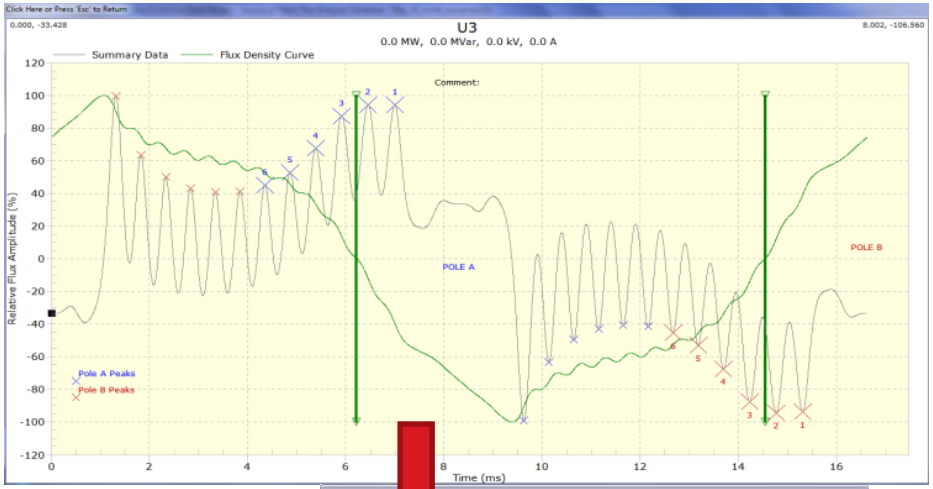
TF Probe FFprobe

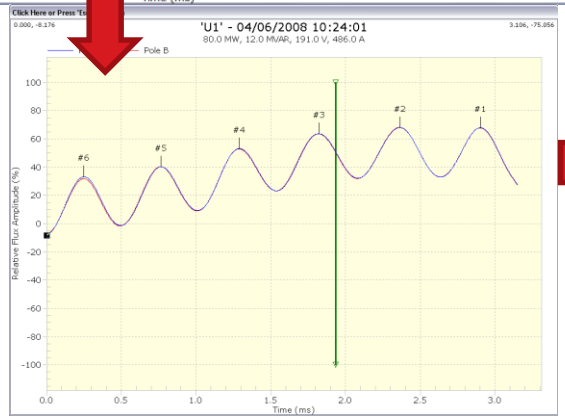


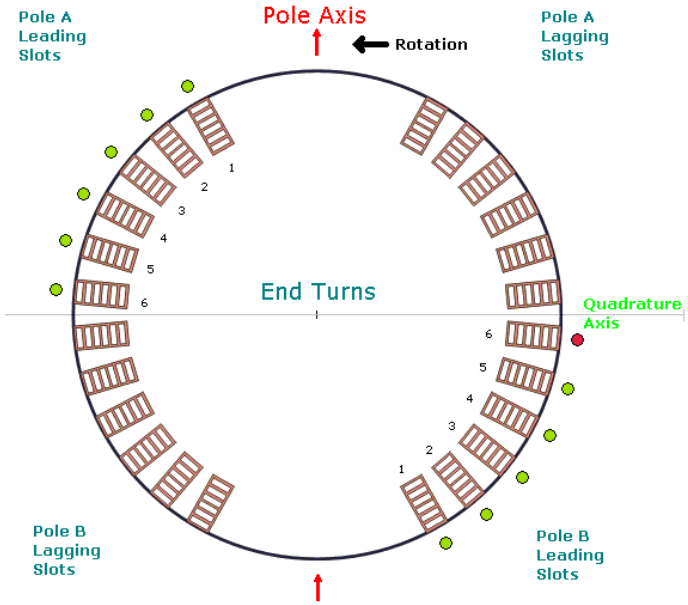


Installation of TF Probe with rotor in place

Round Rotor Shorted Turns Detection







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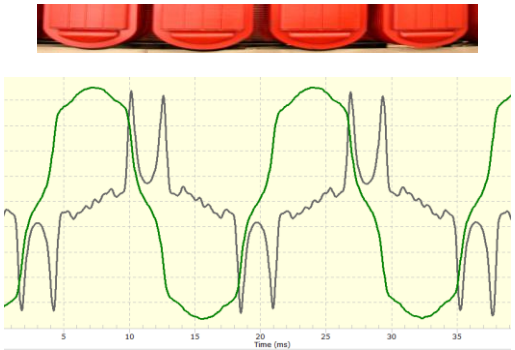
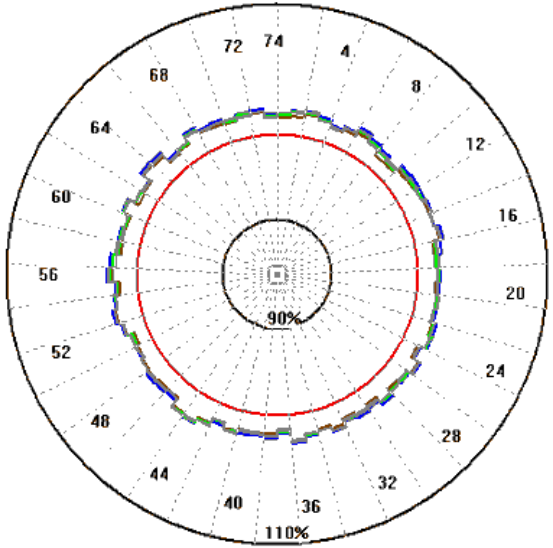
Salient Pole Rotor Shorted Turns Detection

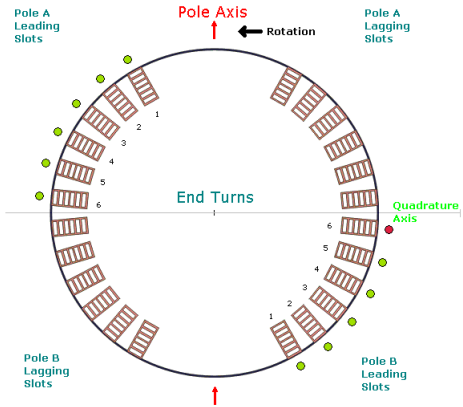
Compare pole to its left and right neighbor

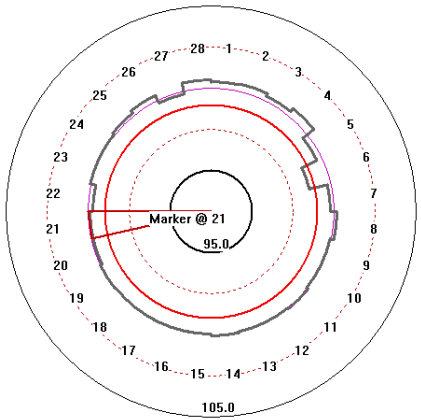


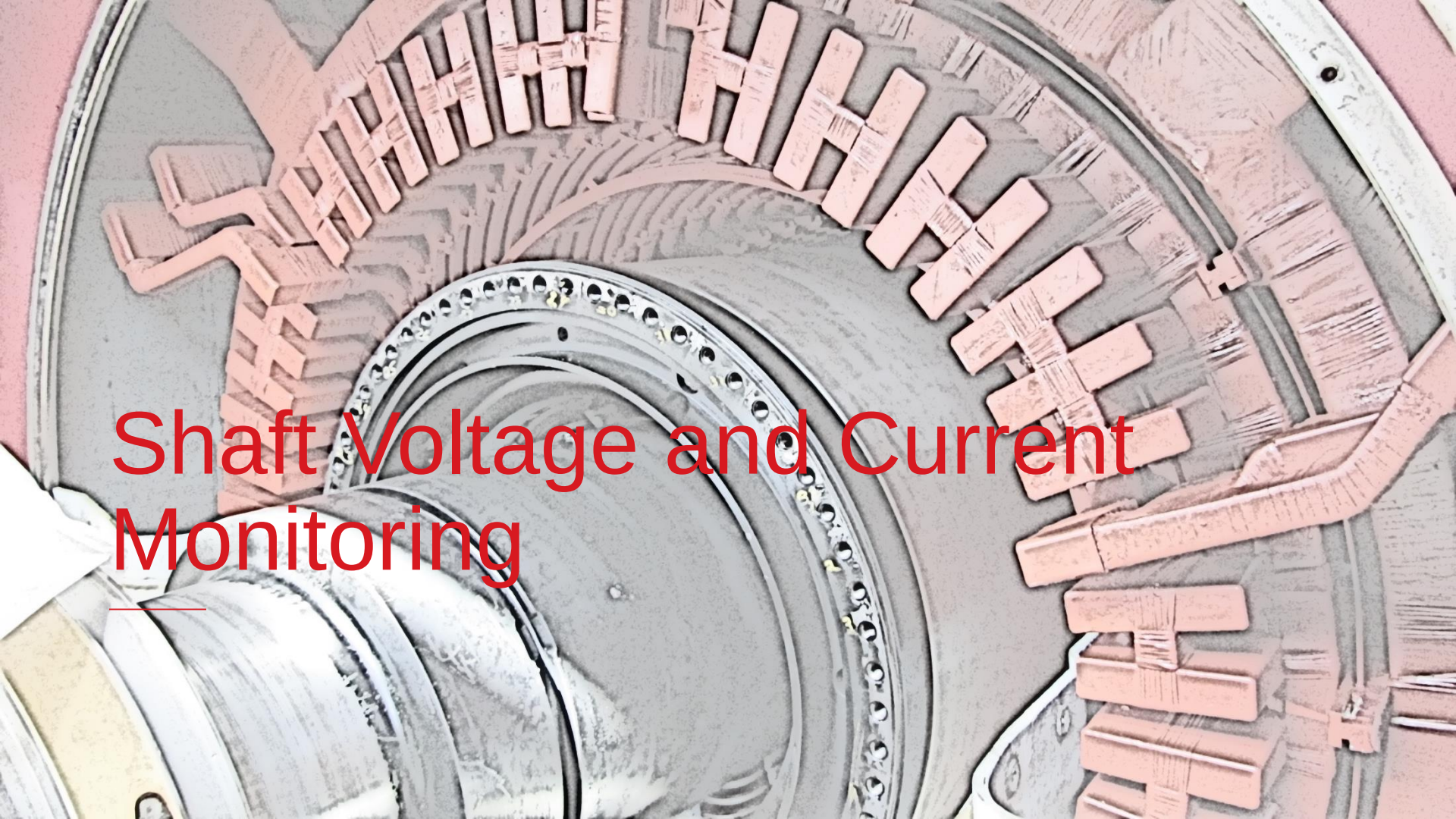


Flux Monitoring Summary

- Portable or Continuous Instruments
- Proven technology in detection of shorted turns in rotor windings
- Used as a Quality Control Test and can be used to assist in vibration analysis
- Trend in turn shorts essential for rotor winding CBM

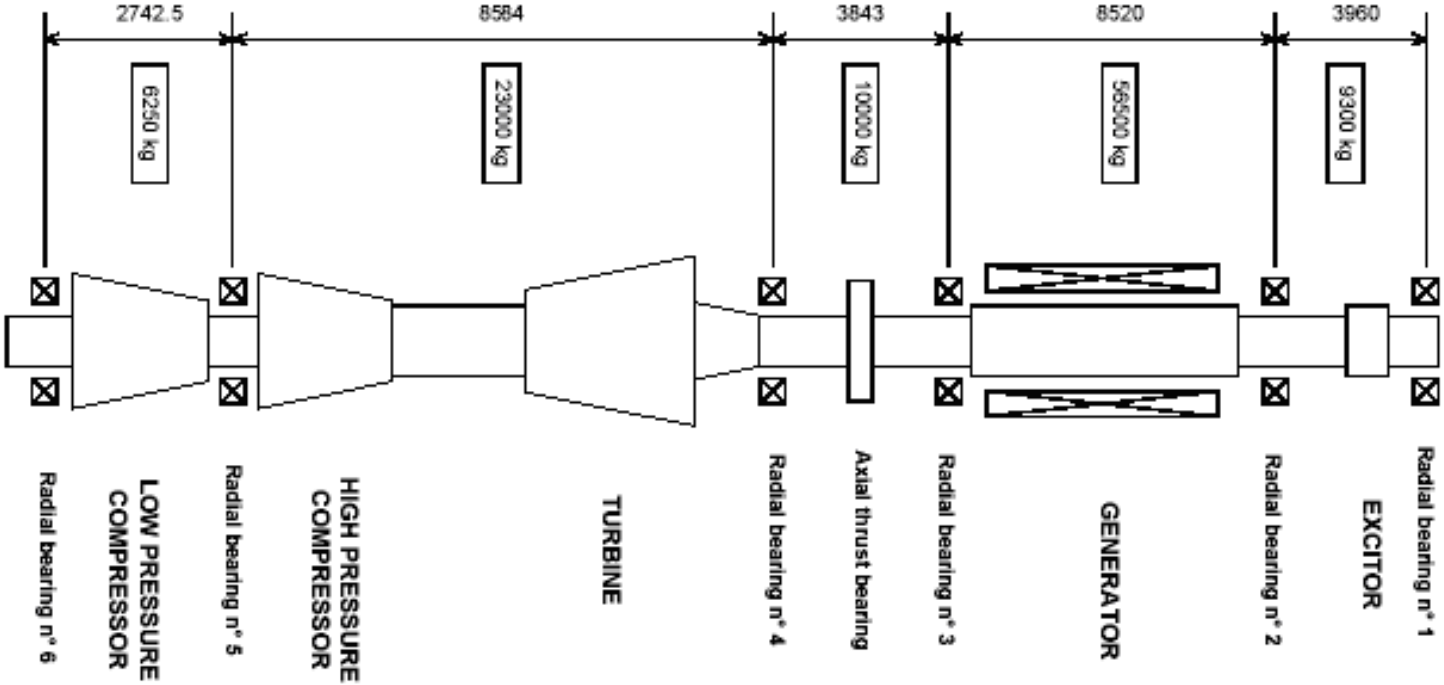






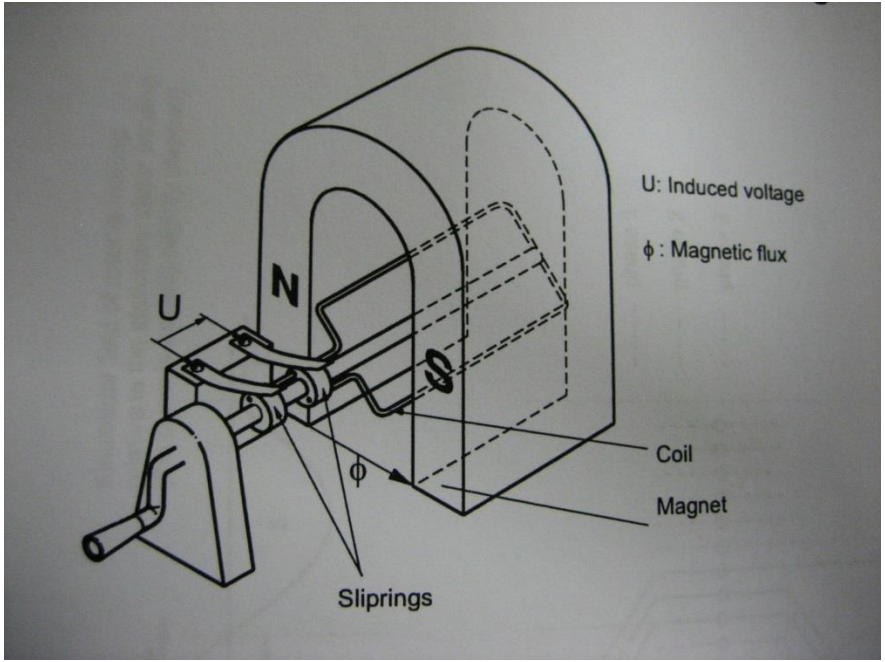
Shaft Voltage and Current Monitoring

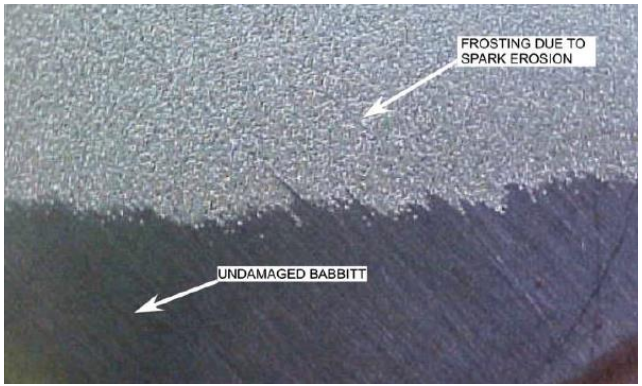
What is Shaft?



All Things Fail Mechanically!

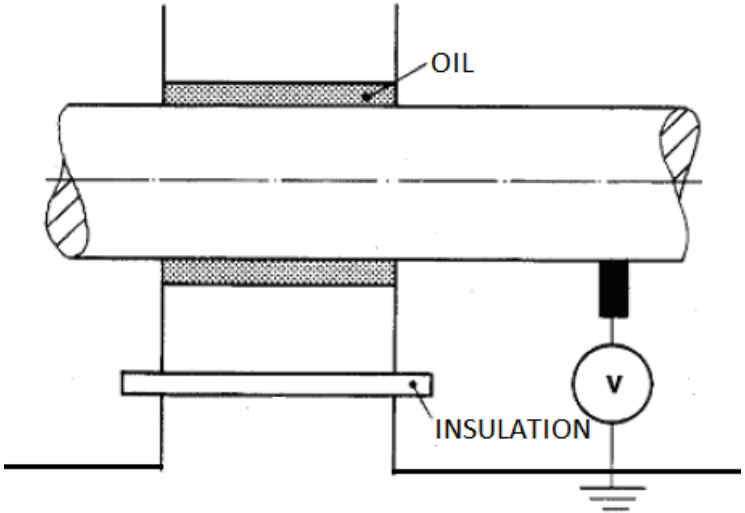
- Electrical things especially!
- But…
- Shaft and bearings can be damaged by electricity



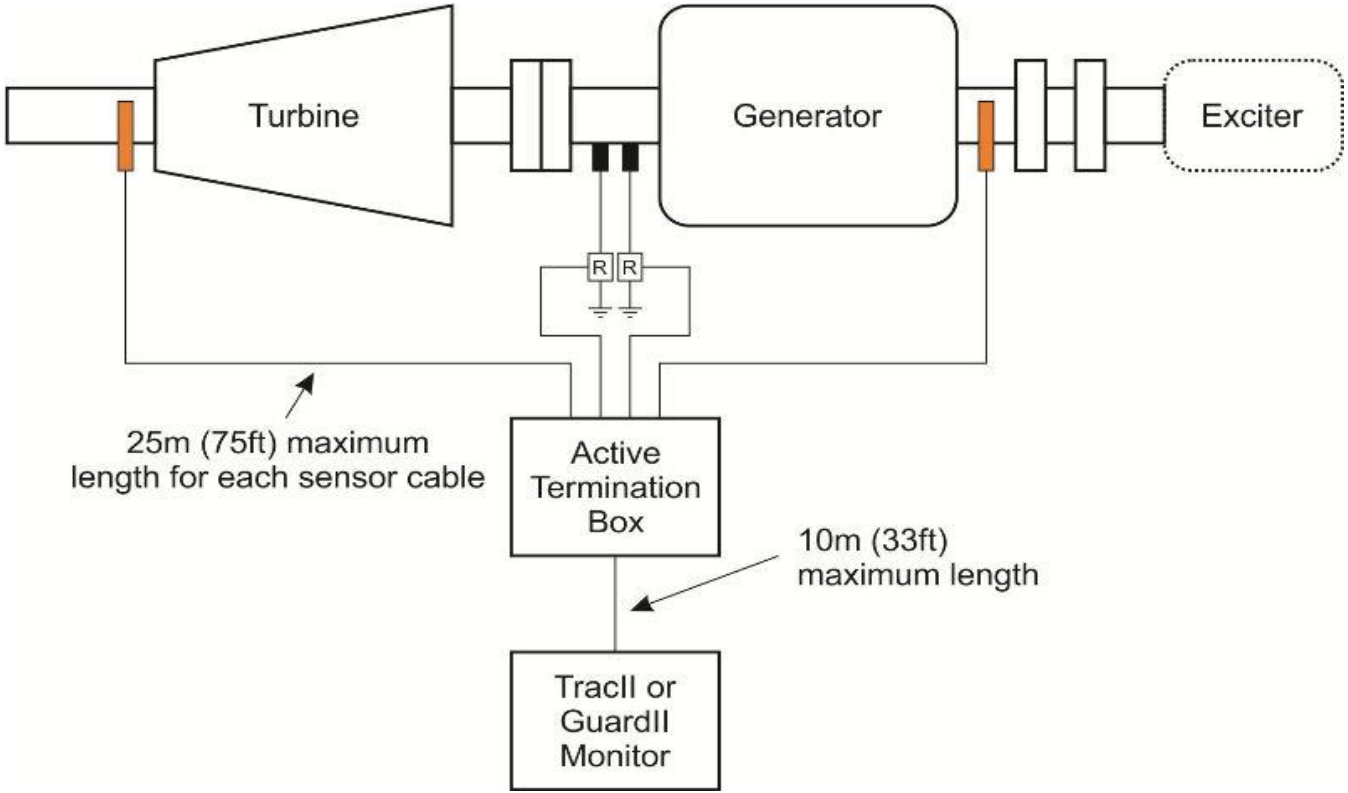


To minimize shaft/bearing problems...

- Voltage can built up on rotor due to magnetic field asymmetries or static charge
- Effective grounding of shaft is important
- If grounding brush is in poor contact with shaft surface, voltages higher than 150 V can be created on a shaft.
- This voltage is high enough to break seal insulation and result in shaft and bearing pitting.



Iris Shaft Voltage and Current Monitoring System



Key Indicators

- Grounding brush current too low: poor grounding, brush not working.
- Grounding brush current too high: multiple grounds present (i.e. shaft rub)
- Voltage brush signal too high: risk of bearing/seals insulation breakdown.

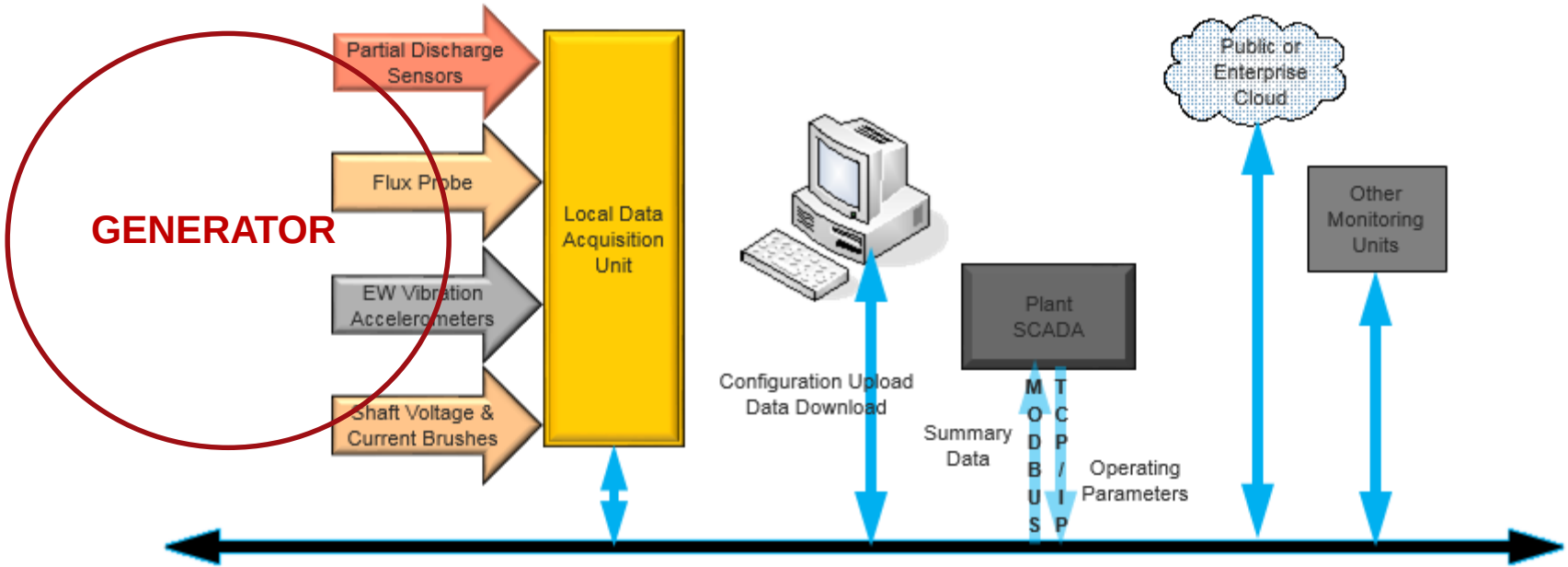
- Normal shaft currents can range from a few milliamps to several amps
- Voltage higher than 10 V considered to be dangerous, an OEM recommends 6 V as a limit
- Current higher than 10 A could indicate various faulty conditions

Shaft Voltage and Current Monitoring Summary

- Shaft Monitoring provides early warning of rotor, stator and bearing insulation problems
- Condition of shaft grounding brush is important for safe operation of large generators
- Should be used as a part of CBM system

INTEGRATED MONITORING SYSTEM

One Monitor for Four Technologies



GuardII+ One Monitor for Four Technologies

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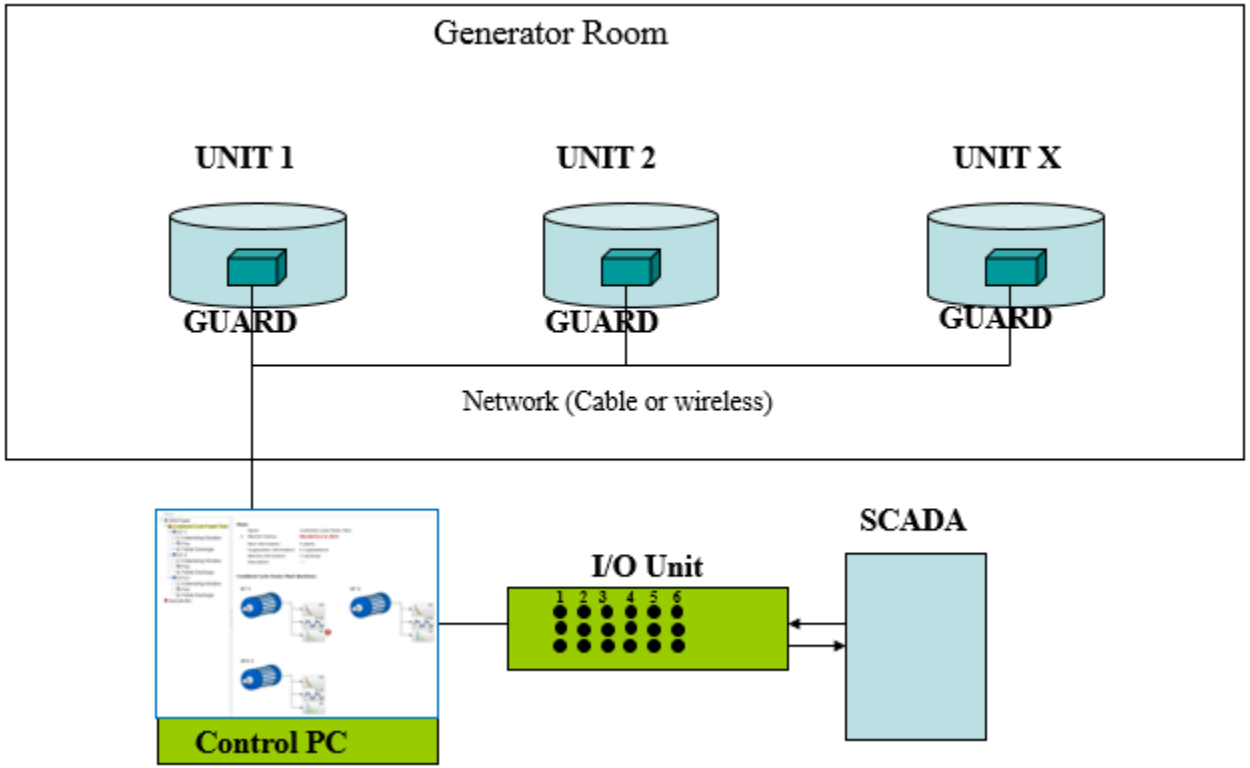
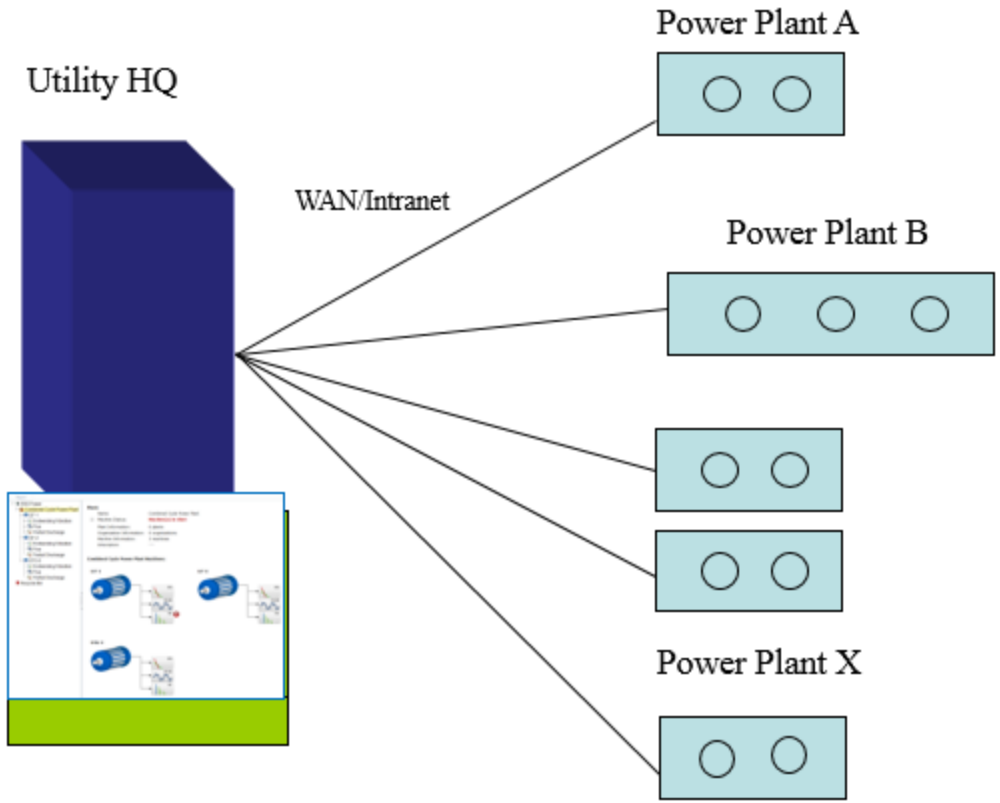
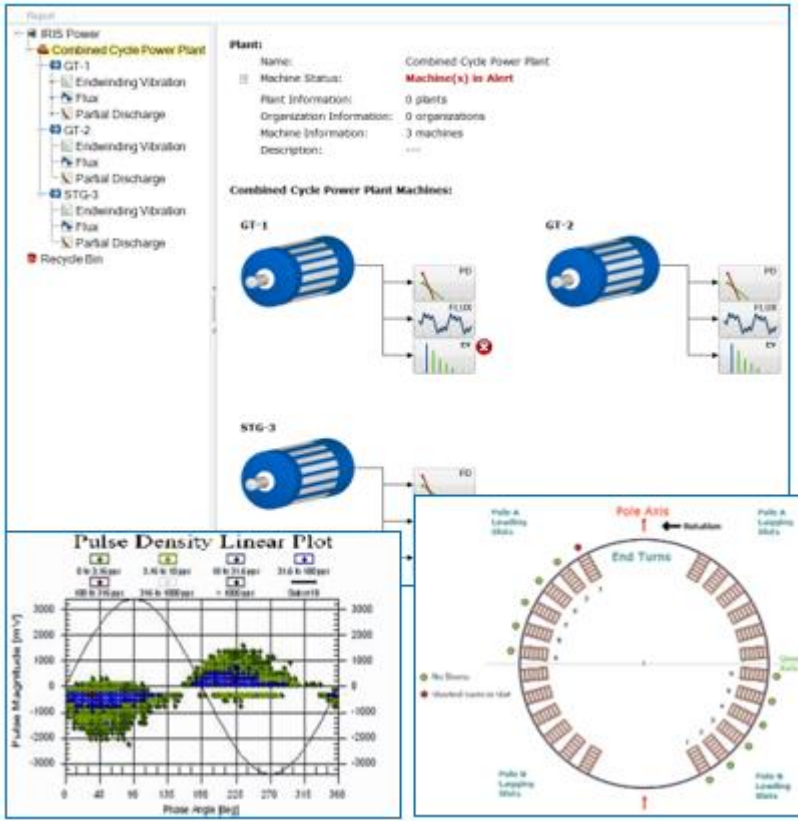
Multiple Units in One Power Plant

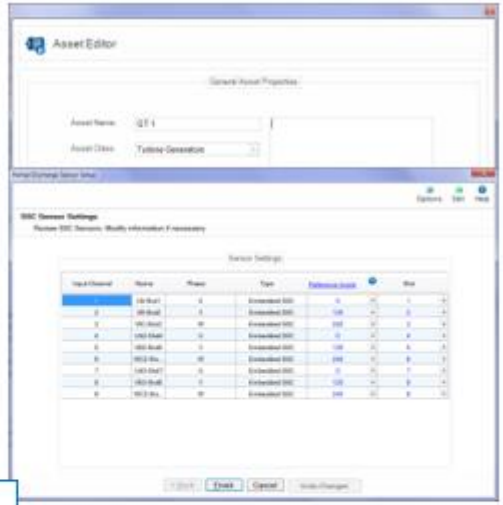


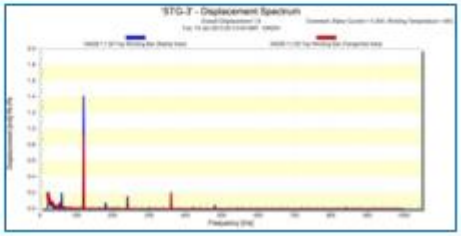
Multiple Plants in one Utility : For Utilities with central CBM Center



Iris Application Manager Software (IAM)







Conclusions

- There is no perfect off-line winding test or on-line monitor.
- Good operation and maintenance records are vital, as well as attention to all available monitoring information, performance of a high caliber inspection, and judicious use of a selected set of appropriate off-line tests.
- On-line monitoring of large generators provides additional diagnostic value and enables better planning.
- The time between generator maintenance shut-downs can be extended, resulting in lower maintenance cost and increased availability.
- Multiple monitoring technologies are integrated in one device and can be further integrated using Modbus over Ethernet protocol.
- GuardII+ is a single hardware/software platform used for configuration and data processing within the endusers facilities.

References:

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