CBM for Generators

April 2nd, 2020

FEW WORDS ABOUT IRIS POWER

- Specialists in diagnostic systems for high voltage electric machinery
- About 100 employees in Toronto
- Employees in USA, China, Brazil, India, Korea, Middle East and Europe
- Established in 1990
- Delivered enough sensors for one PD installation EVERY DAY for last 30 years (=more than 80,000)
- IRIS is the World's largest supplier of Partial Discharge equipment for rotating machines
- Only IRIS provides statistical PD data base

WHO WE ARE?

1945

FOUNDED

By George Ford in Fairport, NY

1986

ACQUISITION BY DANAHER

Qualitrol becomes part of Danaher's Instrumentation Unit

1998

ACQUISITION OF AKM

Temperature Measurement

2002

ACQUISITION OF HATHAWAY

Digital Fault Location and Recording

2005

ACQUISITION OF BEN

Digital Fault Recording and Power Quality

2009

ACQUISITION OF DMS

Partial Discharge Monitoring

2010

ACQUISITION OF NEOPTIX

Fiber Optics

2010

ACQUISITION OF IRIS POWER

Power Generation Monitoring

2013

ACQUISITION OF SERVERON

Dissolved Gas Analysis

QUALITROL | FORTIVE

Qualitrol is part of Fortive and operates within the Professional Instrumentation, Field Solutions division.

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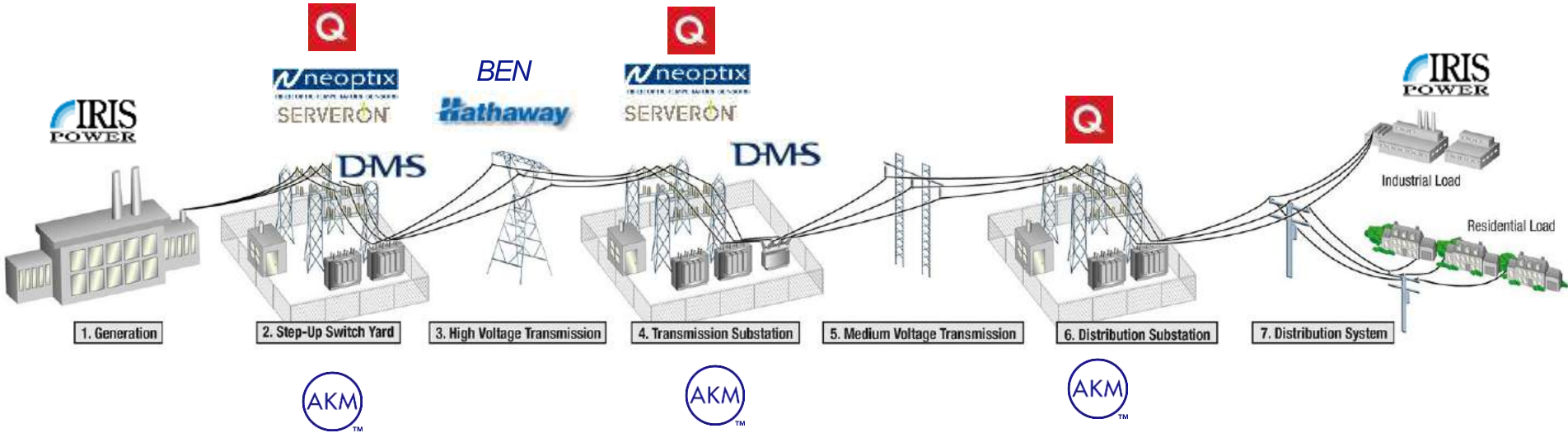
ELECTRIC POWER GRID



IRIS Power customers are Power Generation, Petrochemical Companies, Steel Mills and manufacturers of generators and motors.

IRIS Products can be divided in:

Stator Core Evaluation

- **EL CID Evolution**
- **RIV-800 Robot Inspection Vehicle and Video Camera**

Stator Insulation Evaluation

- **Portable and Continuous PD**
- **Couplers (Cable / EMC/ SSC)**
- End winding vibration
- DCR 60/ **Corona (TVA) Probe**

Wedge Tightness Evaluation

- SWA **Wedge Tightness Testing with/without rotor in-situ**

Shorted Rotor Turns Detection

- **RFA // S**
- **RFA // R**
- **Flux Trac II**

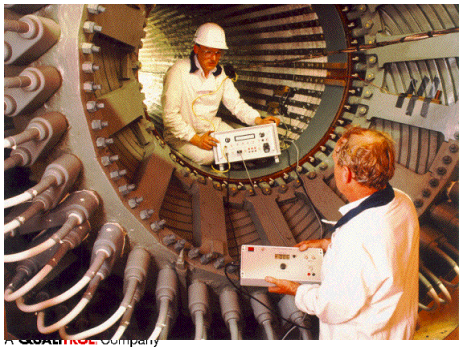
OFF-LINE vs. ON-LINE

Off-line

- Machine out of service
- Expensive
- No load
- Cold winding
- No vibration
- Testing voltage
- Localized issues

On-line

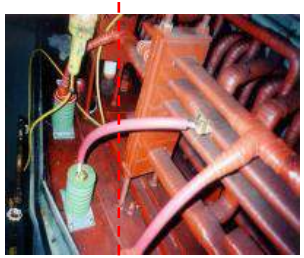
- Machine in operation
- Inexpensive, saves time
- Load of operation
- Temperature of operation
- Vibration
- Normal operation voltage
- Generalized issues



Terminology

ON LINE

Machine is running



SENSORS

- Sensors permanently installed

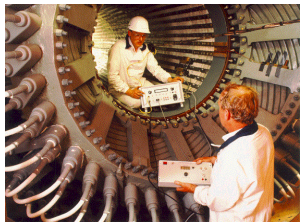
CONTINUOUS MONITOR

PORTABLE UNIT

- Permanently installed
  Captures and stores data continuously
- Used periodically by maintenance personnel
- Connected to sensors for the duration of the test

OFF LINE

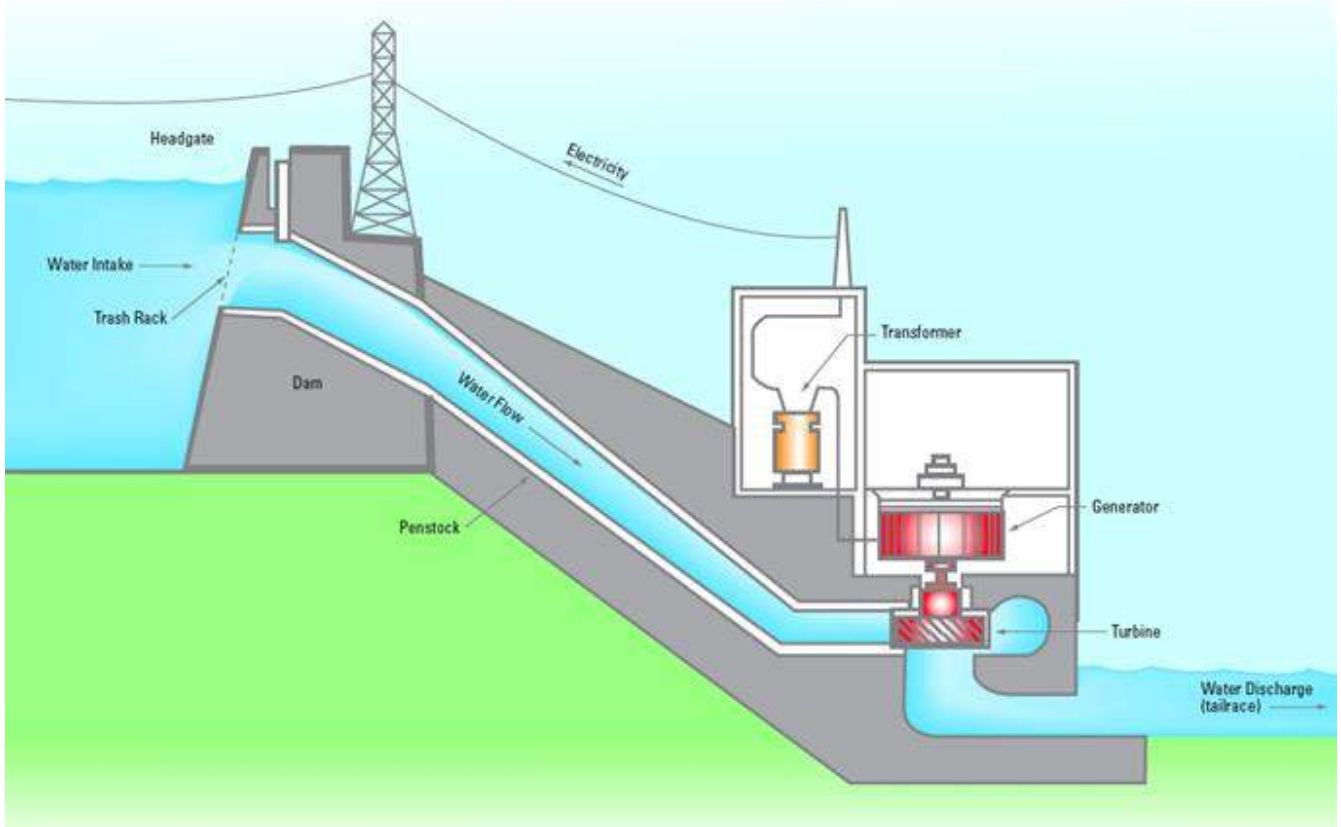
Performed during an outage
Machine is partly disassembled



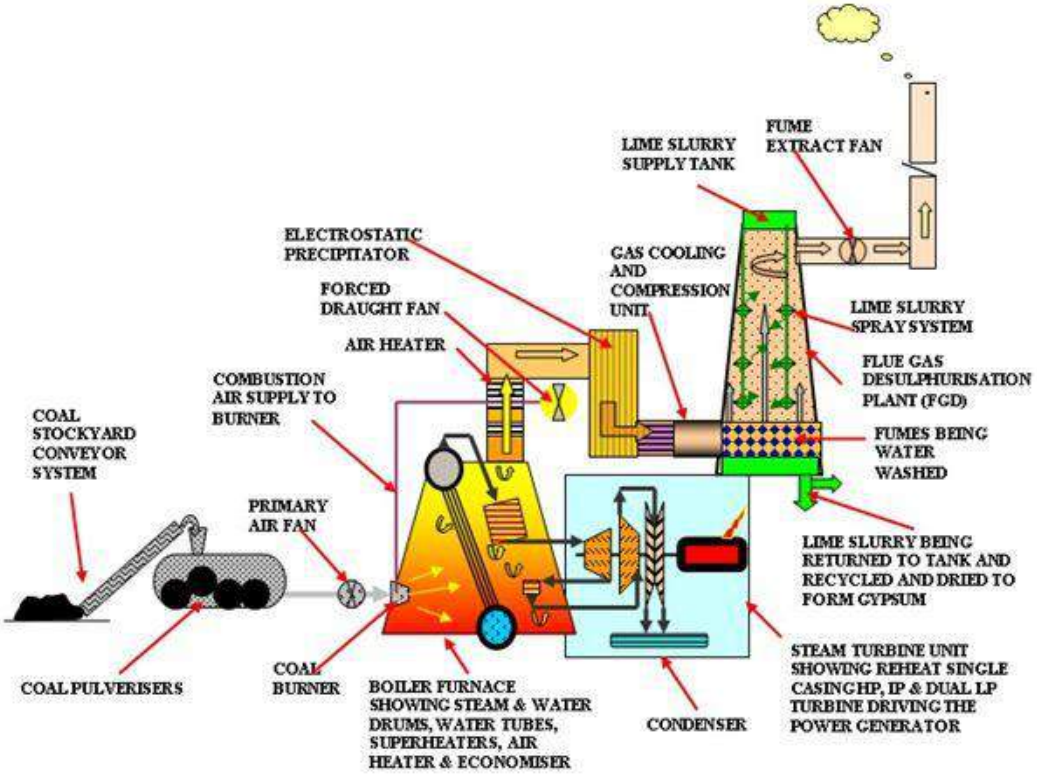
PORTABLE UNIT

- Used periodically by maintenance personnel
- Connected to portable sensors for the duration of the test

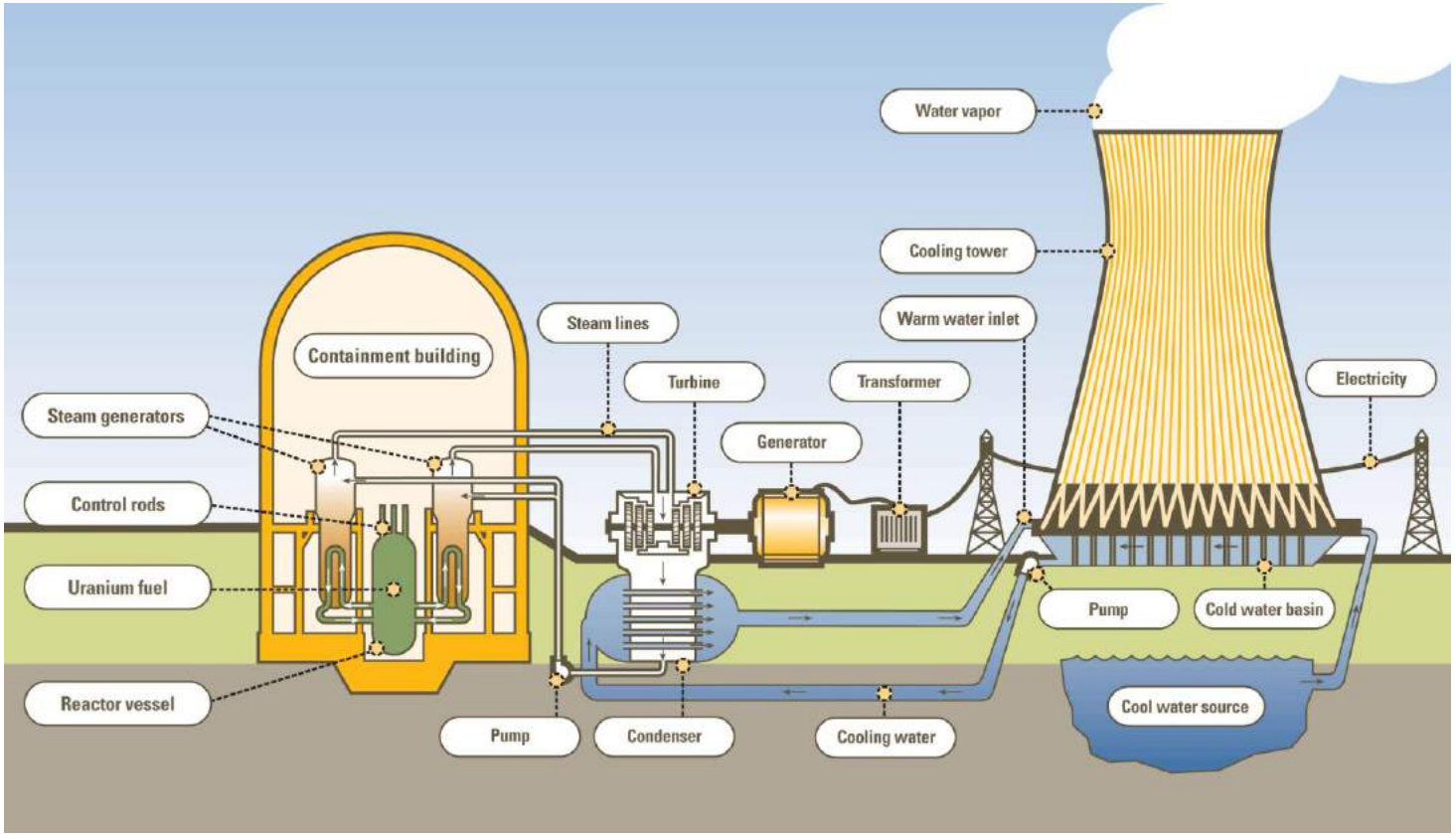
HYDRO POWER PLANT



COAL FIRED POWER PLANT



NUCLEAR POWER PLANT



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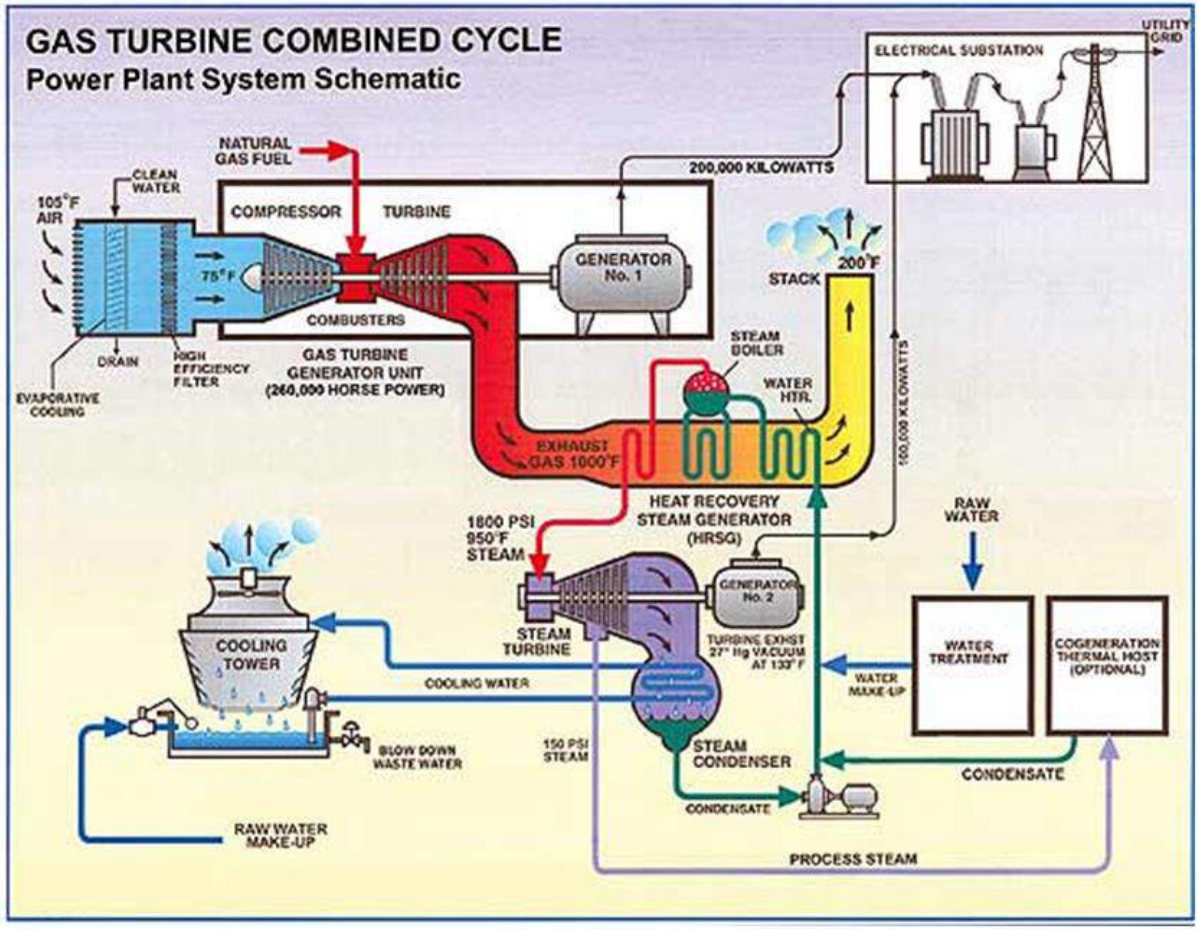
COMBINED CYCLE POWER PLANT



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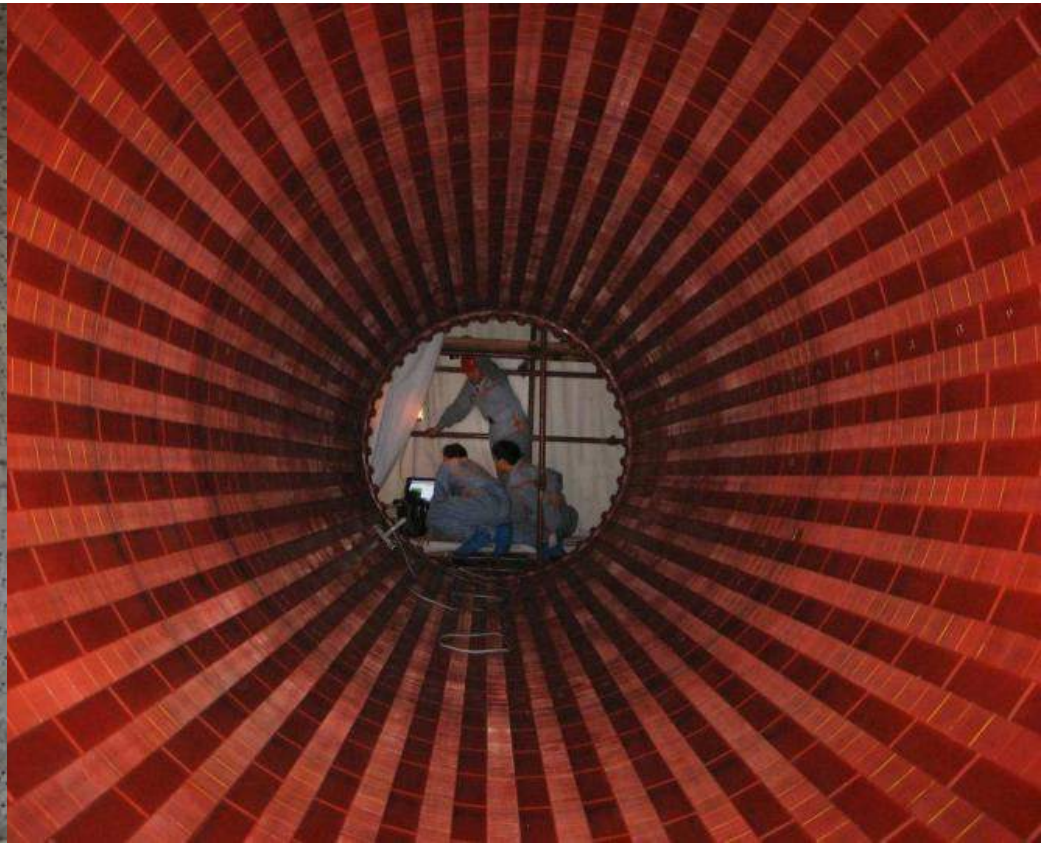
Rotating machines can be large…



…or huge!

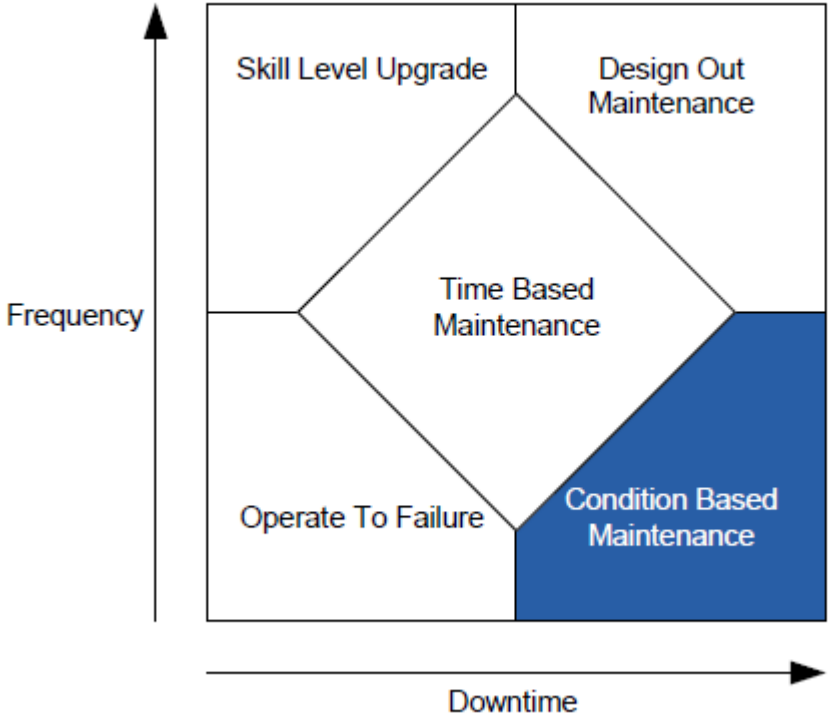
Motors – 4.16 to 13.8 kV, up to 80 MW
Hydrogenerators – to 23 kV, 856 MVA
Turbogenerators – to 27 kV, 2235 MVA

Turbo Generator Rotor

Stator Frame Three Gorges Generator

What is CBM

- Condition Based Maintenance (CBM) is a predictive maintenance technique focusing on performing a maintenance action based on the actual condition of a system
- Roles of Monitoring, inspection and testing
- If all 3 tools are used judiciously, it is possible to decrease but not eliminate exposure to forced outages.

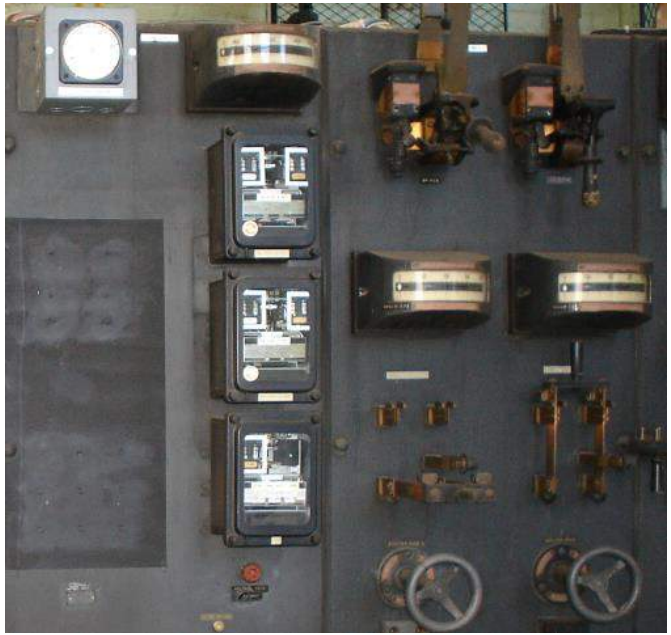


General principles of Testing, Monitoring and Maintenance

Off-line testing and on-line monitoring

Maintenance can be:
-Breakdown or corrective
-Time based or preventive
-Condition based or predictive

- The goal of CBM is:
- Prioritize maintenance
- Acceptance testing
- Determine root cause of failure



Protection
Metering
Monitoring
Testing

OFF-LINE vs. ON-LINE

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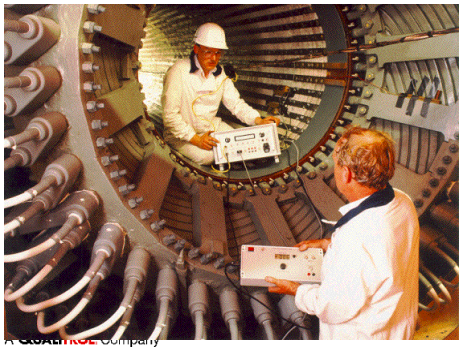
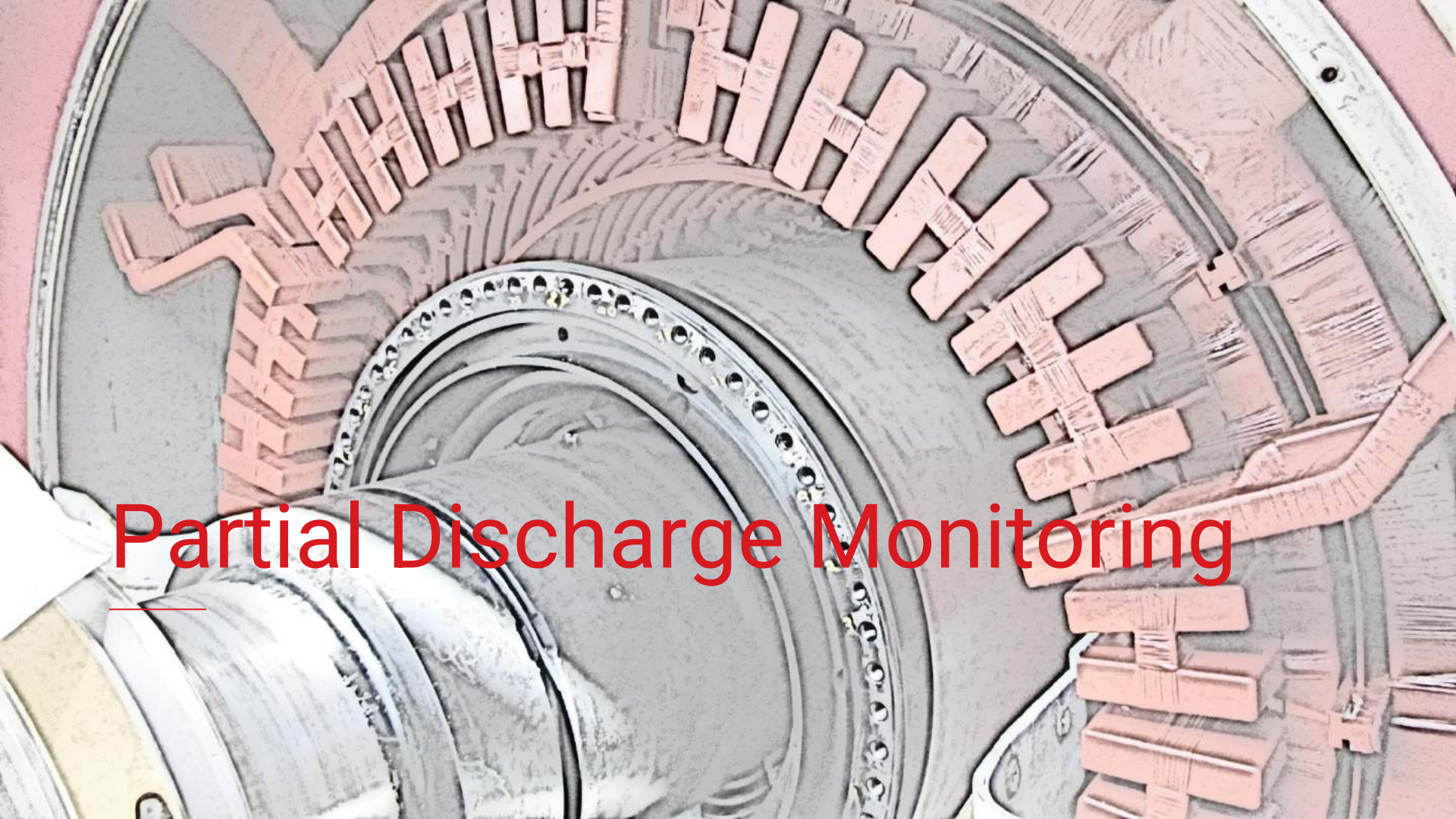


Five Ws

- Which Unit (asset) to choose
- What measure describes degradation
- When is the unit failure likely to occur
- What maintenance action to perform
- When to perform a maintenance action

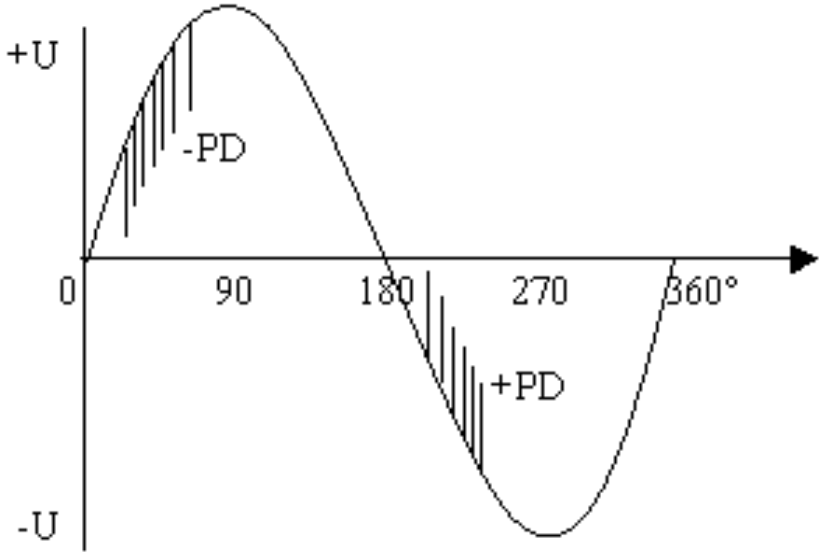
Monitoring helps bridge the gap between measurement and diagnostic.



Partial Discharge Monitoring

What is Partial Discharge?

Partial Discharges are “sparks”, or surges 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.



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

Effects of PD

Generation of ultraviolet radiation.
Nascent oxygen and ozone.
Nitric acid in the presence of moisture.
Oxalic acid and other materials within enclosed voids of polyethylene and other insulations.
Heat generation in the discharge channel.
Mechanical erosion of surfaces by ion bombardment.
Creation of pulse with wide band frequency spectrum.

ALL INSTRUMENTS ARE BASED ON CAPTURING SOME OF THE EFFECTS NO EFFECTS=NO INDICATION

Why PD testing?

- 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 mica which is PD resistant is used – 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 to warn of failure in a few years

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.
- 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

More than 80,000 PD sensors installed

- Termination Box

On more than 16,000 machines

- Instrument

Portable or Permanently Installed

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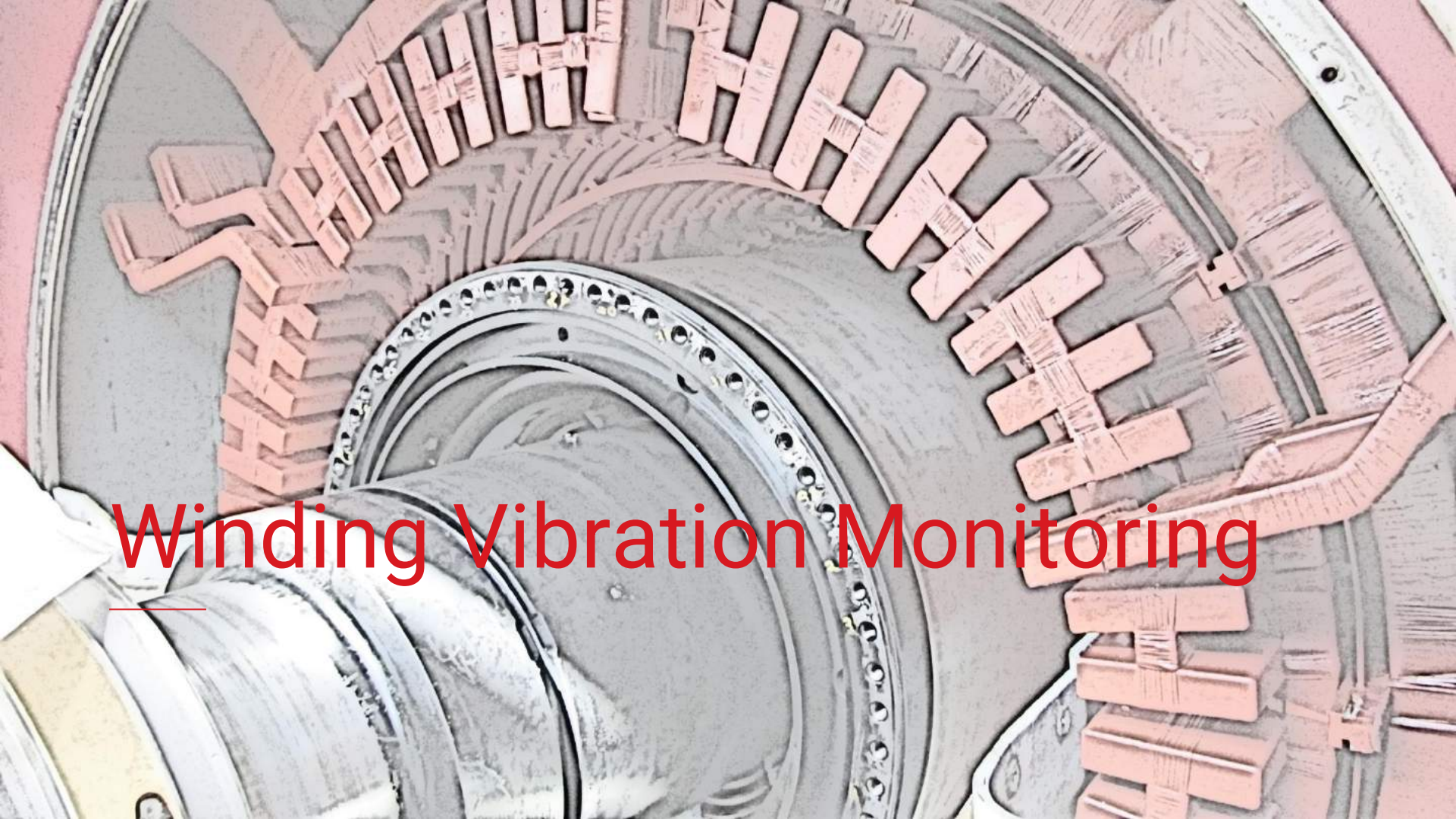
IRIS Rotating Machines PD Database

- Over 640,000 test results from thousands of machines/IRIS sensors 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 then winding is deteriorated

	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	218	473	514

IRIS PD Monitoring Summary

- Well established method for ON-LINE monitoring of stator winding insulation
- Applicable for all rotating machines rated higher than 4000 V
- Different sensors and instruments (portable and continuous) available



Winding 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 forces
- Provide flexibility for thermal expansion

Why Monitor Vibration of Stator Winding?

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

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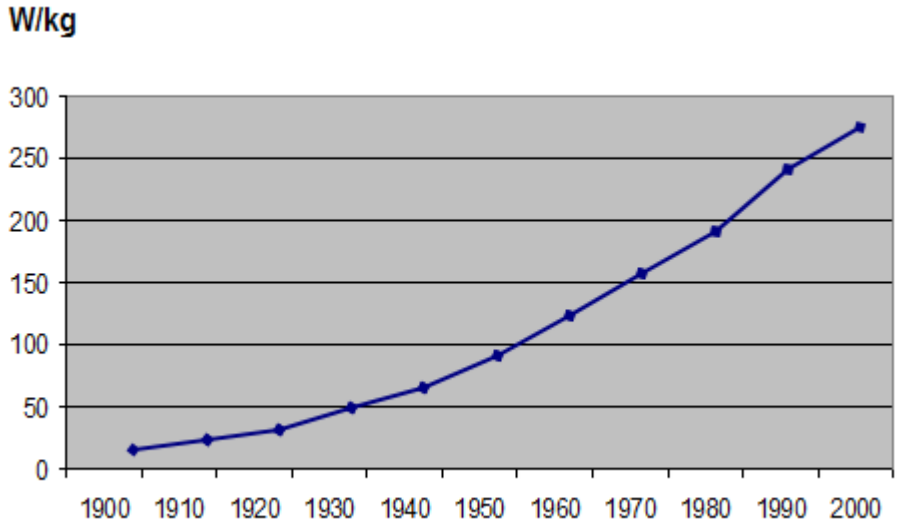
Accountants in charge of motor design

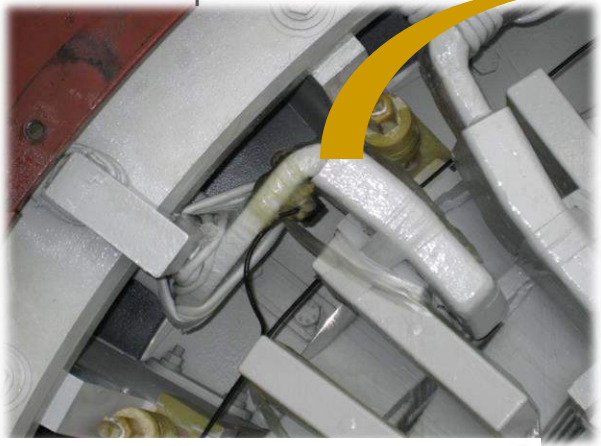
Over the last century electric motor output per kg has increased 14 fold ~ 3% pa rise!



In the other words, 14 times less material is used
now compared to 100 years ago for motor of the same rating.

Typical Endwinding Installation

Fibreoptic Sensor

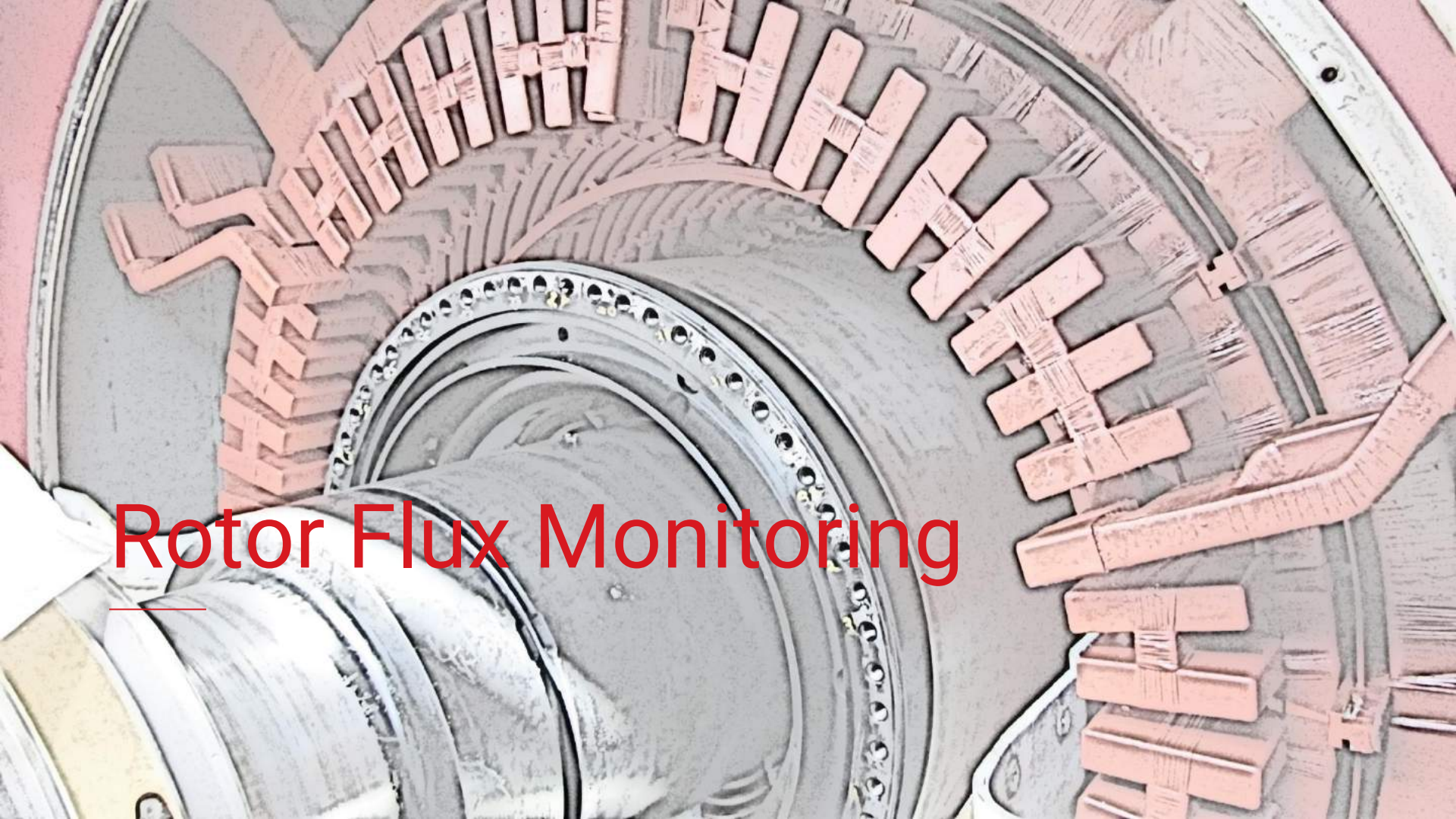


Electro-optical Converter

EV Monitor

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 micro m) peak to peak is considered acceptable
  - >10 mil (250 micro m) 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.



Rotor Flux Monitoring

Why Monitor Rotor Flux?

- Little on-line monitoring is available for machine rotors.
- Air gap 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
- Result in higher electrical loss – and therefore decreased generator power and efficiency – may limit machine output
- Can result in thermal and magnetic unbalance and mechanical vibrations since shorted coils run cooler

Flux Sensors

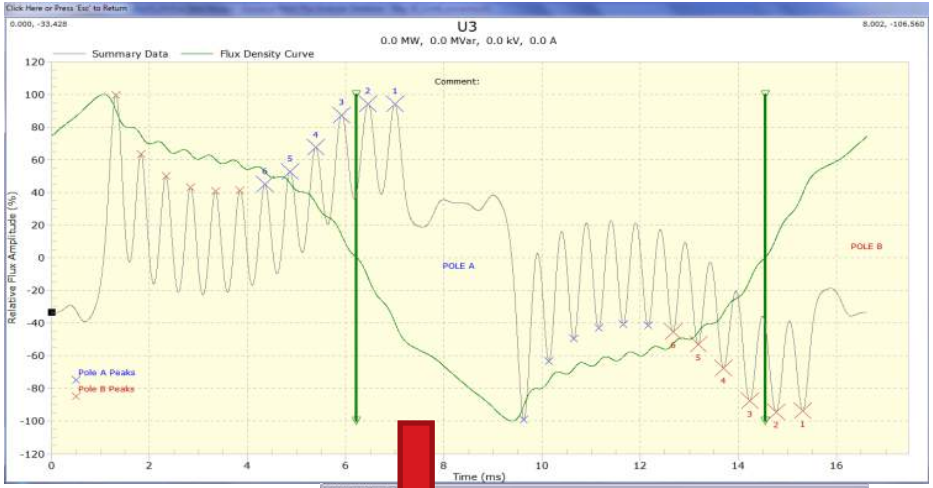
Two types of Flux Probes

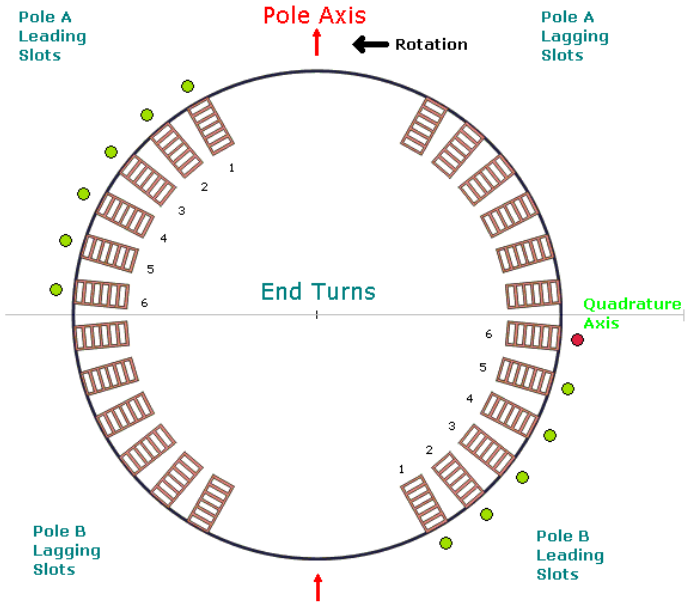
TF Probe

FF probe

Installation of TF Probe with rotor in place

Round Rotor Shorted Turns Detection





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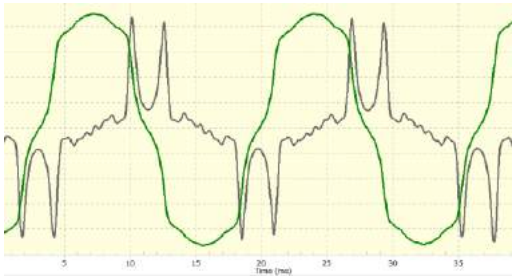
Salient Pole Rotor Shorted Turns Detection

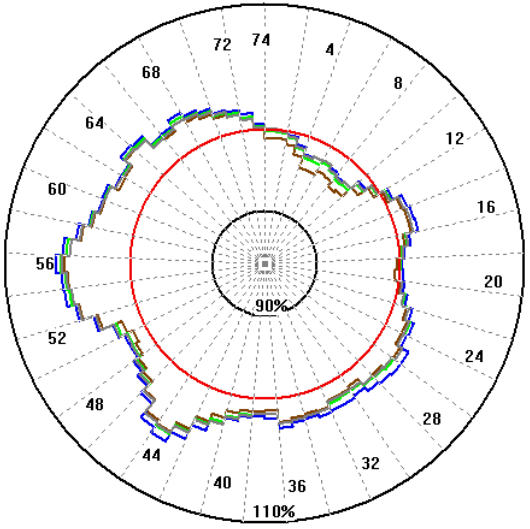
-Compare pole to average of all poles

-Compare pole to its left and right neighbor

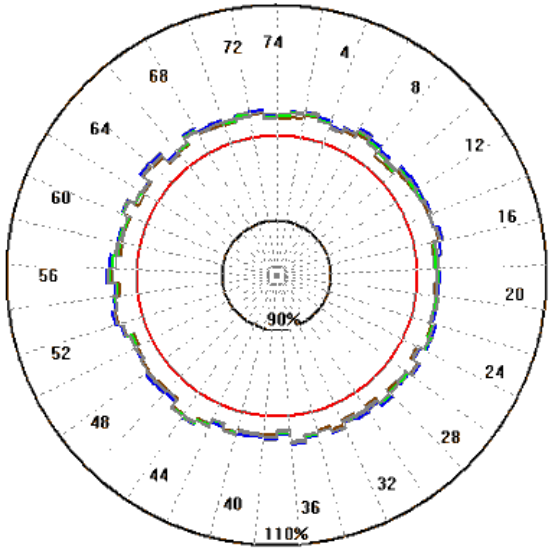
-Compare pole to poles of same polarity



Compare to average



Compare to adjacent



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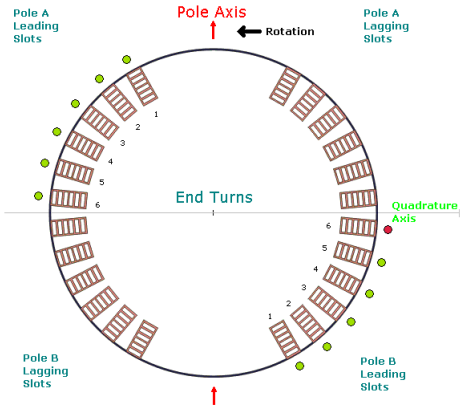
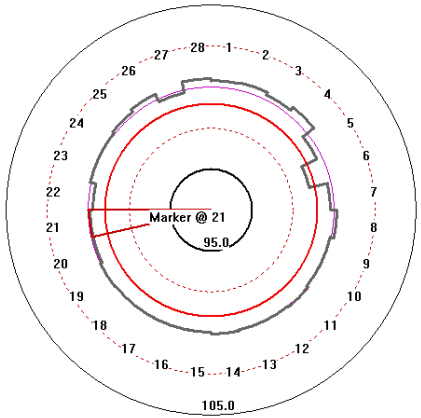
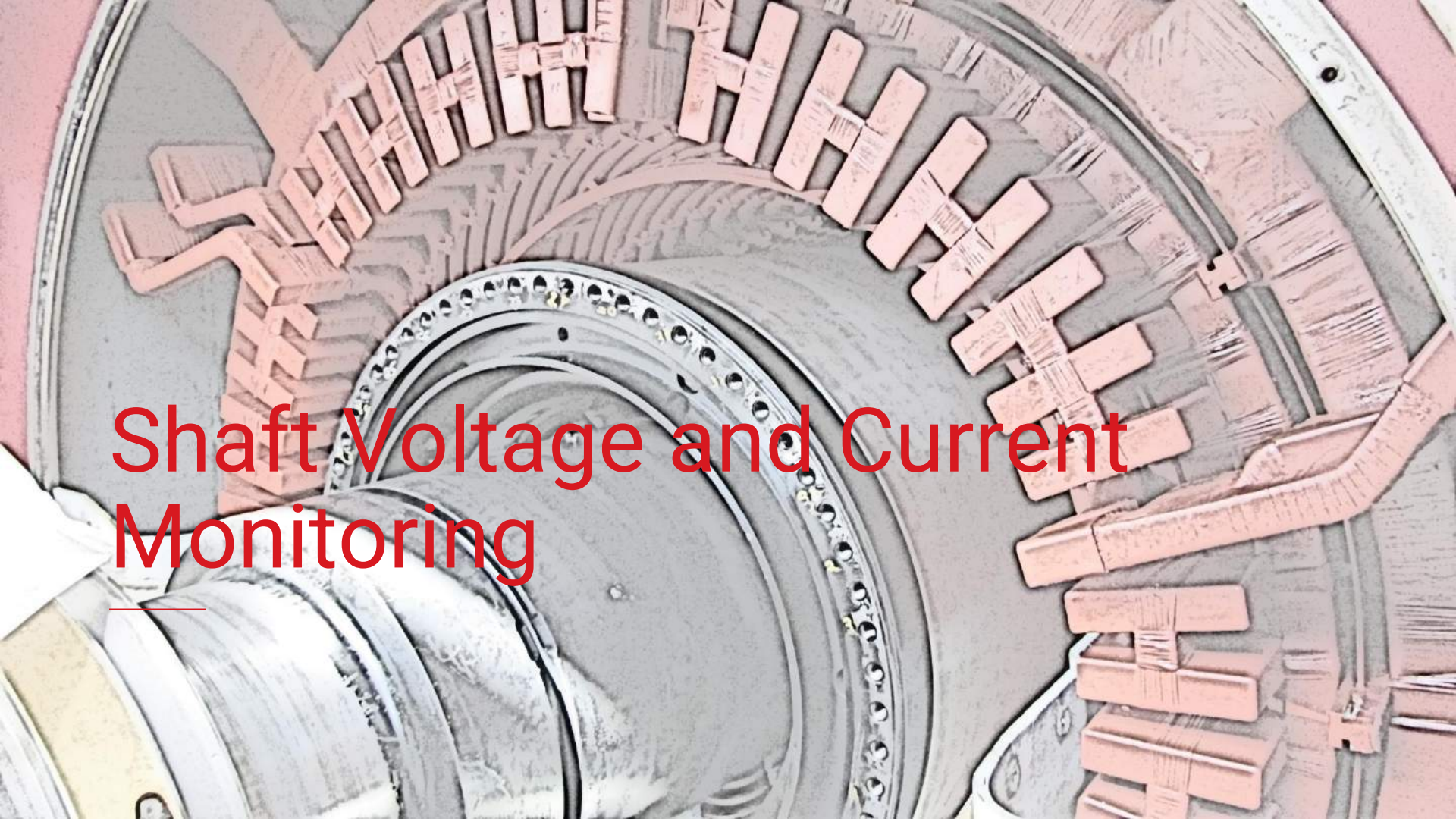
Flux Monitoring Summary

- Simple to perform ON-LINE test for Asynchronous machines
- 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

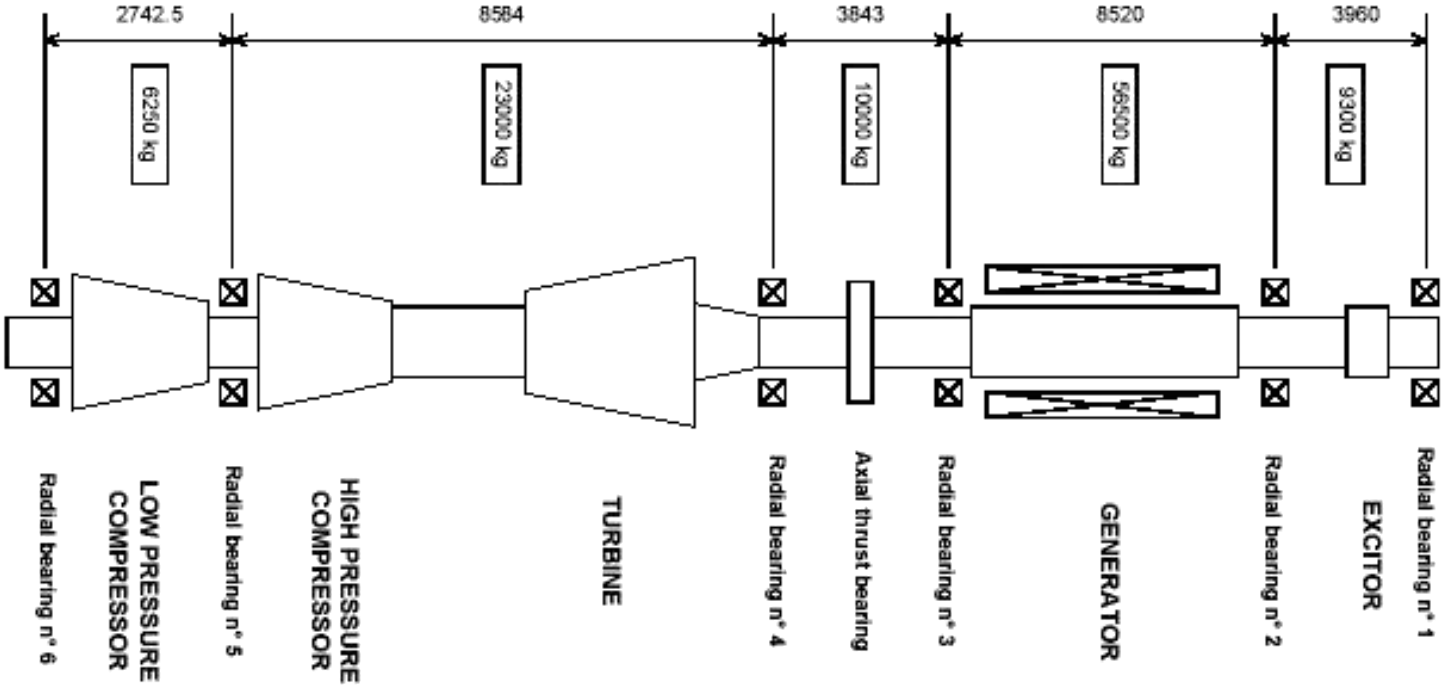






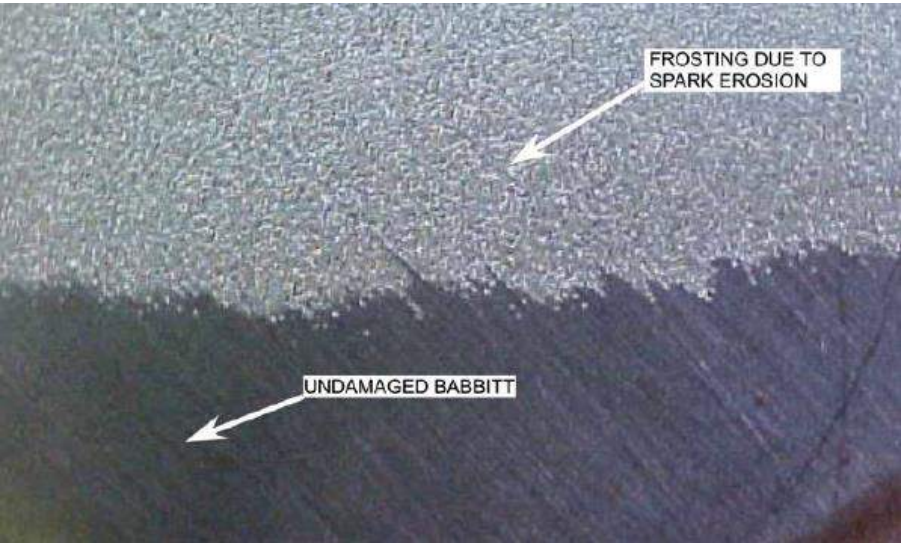
Shaft Voltage and Current Monitoring

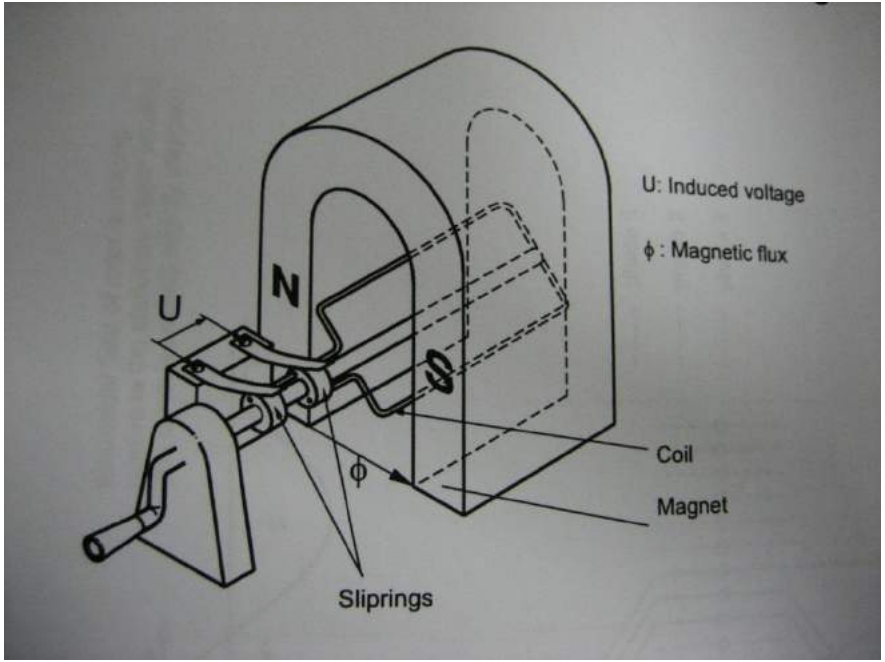
What is Shaft?



All Things Fail Mechanically!

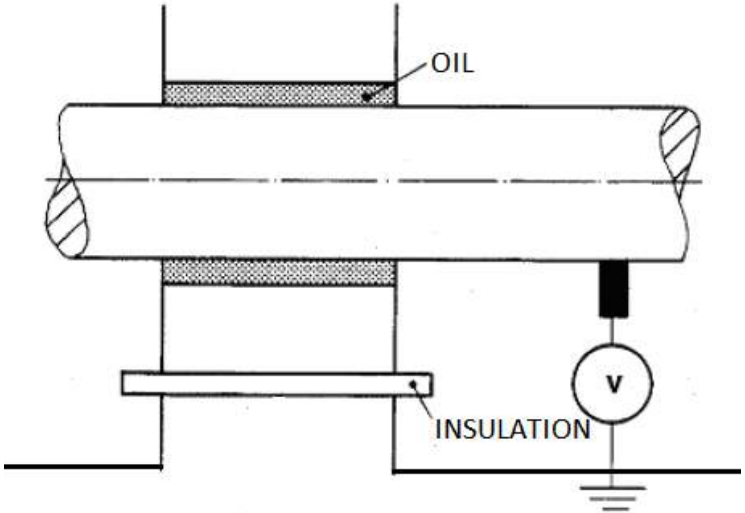
- Electrical things especially!
- But…
- Shaft and bearings can be damaged by electricity



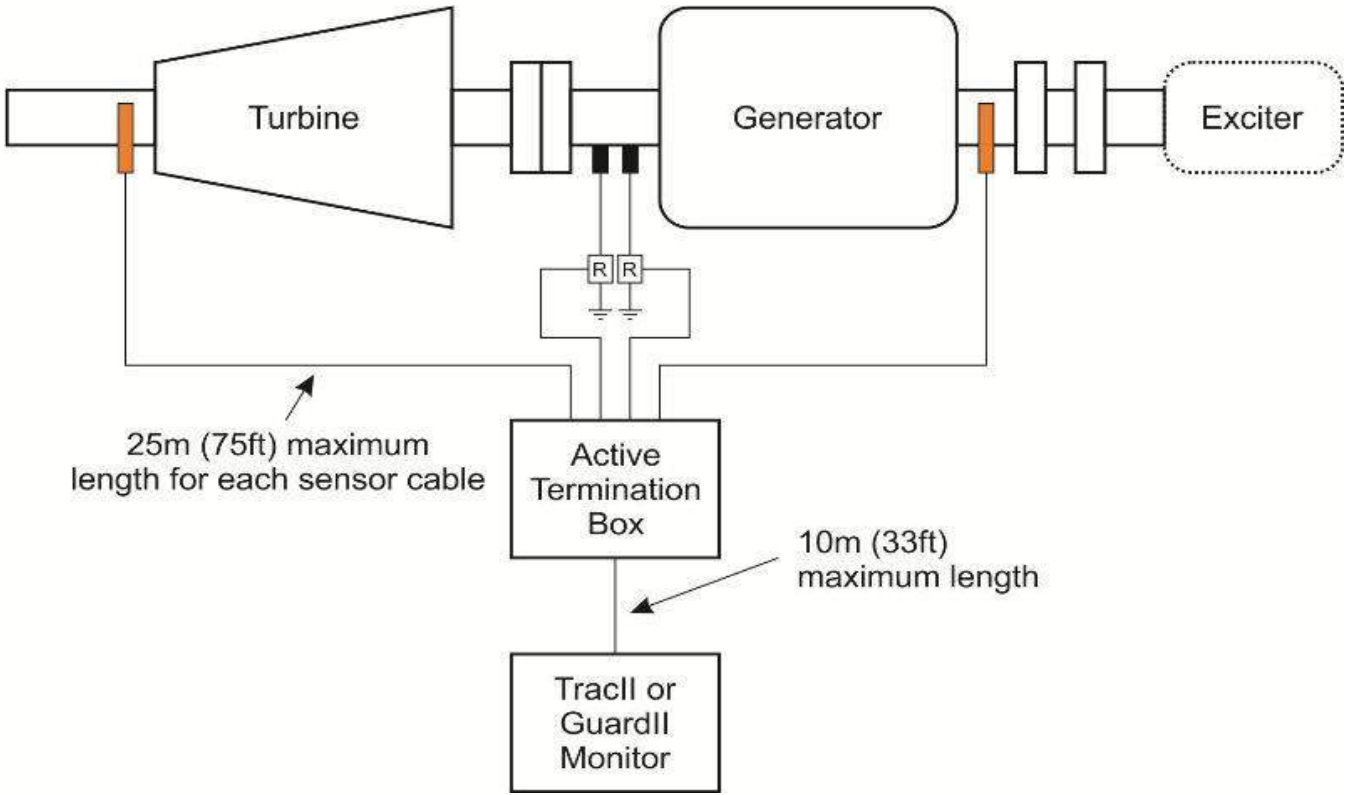


To minimize shaft/bearing problems...

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

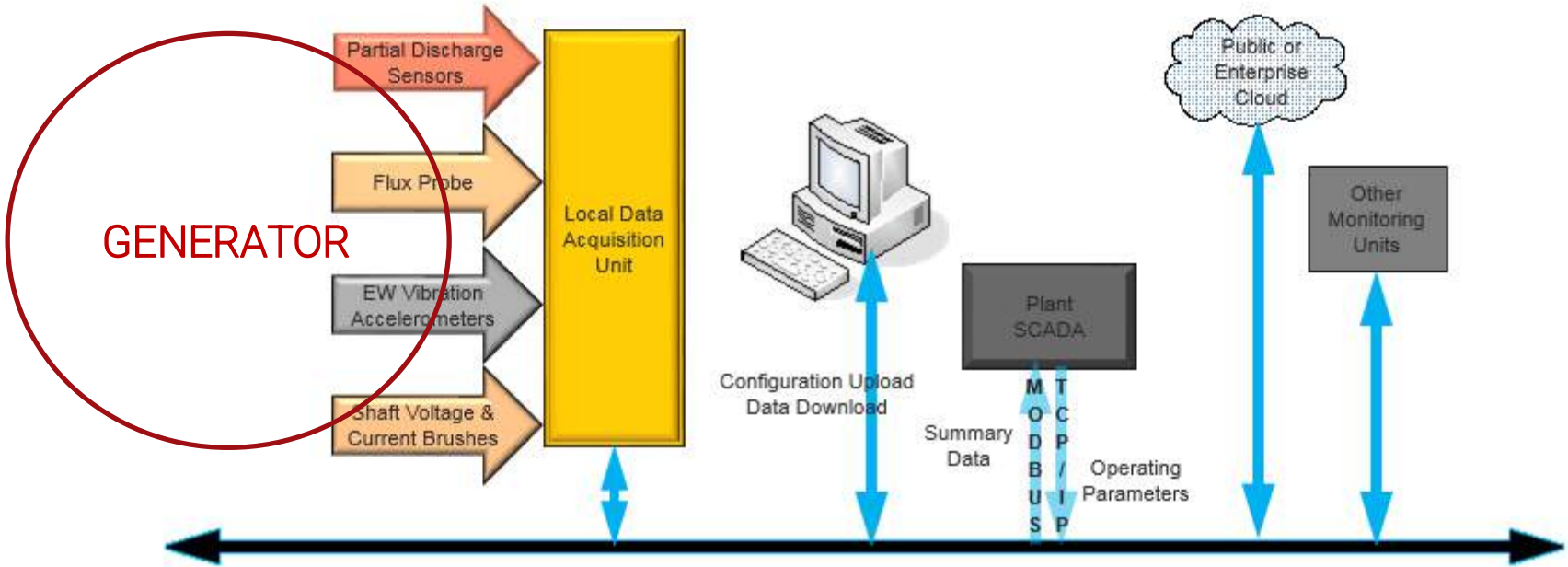
- Grounding brush current too low: poor grounding, brush not working.
- Grounding brush current too high: multiple grounds present (i.e. shaft rub)
- Voltage brush signal too high: risk of bearing/seals insulation breakdown.
- Normal shaft currents can range from a few milliamps to several amps
- Voltage 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

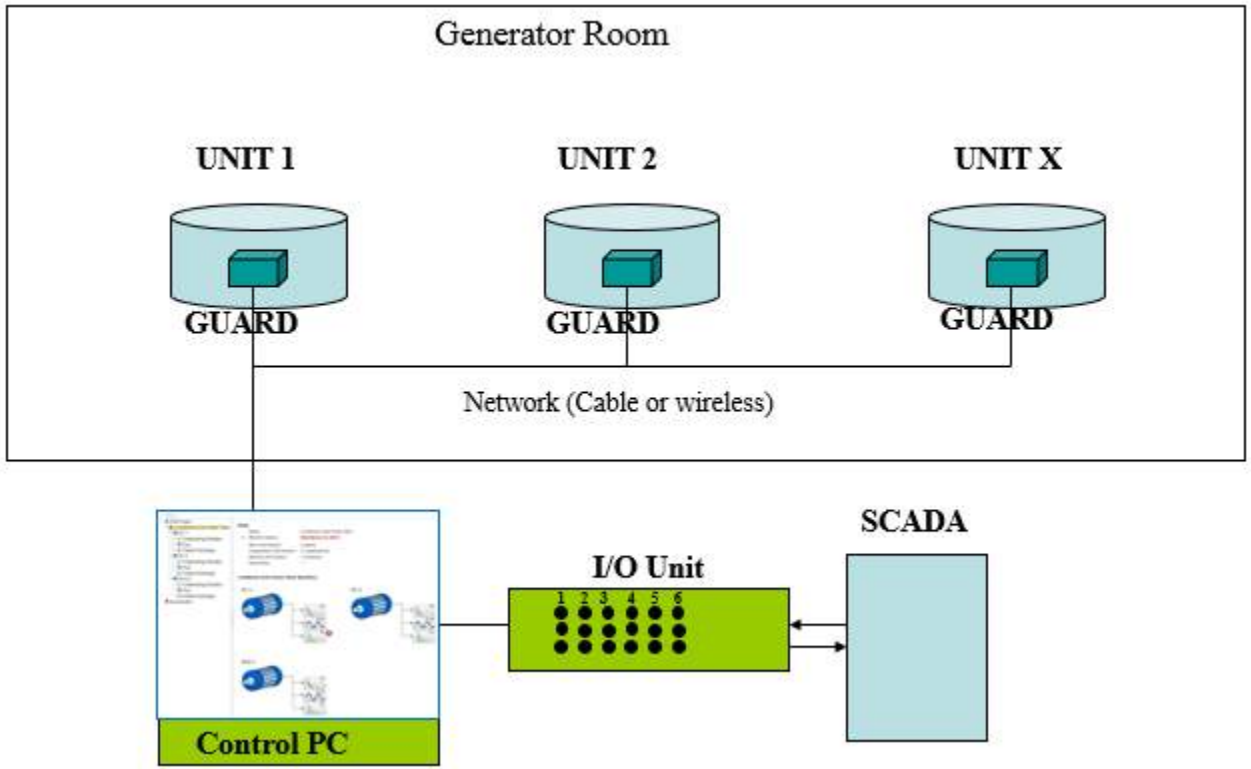
INTEGRATED MONITORING SYSTEM

One Monitor for Four Technologies

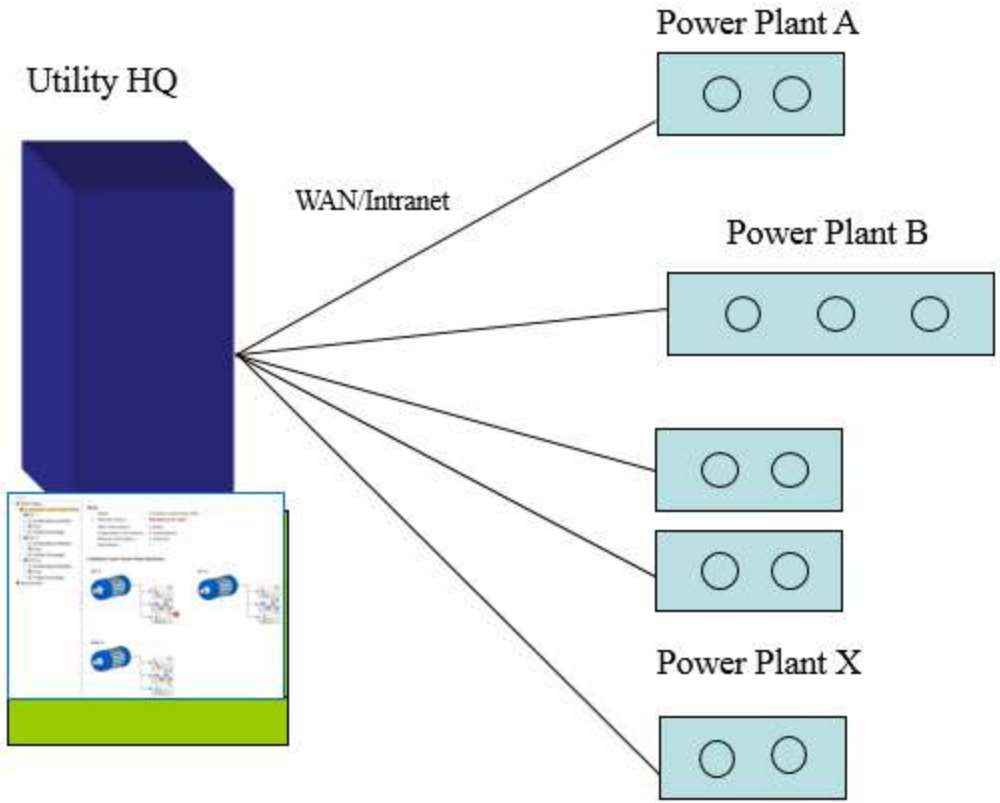


One Monitor for Four Technologies

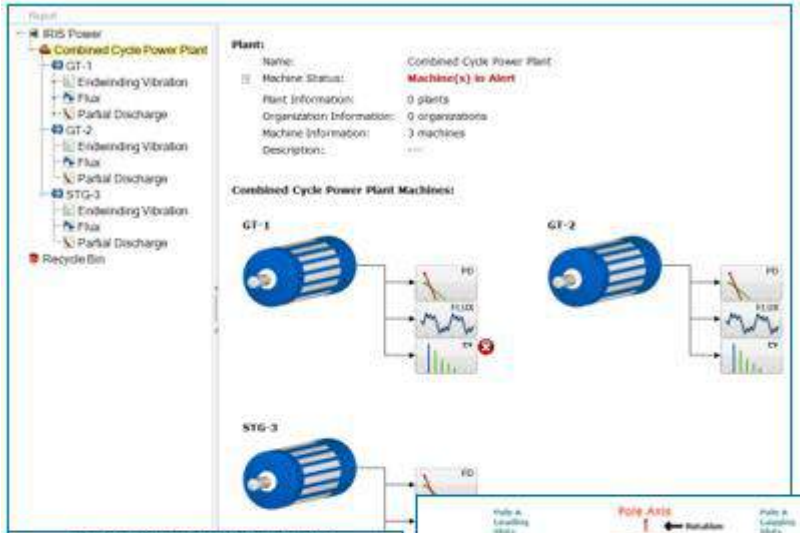
Multiple Units in One Power Plant

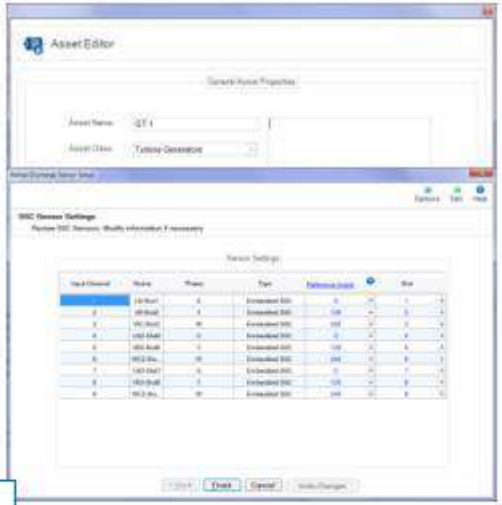


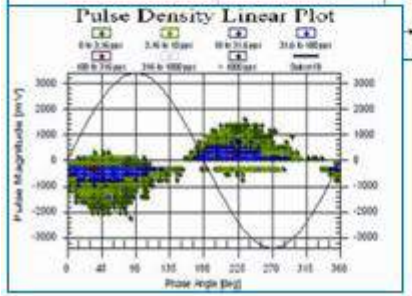
Multiple Plants in one Utility

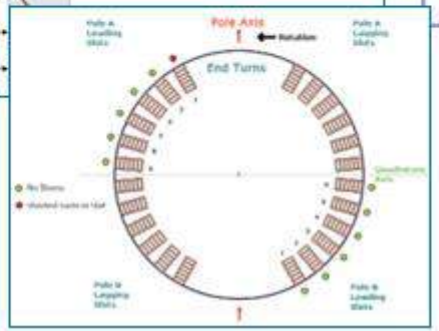


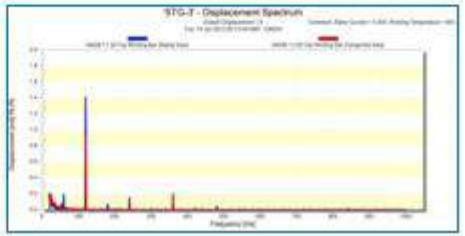
IRIS Application Manager Software











Conclusions

- Different on-line monitors can warn of developing problems in rotating machines
- Selection of sensors and detectors is critical for successful diagnostic
- Benefits of CBM include reduced maintenance cost, extended life and maximized operation of assets

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