Generator diagnostics

From failure modes to risk for forced outage

IRMC 2018, Long Beach
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Fortum TGS

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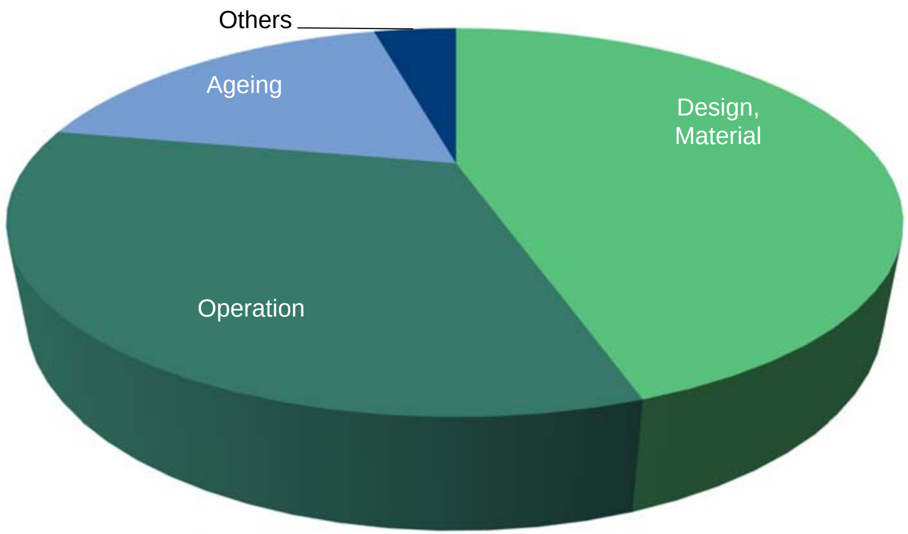
Diagnostics based on failure modes

- Risk statistics and failure modes
- Diagnostic tools
- Generator inspection levels
- Inspection levels ability to detect failure modes
- Risk assessment and recommendations
- Examples
- Summary

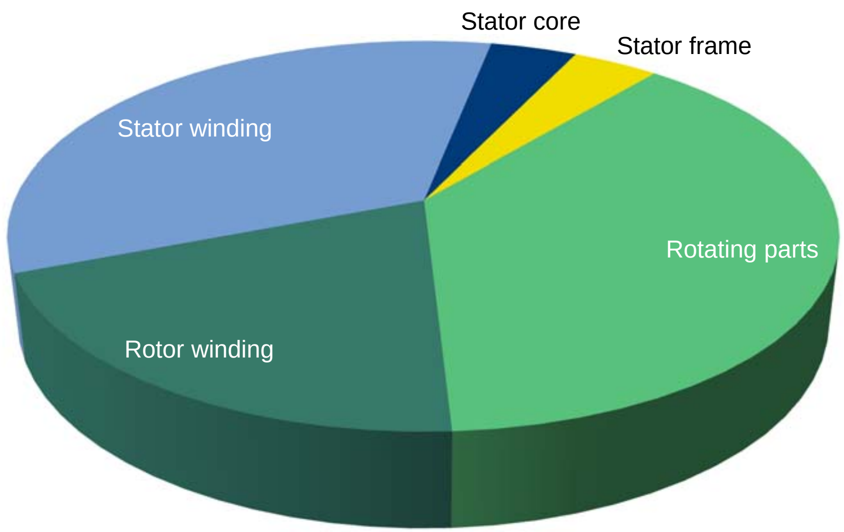
Turbogenerator failures, causing forced outage



Source: Allianz insurance company

Cause for failure

Component that failed



Source: NERC - North America Electric Reliability Analysis

What is generator maintenance?

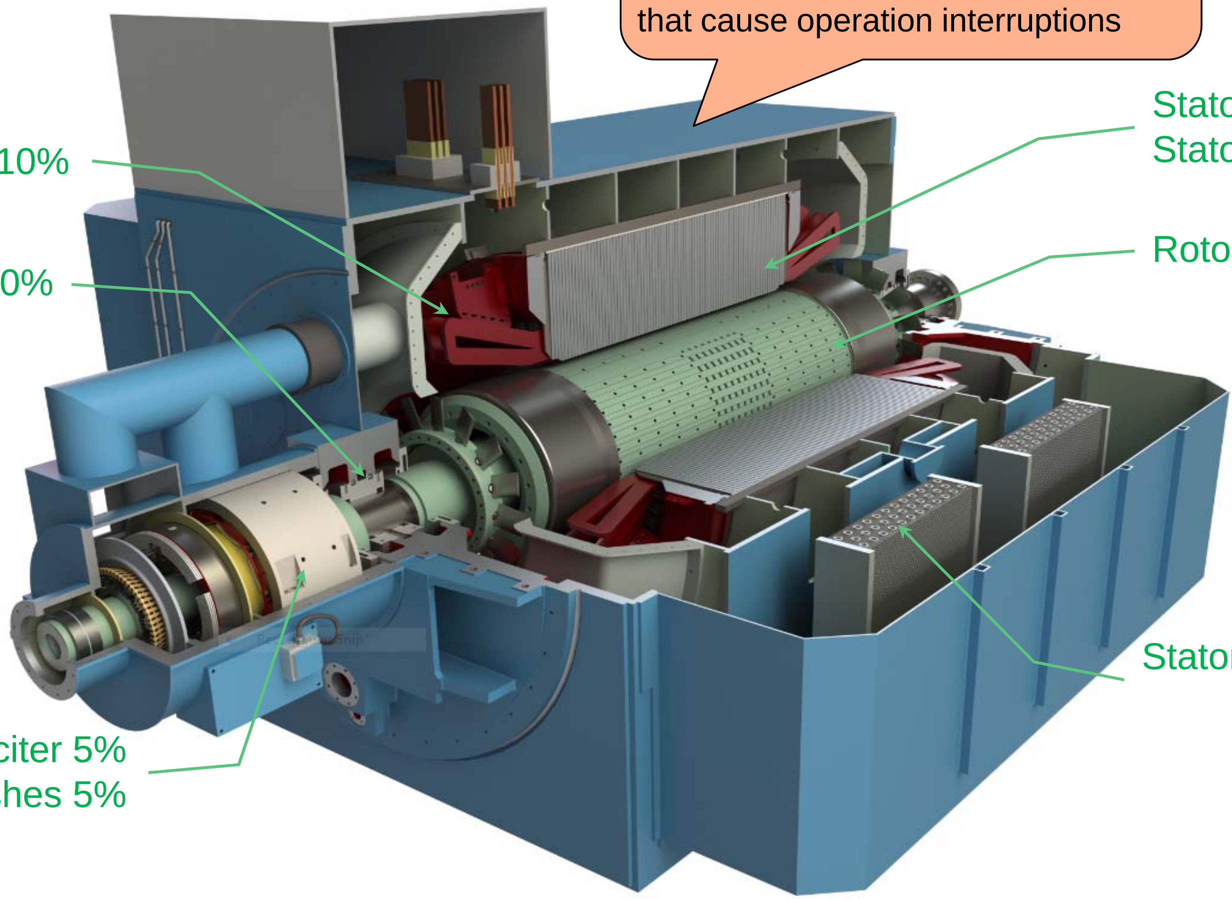
- Turbogenerators are inherently reliable, yet technically complex item of machinery, designed for a long life.
- Performance of a generator does not deteriorate with time.

➡ Generator-OH = 10% reconditioning + 90% diagnostics

- Example of reconditioning
  - Cleaning
  - Changing of gaskets
  - Slot wedge tightening
  - Grinding of slip rings

What shall be diagnosed?

Failure modes are the ways a fault can occur in the generator's function. Interesting failure modes are those that cause operation interruptions



About 100 failure modes can occur on an air-cooled generator

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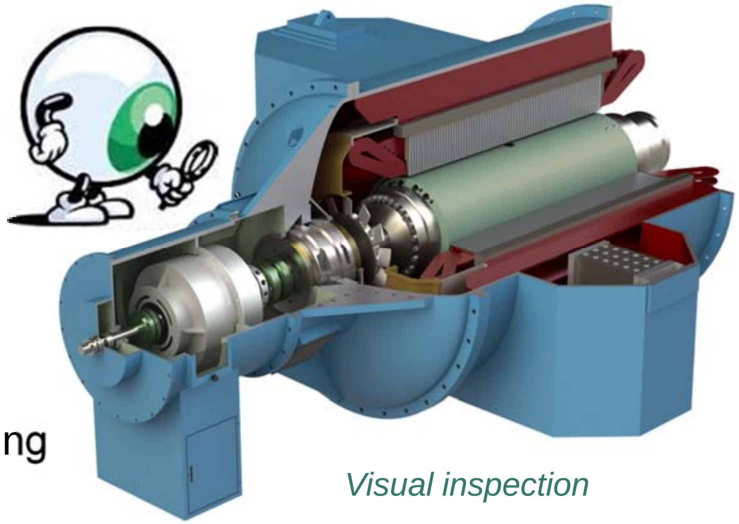
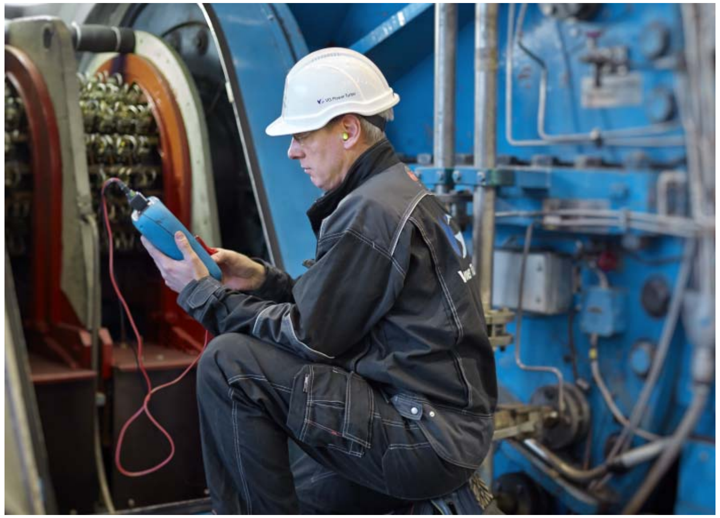
Diagnostic tools

- Electrical tests are performed to identify:
  - Short circuits in stator core
  - Breakage in rotor and stator windings
  - Condition of the main insulation in rotor and stator winding
  - Defects in contact between stator bars and stator slots
  - Short circuits in the rotor winding
- Visual inspection with the “trained eye” is and important tool to gather information.
  - Overheating, signs of vibration,
  - Contamination, signs of PD, and others
- All information is analyzed together with our fleet experience to form a diagnose.



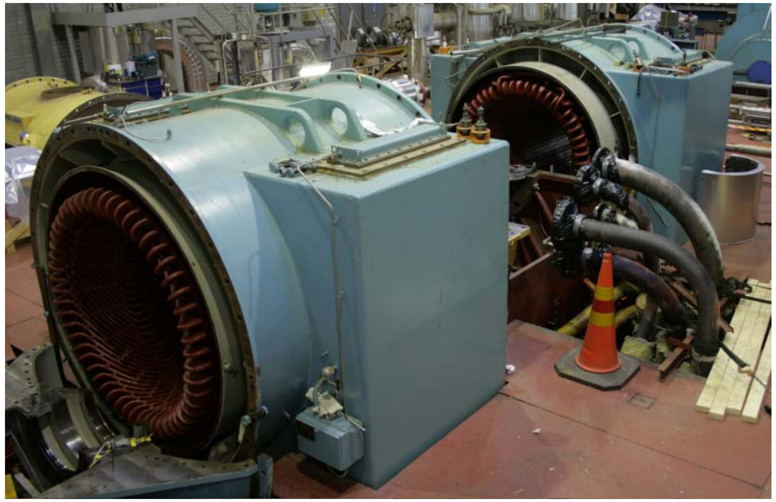
Visual inspection

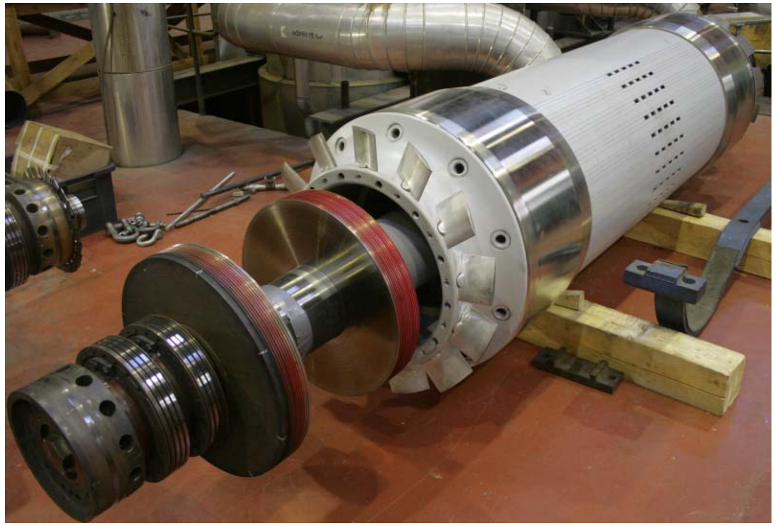


Electric testing

Inspection levels for turbogenerator

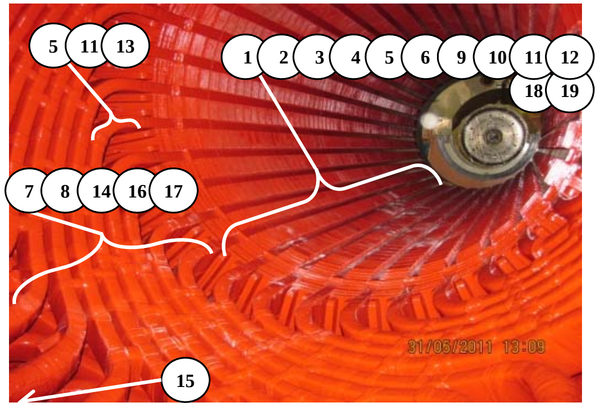
- Normally there are three inspection levels:
  - Major Overhaul (MO) where bearings, coolers and the rotor are disassembled.
  - Limited Inspection (LI) where parts of bearings and some winding covers are removed.
  - Safety Check (SC) where only inspection hatches are removed / opened.
- Major overhaul is the most important part of the maintenance plan.
- Complete disassembly enables inspections and complete diagnostics of components.





Which method can detect which failure mode?

- Approx. 100 modes are identified and described.
- Detected = something is wrong, we are not exactly sure on which failure mode.
- Identified = we know which failure mode has occurred, a more precise risk assessment can be made.
- Possibility to detect and identify failure modes depends on the inspection level being performed.



Failure modes: stator winding and core

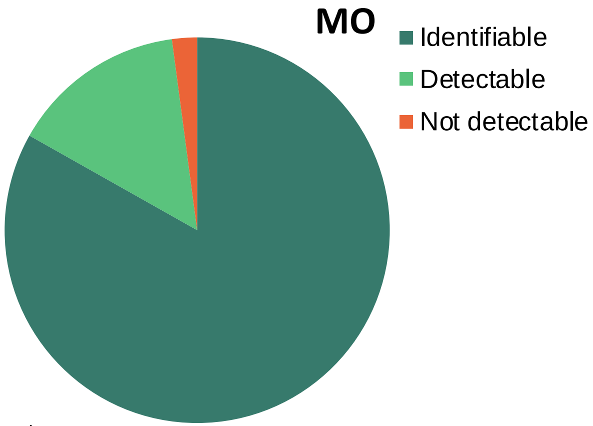
Detection and identification of failure modes – Examples

Felmod	Major Overhaul								Limited Inspection					Safety Check				
	Visual	El-test basic	PD measure	HV-test	ElCID	RSO	Ultra sonic	Penetrant / EC	Visual	El-test basic	PD measure	HV-test	RSO	Visual	El-test basic	PD measure	HV-test	RSO
Aging of main insulation stator winding	d	d	i	i						d	i	d			d	i	d	
Contaminated stator end winding	i		d							i	d					d		
Cracks in rotor fans	d							i	d									

- Measurement of partial discharges (PD) → identification of aging insulation of stator winding at all inspection levels.
- Contamination of stator end winding, detection by using PD measurements, identification visually and possible to correct during Major Overhaul.
- Cracks in rotor fans, can be detected at visual inspection but requires Major Overhaul to be identified an corrected.

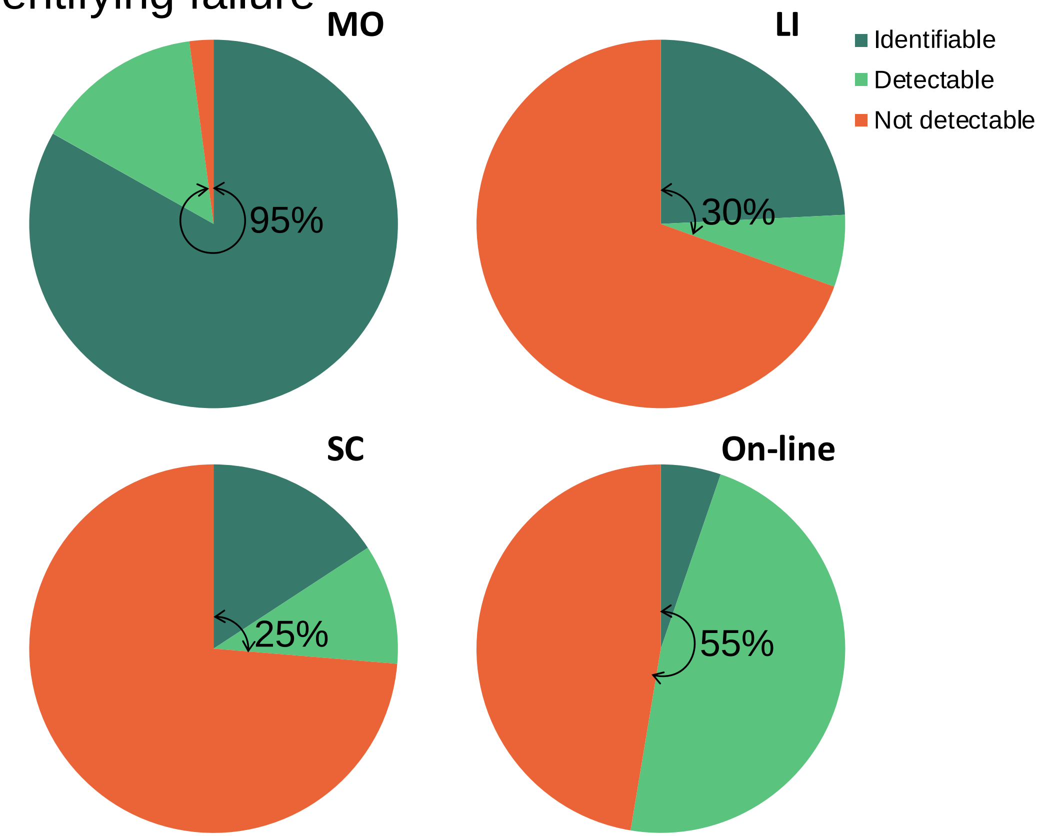
Detectability at Major Overhaul

- Major Overhaul is the most important part of the maintenance plan
- Complete inspection and diagnostics of all critical components possible.
- Gives possibilities for reconditioning
- A complete MO contains:
  - Removing bearings, winding covers, rotor and coolers
  - Visual inspection of all components
  - Diagnostic tests of all critical components
- A major overhaul can:
  - Identify 85% of failure modes
  - Detect another 10%.
  - Remaining 5% of failure modes can be identified during operation.

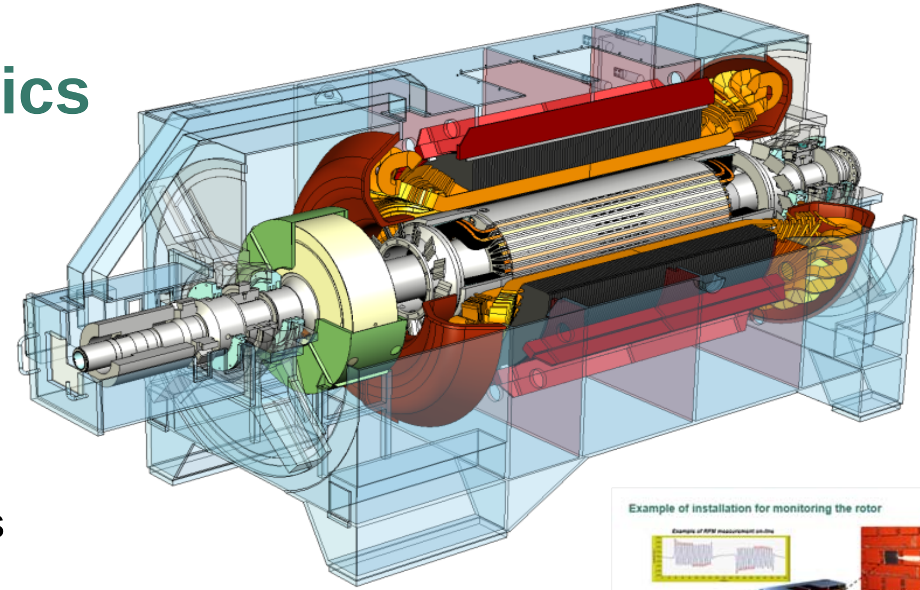


Detectability at different inspection levels Conclusions

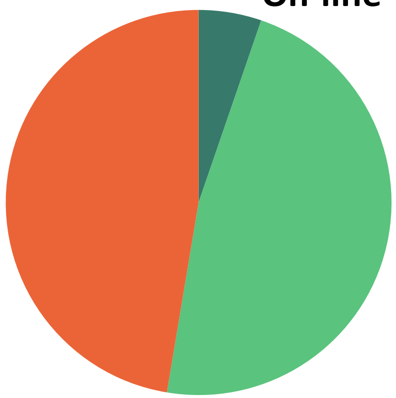
- Major Overhaul is the most powerful tool identifying failure modes that can cause unplanned outages.
- A Limited Inspection is marginally better than a Safety Check
- On-line diagnostics is the next most powerful tool and it can be performed at any time during operation.

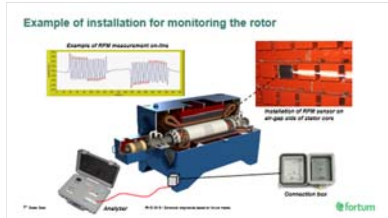


Detectability using on-line diagnostics



- Failure modes can also be detected during operation by on-line diagnostics.
- Air-cooled turbogenerator can be fitted with:
  - PD monitoring in each phase of the stator winding
  - Rotor Flux Monitoring
  - Monitoring stator winding and cooling air temperatures
  - Monitoring bearing vibration
  - Operating parameter trends
  - Generator protection relays
- On-line diagnostics can:
  - Identify 5% failure modes.
  - Detect an additional 35%.
  - Protection system detects an additional 15% of the failure modes, but the reason for the trip must be investigated before the restart.





RFM

PD

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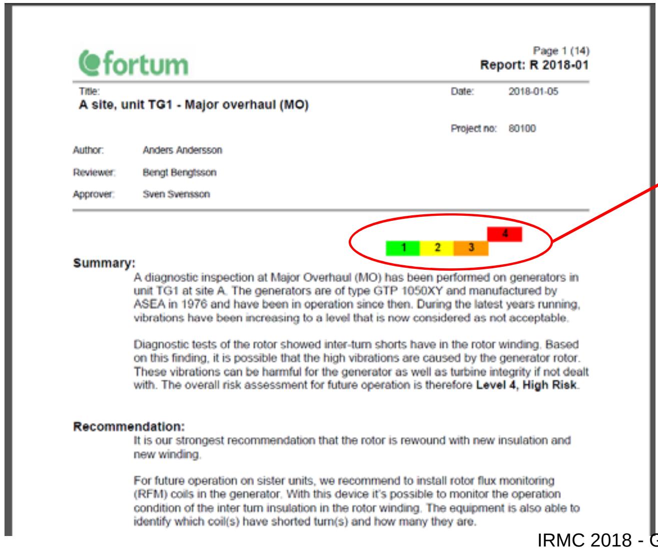
Result of inspection with diagnostics

- We supply You with the present risk situation!
- Analysis of the data results in a risk assessment at component level.
- The risk to the generator is equal to that of the highest-risk component, taking into account planed operation until next MO
- Results are reported as four risk levels from Base Risk to High Risk.



1 Base risk

2. Increasing risk

3. Medium high risk

4. High risk

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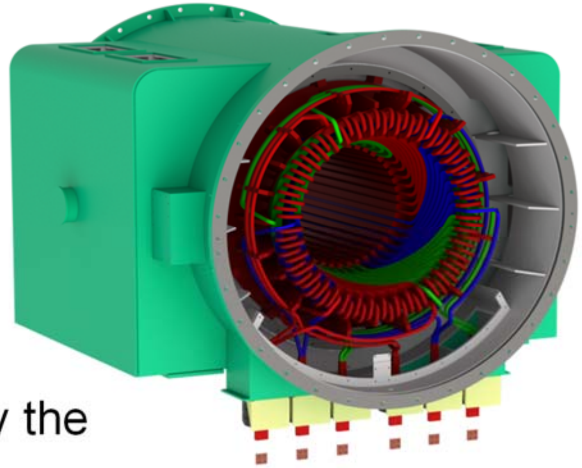
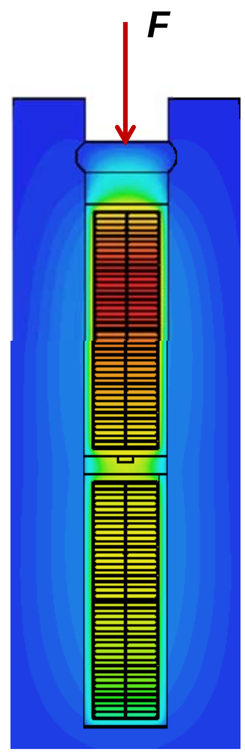
Recommendations for risk reduction

- All reports contains recommendations of:
  - actions that can reduce the risk for operational disturbance, e.g. monitoring equipment or changing time between MO's
  - actions that can reduce the consequence of such an outage, e.g. spare parts or spare components
- Purpose is to maintain the risk at an acceptable level until next planned major overhaul or to reduce the risk level.
- The result gives the plant owner a powerful basis for updating the maintenance plan. It also gives guide to future investments needed to maintain risk at an acceptable level.

Example: Loosening of stator slot wedges

- Slot pretension force ***F*** may reduce with time.
- Vibration starts → wear of corona protection → partial discharges → accelerated wearing
- Eventually an earth fault occurs → damages on stator bars, in worst case also core.
- Diagnostics performed at MO or on-line can identify the failure mode. It can not be detected at LI or SC.

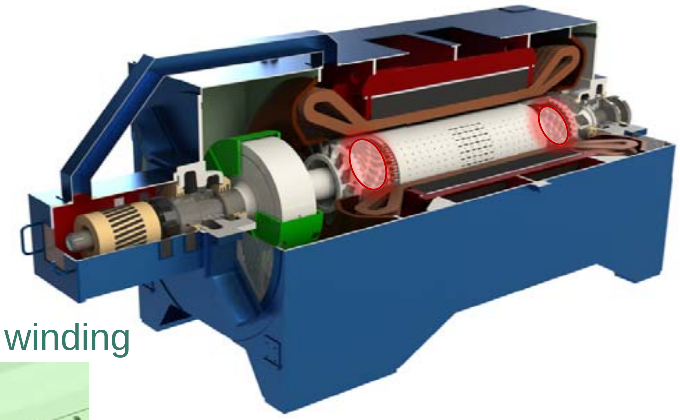




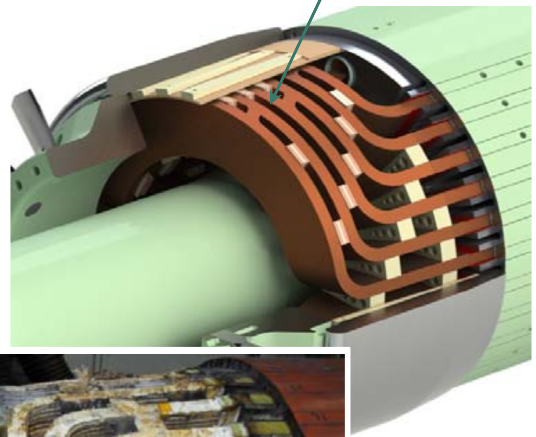
Insulation dust from partial discharges

Example:
Turn-to-turn short circuits of rotor coils

- Start/stop cycling leads with time to elongation of rotor coil ends.
- Elongation can for instance lead to:
  - Turn-to-turn shorts → vibrations
  - Broken winding → earth faults
- Both problems eventually lead to outage and repair of rotor.
- Failure mode can be identified using RSO at standstill (SC, LI or MO).
- At MO it is recommended to install RFM for detecting turn-to-turn shorts during operation.



End winding



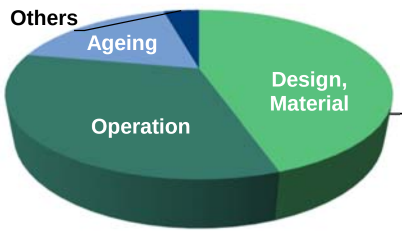
Elongation of coils

Summary

- Approximately 100 fault modes have been identified for a turbogenerator
- Ability to detect failure modes at different inspection levels have been mapped.
- Risk level in 4 steps are defined.
- Diagnostic results from electrical tests and visual inspections are weighted together with operation history, design weaknesses and planned operation.
- The results of the analysis are presented in a report where each component is classified by risk. The highest component risk gives the generator risk.
- The first page of the report shows summary with total risk as well as recommendations for reducing risk levels.
- The methodology can also be applied to other parts of the plant, such as turbine, gear box or transformer.

Summary of Generator diagnostics

Operation disturbance statistics

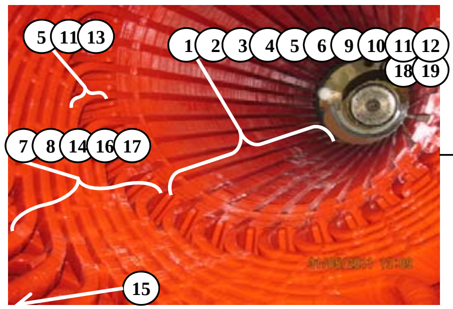


Historical and operational data

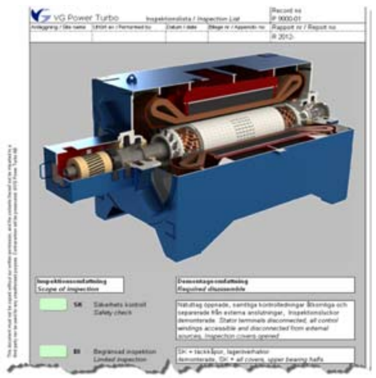
Operation data	
Op. type: Continuous	Env: Paper mill
Op. hours: 175000	Starts: 975
In op. since: 1977	
Maintenance history:	
Stators rewound 1998 by ABB	
Exciter rewound 1988 by ABB	
Rotors rewound 1995 by ABB	

Specific failure modes

Engineering competence and own experiences



Tailor made diagnostics program



Inspection, prel. analysis, evaluation against criteria

Oper. data Deviations

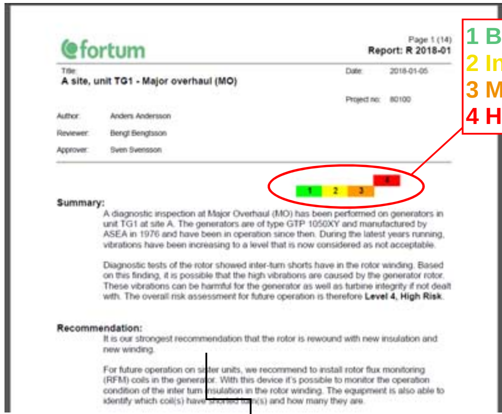
Visual inspection

Mechanical inspection

Electrical testing

Report with Risk classification

per component and unit



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Report: R 2018-01

Title: **A site, unit TG1 - Major overhaul (MO)**

Date: 2018-01-05

Project no: 80100

Author: Anders Andersson

Reviewer: Bengt Bengtsson

Approver: Sven Svensson

Summary:

A diagnostic inspection at Major Overhaul (MO) has been performed on generators in unit TG1 at site A. The generators are of type GTP 1050XY and manufactured by ASEA in 1976 and have been in operation since then. During the latest years running, vibrations have been increasing to a level that is now considered as not acceptable.

Diagnostic tests of the rotor showed inter-turn shorts have in the rotor winding. Based on this finding, it is possible that the high vibrations are caused by the generator rotor. These vibrations can be harmful for the generator as well as turbine integrity if not dealt with. The overall risk assessment for future operation is therefore **Level 4, High Risk**.

Recommendation:

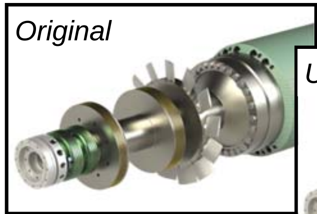
It is our strongest recommendation that the rotor is rewound with new insulation and new winding.

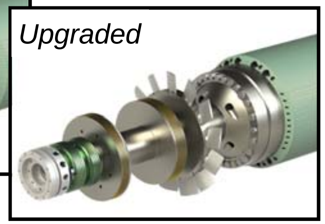
For future operation on sister units, we recommend to install rotor flux monitoring (RFM) coils in the generator. With this device it's possible to monitor the operation condition of the inter turn insulation in the rotor winding. The equipment is also able to identify which coil(s) have shorted turn(s) and how many they are.

1 Base risk
2 Increasing risk
3 Medium high risk
4 High risk

Recommendations for <u>Risk reduction</u>

and suggestions for Service and Retrofit products





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Life time assessments using failure mode concept

Life Time Assessment (LTA)

- What is the life time? The generator does not have a life and therefore no life time.
- The life time for a generator is when the function does not fulfill the economic expectations in terms of power output capacity, availability and maintenability.

- A life time assessment consist of:
  1. A desk top study based on history, operational data and design solutions
  2. Taylor made diagnostics, usually as an extension of a major overhaul
  3. Evaluation of collected data and analysis against planned future operation, resulting in a report with recommendations and their effect on risk reduction.

A Major Overhaul looks forward to the next MO.

A Lifetime Assessment looks forward as far as the plant is planned to run.

Example of Life Time Assessment using failure mode concept

- Generator
  - Type: ASEA GTL
  - Delivered: 1980ies
  - Power: 100 MVA, cosphi 0.85
  - Op. time: ~250’000 hours
  - Starts: ~500

  } AOH*) ~= 260’000

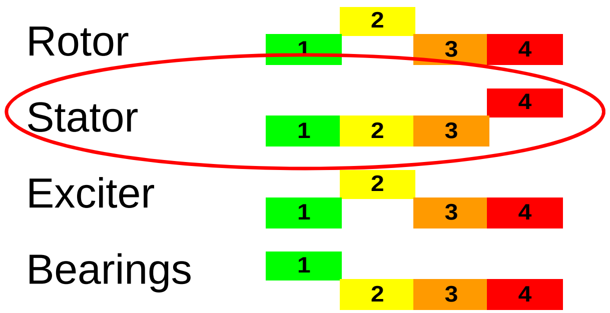
  - Operation: continuous, ~5000 hours/year

- Assignment: Perform life time assessment for future operation of 85’000 hours.

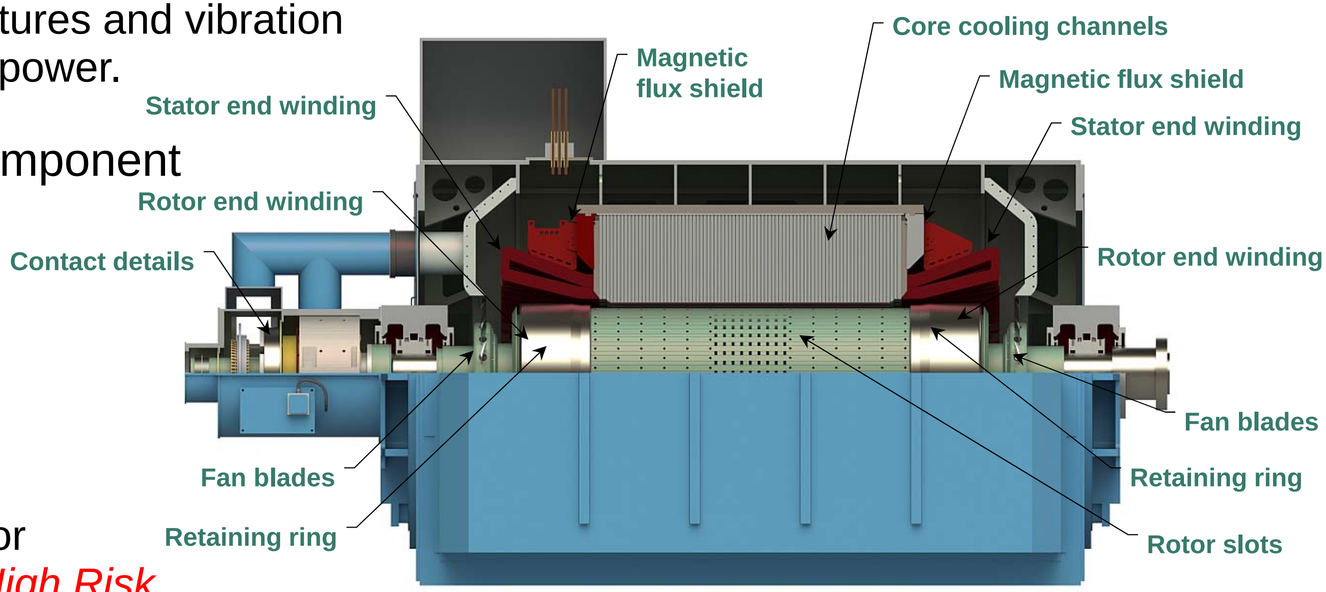
*) Adjusted operation hours (AOH) =
Actual hours + Number of starts x 20 hours

Life Time Assessment, phase 1: Desktop study

- Collection of historic data ~1980 – 2016.
  - Interviews with key personnel from maintenance department
  - Review of inspection reports in archive at site
  - Analysis of operation data vs temperatures and vibration over time and compared to generator power.
- Analysis and risk assessment per component
  - Rotor
  - Stator
  - Exciter
  - Bearings



  - The total risk equals the highest risk for individual components, here level 4, *High Risk*.
- Recommendations for further investigations, Phase 2.



Potential weak areas ASEA/ABB GTL-type

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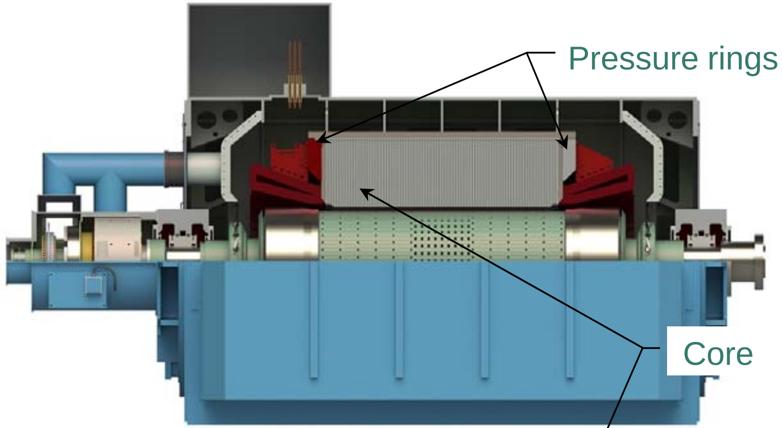
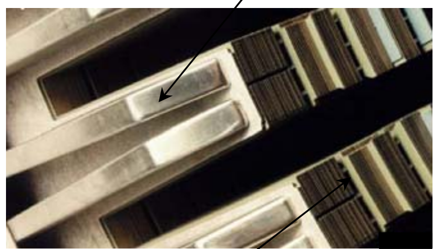
Details of phase 1 - Analysis of stator core

- Stator core built up of laminations, assembled segment by segment.
- Channels for cooling air flow placed periodically to lead away hot air from rotor and to cool the stator.
- Generator designed with pressed ”warts” out of core sheets in order to form cooling channels.
- Warts collapse → low pressure → vibration damages and less cooling.
- Recommendations
  - Design testing equipment to quantify looseness in core
  - Update risk analysis and propose solutions





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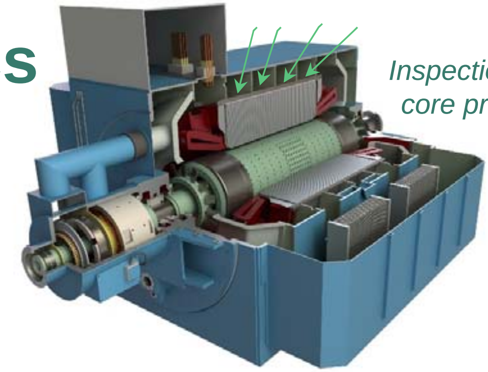
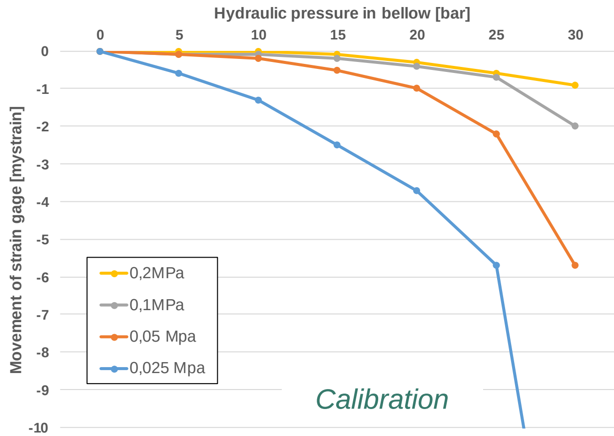
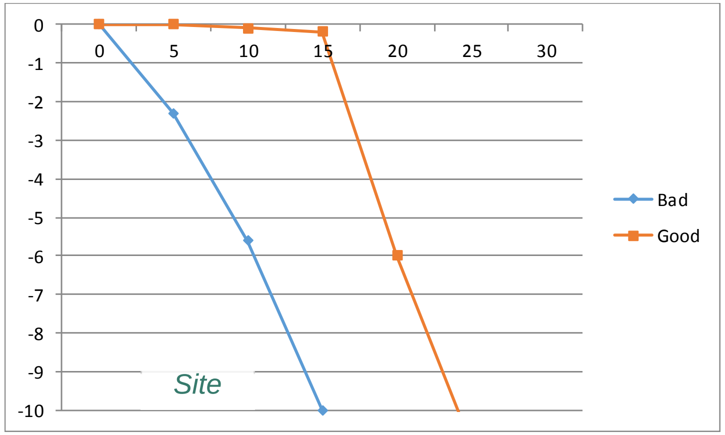
Phase 2: Major Overhaul + Tailor made diagnostics
Test of core pressure



Inspection plan core pressure

- A newly built core has a pressure of 1 MPa, for ASEA design.
- After initial settlement it will be less.
- Experience say that >=0.1 MPa is acceptable.
- Test equipment consisting of pressure bellow and movement detector calibrated at pressure 0.025 – 0.2 MPA.
- Tests at site, see example
- Over all result gave core pressure assessed to be << 0.1 MPa





Movement detector

Pressure bellow

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Life Time Assessment, phase 3: Update of risk assessment

- There are deviations in the stator winding, but the most serious problems are in the stator core due to very low core pressure.
- Assessment is that the stator is at level 4, ***High risk***.
- Overall conclusion for the stator is that the desired operation, 85'000 hours, will most likely not be possible to reach.

- To reduce the risk to acceptable level, a new core is needed and a new winding.
- Recommendation was to purchase a new stator.
- Customer decided to replace the complete generator with a new one.

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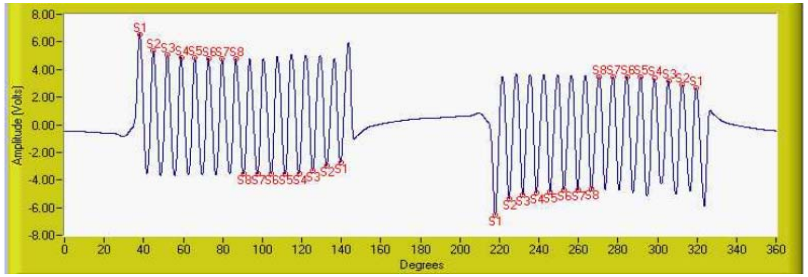
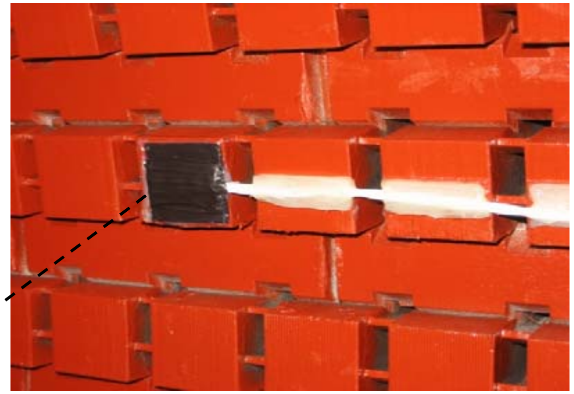
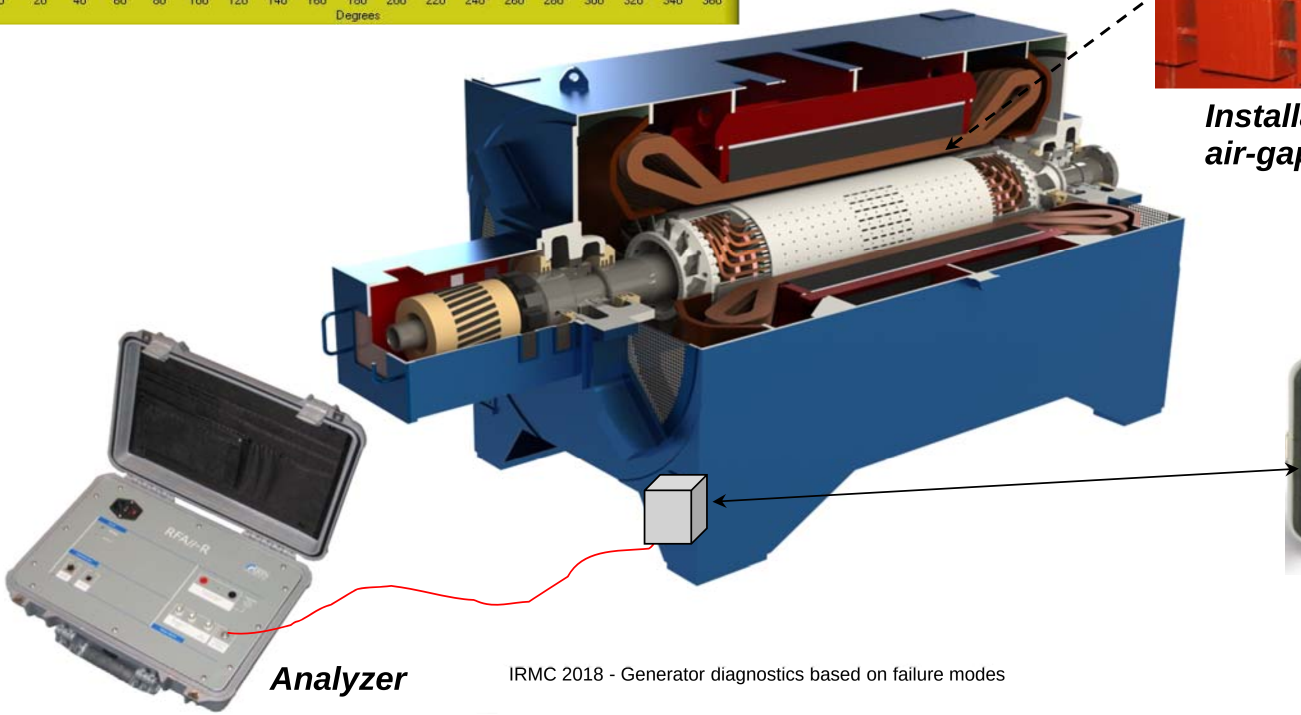
Example of installation for monitoring the rotor

Example of RFM measurement on-line





Installation of RFM sensor on air-gap side of stator core

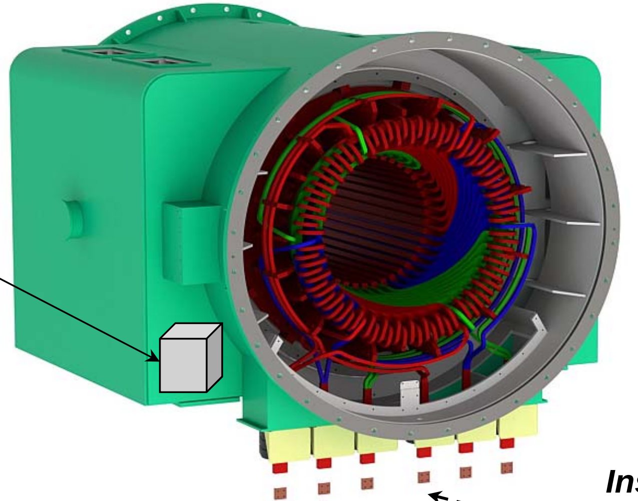


Analyzer

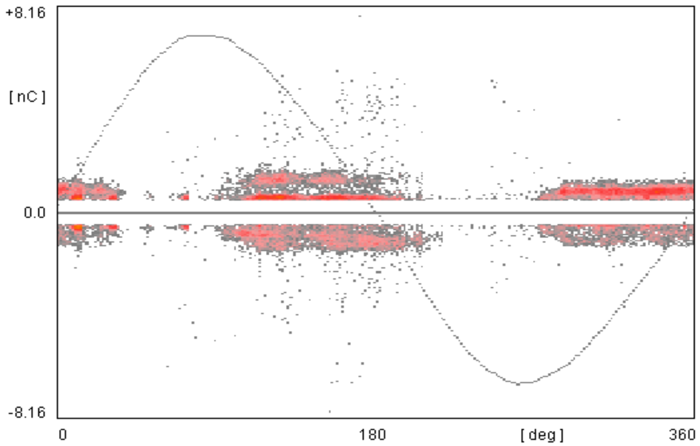
Connection box

Example of installation for monitoring the stator

Connection box



Example of PD measurement on-line



Installation of PD couplers