Generator Maintenance
6B User Conference

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Agenda

Fleet Trends & Lifecycle Considerations
Generator Maintenance GEK 103566
Robotic Inspections
Generator Monitoring
Fleet Trends & Lifecycle Considerations
Generator lifecycle considerations

Cyclic operation
- Additional stresses
- Increased FO risk
- Increased probability of rewind

Historically, rewind risk increases
- 15-20 years of age for rotor
- 25-30 years of age for stator

Rotor Findings – All OEMs
1. Blocked Ventilation
2. Shorted Turns
3. Insulation migration

Stator Findings – All OEMs
1. Mech Wear End Winding Shorts
2. Mech Wear on Bars (loose slot)
3. Insulation Degradation
Combining GE with Alstom

- Added Low Oxygen Stator Cooling Water System recommendations
- Combined Stator and Rotor Test and Inspections
- Added retaining ring and “when to remove rotor” recommendations
- Updated rotor life management recommendations

Terminology changes:

- 1st Year Inspection (Major Scope) → First Inspection
- Minor inspection/inspection A → Borescope inspection
- Major inspection/inspection B → Robotic inspection
- MAGIC*/DIRIS* → Robotics

Borescope inspection:

- Visual inspection through the end shields or cooler(s)
- Electrical tests per Tables 3 → 5

Robotic inspection:

- Rotor In-Situ inspection via robotics
- Stator and rotor tests and inspections per Tables 3 → 5

Remove Rotor only for Repairs, NOT Inspections

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GEK 103566 – Creating an effective generator maintenance program

Revision L - Rotor removal recommendations

<table>
<thead>
<tr>
<th>Events or trends predicating rotor removal</th>
<th>Required maintenance or repair activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal operating events as listed in Section 2: Maintenance Planning</td>
<td>Rotor tooth and wedge inspection and repair to remove hardened material</td>
</tr>
<tr>
<td>Rotor vibration trends coupled with flux probe shorted turns or blocked ventilation passages</td>
<td>Rings off cleaning up to field rewind</td>
</tr>
<tr>
<td>Stator wedge looseness trends</td>
<td>Partial or full stator re-wedge, retighten</td>
</tr>
<tr>
<td>Air gap foreign object damage</td>
<td>Core or wedge repair</td>
</tr>
<tr>
<td>Stator winding insulation degradation indicated through DC leakage or Partial Discharge trending</td>
<td>Partial or Full stator rewind</td>
</tr>
</tbody>
</table>

Driving towards online trending, in-situ testing and inspection and rotor removal for repair purposes

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GEK 103566 – Creating an effective generator maintenance program

Revision L updates – Inspection and maintenance intervals examples

<table>
<thead>
<tr>
<th></th>
<th>8K</th>
<th>32k</th>
<th>64k</th>
<th>96k</th>
<th>128k</th>
<th>160k</th>
<th>184k</th>
<th>208k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factored or Actual Turbine hours (hrs.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gen Insp Type</td>
<td>1st</td>
<td>Robotic</td>
<td>Borescope</td>
<td>Robotic</td>
<td>Borescope</td>
<td>Robotic</td>
<td>Robotic</td>
<td>Robotic</td>
</tr>
<tr>
<td>Expected Interval for 6K hrs per year units</td>
<td>≤18 months</td>
<td>5 yrs.</td>
<td>10 yrs.</td>
<td>16 yrs.</td>
<td>21 yrs.</td>
<td>26 yrs.</td>
<td>30 yrs.</td>
<td>34 yrs.</td>
</tr>
</tbody>
</table>

For this specific example, it is assumed that the turbine generator inspection and maintenance interval is determined by factored hours or actual hours, typical of a unit that is operating over 6000 hours per year.

Consult the appropriate maintenance and inspection manual for interval guidance. This example is meant to demonstrate how generator inspection and maintenance intervals would be synchronized for a gas turbine with the referenced intervals.
Robotic Inspections
Robotic inspection by generator model

**Types of robotic inspections:**
- In situ air gap inspections
- In situ retaining ring inspections
- Wedge tapping

<table>
<thead>
<tr>
<th>Generator Model</th>
<th>Robot Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>6A2</td>
<td>✓</td>
</tr>
<tr>
<td>6A3</td>
<td>✓*</td>
</tr>
<tr>
<td>6A6</td>
<td>✓</td>
</tr>
<tr>
<td>T214-234</td>
<td>✓</td>
</tr>
</tbody>
</table>

* Depends on entrance gap
In-situ (air gap) inspection

**GE offers fast and reliable inspection of the generator without the need to pull the rotor out (OEM and OOEM)**

1. Robotic visual inspection (via air gap)
2. Robotic low flux/EL-CID
3. Robotic slot wedging tightness test
4. HV tests
5. Brush gear inspection
6. Partial visual inspection (end winding)
7. Insulation resistance measurement
8. Rotor inter turn short circuit detection (optional on legacy GE)
9. Instrumentation check
10. Bump test (optional)

### Customer benefits

- Up to 40% time saving compared to conventional inspection with rotor out
- Reduced costs by keeping rotor in, simplify crane support and lay down space
- Reduced risk during overhauls due to reduced dismantling
- More accurate and reproducible assessments
- Faster return to grid without sacrificing safety and quality
- Supports condition-based maintenance program development

### Retaining ring scanner

18-5 Retaining Rings:
- Visual at the borescope inspection
- NDT at the robotic inspection

### Air gap robots

18-18 Retaining Rings:
- ID inspected each time they are removed
- NDT
  - Prior to 30 years of service or 10K start\|\starts
  - Then every 10 years after or 2K start\|\starts

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Can my RR be tested

**Information required for applicability check:**
- Ring nose to stator distance
- Nose angle
- Position of the bearing block
- Diameter of the ring
- Length of the ring
- Ring material
- Type of fit
- Cross sectional drawing (1/2 day of measurement)
- Any dowels or pins

**A few figures:**
- Theoretical RR range: Dia: 620mm to 1300mm Len: >900mm
- Inspection duration: 2-3 shifts (1 Inspector + 1 Helper)
- Rotor in or out
- Over 200 rings inspected
Wedge tapping and Wedge inspection test system (WITS)*

- Applicable to units with a Conformal wedging System
- Methods including acoustic tapping and hardness measurement rely on very low force applied to the wedge surface
- The resulting response is different for a tight wedge vs. a loose wedge
- These methods are very sensitive but prone to variation due to wedge surface condition, oil, grease, and paint

- Applicable to units with Top Ripple Springs (TRS)
- WITS applies a load large enough to deflect the wedge and compress the TRS
- It is not sensitive to the surface conditions of the wedge
- The load of the TRS on the wedge is determined precisely and repeatable

Anvil: Applies and measures load on wedge

Induction Sensors: Measure Deflection to 0.001”

Available for 6A3, 6A6, 6FA, 7A6, 7FH2/B, 9A5, 9H2, 324, 330H, 450H, SPL-LW and oOEM
Case study – Generator rewind based on robotic findings

• A 2016 robotic inspection included a partial stator slot wedge tightness check, an ELCID test and a visual inspection on; the field parts, the stator core, field/stator windings

• Wedge tightness check showed slot wedges in good condition

• Visual showed some FOD impact to core by ELCID <50mA – good condition

• Minor dusting in stator

• One main lead terminal stud was found with 4 broken leaves

• Several slots were found with moved springs and nearly closed vent holes. The closed vent ducts could have been a possible reason for the field to be thermal sensitive
Borescope inspection – End windings and core

Don’t forget the electrical testing
Generator Monitoring
Generator health monitoring

- Partial discharge
- Rotor flux
- Rotor shaft voltage
- End winding vibration
- Stator temperature
- Collector health*
- Stator leakage*

Moving to condition-based maintenance

* Stand alone, check for applicability

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Generator health monitoring

**L1 Sensors**
PERMANENTLY INSTALLED, INCLUDING CABLELING & CONNECTION BOXES (GE OR MOST THIRD PARTY)

**L2 GOLD* Service**
- Portable DAU
- Site visit twice a year
- Report on collected data

**L3 Service**
- Permanently installed DAU
- Half yearly full report

**L4 Remote Service**
- Permanently installed DAU
- Permanent data link & storage
- Weekly checks
- Quarterly full report

**Periodical Monitoring**

**Continuous Monitoring**

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GHM - Rotor Flux

**Sensors**
- Rod-type probe
- Wedge mounted flip-up probe
- Wedge mounted pop-up probe

**Monitoring**
- Rotor inter-turn short circuits
- Accurate identification of effected slot
- Magnitude of fault
- Trend deterioration

**Identification of**
- Electrical breakdown of inter-turn insulation
- Mechanical breakdown of inter-turn insulation
- Carbon and oil contamination of windings
- Copper dusting due to excessive barring
- Turn to turn contact due to coil shorting, distortion or elongation
Success story

Location: Europe
Type: STG

Remote Monitoring Scope
- Weekly generator health checks
- Quarterly reports
- Data hosting

Benefits
- Early fault detection
  Controlled operation to limit deterioration
- No forced outage, ensured availability
  No profit loss
- No additional downtime, repair during planned outage
GHM – Partial discharge

**Sensors**
- Capacitive bus couplers
- Low frequency 9 nF sensors
- 1 Per phase + 1 at neutral point

**Monitoring**
- Slot PD
- Void/delamination PD
- Surface PD
- Phase to phase PD
- Vibration sparking
- Partial discharge location

**Identification of**
- Stator bar insulation condition
  - Aging of insulation
  - Semi-conductive coating deterioration
- Loose stator bars
- Generator contamination
Success story

Background

**Air Cooled Unit**

**Partial Discharge Monitoring**

Analysis conducted using the phase bus sensors and neutral point sensor
- Turbo generator constructed in 1994
- Rated output: 250 MVA
- Rated voltage: 15 kV
- Rated frequency: 50 Hz
- Coolant: Air

**Scope**
- Online PD monitoring installed to monitor the bar condition to prevent unplanned failures
- Interim reporting on site and final reporting with rend analysis from Engineering

GE Solution

**Online conditions:**

**Measurements taken**
- Patterns show slot discharges which have been present since the first online PD measurement (characteristic asymmetry)
- Amplitudes have been gradually increasing over time

**Offline conditions:**
- Removed stator bars show clearly the damage resulting from strong slot PD

Generator was taken out of service for corrective action (rewind).
Preventing an in-service failure and downtime
GHM – Collector health monitor

**Sensors**
- A passive system; detecting RF signatures on the collector through CT sensors
- On-line continuous measurement at a sampling rate of 1Mhz

**Monitoring**
- Applicable to all generators with a collector and brush assembly and an EX-series exciter with a shaft voltage suppressor – EX2000, EX2100, EX2100e
- Milliamp variation in excitation current
- Disruption of current flowing from the collector brushes to the collector rings
- Adjustable alarm outputs configured for 20% and 80% spark rate over the last 1 minute of data collection

**Identification of**
- It is continuously calculating a Spark Rate – which is a measure of the energy discharge or sparks happening over a certain time period (one minute)
- Sparking which is correlated to collector ring flashover
Success story

5% Spark Rate over a 3-hour period on month 1

Deep dive of data found a spike 10X of the threshold on month 2

- Site had an outage in month 3 and was instructed to closely inspect the collector/brush assembly
- A brush was found that was heavily worn and the brush holder appeared to, at some point, have carried current
- The collector surface was found to have salt deposits and corrosion
Borescope inspection quality
Questions?