Water-Cooled Stator Windings

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Water-cooled Stator Windings

- Stator Winding Design Considerations
- Service Considerations
- Stator Water Chemistry
- Monitoring and Preventing Flow Restrictions
- Removing Copper Oxide Buildups
- Conclusion
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Importance of Water Cooling

- First oil-cooled generators in 1954
- Almost immediately changed to water as coolant
- With water cooling came copper oxide issues
Effects of Restrictions of Loss of Water Flow

- Temperature limit to prevent boiling water
- Steam could block water flow
- Damage to bar consequence of overheating
- Severe damage to generator possible
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Monitoring, in General

- Copper oxide buildup cannot be directly monitored
- Migrating oxides are caught in filters raise concern on bars
- Flow and dp
- Indirect monitoring of water flow in each bar via TC
- Slot RTD very indirect and insensitive
Industry Experience

• Copper oxide buildup rather common
• Actual winding failure rare
  – Windings designed with high temperature margin?
  – Monitoring does provide early warning?
  – Cleaning capability readily available
  – Failure mode similar to other causes of winding failure?
• Stainless steel hollow conductors eliminate copper oxides
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Water Oxygen Content

- Copper in water is prone to oxidation
- Stable with very low or saturated oxygen content
- Intermediate oxygen contents cause problems
Alkaline Chemistry

• Increased pH can help stabilize the oxide layer
• Buffers effects of oxygen excursions
• Requires additional subsystem to inject NaOH
• Needs extra attention from chemist
Conversion Between Regimes

• All regimes have advantages, all can have problems
• Changing chemistry challenges oxide layer stability
• Changing regimes needs to be carefully evaluated
• Usually not recommended
Plugging With Copper Oxides

Plugging mechanism
1. Oxidation
2. Release
3. Migration
4. Deposition
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Oxide Formation

- Normal uniformly distributed oxidation no problem
- Changes in chemistry can mobilize oxides
- Flow restrictions can manifest externally
- Once visible, condition usually in advanced stage
- Can lead to plugging and winding failure
- Plugging normally not uniform, better visible in individual bar monitoring
Monitoring and Assessing Oxide Buildup

- Generator history / fleet comparison
- Visual inspections
- Physical parameters
  - Temperatures
  - Stator cooling water flow and pressure drop
- Chemical parameters
  - Copper release rate
  - Dissolved oxygen (dO)
  - Electrochemical corrosion potential (ECP)
Preventing Copper Oxide Flow Restrictions

• Every machine is different
• Best way to prevent problems is to follow guidelines
• Intervene early in case of deviations
• The following rules can help with reliable operation
General Precautions

• Keep conditions stable and within prescribed range
• Keep conductivity low
• Minimize leaks
  – Gas-to-water leaks
  – Water leaks
• Minimize make-up consumption
• Follow proper layup procedures
Examples of Case-Specific Plugging

- Control hydrogen purity and gas-to-water leaks
  - Impurities in hydrogen enough to affect dO
  - Fixing leaks and hydrogen purity solved problem
- Ensure proper operation of tank aeration
  - Vent line was malfunctioning, starving system of oxygen
  - SLMS restored high-oxygen conditions
- Minimize water losses
  - Water was lost through the gas vent line
  - Oxygenated make-up caused excessive oxidation
  - Expansion tank in line allows water to remain in system
Examples of Case-Specific Plugging

• Dry stator thoroughly during outages
  – Improper layup during several outages caused oxide plugging
  – Stator was only partially drained and not dried

• All of these examples required chemical cleaning
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Removing Copper Oxide Buildups

- Finding and eliminating root cause most important
- Slow down / reverse oxide buildup if possible
- Chemical cleaning is a reliable method to remove oxides
- Once completely plugged, chemical methods ineffective
Mechanical Cleaning

- Only removes oxides locally
- Can open completely blocked hollow conductors
- Requires varying degrees of access to water box
- Common methods:
  - Hot reverse flush
  - Scraping with brushes or wires
Chemical Cleaning

- Can remove all oxides from system
- Carries risks if done incorrectly
- Acid cleaning oldest method in use
  - Attacks copper and brazes as well as oxides
  - Number of applications limited
- EDTA cleaning more modern approach
  - Only removes copper oxides, no system materials
  - Can be applied during operation and outages
- Chemical cleaning requires expert know-how to minimize risks and ensure effectiveness
Best Practice

- Identify and eliminate root cause
- Carry out coordinated EDTA cleaning
- If completely blocked hollow conductors present:
  - Combined mechanical and chemical cleaning
- Proactive approach contains and eliminates problem
- Preventive maintenance cleaning, depending on
  - Age of machine
  - Machine history
  - Importance of availability
  - Routine schedule
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Conclusion

• Numerous problems in operation and maintenance
• This paper focuses on providing basic design, operation and maintenance information
• Plant personnel should pay close attention to OEM operating instructions
• Close attention to monitoring systems
• Early corrective action may prevent costly outages
• Scope of potential problems and root causes wide
  – Advisable to obtain expert technical service from OEM or other sources