



# 2026 International Conference of Doble Clients

Recommendations for a Successful Internal Inspection  
or Repair

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Tri-State Generation and Transmission

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Boston, Massachusetts USA



# TRI-STATE GENERATION & TRANSMISSION ASSOCIATION, INC.

- Member owned, not-for-profit bulk electric provider in the west
- Owned by 40 rural cooperatives
- 1M users across 200,000 square miles
- 4750MW total generation
  - 50% renewables in 2025
- 345, 230, 115, 69kV transmission assets
- 400 substation transformers
- 900 circuit breakers



# AGENDA

- Definitions
- When is the time right?
- Offline testing
- Develop a plan
- Necessary materials
- Safety
- Initial inspection
- Detailed inspection
- Post-inspection considerations and planning
- Take-aways

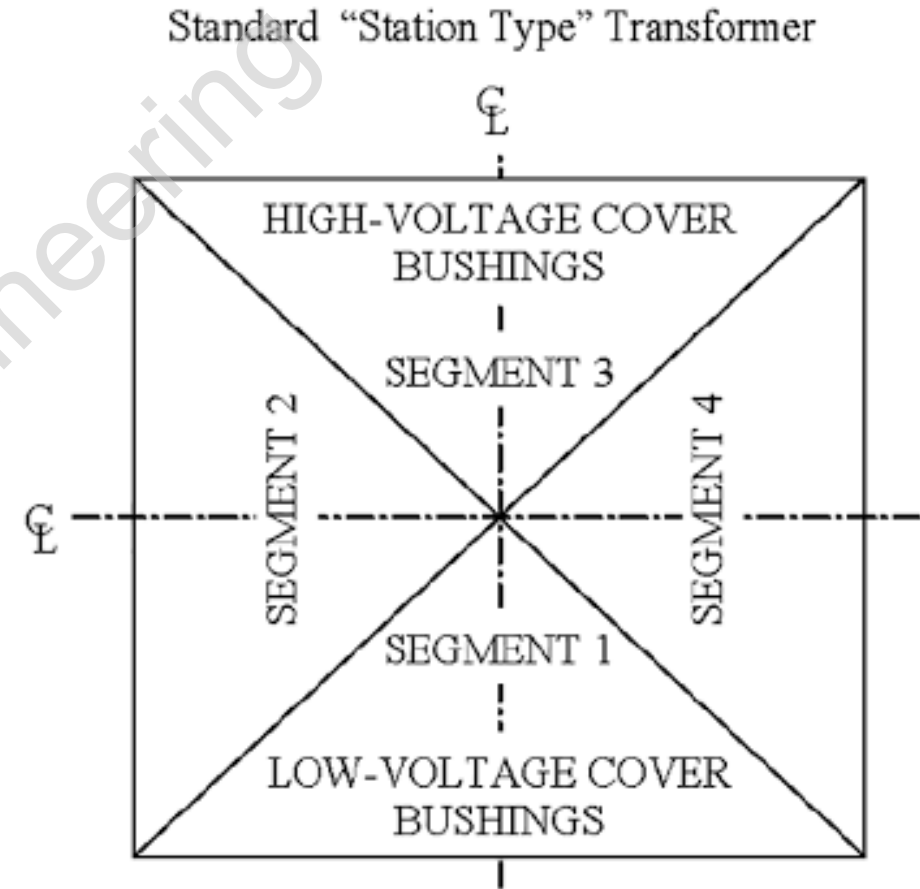
# DEFINITIONS

- **Internal inspection**
  - Inspection inside of a normally oil filled tank
- **Inspection with coils under oil**
  - An inspection that occurs with a lowered oil level that still covers the coils (windings)
- **LTC internal inspection**
  - Visual assessment of contacts, measurements, and checks inside a drained LTC tank



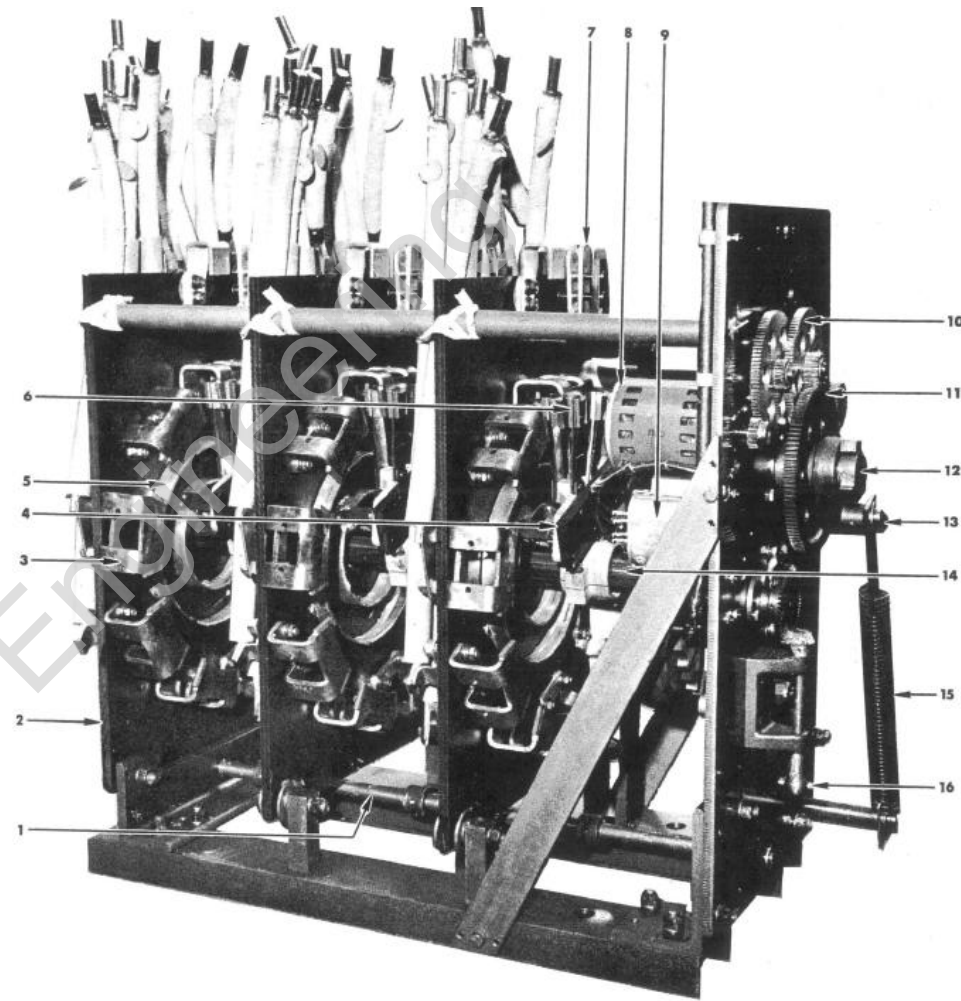
# DEFINITIONS

- **Make sure inspecting team is all using the same terminology for the same components**
- **Transformer specifics:**
  - **Core**
  - **Frame**
  - **Windings**
  - **Phase barriers**
  - **Winding wraps**
  - **Leads**
  - **Segments**



# DEFINITIONS

- **Make sure inspecting team is all using the same terminology for the same components**
- **LTC specifics:**
  - **Phase units**
  - **Selector switches**
  - **Reversing switch**
  - **Diverter/transfer switch**
  - **Vacuum interrupter**
  - **Collector rings and slip contacts**
  - **Barrier board**



1. OPERATING SHAFT FOR REVERSING-TRANSFER SWITCH	9. MOTOR CAPACITOR
2. INSULATING PANEL	10. REDUCTION GEARS
3. STATIONARY CONTACT	11. WINDING GEAR (LOOSE ON SHAFT)
4. MOVABLE CONTACT ASSEMBLY	12. DRIVE SHAFT
5. SLIP RINGS	13. CRANK
6. MOVABLE CONTACT FINGERS	14. MAIN ROTOR SHAFT
7. REVERSING-TRANSFER SWITCH	15. DRIVE SPRING
8. MOTOR	16. POSITION-INDICATOR DRIVE SHAFT

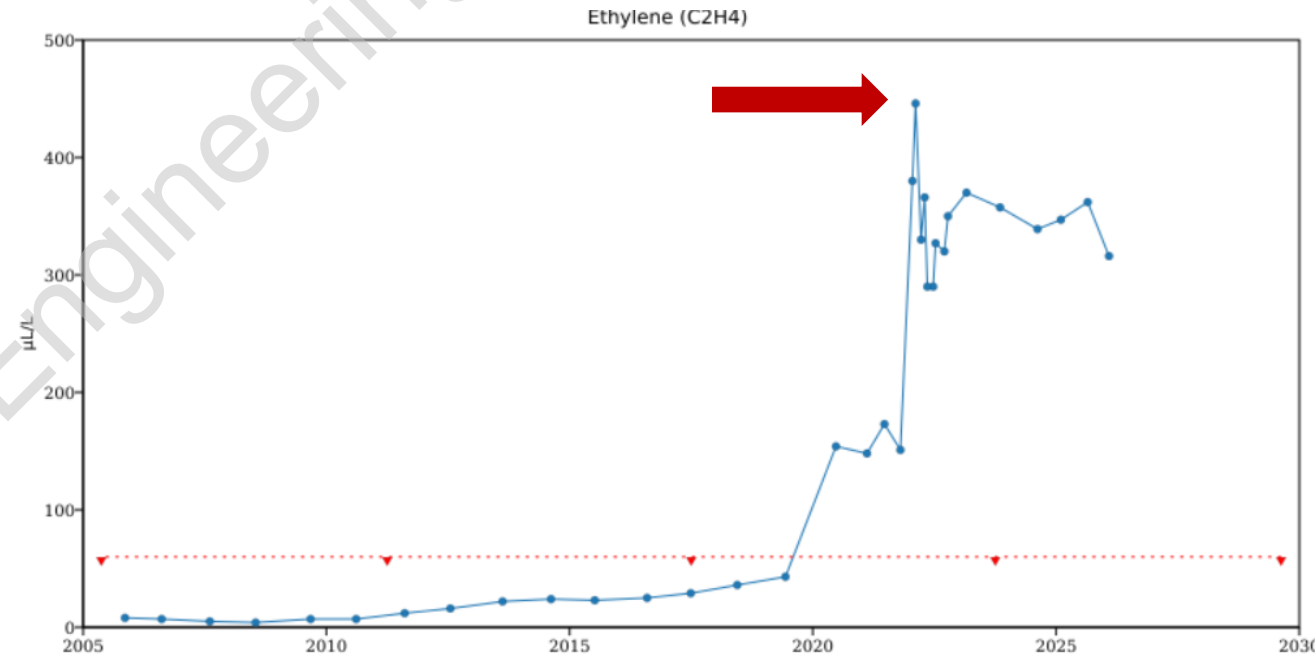
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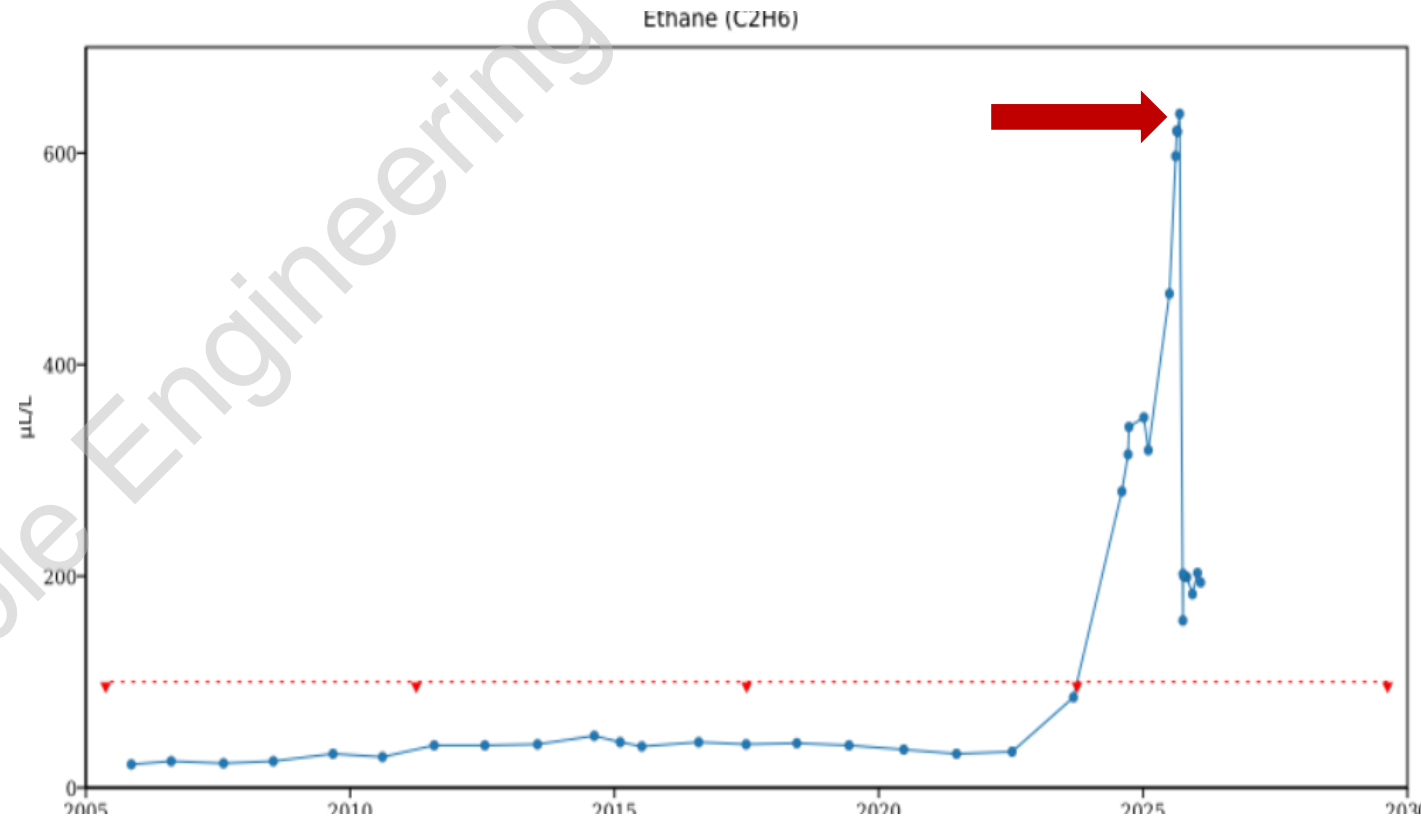
# WHEN IS THE TIME RIGHT?

- **Driven by online assessments (DGA)**
  - **Must confirm bad samples not result of cross contamination**
    - Always resample
    - Does gassing coincide with recent service work?
  - **Need to set up internal inspection for success without assuming too much risk**
  - **May need to let defect progress in order to be find-ably severe**
  - **Best likelihood of finding defect**
    - Set gassing limit based on experiences and acceptable risk
    - More frequent DGA sampling or monitoring



# WHEN IS THE TIME RIGHT?

- Driven by online assessments (DGA)
  - Financial/resource impact of “going in too early”
  - Balancing act
    - Wait for defect to develop to be find-able, don’t wait long enough for defect to result in unacceptable risk or failure
    - Seek second opinions from others with similar equipment or experiences
    - *Someone, somewhere has already made this decision*



# WHEN IS THE TIME RIGHT?

- LTC DGA considerations
  - Inspect LTCs with suspicious gassing when out for normal maintenance/diagnostic inspection anyway
    - Start to build a knowledgebase on what different gas levels mean to different models
  - Save contacts that are removed from overheating concerns, document gas levels
    - Gives a visual indication of gas levels



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# OFFLINE TESTING

- Full set of electrical offline tests once out of service
- Full physical assessment of transformer and/or LTC
- Cast a wide net – defect may have reach to other systems
  - Overall PF/cap
  - Bushing PF/cap
  - Arrester mA/W
  - Excitation (16L to 16R)
  - Ratio (16L to 16R)
  - SFRA
  - Leakage reactance
  - Core ground insulation resistance
  - DC winding resistance

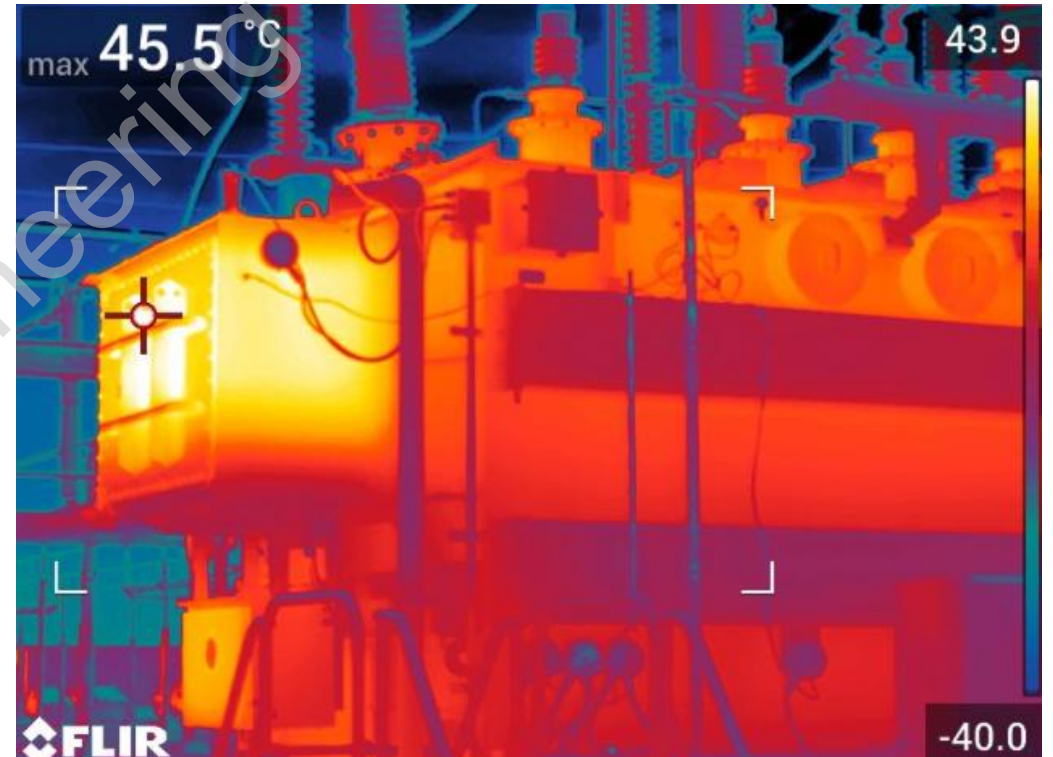
# OFFLINE TESTING

- **Full verification of components**
  - Check alarms and gauges
  - Check fans and pumps
    - Pumps – note any unusual noises or flow indicator activity
- **Thorough physical assessment**
  - Oil levels, physical damage, LTC operation, etc...
  - Safely climb over and under, inspect all aspects



# OFFLINE TESTING

- Evaluate data to find commonality
  - Compare with motivating test – DGA, IR scan, etc...
  - Do electrical test results line up with suspicions from DGA?
    - If no – that’s meaningful!
    - Consider alternative possibilities or severities
  - Seek second opinions



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## DEVELOP A PLAN

- **Create hypothesis and narrative with all available data**
- **Devise multiple options based on likelihood**
- **Inspection first focused on most likely areas**
- **Common points between related test results, conditions, and observations**
  - **Plan to inspect those first**
- **LTC specifics:**
  - **Understand sequence of operation – read and understand instruction manual**
  - **Understand electrical identity of contacts – read and understand nameplate**
  - **Review IR scans of concern (if applicable) and relate to components**

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# NECESSARY MATERIALS

- **Safety materials**
  - **Confined space entry products**
  - **Rescue davit arms, hoists**
  - **Follow all company standards**
- **Lighting**
  - **Battery powered**
  - **2x area lights (light bars or lanterns)**
  - **2x focus lights (pistol style or box style)**
  - **Full second set of charged batteries**
  - **Appropriate chargers ready to go**
  - **Tethers – mule tape and knots**
- **Mirrors**
  - **Small inspection mirrors of various sizes**
  - **Long reach illuminated articulating mirrors**

# NECESSARY MATERIALS

- **Tools**

- **Tethers as practical**
- **Long reach needle nose pliers**
- **Machinists rulers**
  - **3 inch, 6 inch, 24 inch available**
- **Zip lock bags**
- **Magnifying glass**
- **Wooden or rubber mallet**
- **Brass pick set**
- **Soft, flexible solid copper wire**
  - **For probing/reaching**
- **Minor insulation repair kit**
  - **Kraft paper, cloth tape, glyptal, pressboard**
- **Full set of mechanic's hand tools**

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# SAFETY

- **Coordinate confined space entry as required by company rules**
- **Check in with local fire department/EMS**
- **Assign duties prior to entry**
- **Develop plan to rotate duties if prolonged hot/cold exposure**
- **Confirm all employees qualified for assigned duties**
- **Detailed pre-job brief with specific scenarios and responses**
- **Permit/paperwork**
- **Supply of breathable dry air**
- **Atmosphere monitoring and log**
- **If partial oil fill, review engulfment hazards, mitigation, and response**

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# INITIAL INSPECTION

- **What oil level to start with?**
- **Always be aware of combustible headspace**
  - **Purge appropriately with dry air before considering entry**
- **Before opening access hatch:**
  - **Ensure pressure is equalized in tank to ambient**
  - **All tools, hardware, buckets, rags away from hatch flanges**
  - **Empty pockets completely**
  - **Remove all jewelry, watches, rings, hair clips/pins**
  - **Clean all PPE and entry clothing/footwear**



# INITIAL INSPECTION

- Allow open hatch to vent prior to starting atmosphere monitoring
- Prepare tool, fastener, or component log to track materials
- Constant atmospheric monitoring and supply of *breathable* dry air
- Once safe, look inside for obvious, easy to reach defect within arms' reach
- Look inside access hole and evaluate potential foot placement locations
- Once confident, use arm strength to lower feet down onto foothold



# INITIAL INSPECTION

- **“Test then go” concept for weight distribution**
  - **Slowly apply weight to potential support before committing**
  - **Immediately stop upon movement or cracking sensation**
- **Good body support locations:**
  - **Frame**
  - **Painted steel**
- **Think two steps ahead prior to moving legs or arms**
  - **Can get bent into challenging positions**
- **Avoid moving or pulling limbs roughly against winding or lead insulation**



# INITIAL INSPECTION

- **Potential movement strategies for particularly tight areas:**
  - Prone and wiggle
  - Lay on back and shrug
  - Hands-over-head and pull
- **Rely on topside attendant to monitor body placement**
  - “what is my foot on right now?”
- **Mobile transformers and small units:**
  - Accept limitations of tank size
  - Use of long-reach large inspection mirrors



# INITIAL INSPECTION

- Inspect in a deliberate and planned manner
- From cardinal direction or physical location (East or segment 2) begin inspecting one phase at a time from atop the frame with flashlight



# INITIAL INSPECTION

- **From cardinal direction or physical location (East or segment 2) begin inspecting one phase at a time from atop the frame with flashlight**
  - **Start at bushing bottom terminal or highest visible point of draw lead, follow leads down into windings**
  - **DETC connections**
  - **In-tank LTC outer drum and connections**
  - **Look down adjacent tank wall to bottom of tank**
  - **Adjacent areas of the top cover**
  - **Core and frame**
  - **Wooden cleat and lead structures**
- **Repeat on next two phases**

# INITIAL INSPECTION

- Defect found from the “top of core and coils” inspection?
  - Does it align with data and one of the likely hypotheses?
  - Yes or no, document fully
    - Photos
    - Voice description transcribed in detail by topside attendant
    - Measure defect size and location relative to major components



# INITIAL INSPECTION

- **Is the defect repairable?**
  - Evaluate onsite capability and knowledge
- **If windings submerged and repairs possible**
  - Put sheets of bubble wrap under the impacted area
    - Will float on oil
    - Catch accidentally dropped hardware, debris, or tools.



# INITIAL INSPECTION

- **If no defects found, proceed to detailed inspection**
  - **Consider detailed inspection regardless**
  - **Additional time and resources may not be much more**
    - **Exception – defect found during inspection with windings submerged**
  - **Extra information may help with justifying replacement if defect goes undiscovered or if additional defects found**



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# POST INSPECTION CONSIDERATIONS AND PLANNING

- **Same full set of electrical tests after filling**
  - **If defect was repaired, do results support that?**
- **Expected response in test results if issue resolved or not resolved**
- **Path forward – if no findings, condition needs to become more severe in test results prior to second attempt. Recommend at least 2x worse schedule, 3x worse as soon as possible.**
- **Document findings, path forward in simple report with photos and clear action points for future reference – may be years away**

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## TAKE-AWAYS

- **Observe defect via DGA of increasing frequency, take out of service when the likelihood of discovering defect is high**
  - **Balance with risk**
  - **Use previous experience and fleet specifics**
- **Use offline test results and DGA data to create hypotheses of decreasing likelihood prior to entering tank**
- **Inspect in a planned and methodical manner**
- **Don't be rushed**

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# QUESTIONS

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