Lessons Learned From Generator Destructive Testing

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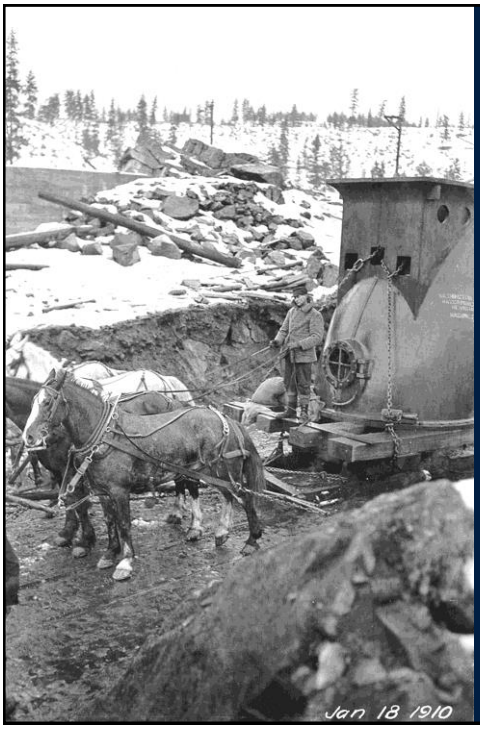
Overview

- History and introduction to Little Falls
- Generator winding layout and fault survey
- Test setup and fault switch requirements
- Test results
- Conclusion

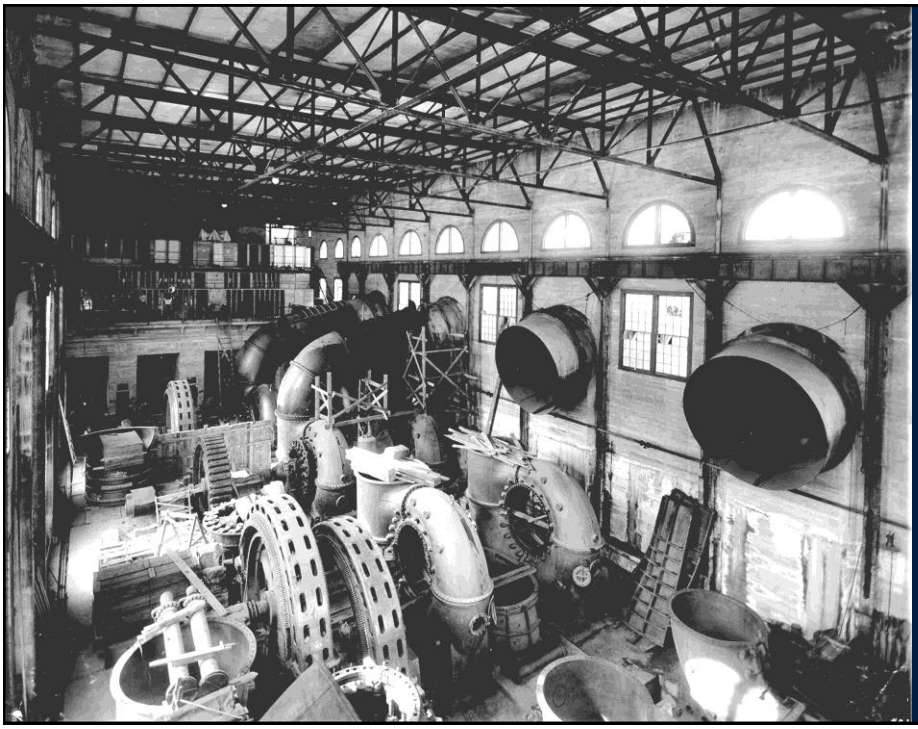
Little Falls Generation Station

Construction of Little Falls Generation Station (Feb. 17, 1910)



Turbine Housing Transported by Horse-Drawn Sled (Jan. 18, 1910)

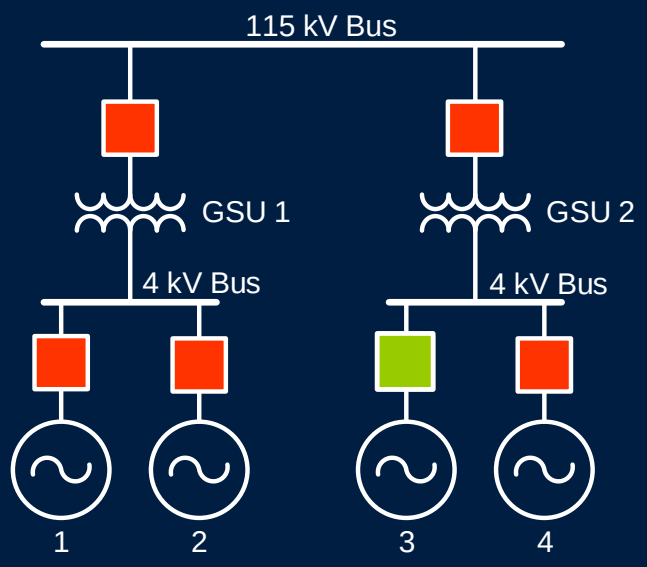
Francis Turbine Delivered by Tractor (April 28, 1910)



Turbine Hall Under Construction (1910)

Little Falls Turbine and Generator Hall

Little Falls Generation System



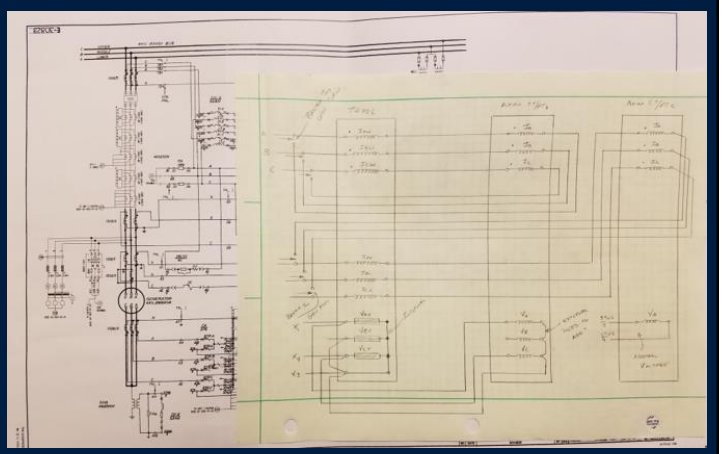
Planning Process

Joint Meetings

- Iterative/collaborative
- Stakeholders from within Avista: technicians, electricians, and engineers

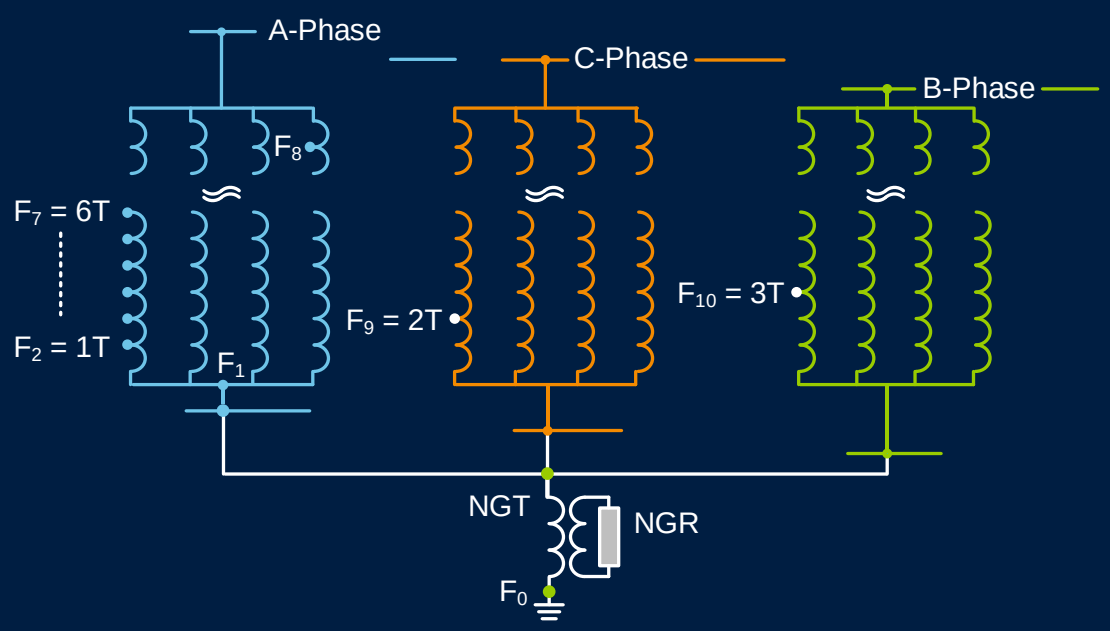
Test Plan

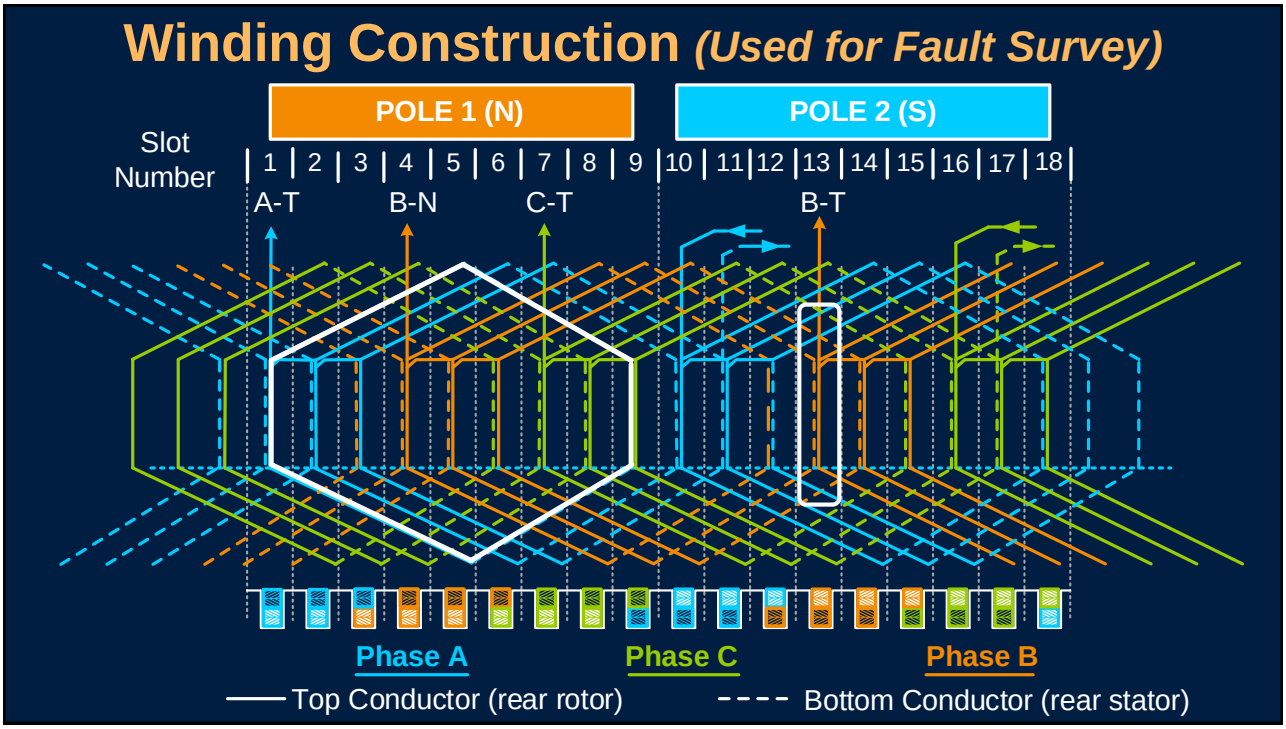
- Detailed test setup
- Drawing markups
- Procedure for placing each fault with diagrams of windings
- Focus on safety

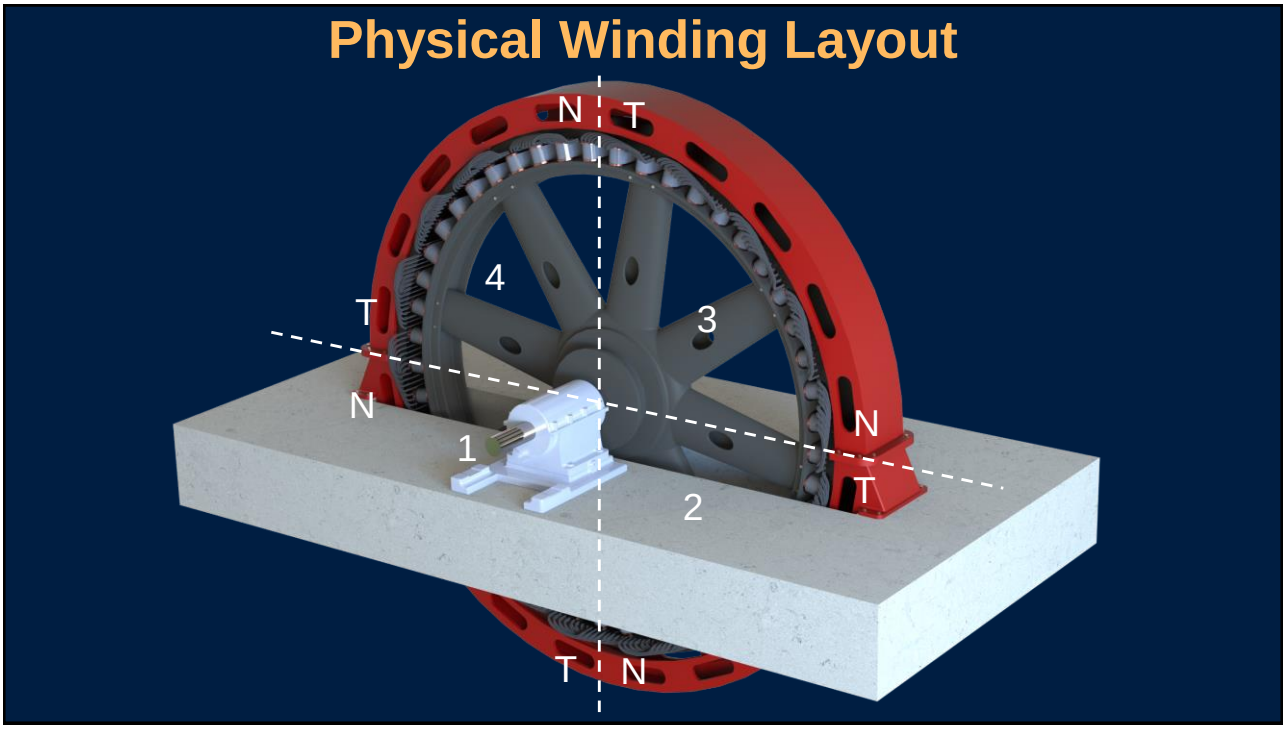


Generator Winding Layout

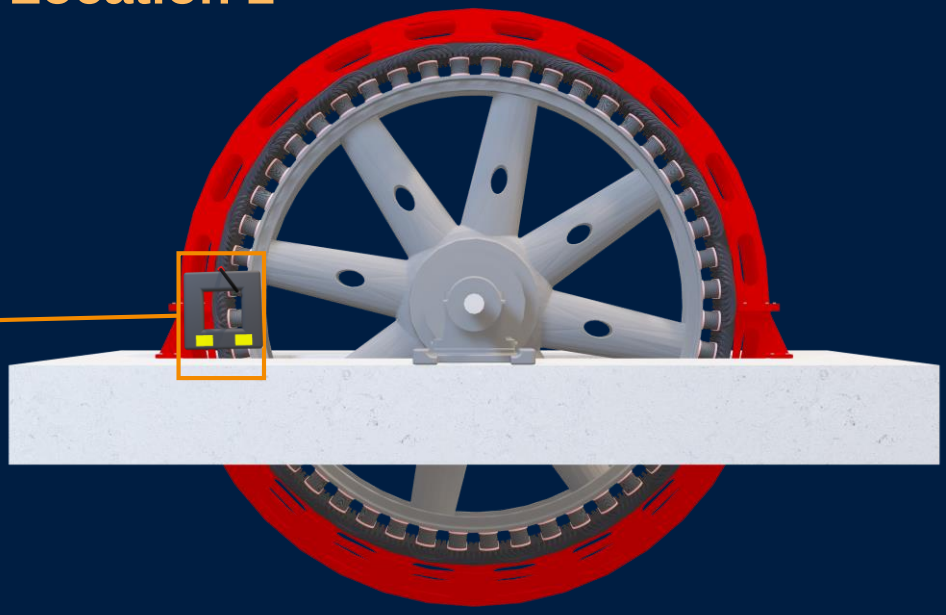
Access Point for Creating Faults



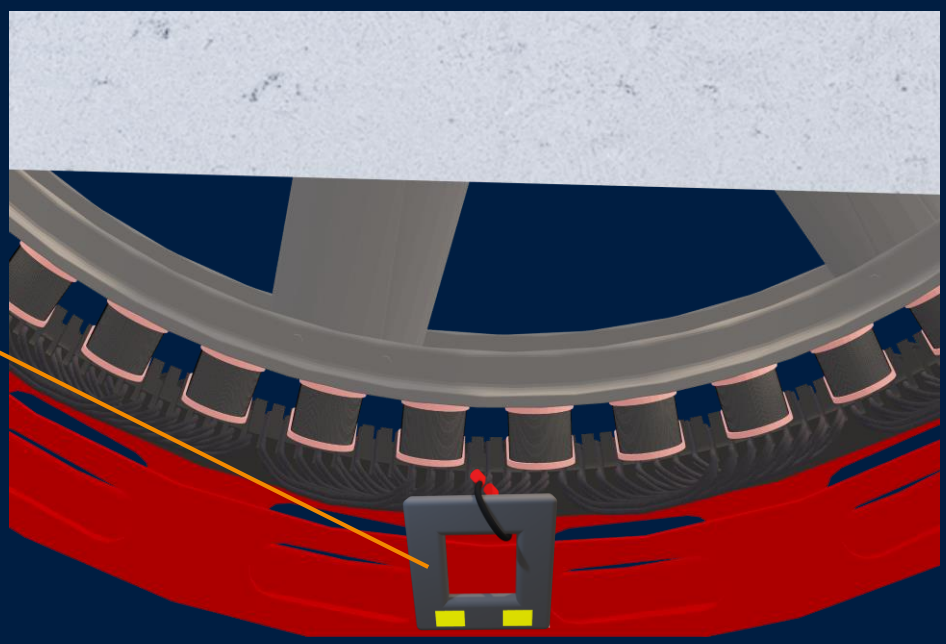

Winding Construction (Used for Fault Survey)
POLE 1 (N)
POLE 2 (S)
Slot Number
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
A-T
B-N
C-T
B-T
Phase A
Phase C
Phase B
Top Conductor (rear rotor)
Bottom Conductor (rear stator)


Physical Winding Layout
N
T
4
3
T
N
1
N
T
2
T
N

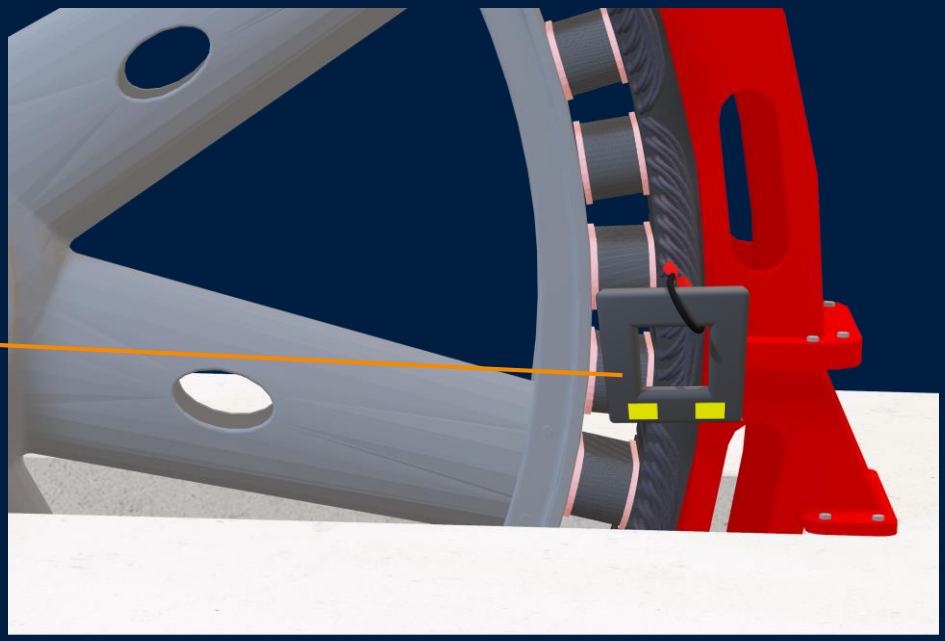
Branch CT Location 1



Branch CT Location 2

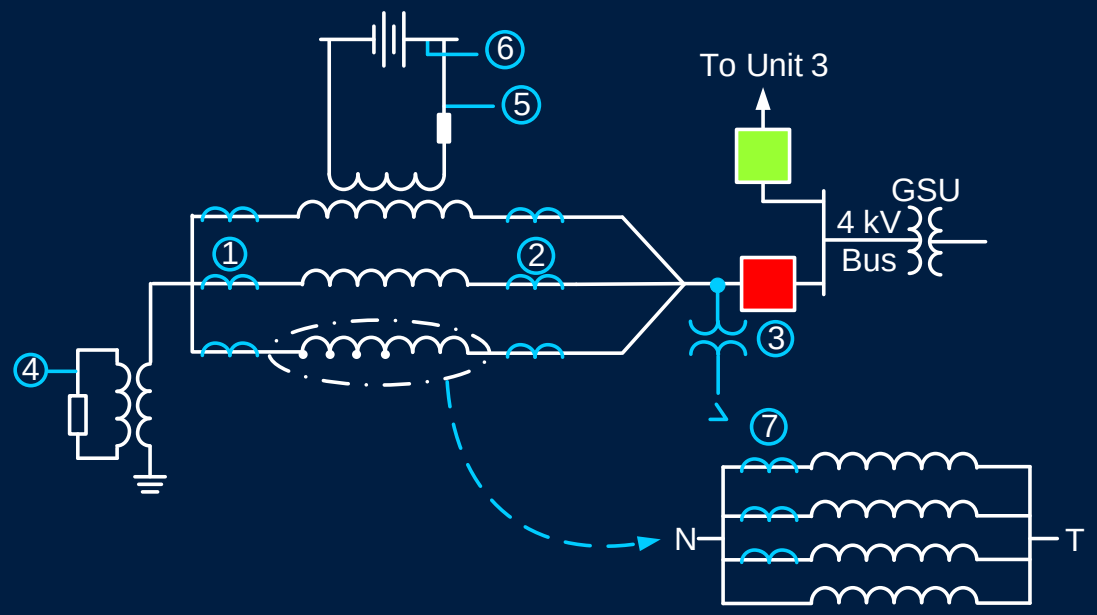


Branch CT Location 3



Test Setup

Data Acquisition for the Test



Fault Switch Rating

Double Phase-to-Ground Fault

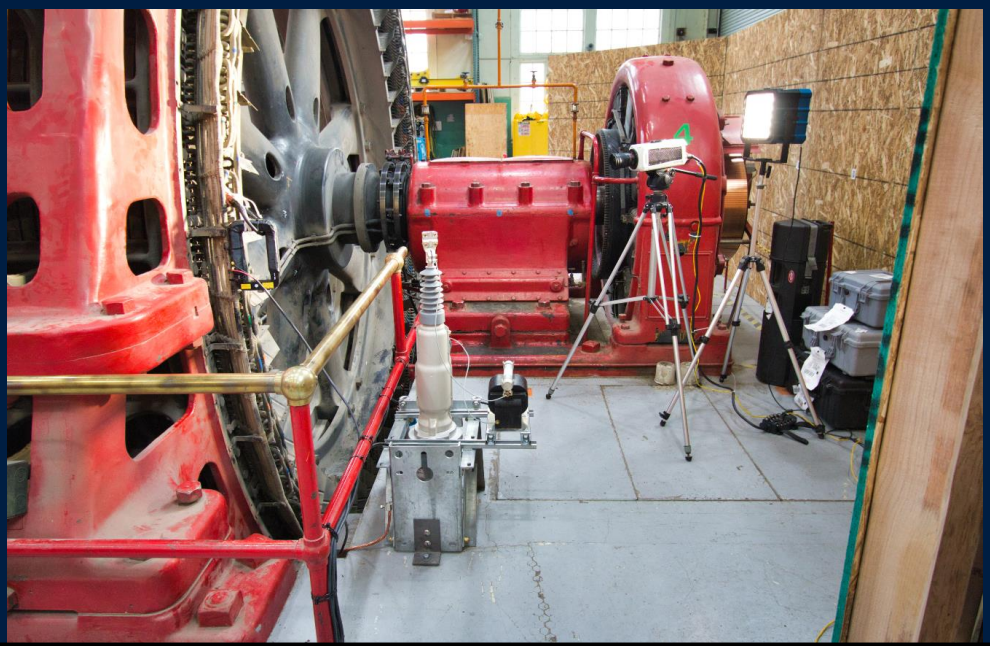
$$I_{FLT} = 3 \bullet \frac{V_1}{X_{d''} + \frac{X_{d''} + X_{q''}}{2} + Z_0} \quad (Z_0 = 0.05\ pu)$$

$$= 8.11\ pu$$

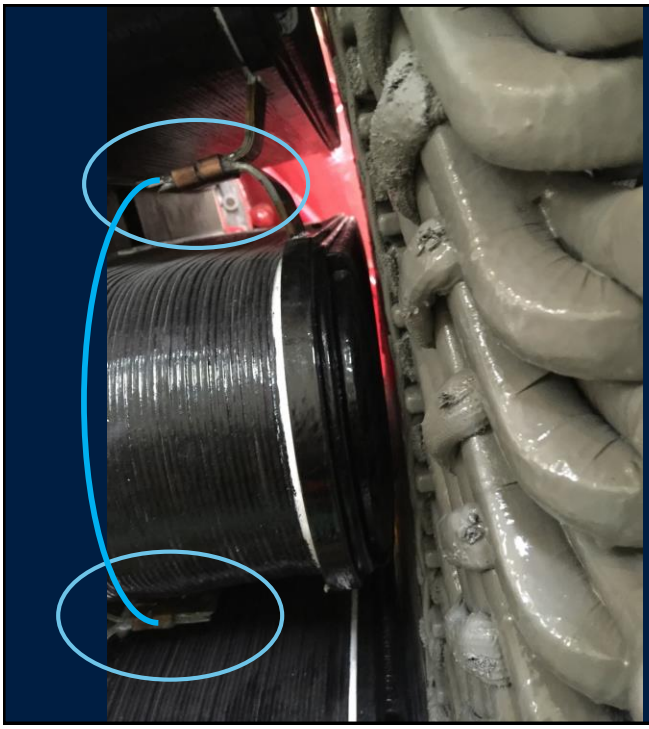
$$I_{FLT\_MAX\_SYM} = 10.41\ kA \ \ (1\ pu = 1.284\ kA)$$

$$\boxed{I_{FLT\_MAX\_ASYM} = 18.3\ kA}$$

The Fault Circuit



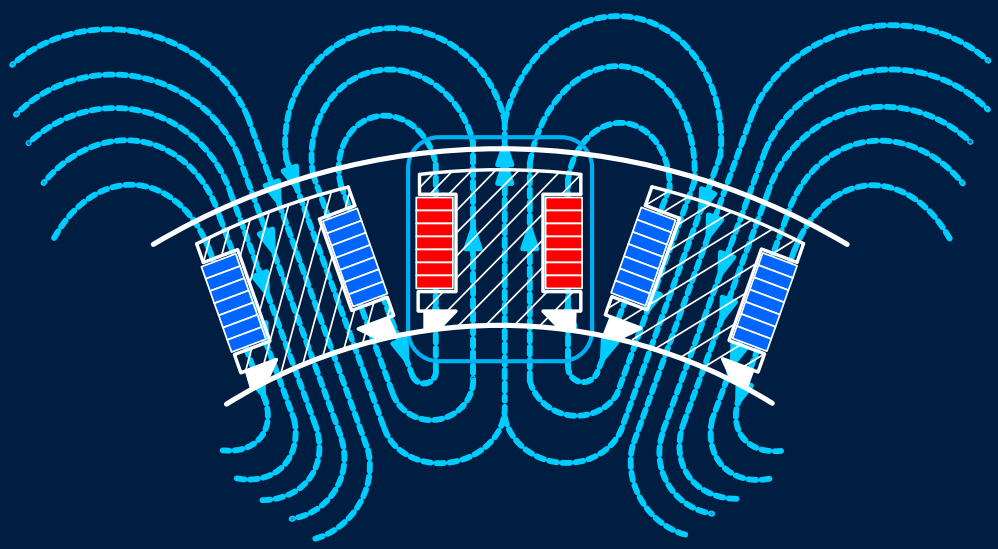
Test Results



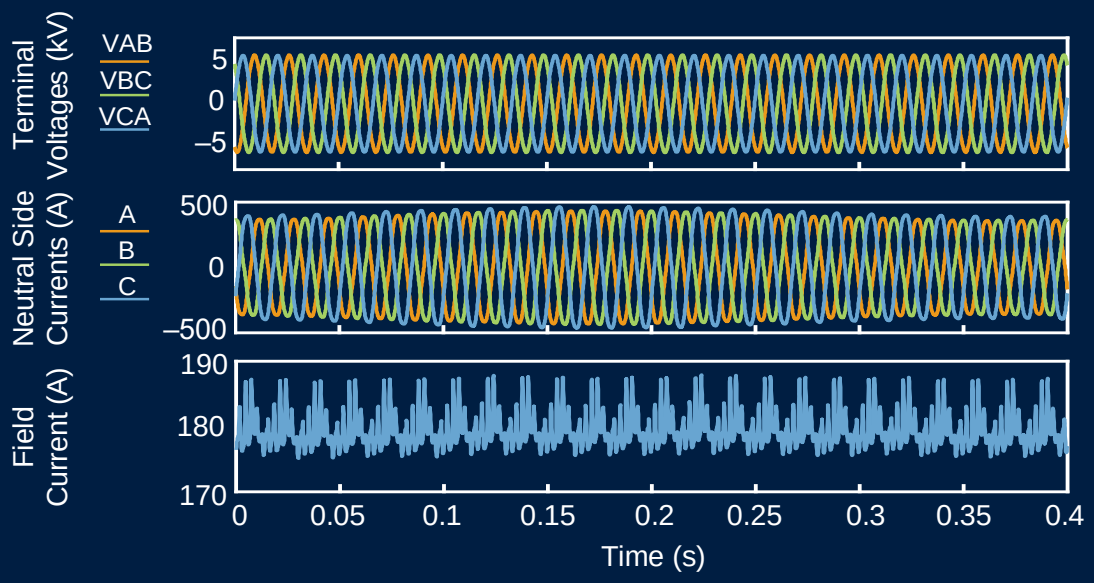
Rotor Turn-to-Turn Fault

What is the effect of a shorted rotor pole?

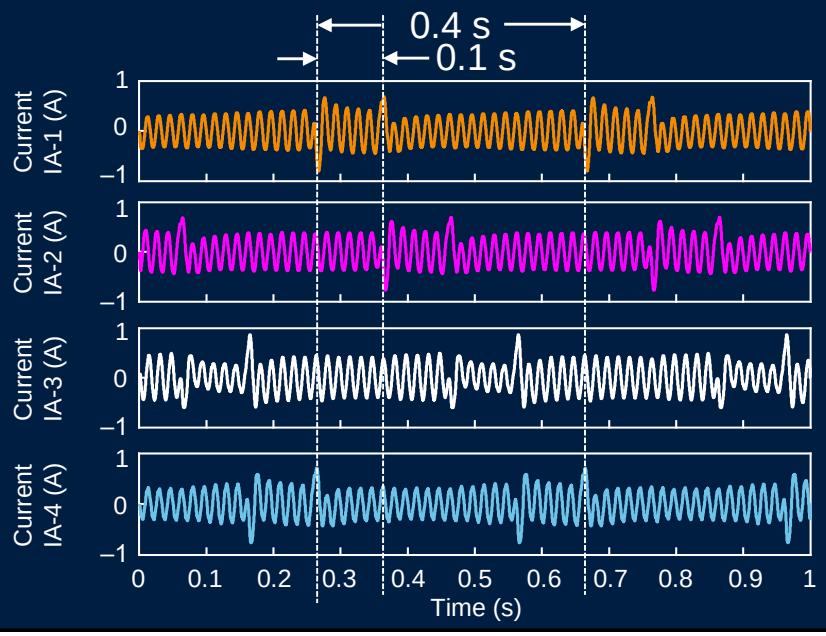
Effect of a Shorted Rotor Pole



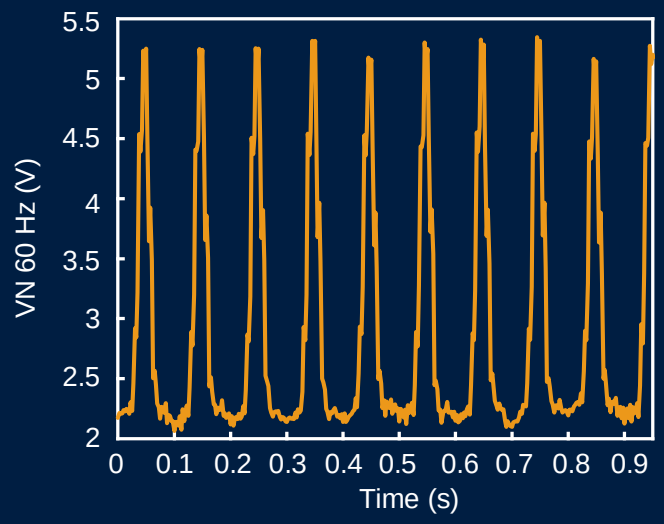
One Out of 48 Poles Is Shorted



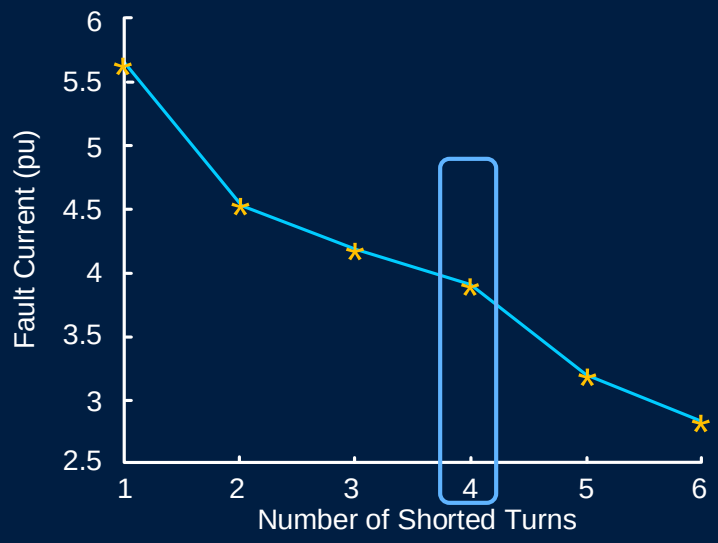
Split Phase Currents for Rotor Interturn Faults



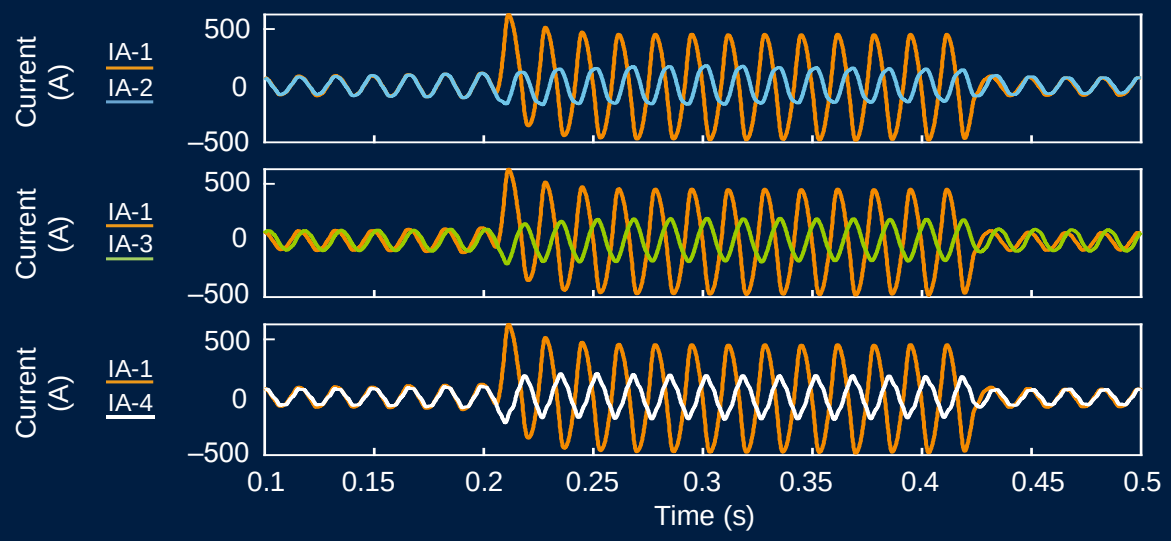
Rotor Turn Faults Can Be Seen in the Stator Zero-Sequence Voltage



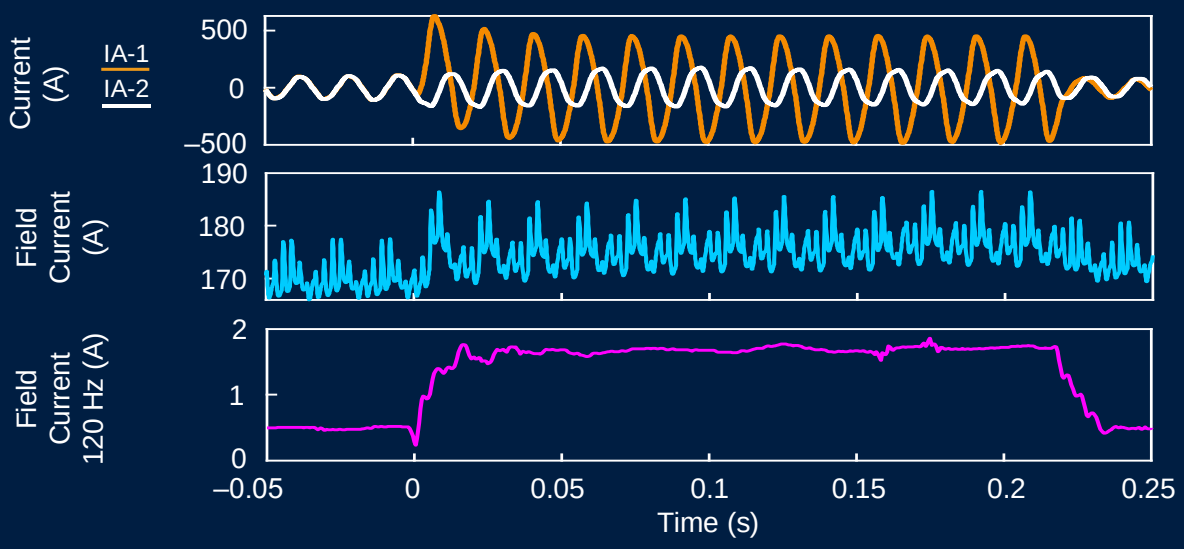
Stator Turn-to-Turn Faults



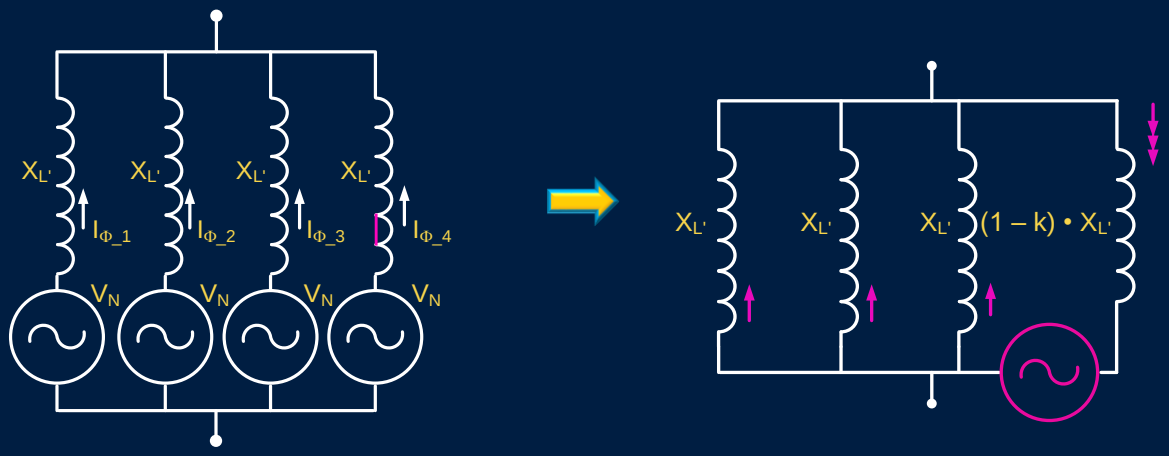
Branch Currents for a Turn-to-Turn Fault (Split Phase Currents)



Effect of a Stator Turn-to-Turn Fault on the Field Current

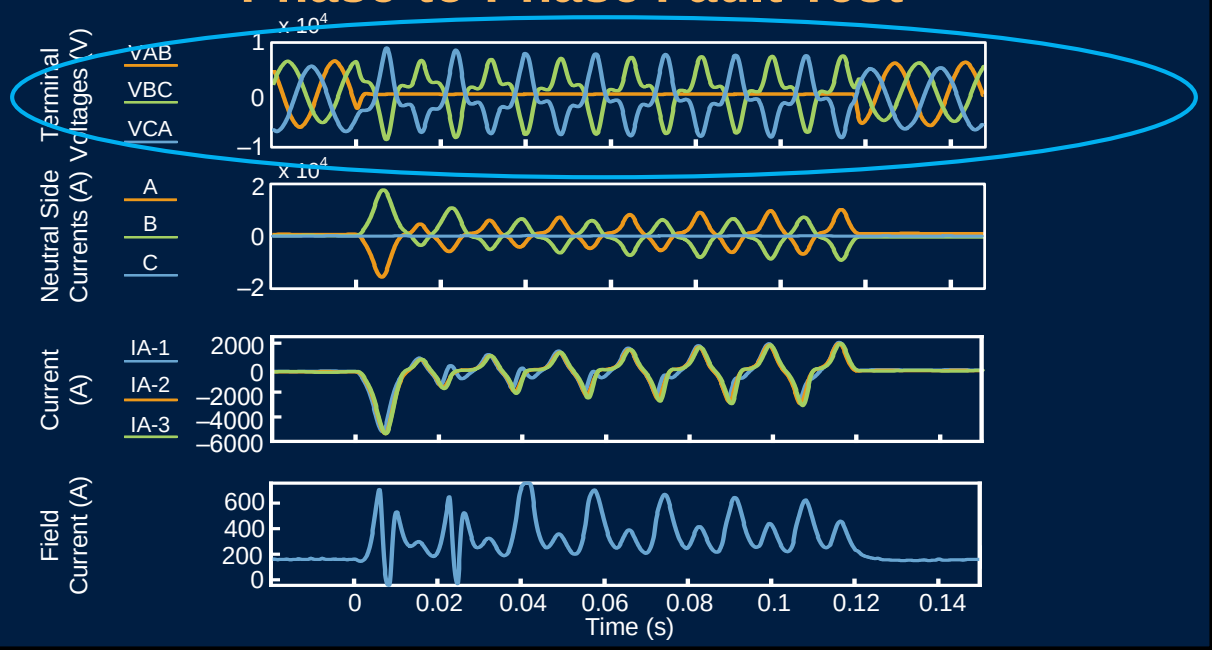


Estimated Circulating Current Calculations

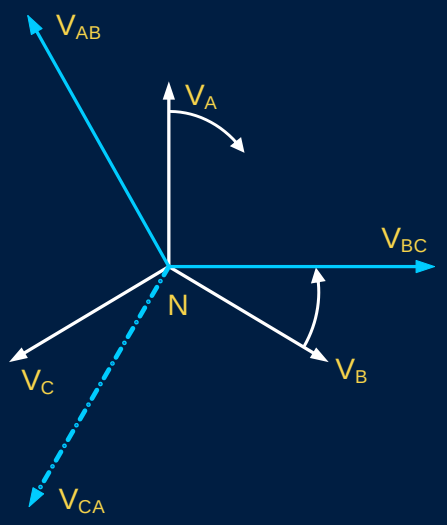


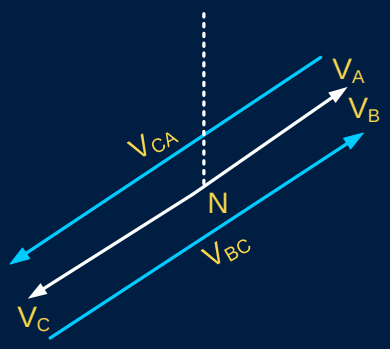
$$I_{CIRC} = \frac{k \bullet V_N}{\left(\frac{X_{L'}}{N_{Branch} - 1}\right) + X_{L'}\,(1 - k)} \qquad \left(k = \frac{N_{Coils\_shorted}}{N_{Coils}}\right)$$

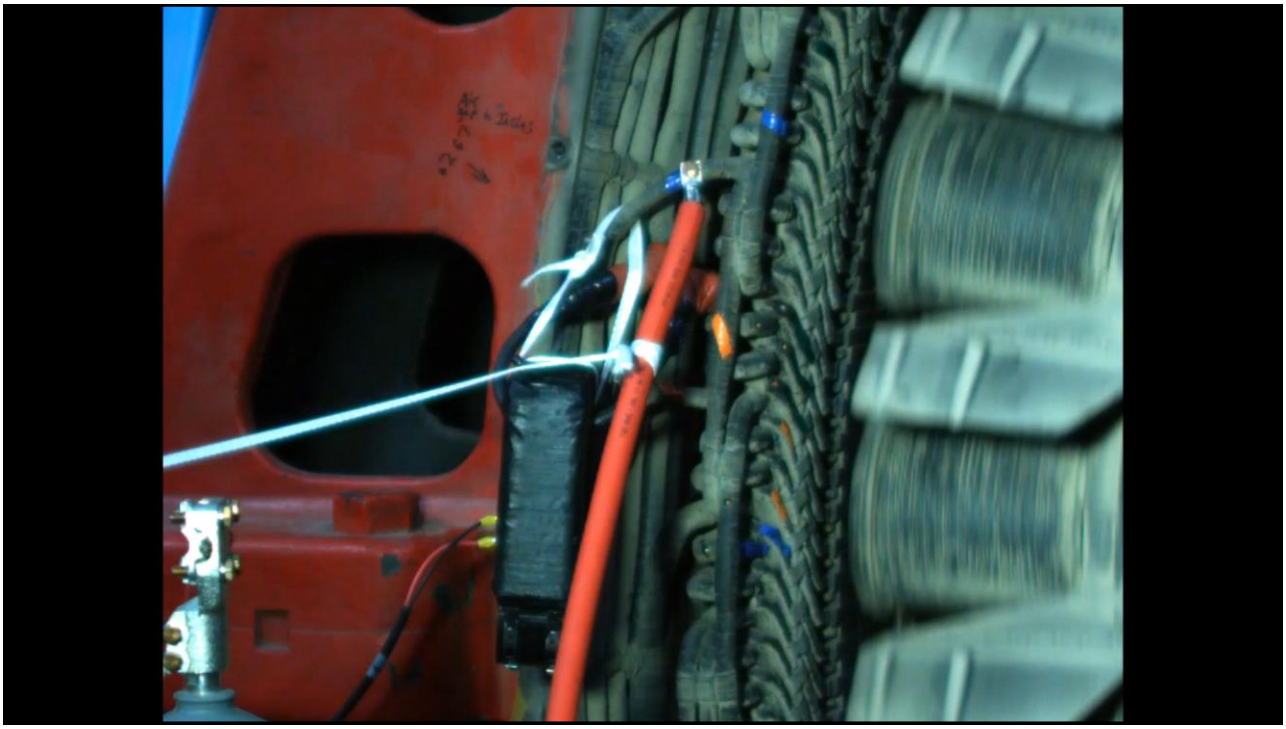
Phase-to-Phase Fault Test



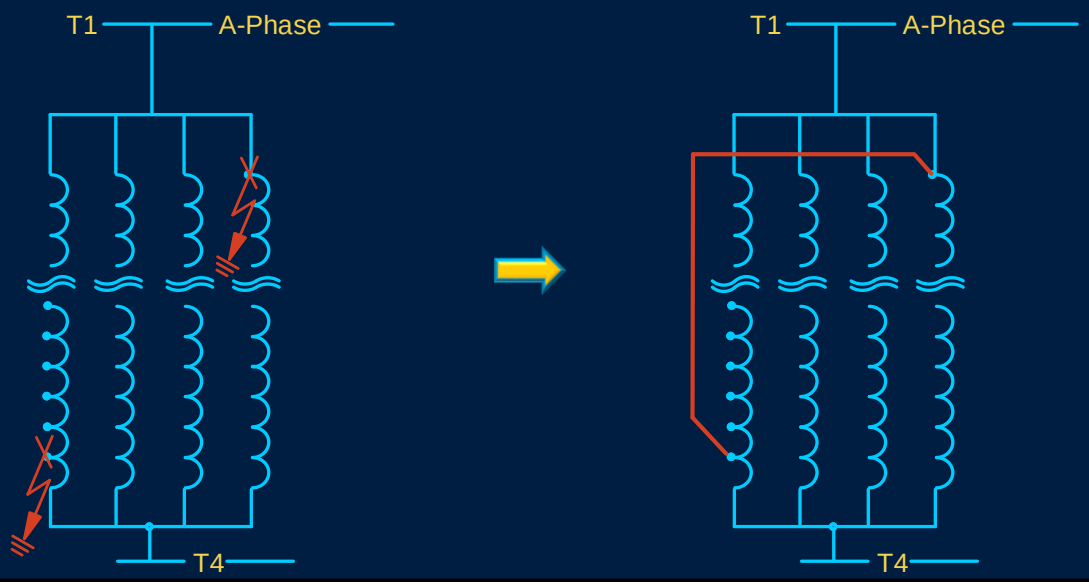
Terminal Voltage



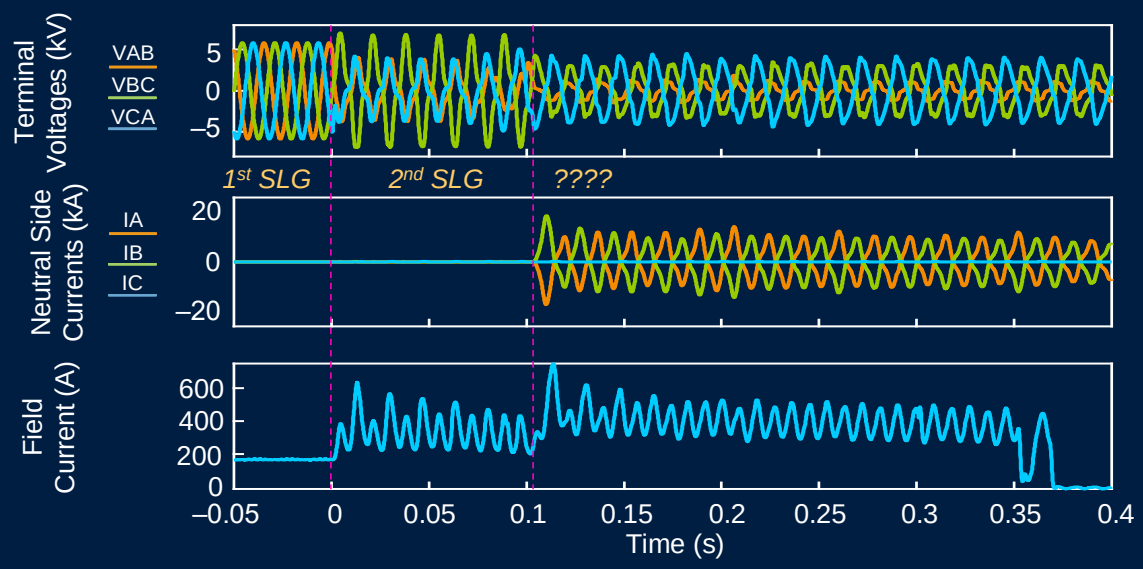




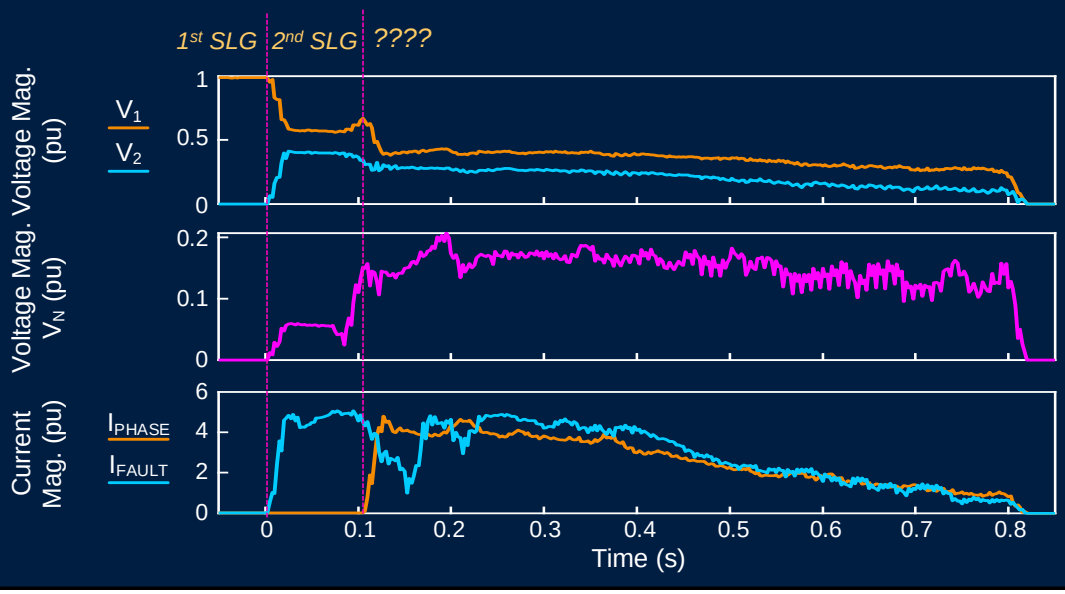
Interbranch Fault or Double-Point Grounding on Same Winding

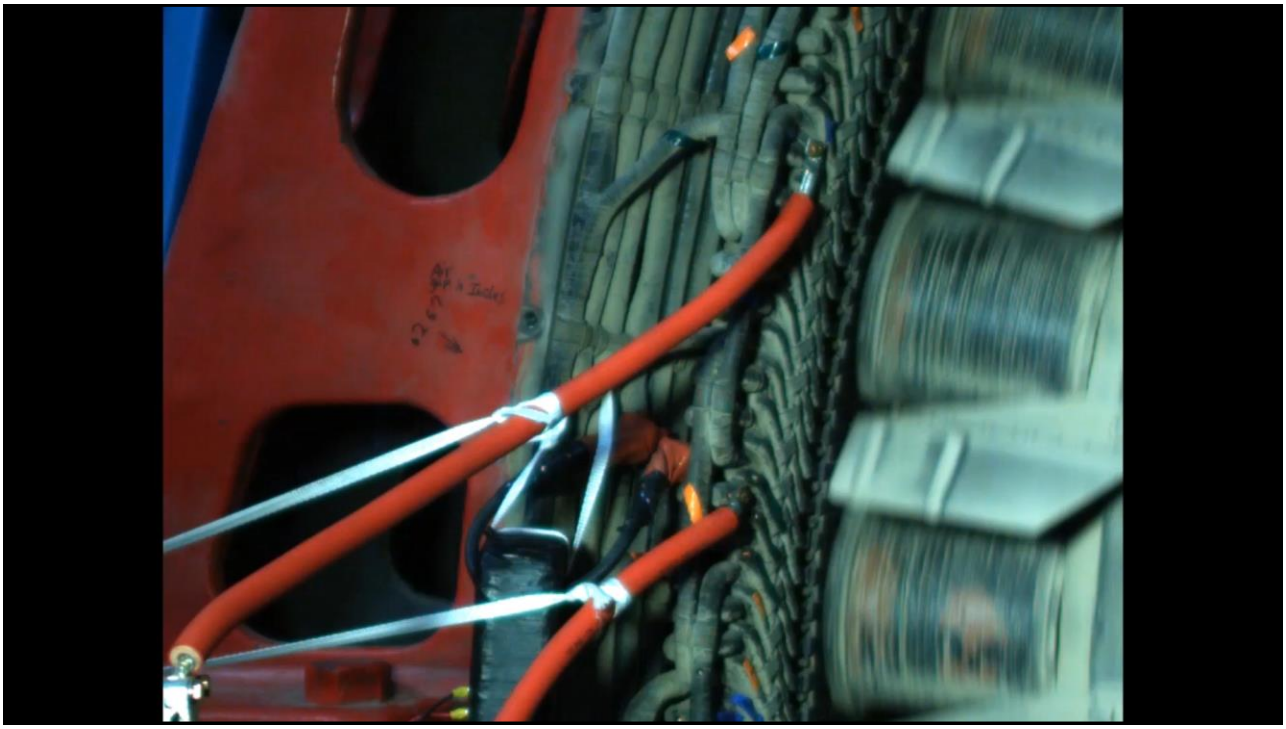


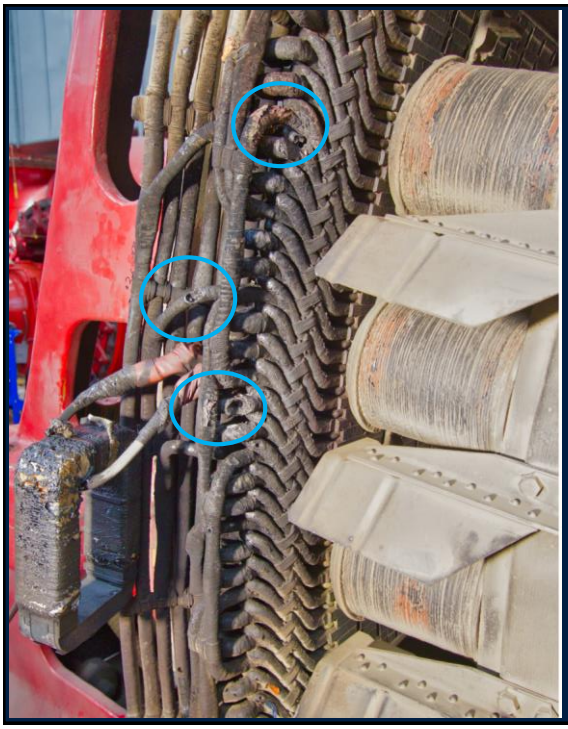
Terminal Voltages and Currents and Field Current



Voltages and Currents for Double-Point Ground Fault

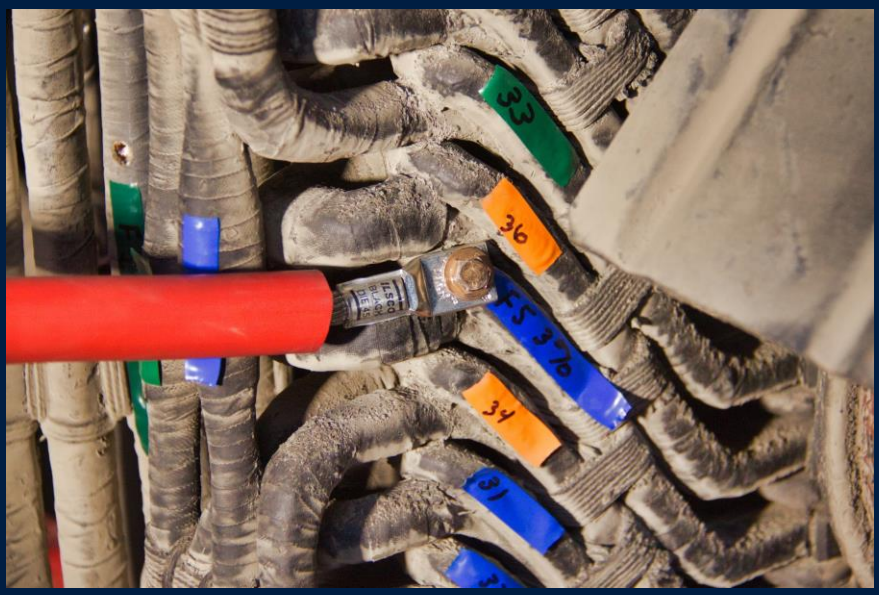




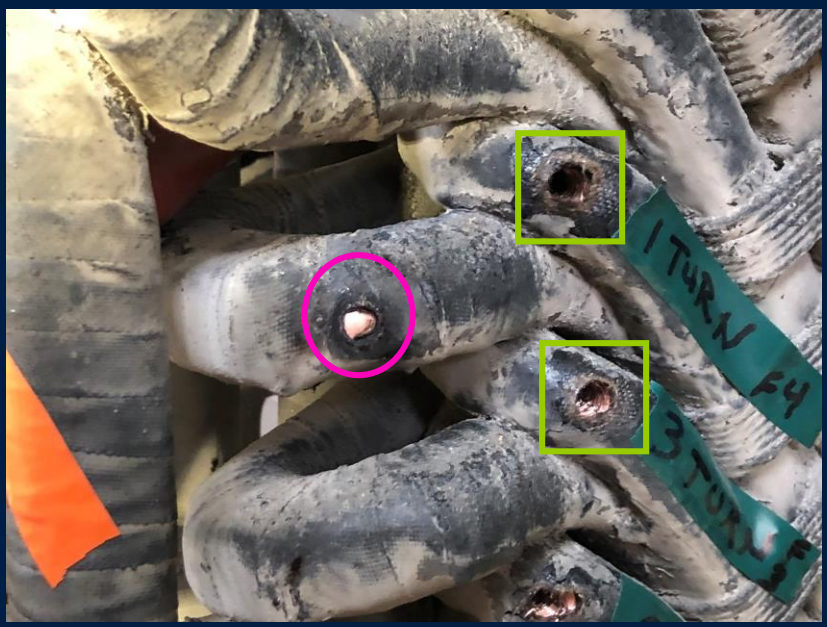


Damaged Windings and the Branch CT

Connection of Fault Switch to Fault Point



Fault Points



Conclusion

- Using the generator winding configuration, we determined which faults are most likely to occur (fault survey)
- Obtained very rare high-resolution stator and rotor voltage and current recordings of generator faults
- Staged fault testing helps engineers:
  - Improve generator protection functions
  - Validate generator simulation models

Conclusion

- Detailed planning is required to select correct fault switch and to reduce testing errors
- Future scope is to validate some of the new protection functions and simulation models

This experience was an absolute "blast"!

How Many Folks Does It Take to “Destroy” a Generator?