



# Open-Phase Validation Test

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# Open-Phase Test

- Conducted at Bellefonte Nuclear Plant
  - construction status plant
  - representative offsite power supply and auxiliary power system design
- First full-scale open-phase test ever attempted at a nuclear plant
- Required months of planning, several days to configure plant for testing, coordination with multiple TVA divisions (nuclear, construction, transmission) and EPRI



# Purpose of Open-Phase Test

- TVA exploring several options to detect open-phase fault conditions and mitigate any vulnerability of the Class 1E power systems
- These design concepts need validation

## Test Objectives

- Collect detailed event data from an actual open-phase fault condition to allow validation of consequences
- Provide opportunity for EPRI to validate their Open-Phase Detection System (OPD) in a full-scale field test
- Demonstrate viability of a protective relay scheme for load protection





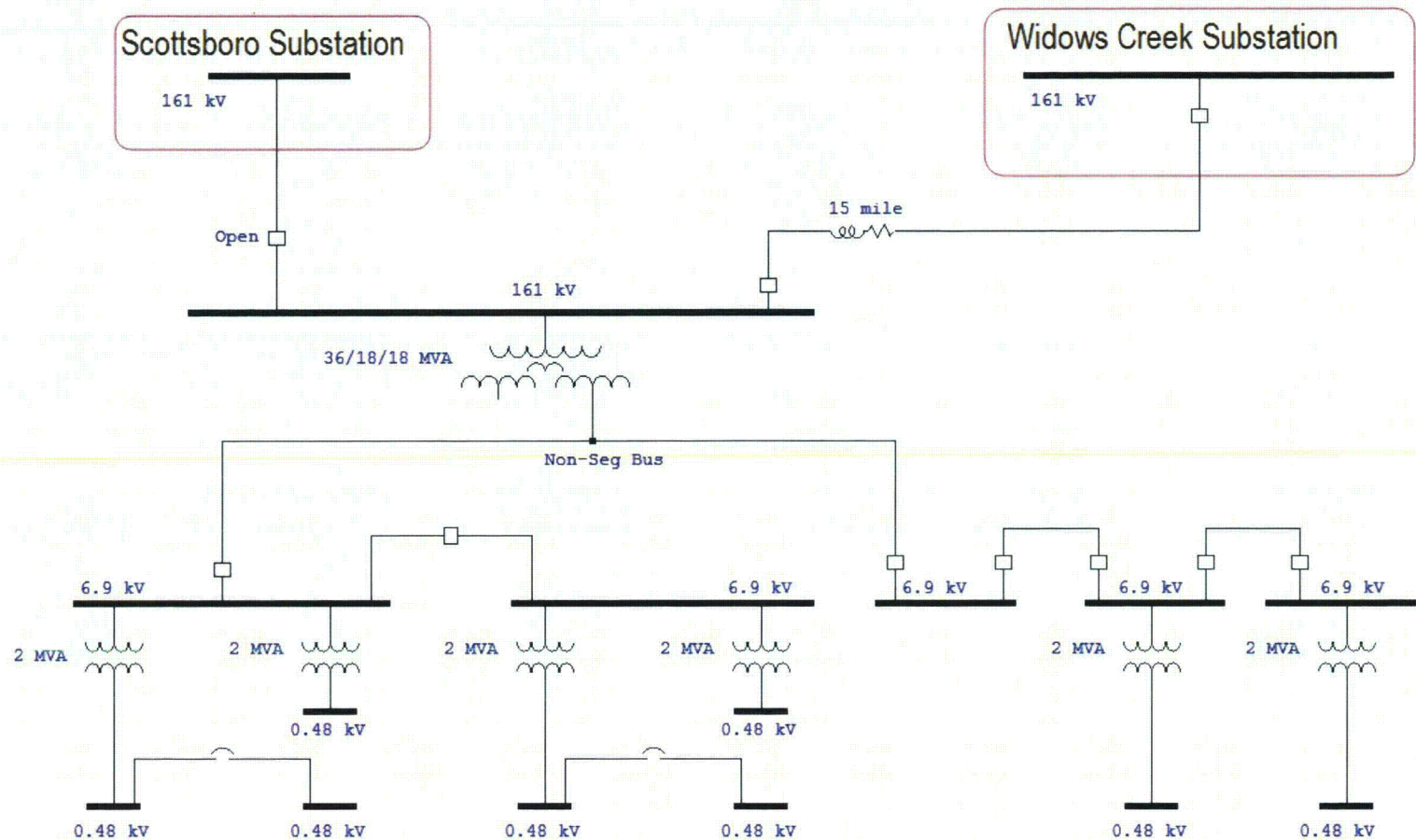
# Test Plan

- Install the EPRI OPD System on one offsite power transformer (36 MVA, 161-13.8/6.9 kV)
- Create an open-phase condition by removing a single 161kV conductor (stinger)
- Test with transformer unloaded
- Test with plant buses/loads connected
  - 13 total buses (switchgear and MCCs), both BOP and Class 1E systems
  - Energize 6.9kV-480V transformers (6-2000 kVA)
  - Start largest available motors (2-250 HP)





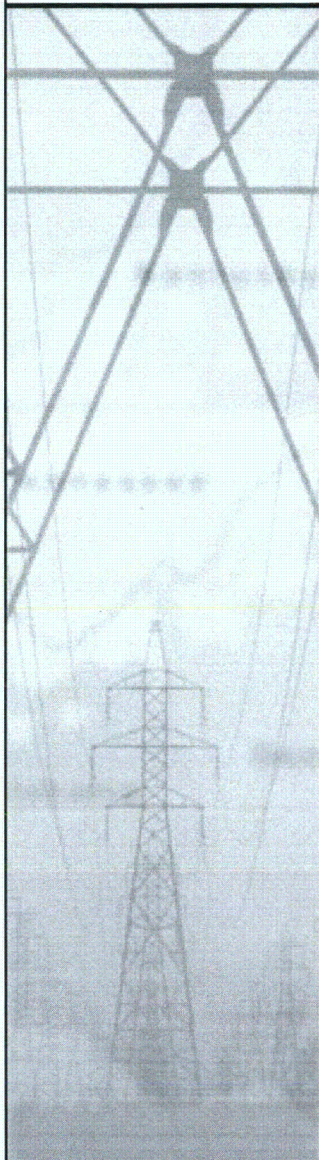
# Test Configuration







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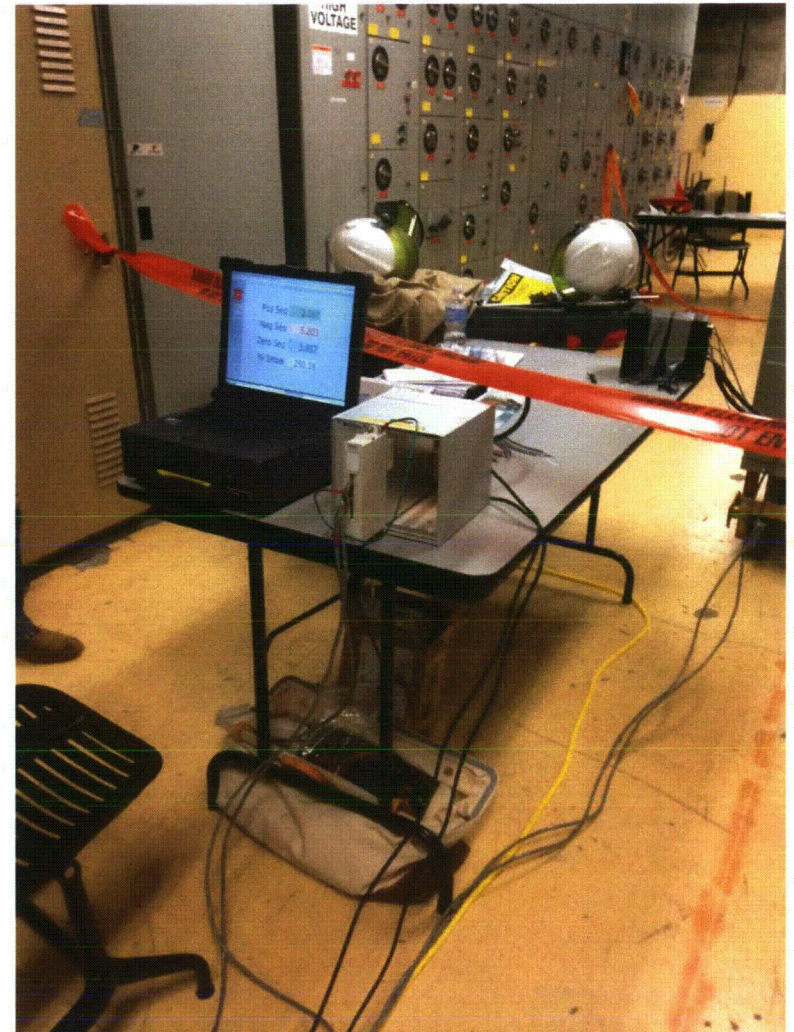






# Test Configuration

- High-speed recorders were installed to capture voltage and current waveforms for all plant buses and the switchyard
- TVA-developed system was used for real-time monitoring of in-plant voltage balance throughout the test





# Test Configuration

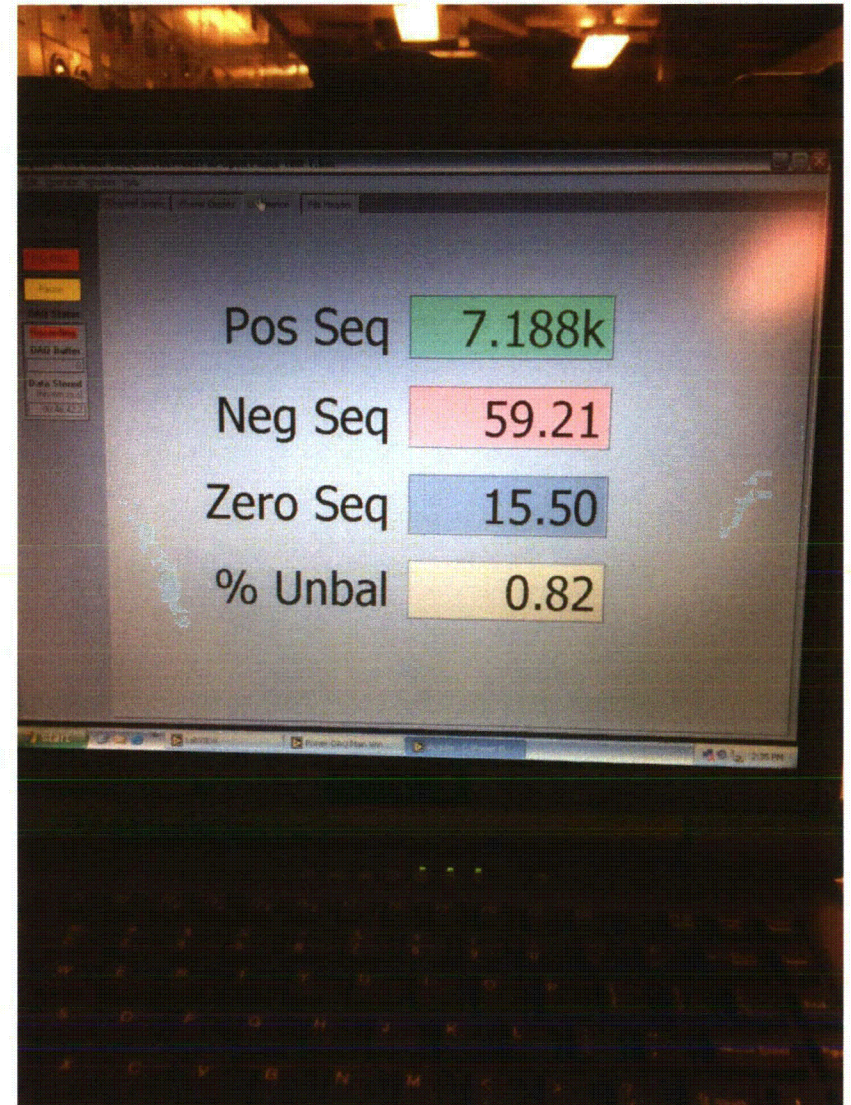
- A voltage balance protective relay was installed to protect plant loads in case of unexpected results
- Provided opportunity to study relay's behavior during normal plant operation (transformer inrush, motor starting, bus transfers, etc.)





# Open-Phase Test Results

- Plant exposed to open-phase condition for ~30 minutes without consequence
- At light loading (5%), in-plant voltages remain nearly balanced ( $<1\%$ ), as predicted







# Open-Phase Test Results

## Phasor Diagram

### Phasor A Reference ☒

Magnitude	Angle
6.776k	0

### Phasor B

Magnitude	Angle
7.011k	-126.37

### Phasor C

Magnitude	Angle
6.338k	114.7

### Positive Sequence

Magnitude	Angle
6.7k	-3.89

### Negative Sequence

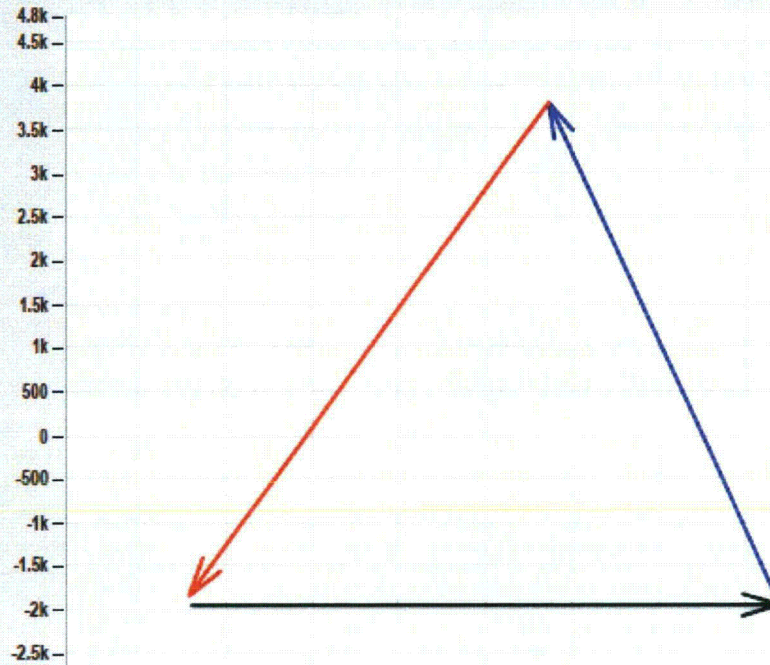
Magnitude	Angle
428.8	76.31

### Zero Sequence




Magnitude	Angle
38.95	104.77

Unbalance  
6.4 %

Phasor Type



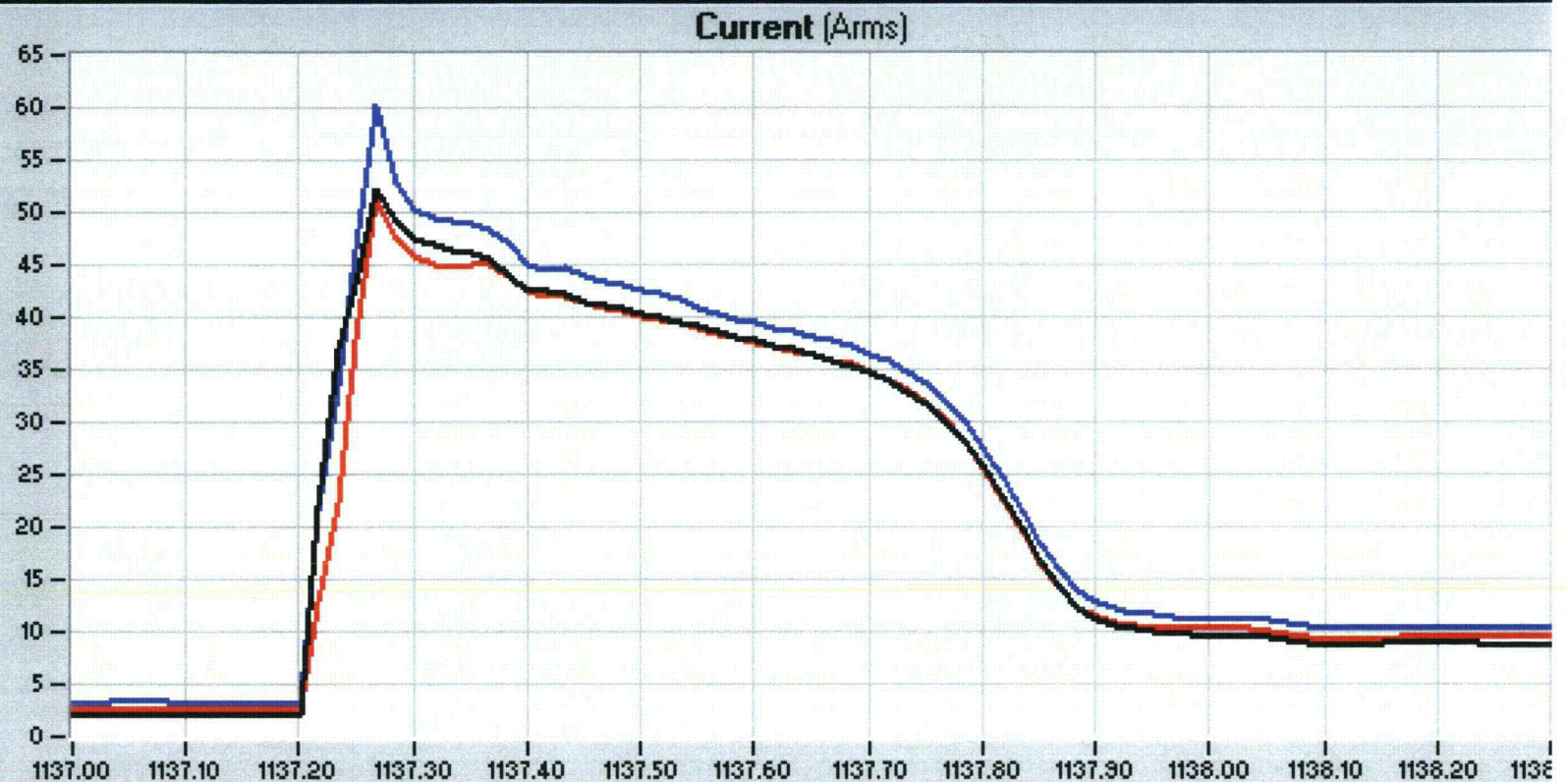
During high peak loading conditions (~80%), in-plant voltages became more unbalanced (> 6%), as predicted

Phasor A   
Phasor B   
Phasor C 





# Open-Phase Test Results



- Motors started within normal timeframes, as predicted





**Questions?**

**Discussion?**

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**TVA**