

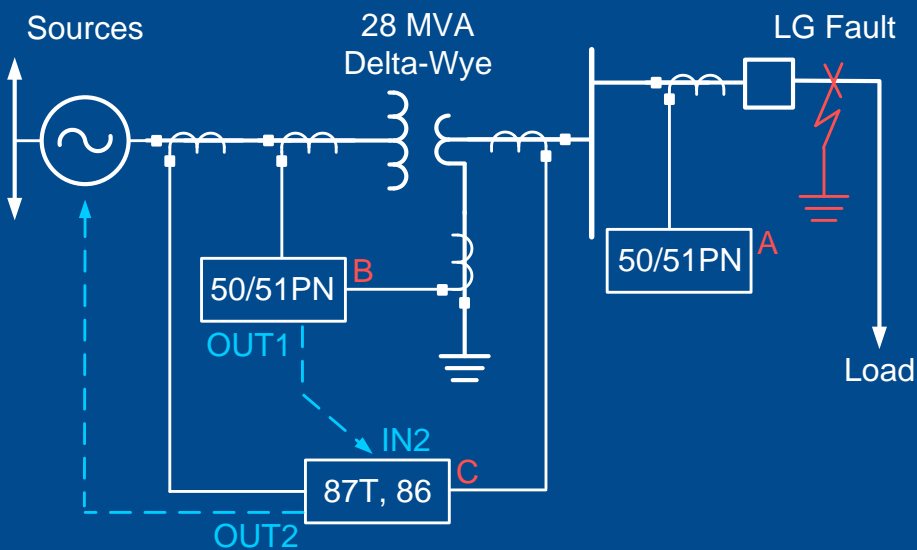


# Transformer Differential Misoperation and Lessons Learned



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## Simplified Protection One-Line Diagram



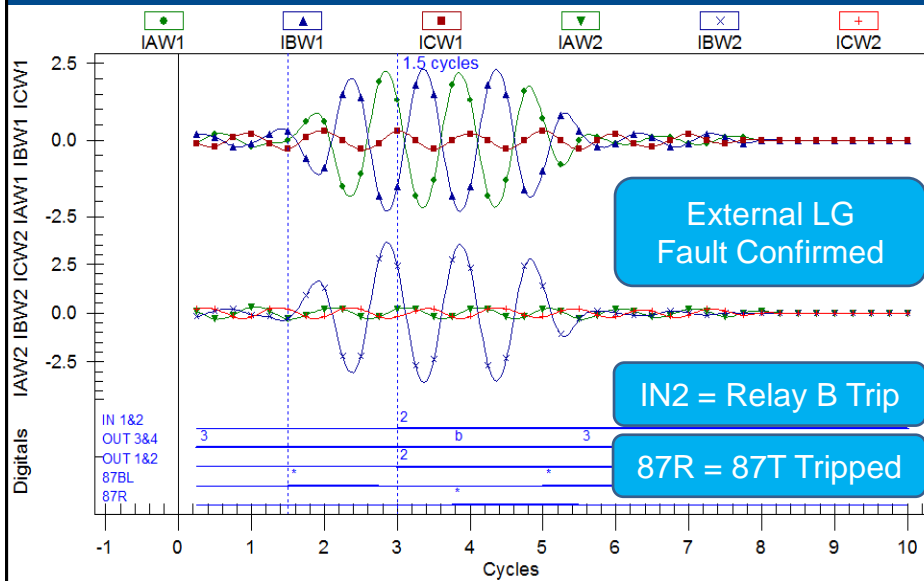
## Feeder Fault Expectations

- Recloser control (A) should operate first
- Transformer back-up overcurrent (B) should operate second
  - ♦ Protect transformer damage curve
  - ♦ Coordinate with recloser control
  - ♦ Trip through Relay C, which acts as lockout relay
- Transformer differential (C) 87T relay should restrain

## Misoperation Quick Facts

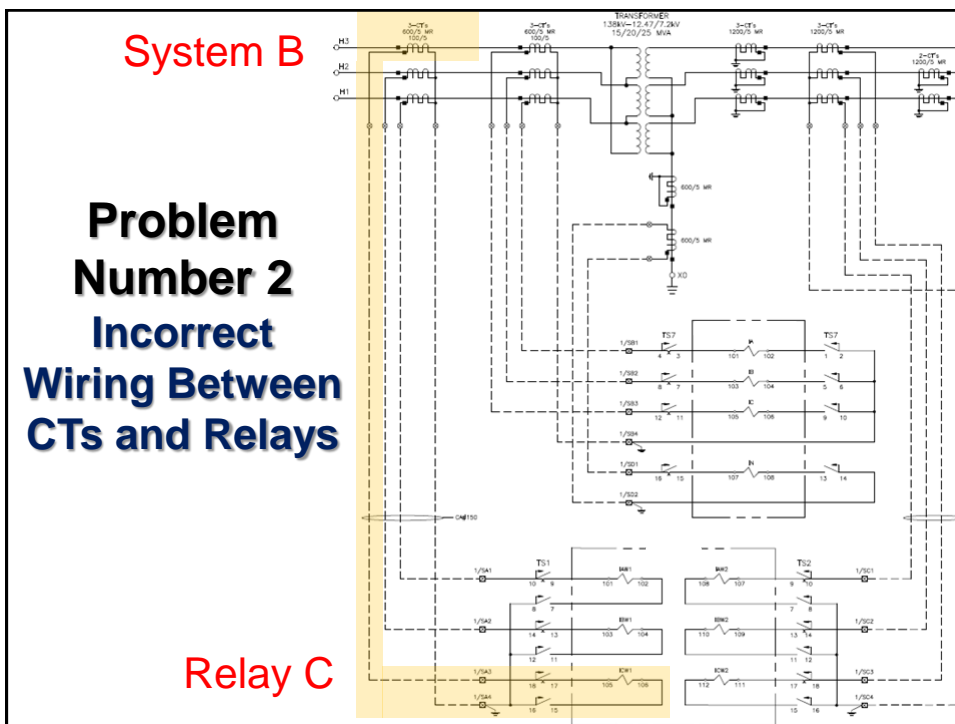
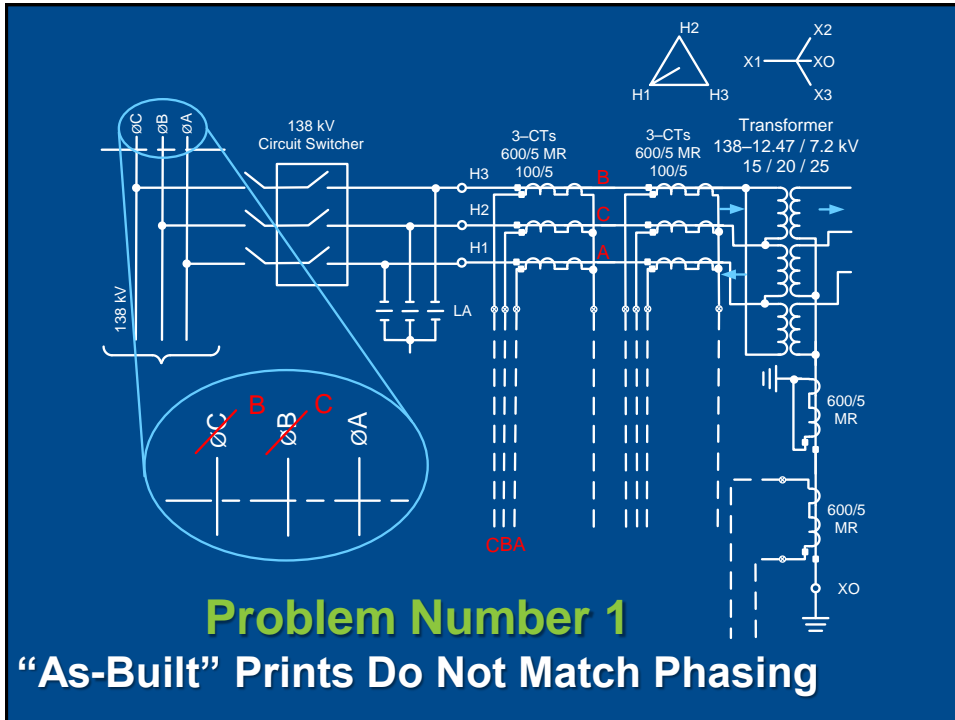
- LG fault occurred February 4
- Recloser did not trip
- High-side circuit switcher did trip
- Entire substation and all load was de-energized
- Root-cause analysis performed

## Fault Data From 87T Relay



## Misoperation Observations

- External-to-zone fault
- LG on distribution side
- Relay says fault was BG
- Transformer backup (B) relay tripped instantly (1.5 cycle)
- 87T (C) relay would have tripped even without miscoordination



## Problems Caused by Incorrect Phasing

- Original prints show DABY or Dy1
- As-built prints show DACY or Dy11
- CT-to-relay phasing rolled
  - ◆ System B to Relay C, and System C to Relay B
  - ◆ Relay phase rotation does not match system
  - ◆ CG system fault looks like BG at relay
  - ◆ 87T transformer and CT compensation settings incorrect

### Problem Number 3 87T Settings Incorrect for Wiring

TRCON Xfmr

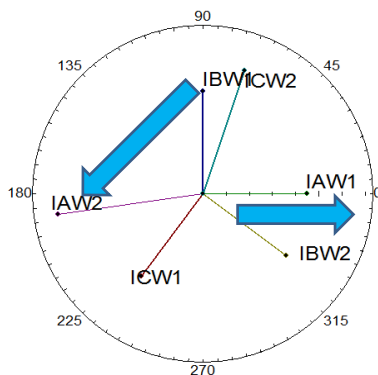
DACY

Select: YY, YDAC, YDAB, DACDAC, DABDAB, DABY, DACY, OTHER

CTCON CT Connection

YY

Select: YDAC, YY



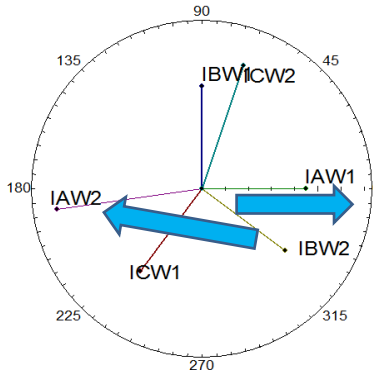
For CONn = DAC

$$I1WnF1C = \frac{(IAWnF1 - ICWnF1)}{\sqrt{3}}$$

$$I2WnF1C = \frac{(IBWnF1 - IAWnF1)}{\sqrt{3}}$$

$$I3WnF1C = \frac{(ICWnF1 - IBWnF1)}{\sqrt{3}}$$

## How to Correct 87T? DABY Would Work



For CONn = DAB

$$I1WnF1C = \frac{(IAWnF1 - IBWnF1)}{\sqrt{3}}$$

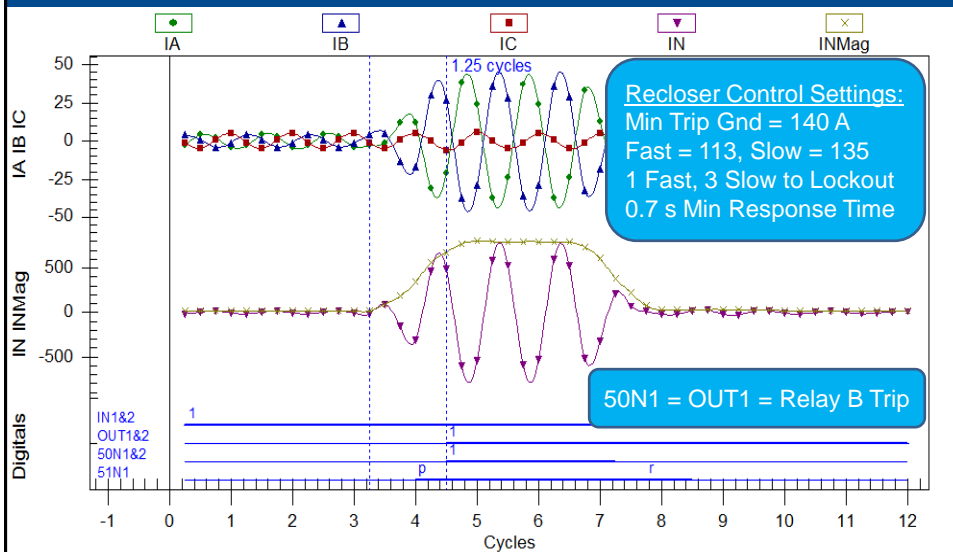
$$I2WnF1C = \frac{(IBWnF1 - ICWnF1)}{\sqrt{3}}$$

$$I3WnF1C = \frac{(ICWnF1 - IAWnF1)}{\sqrt{3}}$$

But...system phases and phase rotation will  
not match relay → fix CT wiring!

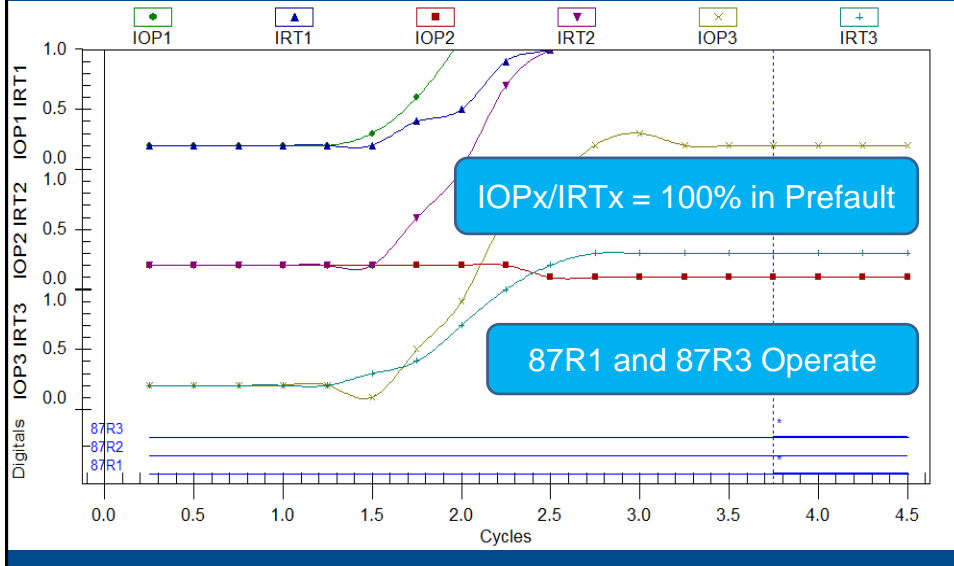
## Real-World Problem Number 4

X0 Bushing 50N Element Not Coordinated With Feeder



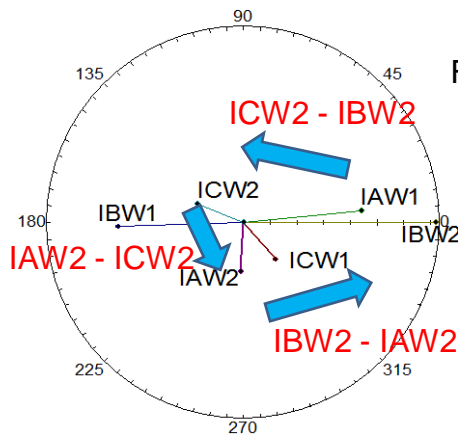
## Real-World Problem Number 5

### Standing Differential Operate = Insufficient Testing



## Why Did 87R1 and 87R3 Operate?

### Matrix Math and Fault Type



For CONn = DAC

$$I1WnF1C = \frac{(IAWnF1 - ICWnF1)}{\sqrt{3}}$$

$$I2WnF1C = \frac{(IBWnF1 - IAWnF1)}{\sqrt{3}}$$

$$I3WnF1C = \frac{(ICWnF1 - IBWnF1)}{\sqrt{3}}$$

## Findings and Recommendations

Phasing	→	Use synchrophasors
Drawings	→	Peer review, document, and control revisions
CT Wiring From System to Relay	→	Use primary injection for testing
Coordination	→	Test protection schemes in lab
Transformer Differential	→	Use primary injection, commissioning checklists
Testing	→	Use lessons to improve

Questions?