Back to the Basics – Event Analysis Using Symmetrical Components

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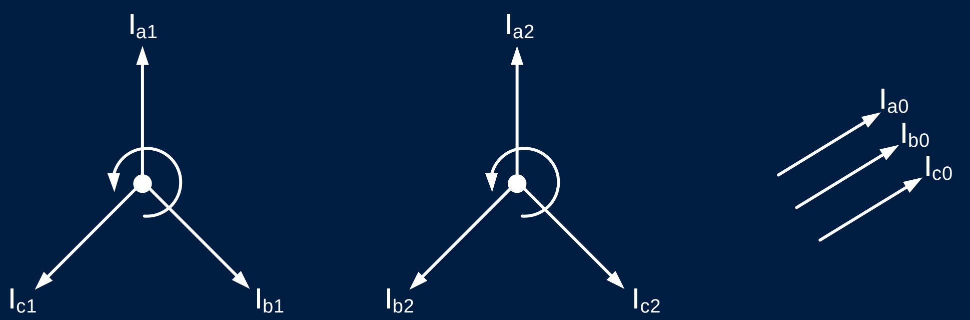
Back to Basics

- Motivation
- Overview
  - Introduction
  - Symmetrical components refresher
  - Event analysis using symmetrical components
  - Case studies
  - Conclusions

Introduction
Symmetrical Components Usage

- Short-circuit calculations
- Protective elements (67G, 59Q, 49, and so on)
- Impedance-based fault location
- Fault identification
- Event analysis

Symmetrical Components Refresher



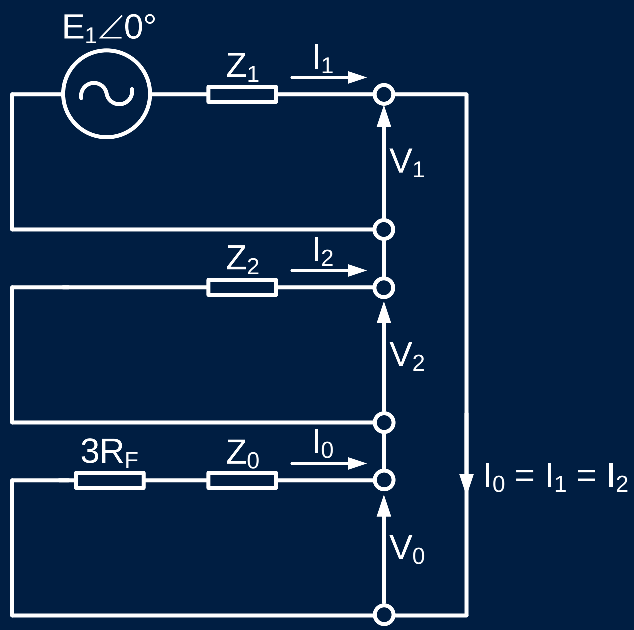
Positive-sequence currents

Negative-sequence currents

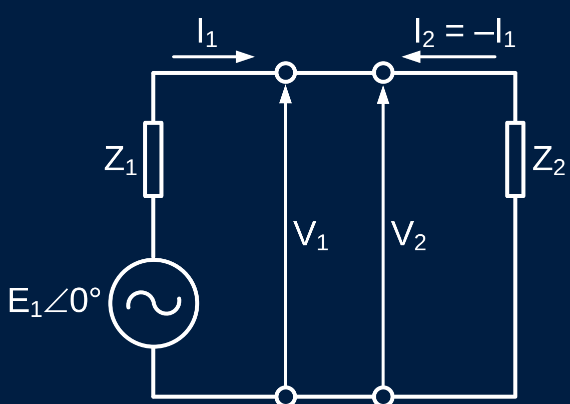
Zero-sequence currents

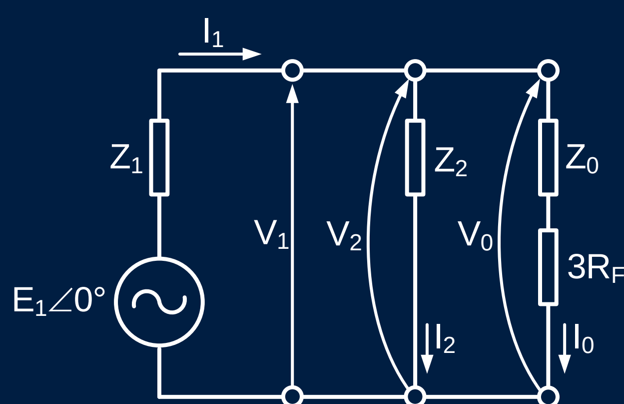
$$I_A = I_{a0} + I_{a1} + I_{a2}$$
$$I_B = I_{b0} + I_{b1} + I_{b2}$$
$$I_C = I_{c0} + I_{c1} + I_{c2}$$

Symmetrical Components Refresher



Symmetrical Components Refresher





General Event Report Analysis

- Captured fault oscillography
- Relay hard-coded algorithm
- User-set relay settings
  - Numeric
  - Logic

Event Report Analysis Using Symmetrical Components

- Captured fault oscillography
- Anatomy of power system
- Relay location in power system

Symmetrical Components-Based Approach

1. Using system one-line diagram, build positive-, negative-, and zero-sequence network diagrams
2. Connect networks based on known or expected fault location and type
3. Using basic circuit theory, reduce connected networks to calculate sequence currents at relay location

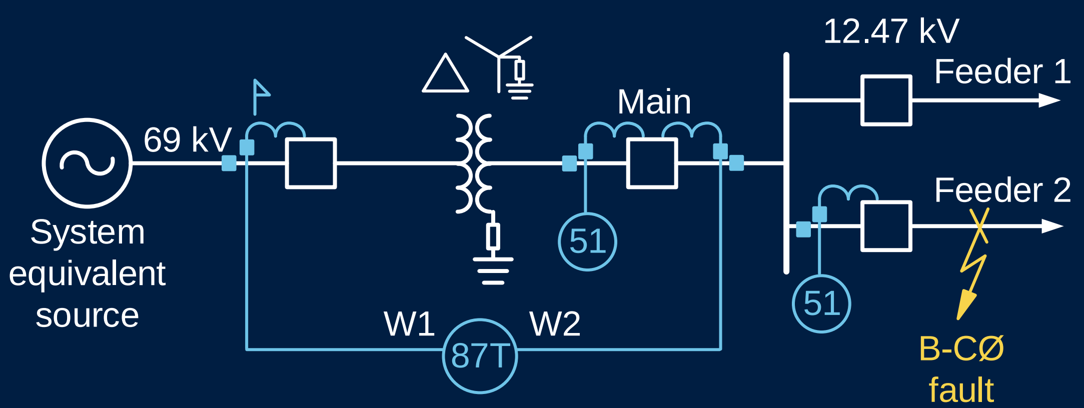
Symmetrical Components-Based Approach

4. Calculate phase currents at relay location and verify they match phase current waveforms recorded in event report (similar procedure applies for voltages)
5. If calculated phase currents do not match event report phase currents, change expected fault location and type, and repeat procedure from Step 2

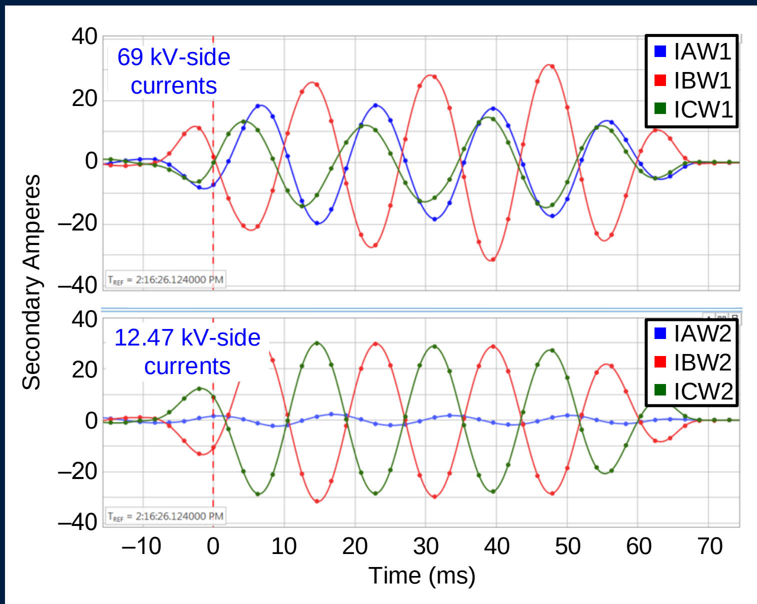
Symmetrical Components-Based Approach Can Be Used to Accomplish Several Tasks

- Explain nature of fault waveforms that may not resemble classic waveforms
- Estimate fault location
- Determine or verify impedance values of various power system elements

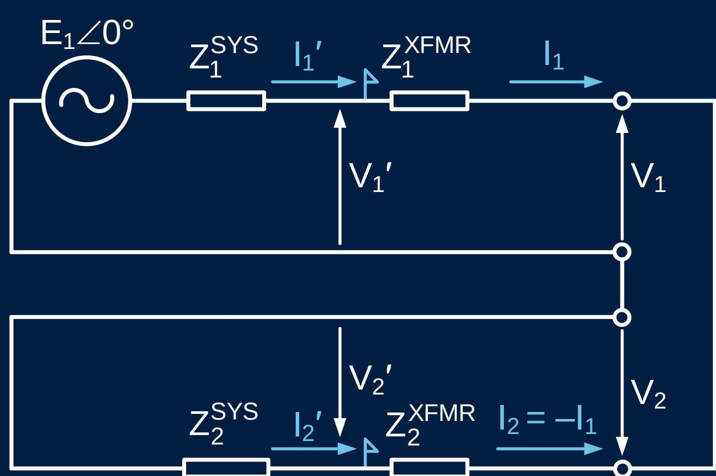
Case Study 1



87T Relay Fault Oscillography



Sequence Network Connection



Sequence Currents

$$I_0 = 0$$
$$I_1' = I_1 \bullet 1\angle 30°$$
$$I_2' = I_2 \bullet 1\angle -30°$$

$$I_A = 0 + I_1 \bullet 1\angle 30° + I_2 \bullet 1\angle -30°$$
$$I_A = 0 + I_1 \bullet 1\angle 30° - I_1 \bullet 1\angle -30°$$
$$I_A = I_1\angle 90°$$

Sequence Voltages

$$V_1' = (V_1 + I_1 Z_1^{XFMR}) \bullet 1\angle 30°$$
$$V_2' = (V_2 + I_2 Z_2^{XFMR}) \bullet 1\angle -30°$$

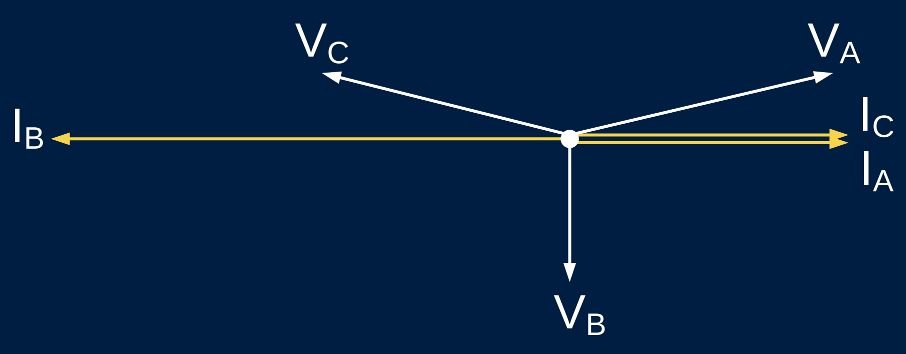
Phase Currents and Voltages

$$V_A = \sqrt{3}V_1\angle 0^\circ + I_1 Z_1^{XFMR}\angle 90^\circ$$
$$I_A = I_1\angle 90^\circ$$

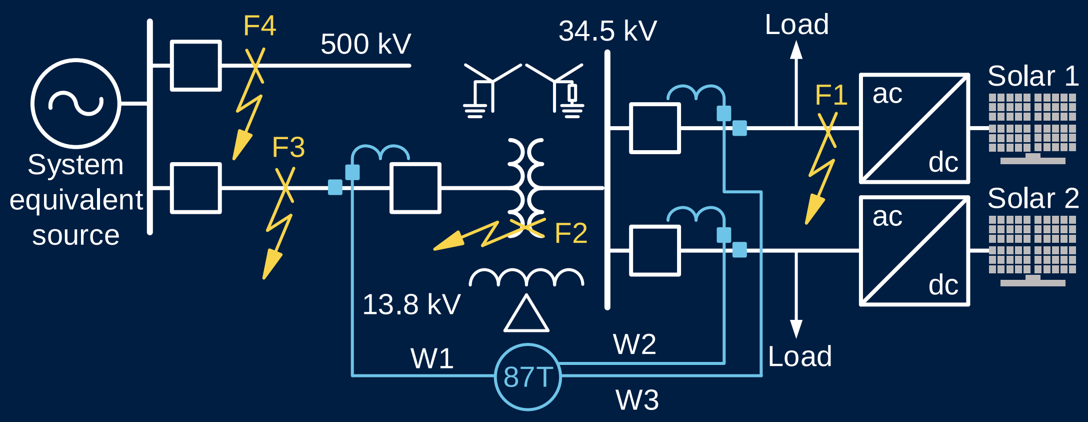
$$V_B = 2I_1 Z_1^{XFMR}\angle 270^\circ$$
$$I_B = 2I_1\angle 180^\circ$$

$$V_C = \sqrt{3}V_1\angle 180^\circ + I_1 Z_1^{XFMR}\angle 90^\circ$$
$$I_C = I_1\angle 90^\circ$$

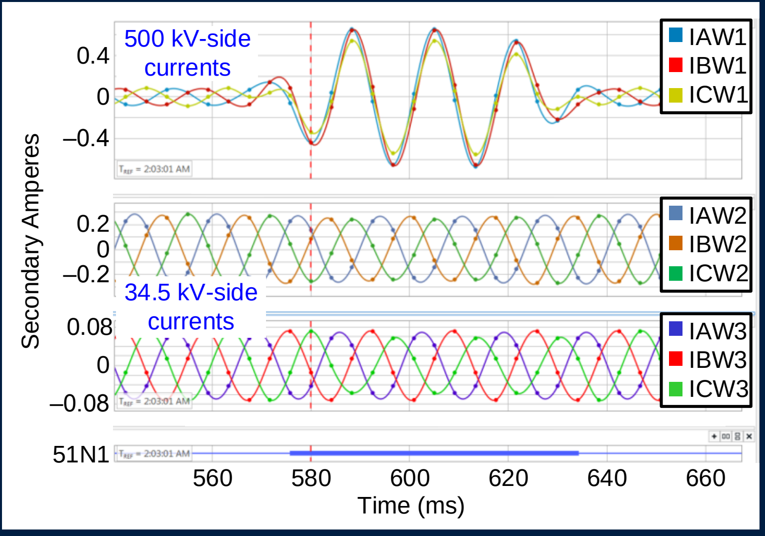
Phasor Diagram



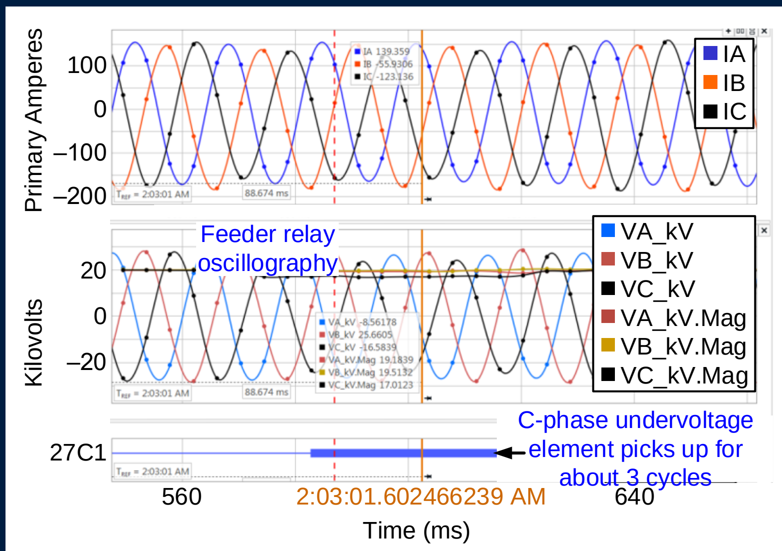
Case Study 2



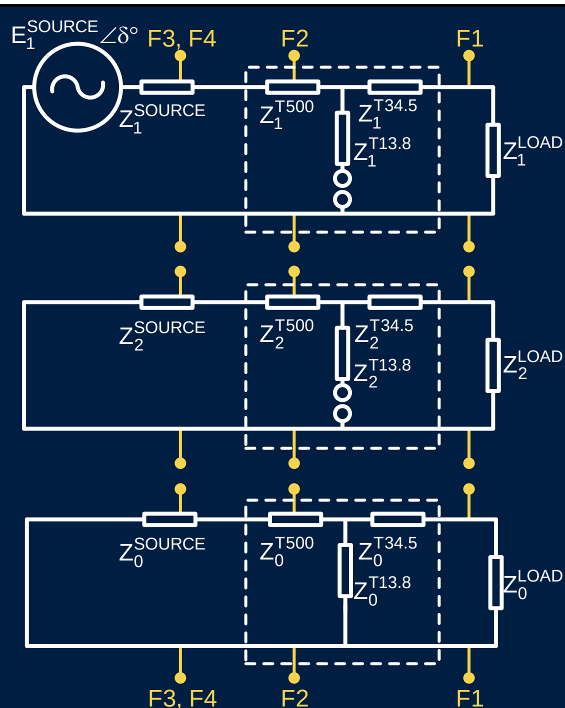
87T Relay Fault Oscillography



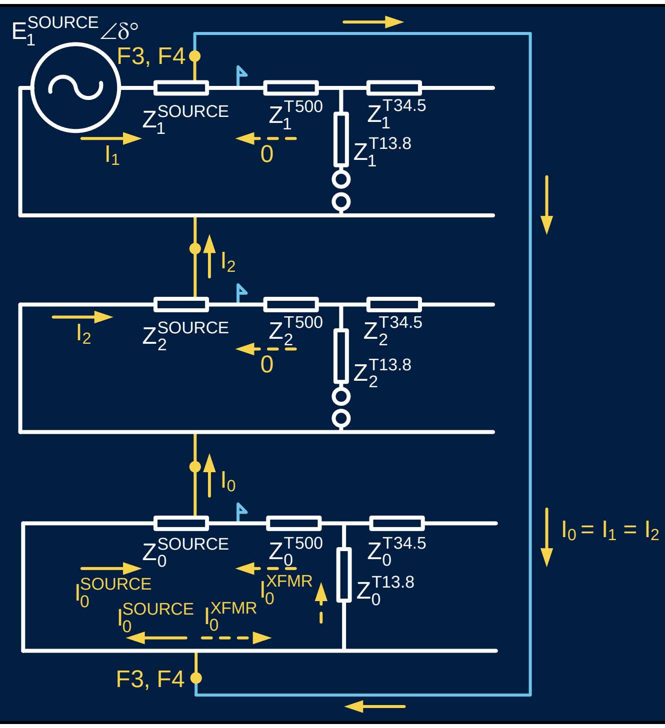
Feeder Relay Oscillography



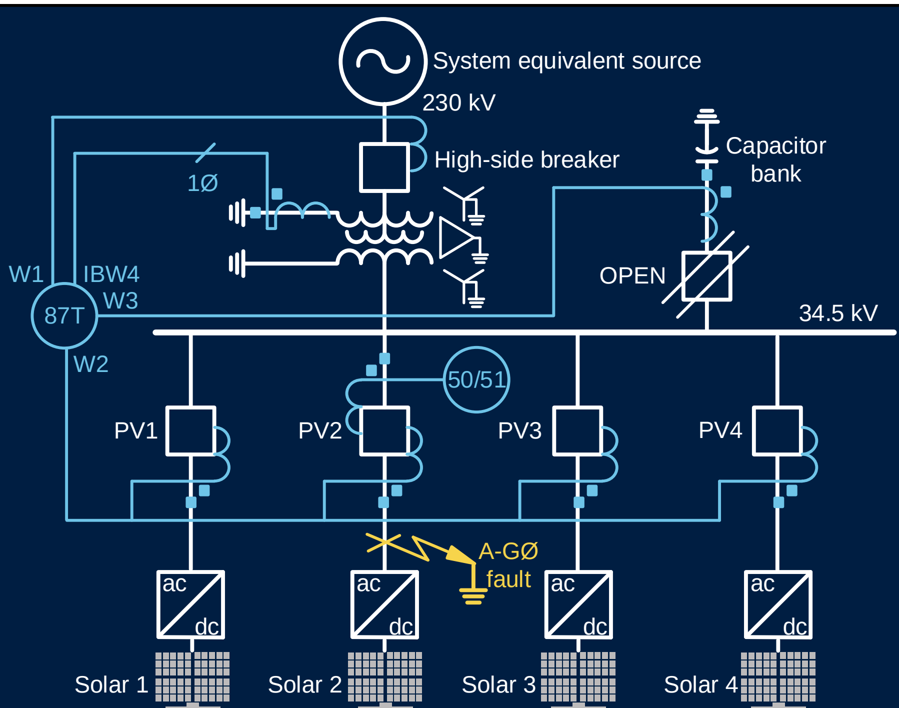
Case Study 2
Fault Possibilities



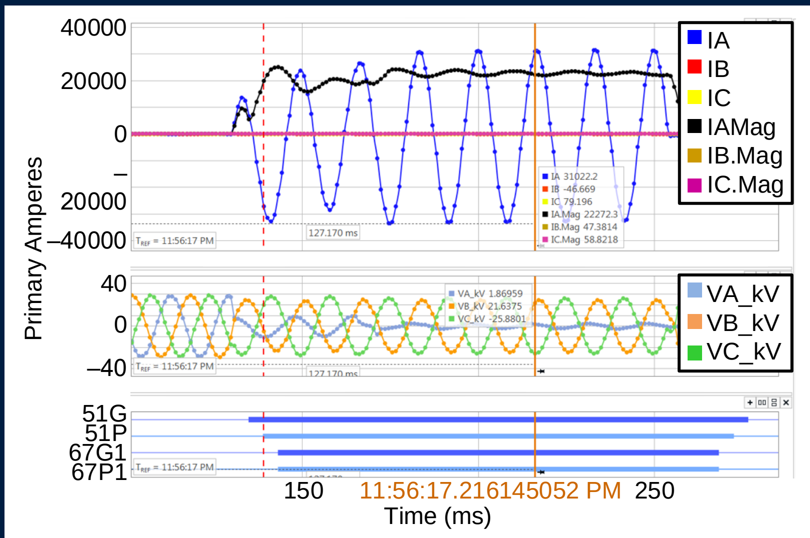
Case Study 2
Sequence Network Connection



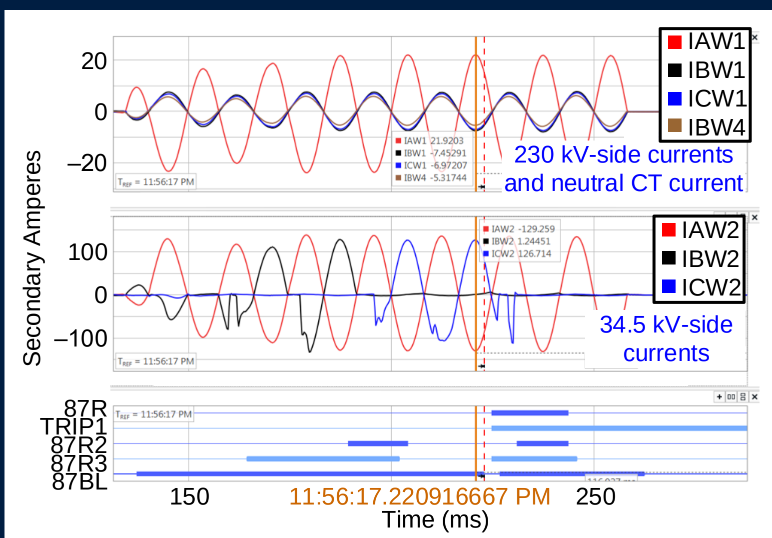
Case Study 3



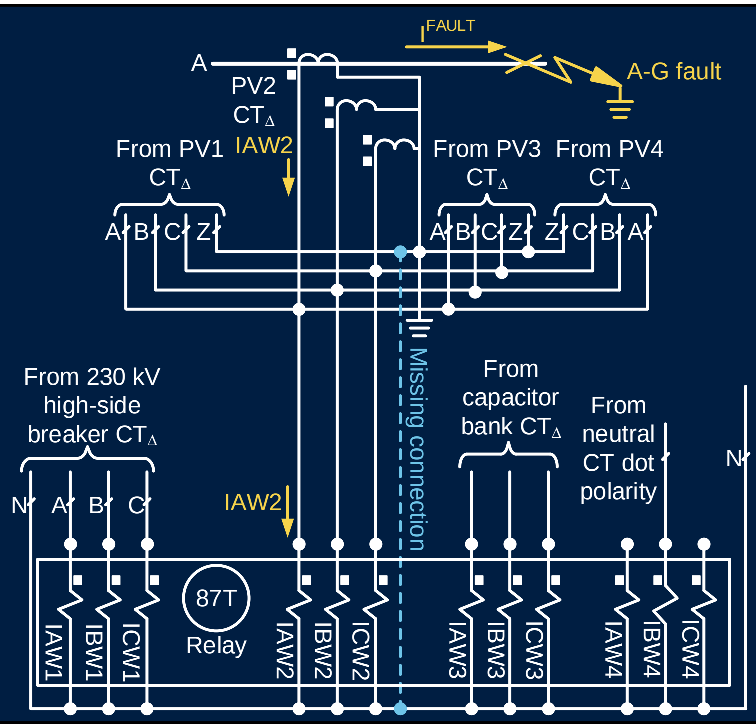
PV2 50/51 Relay Fault Oscillography



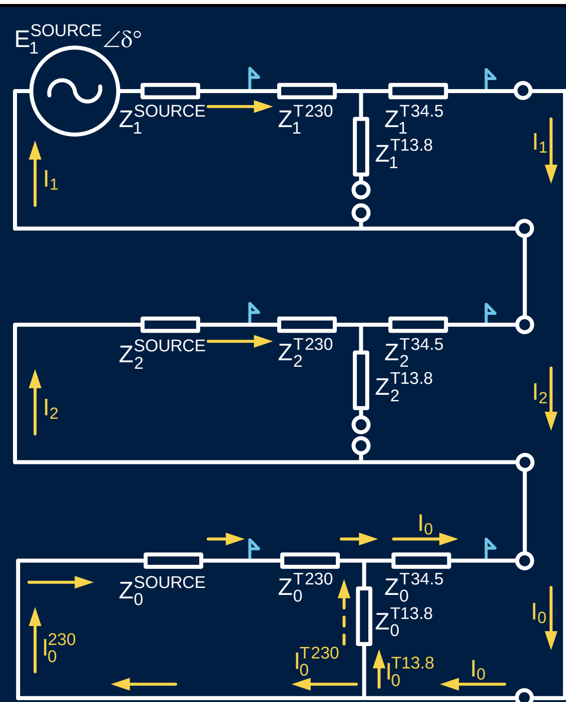
87T Relay Fault Oscillography



Case Study 3
87T Relay Secondary Circuit Wiring



Case Study 3
Sequence Network Connection



Case Study 3
Sequence Current Calculations

$$I_0 = I_1 = I_2 = I_0^{T230} + I_0^{T13.8}$$

$$I_0^{T230} = m \bullet I_0$$

$$m = \left(\frac{Z_0^{T13.8}}{Z_0^{T13.8} + Z_0^{T230}} \right)$$

$$I_0^{T13.8} = (1 - m) \bullet I_0$$

$$\begin{bmatrix} IAW1 \\ IBW1 \\ ICW1 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} I_0^{T230} \\ I_1^{T230} \\ I_2^{T230} \end{bmatrix}$$

$$\begin{bmatrix} IAW1 \\ IBW1 \\ ICW1 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} m \bullet I_0 \\ I_0 \\ I_0 \end{bmatrix}$$

$$IAW1 = (m + 2) \bullet I_0$$
$$IBW1 = (m - 1) \bullet I_0$$
$$ICW1 = (m - 1) \bullet I_0$$

$$IBW1 = ICW1 = \left(\frac{m-1}{m+2} \right) \bullet IAW1$$

$IAW1 = 21.9\angle 0°$

$IBW1 = 7.45\angle 180°$

$ICW1 = 6.97\angle 180°$

$$\Rightarrow \frac{m+2}{m-1} = -3$$
$$\Rightarrow m = 0.25$$

Conclusions
Event Reports

- Performance report card
- Hold valuable information about power system

Conclusions

Event Report Analysis Using Symmetrical Components

- Provide holistic view of power system
- Explain non-classic fault waveforms at relay location
- Estimate fault location
- Determine or validate power system element impedance, or build relationships between fault oscillography and element impedance

Questions?