Ongoing List of Topics:
- URL: http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm
- Term Project - project topic (2-3 sentences) submit for approval ASAP!
- March 2nd - Detailed outline and reference list for term project.

Today:
- Exercise 8 due Thurs Mar 1st. Solution strategy discussed.
- Show and tell - 67 relays
  - G1: electromechanical KRD-4 (Ground relay)
  - G2: electronic BE1-67N (Ground Relay)
  - G3: uProc SEL-311(multi-function uProc relay)
- Symmetrical Components overview
  - Basic pos/neg/zero networks
  - Fault current is only first step of calc. Need fault contributions at relays!
  - Use of sequence networks

Next:
- Transformer connections in zero seq, and phase shifts in pos/neg.
- Overview of impedance protection concepts
- Overview of differential protection concepts - for bus, line, transformer
- Continue on with specific protection schemes.
Work with your term project team. The EE5223 student should provide organizational leadership with calculations and possible Matlab programming and/or application of ASPEN, and make themself available as mentors/tutors and technical experts. The undergraduate students are now learning about symmetrical components - this background is helpful but not essential for this assignment.

Problem Definition:

The main focus in line protection (both for distribution and for transmission) is to determine what the relay will "see" for each possible kind of fault. Review section 4.16.4 in your text, and especially figures 4.34 and 4.35. Figure 3.8 (top part of figure) can also be helpful, since it shows the "three-line" connections of VTs, CTs, and relays. It is important to have a good understanding of how the voltages and currents being monitored by the relay change, how the relay is using these voltages and currents, and then finally to be able to set the relays to properly discern between a no-trip condition (normal system operation or a fault that is outside of the relay's zone of protection) and a trip condition (a fault within its zone of protection).

The simplest way to gain insight about how the voltages and currents monitored by a relay will change for various types of faults is to study the most basic circuit:

![Diagram](image)

The source impedance $Z_s$ and the line impedance $Z_l$ each can be defined either as phase impedances [$Z_p$] (i.e. $Z_A$, $Z_B$, $Z_C$, $Z_w$) or as sequence impedances [$Z_s$] (i.e. $Z_0$, $Z_1$, $Z_2$). Conversion back and forth between these impedances can be done via the transformation matrix [$A$].

a) Work together to design/draw a detailed "3-line" diagram that includes the source, line, bus, impedances, VTs, and CTs. Extend the CT and VT secondary connections to a generic relay that is monitoring the line. (These relays are 67, but could be 50/51 or 21). For the source, assume that it is wye-connected with the possibility of a non-zero neutral grounding impedance $Z_{Nc}$. Various types of faults can appear anywhere along the length of the line, and include a fault impedance $Z_f$.

b) Working with phase domain impedances, develop a strategy for calculating the phase voltages and currents input to the relay for all 4 types of faults, both near- and far-end. You can use MatLab (if that makes sense) and/or ASPEN (if that makes sense), with the goal of teaching the undergrad students the most important concepts. Do hand calcs to verify correct calculation is being done.

c) The "deliverable" of this assignment can be achieved either in Matlab or ASPEN: given the numeric values of source and line impedances, CT and VT ratios, fault location, and fault type (LG, LL, LLG, or 3ph), provide a) a phasor plot of the Vs and Is that each 67-relay element "sees" for each fault. b) Recommend appropriate "max torque angle" setting for phase and ground elements such that every fault will be correctly detected.
L-G Fault, A-G

\[ V_A \]
\[ V_C \]
\[ V_B \]

Source \( V \)

Bus \( V \)

Fault \( V \)

8 scenarios, plus play with \( Z_F \) & \( Z_N \)
Hmwk 8 Strategy

INPUTS

Source

\[ V_{A1} = 1.05 \angle 0° \]

\[ V_{A0}, V_{A2} = ? \]

Line

Fact:

- LG/LLG/LL/3Ø
- Loc: 0-100%
- 2F

\[ Z_0 = \]
\[ Z_1 = \]
\[ Z_2 = \]

"Outputs": At Relay, \[ I_a, I_b, I_c, I_0 \]
\[ V_{A0}, V_{B0}, V_{C0} \to V_{AB}, V_{AC}, V_{CA} \]
3V_{A0}
Types KRD-4 and KRQ Directional Overcurrent Ground Relays

The directional unit compares the phase angle relationship between the ground fault current and the polarizing quantity to produce contact-closing torque for faults in the trip direction, and contact-opening torque for faults in the non-trip direction. Relay operation occurs when both the directional unit and the instantaneous overcurrent unit close their contacts. The fault current must therefore be greater than the tap setting of the overcurrent unit.

Type KRQ

The KRQ relay is a high-speed directional overcurrent ground relay in which the directional unit operates on negative sequence current and voltage, and the over-current unit operates on residual or ground current.

The phase angle between negative sequence voltage and negative sequence current is used for directional discrimination. Negative sequence polarization is applied as follows: (1) where zero sequence voltage or polarizing current is not available or the current is not a reliable source, ω; (2) where incorrect zero sequence polarization of directional units results from mutual indication between transmission lines.

The negative sequence current and voltage are obtained by means of self-contained negative sequence filters connected between the directional unit and the current and potential transformers.

The KRQ relay is for use at locations where the present equipment or system conditions do not permit the use of the conventional types of directional ground relays operating entirely on residual current and voltage.

It is applicable for ground protection at underground substations or grounded systems where only two potential transformers are available, or where the potential transformers are on the low-tension side of a wye-delta or delta-wye power transformer bank.

Application

Types KRD-4 and KRQ relays are high-speed, directional overcurrent relays. They are used for the detection of ground faults on transmission lines, feeder transmission lines, and feeder circuits.

They can also be used, without modification, to provide directional ground fault protection in K-Dar carrier relaying schemes.

Type KRD-4

This dual polarized relay can be polarized from a potential source, a local ground source, or from both simultaneously.
Construction

Fig. 1
KRD-4 Front View

Fig. 2
KRD-4 Rear View

Fig. 3
KRO Front View

Fig. 4
KRO Rear View

Overcurrent Trip Contact (I)
Directional Trip Contact (D)

Polarizing Resistor
Decoupler Calibration Reactor
Polarizing Reactor
Decoupler Reactor
Varistor
Polarizing Capacitor
Decoupler Capacitor
Phase Shifting Capacitor
Saturating Transformer
1) Overcurrent Unit (I)

The ground instantaneous overcurrent section consists of an induction cylinder unit with moving and stationary contact, phase shifting capacitor, varistor, saturating transformer with a tapped primary winding and a secondary winding, and a tap block for current pickup settings.

A varistor is connected across the secondary winding to reduce the voltage peaks applied to the induction unit and to the phase shifting capacitor.

2) Tap Block

The primary winding is tapped, and these taps are brought out to a tap block for ease in changing the pick up of the overcurrent unit. By using a tapped transformer, the relay can provide approximately the same energy level at a given multiple of pickup current for any tap setting, resulting in one time curve throughout the range of the relay.

3) Directional Unit (D)

KRD-4

The KRD-4’s directional unit consists of an induction cylinder unit, phase shifting network, and a die-coupling network.

Since this single unit can be polarized from a potential source, from a local ground source, or from both simultaneously, a simplified trip circuit and one, instead of two, back contacts can be used in the overcurrent torque control circuit.

KRG

The KRG directional unit is a product induction cylinder type, which operates on the interaction between the polarizing circuit flux and the operating circuit flux.

4) Indicating Contactor Switch (ICS)

When the dc operated ICS is energized, the moving contacts bridge two stationary contacts, completing the trip circuit.

Characteristics

Current Ranges

Both the KRD-4 and the KRG relays are available in the following current ranges:

<table>
<thead>
<tr>
<th>Range: Amps</th>
<th>Taps</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5-2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>1-4</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>2-8</td>
<td>2.0</td>
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<td></td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
</tr>
<tr>
<td>4-16</td>
<td>4.0</td>
</tr>
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<td></td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
</tr>
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<td>8-40</td>
<td>8.0</td>
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<td></td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>12.0</td>
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<td>10-40</td>
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<td>20.0</td>
</tr>
<tr>
<td></td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td>40.0</td>
</tr>
</tbody>
</table>

* Tap value is the minimum current required to just close the relay.

Torque Angle (KRD-4)

When the relay is potential polarized, maximum torque angle occurs when operating current lags polarizing voltage by approximately 65 degrees.

When current polarized, maximum torque angle occurs when operating current is in phase with the polarizing current.

Trip Circuit

The main contacts of both the KRD-4 and KRG relays will safely close 30 amperes at 250 volts dc, and the seal-in contacts of the ICS unit will safely carry this current long enough to trip a circuit breaker.

The ICS has a pickup of approximately 1 ampere. Its dc resistance is 0.1 ohms.

Directional Unit Sensitivity

<table>
<thead>
<tr>
<th>Polarizing Quantity</th>
<th>Minimum Pickup Values</th>
<th>Phase Angle Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.4</td>
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<tr>
<td>Current</td>
<td></td>
<td>0.5</td>
</tr>
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</table>

Further Information

List Prices: PL 41-020
Technical Data: TD 41-025
Instructions:
Type KRD-4, IL 41-137.3
Type KRG, IL 41-164
Renewal Parts: RPD 41-963
Flexительно Case Dimensions: DB 41-076
Contactor Switches: DB 41-081
Other Protective Relays:
Application Selector Guide, TD 41-016

September, 1990
### Type KRD-4 and KRQ Directional Overcurrent Ground Relays

#### Overcurrent, Instantaneous, Directional, Single Phase (Device Number: 67N)

<table>
<thead>
<tr>
<th>Type</th>
<th>Application</th>
<th>Indicating Contactor Switch©</th>
<th>Current Range: Amps Ac</th>
<th>Relay Data</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Internal Schematic</td>
</tr>
<tr>
<td>KRD-4© ©</td>
<td>Ground Detection</td>
<td>1.0 amp dc</td>
<td>0.5-2.0</td>
<td>629A509</td>
</tr>
<tr>
<td>Instantaneous</td>
<td></td>
<td>1.0 amp dc</td>
<td>1-4</td>
<td>293B307A10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-8</td>
<td>2-8</td>
<td>293B307A11</td>
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<tr>
<td>Spst-cc</td>
<td>208 volts/30 sec</td>
<td>0.2/2.0 amp dc</td>
<td>0.5-2.0</td>
<td>762A542</td>
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<td></td>
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<td>1-4</td>
<td>2-8</td>
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<td>10-40</td>
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<td>293B307A15</td>
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#### Overcurrent, Instantaneous, Directional, Negative Sequence (Device Number: 67N)

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<th>Application</th>
<th>Indicating Contactor Switch©</th>
<th>Current Range: Amps Ac</th>
<th>Relay Data</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Internal Schematic</td>
</tr>
<tr>
<td>KRQ</td>
<td>Ground Detection</td>
<td>1.0 amp dc</td>
<td>0.5-2.0</td>
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<tr>
<td>Instantaneous</td>
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<td>1.0 amp dc</td>
<td>1-4</td>
<td>774B232A09</td>
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<td></td>
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<td>2-8</td>
<td>2-8</td>
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<td>4-16</td>
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<td>10-40</td>
<td></td>
<td>774B232A12</td>
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<tr>
<td>Spst-cc</td>
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<td>0.2/2.0 amp dc</td>
<td>0.5-2.0</td>
<td>188A308</td>
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<td>2-8</td>
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</table>

#### Potential Polarizing Transformers, Single Phase (Product Bulletin 42-871 for dimensions)©

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</thead>
<tbody>
<tr>
<td>50</td>
<td>50/60</td>
<td>115</td>
<td>66.5</td>
<td>115</td>
<td>25</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Connect wye/broken delta</td>
<td>9626A06G01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200</td>
<td>115</td>
<td>66.5</td>
<td></td>
<td>9626A06G02</td>
</tr>
<tr>
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<td></td>
<td>200</td>
<td>115</td>
<td>115</td>
<td></td>
<td>9626A06G03</td>
</tr>
</tbody>
</table>

© 50-Hertz relays and auxiliaries can be supplied at same price. Order “Similar to Style Number ........., except 50 Hertz”.
© See potential polarizing transformers, this page.
© ICS: Indicating Contactor Switch (dc current operated) having seal-in contacts and indicating target which are actuated when the ICS coil is energized at or above pickup current setting. Suitable for dc control voltages up to and including 250 volts dc. Two current ranges available: (1) 0.2/2.0 amps dc, with tapped coil. (2) 1.0 amp dc, without taps.
Rating of ICS unit used in specific types of relays is shown in price tables. All other ratings must be negotiated.
When ac current is necessary in a control trip circuit, the ICS unit can be replaced by an ACS unit.
The ACS unit may be supplied in place of an ICS unit at no additional cost. Specify system voltage rating on order.
© Refer to LVIT Sales, Low Voltage Instrument Transformer Division, Pineville, NC, for price and shipment.
Figure 4: Internal Schematic of the Type KRC Relay in the FT-31 Case

Figure 5: Typical Operating Times for the D-Unit of the Type KRD, KRP, and KRC Relays
Figure 6: Typical Operating Times for the D-Unit of the Type KRD, KRP and KRC Relays
Figure 7: External Schematic of the Type KRC Relay

DEVICE NUMBER CHART

- 67N - DIRECTIONAL OVERCURRENT GROUND RELAY TYPE KRC
- 67N - OVERCURRENT UNIT OF TYPE KRC
- 67N - DIRECTIONAL UNIT OF TYPE KRC
- 52 - POWER CIRCUIT BREAKER
- ICS - INDICATING CONTACTOR SWITCH
- a - BREAKER AUXILIARY CONTACT
- TC - BREAKER TRIP COIL
Figure 8: External Schematic of the Type KRP Relay
Protect Lines With Easy-to-Use Current Differential Relays

Use SEL-311L Line Current Differential Relays with full-scheme backup for easy-to-apply high-speed line protection.

Features and Benefits

- **Protect**
  Apply single-pole or three-pole subcycle current differential protection. Reduce protection system costs by using built-in distance and/or overcurrent backup functions.

- **Simplify**
  Innovative operating characteristic makes settings easy. No fault studies are required for most differential applications.

- **Optimize**
  Use single or dual channels for reliability. Apply on two- or three-terminal lines with or without tapped lines.

- **Monitor**
  Incorporate synchrophasor measurements into wide-area protection and control systems. Use high-accuracy time correlation to improve event report analysis.

- **Automate**
  Reduce total project construction and operation costs by integrating four-shot recloser and relay logic operators into your automation system. Use serial or Ethernet communications to improve station integration.

Making Electric Power Safer, More Reliable, and More Economical®
Functional Overview

SEL-311L Relay

- Advanced SELogic® Control Equations
- Event Reports With Oscillography
- Sequential Events Recorder
- Breaker Wear Monitor
- Station Battery Monitor
- Ethernet Communications Port*
- DNP3 Level 2 Slave Protocol*
- IEC 61850 Protocol*
- MIRRORED BKVs® Communications and Advanced Scheme Logic
- Remote and Local Control Switches
- Local Display
- Fault Locator
- CCVT Transient Overreach Supervision

* Optional Functions

Superior, Sensitive, and Simple

- The SEL-311L Relay uses a vector ratio of the local and remote phase and sequence currents (Alpha Plane restraint) to provide high-speed protection, independent of line loading, CT saturation, or tapped load.
- Proven negative-sequence elements provide sensitivity for unbalanced faults. High-impedance fault detection gives secure operation for faults below load current or line-charging current levels.

Alpha Plane Restraint and Operate Regions

- Use factory default settings for basic line current differential applications. Configure the channels, select the CT ratios, and the SEL-311L Relay is ready for operation.
- Improve stability for critical systems using optional single-pole differential elements for high-speed fault clearing.

Differential Trip Speed

Accommodate channel asymmetry and CT saturation.

High-speed protection.
Full Scheme and Overcurrent Backup Included

- Backup protection in the SEL-311L Relay is identical to the complete functionality of the SEL-311C Relay, including four zones of positive-sequence, memory-polarized distance relaying. Sufficient memory time during zero-voltage faults allows distance element backup on short lines. Best Choice Ground Directional Element™ overcurrent relaying automatically selects the optimal directional unit for changing system conditions. Use MIRrored Birs® communications or a traditional channel interface for independent, communications-assisted tripping (e.g., POTT and DCB).
- Set independent backup upon loss of differential channels.
- A complete four-shot recloser with synchronization check is included. Use SELogic™ control equations to change the protection based on shot count. Use local, remote, and latched control switches to customize the protection system. Change the reclosing logic based on fault type or an external input.
- Six levels of overfrequency and/or underfrequency are included for load shedding and restoration. Combine with protective functions using SELogic control equations to optimize relay response, preserving system integrity.

CT Characteristic Security

- Remain secure during external faults when CTs saturate at one or more terminals.
- Accommodate CT saturation, even in the first half cycle.
- Use existing CTs without ratio or characteristic matching.

Flexible Channel Selection

- Select either single- or dual-channel operation using any combination of ITU-T G.703, EIA-422 (56 or 64 kbps), multimode fiber, or single-mode fiber.
- Use hot standby channel to increase dependability and security. Protection is not delayed and security is not compromised when the primary channel fails.
- Accommodate nonsymmetrical channel delays and channel-delay changes without desensitizing or delaying protection.

Tapped Line Coordination

- Use SEL-311L Relays on tapped lines without misoperation due to faults on the tap. Differential time-overcurrent elements calculate tap current to coordinate with tap protection.
- Choose between fuse-saving and trip-saving schemes for tapped loads. Use recloser shot count to select protection characteristic.
SEL-311L Line Current Differential Protection and Automation System

Three-Terminal Application

- Protect three-terminal lines with two or three channels. If three channels are used, the loss of any channel does not compromise protection.
- Provide high-speed operation for all terminals, even with weak infeed.
- Apply a third SEL-311L Relay at a tapped load, even without a breaker. Differential elements provide high-speed line operation without overtripping for faults on the tap.

Wide-Area Measurements

Synchrophasor Measurements
View absolute phase angles from across the power system.

High-Accuracy Timing
Use precise timestamping to improve analysis of wide-area events.

General Specifications

Output Contacts (14 total)
6 High-Speed, High I/C Contacts
  Pickup time <200 μs
  6 A continuous
  30 A make per IEEE C37.90-1989
  Break 10 A
8 Standard Contacts
  Pickup time <5 ms
  6 A continuous
  30 A make per IEEE C37.90-1989

Differential Ports
Any combination of one or two of the following:
  ITU-T G.703 codirectional at 64 kbps
  EIA-422 at 56/64 kbps
  850 nm multimode fiber
  1300 nm single-mode fiber

Operating Temperature
-40° to +85°C (-40° to +185°F)

Commitment to Quality

Schweitzer Engineering Laboratories, Inc. is committed to quality. Our certification to the ISO 9001 quality standard and our worldwide, ten-year product warranty are examples of this commitment. We encourage and appreciate your feedback about the use of SEL equipment, and we will use this information to continually improve our products and services.

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1 Eye-safe. Class I laser product per EN 60825-1

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2350 NE Hopkins Court • Pullman, WA 99163-5603 USA
Tel: 509.332.1890 • Fax: 509.332.7990 • Email: info@selinc.com
www.selinc.com • www.selindustrial.com
Making Electric Power Safer, More Reliable, and More Economical®
\[ V_{TH} = V_{OC} \]
\[ Z_{TH} = \frac{V_{OC}}{I_{SC}} \]
\[ I_{SC} = I_{N} \]
i.e. \[ \begin{bmatrix} \tilde{V}_{ao} \\
\tilde{V}_{al} \\
\tilde{V}_{a2}
\end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\
1 & a & a^2 \\
1 & a^2 & a
\end{bmatrix} \begin{bmatrix} \tilde{V}_a \\
\tilde{V}_b \\
\tilde{V}_c
\end{bmatrix} \]

Sequence Networks
Per Phase, A-N, P.u.

POS

NEG

Zero 32

See details on next page.
Seg: Networks

\[ Z_1 \]

\[ + \quad T_{11} \quad V_{11} \quad - \]

Pos ref

\[ Z_2 \]

\[ + \quad T_{22} \quad V_{22} \quad - \]

Neg ref

\[ Z_0 \]

\[ + \quad T_{00} \quad V_{00} \quad - \]

Zero ref

L-G: Pos, Neg, Zero in series

L-L: Pos, Neg in parallel

L-L-G: Pos, Neg, Zero in parallel
\[ I_{a1} = I_{a2} = I_{ao} \]

\[ \frac{I_F}{3} = \bar{I}_{a1} = \bar{I}_{a2} = \bar{I}_{ao} \]

\[ [V_p] = [A] [V_s] \]
Pos: $\text{Bus 1: } V_{A1,1} = V_{A1,\text{fault}} + I_{1F} \bar{Z}_L,1F$

$\text{Bus 2: } V_{A1,2} = V_{A1,\text{fault}} + I_{2F} \bar{Z}_L,2F$

NEG: $\text{Bus 1: } \tilde{V}_{A2,1} = \tilde{V}_{A2,\text{fault}} + I_{a2,2F} \bar{Z}_L,1F$

$\text{Bus 2: } \tilde{V}_{A2,2} = \tilde{V}_{A2,\text{fault}} + I_{a2,2F} \bar{Z}_L,2F$

Zero: $\tilde{V}_{ao,1} = \tilde{V}_{ao,\text{fault}} + I_{ao,1F} \bar{Z}_0,1F$

$\tilde{V}_{ao,2} = \tilde{V}_{ao,\text{fault}} + I_{ao,2F} \bar{Z}_L,2F$
Then you'll have \([I_s] \& Lvel\)

\[
\begin{bmatrix}
V_{a1} \\
V_{a2}
\end{bmatrix}
\]

Phase Qths: [A]

21 relays: Seg Qths (i.e. Pos, Neg, 20)

Then can "apply" relay, i.e. do settings.
\[ Z_0 = \frac{V_{AC}}{I_{AC}} \]

For Relays:

\[ Z_0 = \frac{V_{AC}}{I_{AC}} \]
\[ Z_1 = \frac{V_{A1}}{I_{A1}} \]
\[ Z_A = \frac{V_{AN}}{I_{A}} \]

Simplest case

If you use \( V_{AC} \):

\[ Z_{AB} = \frac{V_{AB}}{I_{AB}} = \frac{V_{A}-V_{B}}{I_{A}-I_{B}} \]

"delta currents"