Phase B Components:
\[
\begin{pmatrix}
IB_0^v \\
IB_1^v := B_{012}^{-1} \cdot IBcp_x^v \\
IB_2^v
\end{pmatrix}
\begin{pmatrix}
IAcpx^v
\end{pmatrix}
\]

Phase C Components:
\[
\begin{pmatrix}
IC_0^v \\
IC_1^v := C_{012}^{-1} \cdot ICcp_x^v \\
IC_2^v
\end{pmatrix}
\begin{pmatrix}
IAcpx^v
\end{pmatrix}
\]

The magnitudes for the phase A, B and C symmetrical components will be the same, but the angles will differ. So this will matter more later.

---

**Relay Model:**

- **Relay Settings**

Instantaneous Overcurrent Elements (secondary Amps, again leave off units) for zero sequence (ground) and negative sequence (designated with a Q). elements. These numbers are just made up so don't base your answers on these. Use magnitudes from the phase A components.

*Enable the relay elements you want to use (1 means enabled, 0 means disabled)*

- E50P1 := 1 E50P2 := 1
- E50Q1 := 1 E50Q2 := 1
- E50G1 := 1 E50G2 := 1
Relay Pickup Settings (default values)

\[
\begin{align*}
\text{Level}_1\_50P := 5 & \quad \text{Level}_2\_50P := 2.5 \\
\text{Level}_1\_50Q := 5 & \quad \text{Level}_2\_50Q := 2.5 \\
\text{Level}_1\_50G := 5 & \quad \text{Level}_2\_50G := 2.5 \\
\end{align*}
\]

determine and modify

Level 2 Time Delays

\[
\begin{align*}
\text{cycles} := 1 \\
T_{\text{DelP}} := 5\text{cycles} & \quad \text{default at 5 cycles} \\
T_{\text{DelQ}} := 5\text{cycles} \\
T_{\text{DelG}} := 5\text{cycles} \\
\end{align*}
\]

- Relay Element Pick Up Logic

Negative sequence element (modified to latch and stay one, no drop out for now)

Initialize arrays with all zeros:

\[
\begin{align*}
\text{Level1}_Q\_pu_v := 0 & \quad \text{Level2}_Q\_pu_v := 0 \\
\text{Level1}_Q\_pu_v := \begin{cases} 
1 & \text{if } |IA_2_v| \geq \text{Level}_1\_50Q \\
1 & \text{if } \text{Level1}_Q\_pu_{v-1} \geq 0.01 \\
0 & \text{otherwise}
\end{cases} \\
\text{Level2}_Q\_pu_v := \begin{cases} 
1 & \text{if } |IA_2_v| \geq \text{Level}_2\_50Q \\
1 & \text{if } \text{Level2}_Q\_pu_{v-1} \geq 0.01 \\
0 & \text{otherwise}
\end{cases}
\end{align*}
\]
Enter Constants. Note that RS is the sampling rate, and the value of 16 here is assuming that the COMTRADE file was sampled at that rate.

\[
a := 1 \cdot e^{j \cdot 120 \text{deg}}
\]

- Phase A symmetrical components transform
  \[
  A_{012} := \begin{pmatrix}
  1 & 1 & 1 \\
  1 & a^2 & a \\
  1 & a & a^2
  \end{pmatrix}
  \]

- Phase B symmetrical components transform
  \[
  B_{012} := \begin{pmatrix}
  1 & a & a^2 \\
  1 & 1 & 1 \\
  1 & a^2 & a
  \end{pmatrix}
  \]

- Phase C symmetrical components transform
  \[
  C_{012} := \begin{pmatrix}
  1 & a^2 & a \\
  1 & a & a^2 \\
  1 & 1 & 1
  \end{pmatrix}
  \]

RS := 16

Enter vector indices for filter and relay calculations (do not change these)
\[
i := 0 \ldots \text{rows(data)} - 1
\]
\[
v := \frac{\text{RS}}{4} \ldots \text{rows(data)} - 1\quad \text{Offset samples by 1/4 cycles for phasor calculation}
\]
\[
d := \frac{5 \cdot \text{RS}}{4} \ldots \text{rows(data)} - 1\quad \text{Offset samples by 5 cycles for trip calculation}
\]
\[
\text{If} := \text{RS} - 1 \ldots \text{rows(data)} - 1
\]

**User Entered Parameters:**

- I am entering typical values the current transformer ration (CTR) and voltage transformer ratio (PTR). You need to change these to match your calculations.
  \[
  \text{CTR} := 1 \quad \text{PTR} := 1
  \]

- Relay Settings

  *Moved later in the file close to the relay model and plots.*
Ground (zero sequence) element (using calculated instead of measured currents):

Initialize arrays with all zeros: \( \text{Level1G}_{\text{pu}_V} := 0 \quad \text{Level2G}_{\text{pu}_V} := 0 \)

\[
\begin{align*}
\text{Level1G}_{\text{pu}_V} & := 1 \text{ if } 3 |I_{A0V}| \geq \text{Level1G}_-50G \\
& \quad 1 \text{ if } \text{Level1G}_{\text{pu}_V-1} \geq 0.01 \\
& \quad 0 \text{ otherwise}
\end{align*}
\]

\[
\begin{align*}
\text{Level2G}_{\text{pu}_V} & := 1 \text{ if } 3 |I_{A0V}| \geq \text{Level2G}_-50G \\
& \quad 1 \text{ if } \text{Level2G}_{\text{pu}_V-1} \geq 0.01 \\
& \quad 0 \text{ otherwise}
\end{align*}
\]

Phase current element (phase A or phase B or Phase C exceed pickup)

Initialize arrays with all zeros: \( \text{Level1P}_{\text{pu}_V} := 0 \quad \text{Level2P}_{\text{pu}_V} := 0 \)

\[
\begin{align*}
\text{Level1P}_{\text{pu}_V} & := 1 \text{ if } |I_{AcpV}| \geq \text{Level1P}_-50P \\
& \quad 1 \text{ if } |I_{BcpV}| \geq \text{Level1P}_-50P \\
& \quad 1 \text{ if } |I_{CcpV}| \geq \text{Level1P}_-50P \\
& \quad 1 \text{ if } \text{Level1P}_{\text{pu}_V-1} \geq 0.01 \\
& \quad 0 \text{ otherwise}
\end{align*}
\]

\[
\begin{align*}
\text{Level2P}_{\text{pu}_V} & := 1 \text{ if } |I_{AcpV}| \geq \text{Level2P}_-50P \\
& \quad 1 \text{ if } |I_{BcpV}| \geq \text{Level2P}_-50P \\
& \quad 1 \text{ if } |I_{CcpV}| \geq \text{Level2P}_-50P \\
& \quad 1 \text{ if } \text{Level2P}_{\text{pu}_V-1} \geq 0.01 \\
& \quad 0 \text{ otherwise}
\end{align*}
\]

- **Trip Logic**

Note that logic AND is Ctrl + shift + 7, the logic OR is Ctrl + shift + 6, the logic not is Ctrl + shift +1.

\[
\begin{align*}
\text{TR50P}_d := & \ E50P1 \land \text{Level1P}_{\text{pu}_d} \lor \ E50P2 \land \text{Level2P}_{\text{pu}_d} \land T_{\text{DelP}} \land RS \\
\text{Note that this includes the time delay for level 2}
\end{align*}
\]

\[
\begin{align*}
\text{TR50Q}_d := & \ E50Q1 \land \text{Level1Q}_{\text{pu}_d} \lor \ E50Q2 \land \text{Level2Q}_{\text{pu}_d} \land T_{\text{DelQ}} \land RS
\end{align*}
\]
Trip equation response
**Alternate Approach for Three Phase Faults**

- An alternate approach instead of the torque equation is to compare the angle single phase impedance calculated from measurements to thresholds

\[-90^{\circ} + Z1A_{L} \neq \theta_{Z1} \neq 90^{\circ} + Z1A_{L}\]

\[\theta_{V1_{v}} := \text{arg}(VA_{1_{v}} + 0.000001)\]

\[\theta_{II_{v}} := \text{arg}[(IA1_{v}) + 0.000001]\]

\[\text{Phase}_{II_{v}} := \begin{cases} 
\theta_{II_{v}} - \theta_{V1_{v}} & \text{if } |\theta_{II_{v}} - \theta_{V1_{v}}| < \pi \\
(\theta_{II_{v}} - \theta_{V1_{v}} - 2\pi) & \text{if } (\theta_{II_{v}} - \theta_{V1_{v}}) > \pi \\
(\theta_{II_{v}} - \theta_{V1_{v}} + 2\pi) & \text{if } (\theta_{II_{v}} - \theta_{V1_{v}}) < -(\pi) 
\end{cases}\]

\[\text{Phase}_{V1_{v}} := \begin{cases} 
\theta_{V1_{v}} - \theta_{V1_{v}} & \text{if } |\theta_{V1_{v}} - \theta_{V1_{v}}| < \pi \\
(\theta_{V1_{v}} - \theta_{V1_{v}} - 2\pi) & \text{if } (\theta_{V1_{v}} - \theta_{V1_{v}}) > \pi \\
(\theta_{V1_{v}} - \theta_{V1_{v}} + 2\pi) & \text{if } (\theta_{V1_{v}} - \theta_{V1_{v}}) < -(\pi) 
\end{cases}\]

\[Z1A_{v} := \frac{j \cdot \text{Phase}_{V1_{v}}}{|VA_{1_{v}}| e^{j \cdot \text{Phase}_{II_{v}} + 0.00001}}\]
- Underlying assumptions with current based directional elements
  - Fault current has a significantly different angle than load current
  - Significant I2 and/or IO for unbalanced

  \[ \text{\textbullet \ works well in the following:} \]
  1. Synchronous generators
  2. Solidly grounded system (low impedance grounded)
**Ungrounded Protection Characteristics**

- Low fault currents, some self-extinction
- Poor relay relay response and direction
- Often protect based on voltage
  - Zero sequence or three phase voltage
  - Or loss of injected signal
  - Or capacitive currents in cables
- Detect first ground fault and alarm, since second ground fault has big current

---

**High Impedance Ground: Resistive Type**

- Large resistance connected to neutral
- Common in large generator protection (sometimes transformer in neutral)
- Size resistance to limit fault current to 25A or less
- Neutral voltage shifts, over voltage relay connected across resistor
- Poor directional capability
Issues with Ungrounded Systems

- No intentional ground on neutral/ phases
- Ground fault causes neutral shift

- Need L-L voltage rating on insulation

Ungrounded Systems

- Parasitic capacitance in all components
- Resonates with line inductance, often doubles transients over voltage
- Equipment damage may result from voltage, but not likely from fault currents unless a second ground fault occurs
Sputtering ground fault
Summary of the Impacts of Grounding on System Protection

Grounding

- System grounding big impact on ability to detect ground faults
- Common ground options:
  - » Isolated ground (ungrounded)
  - » High impedance ground
  - » Low impedance ground
    » Solid or effective ground