Lab 2B: Directional Overcurrent Relay Model

The MathCAD sheet below implements some basic relay calculations. The file takes data read from a Comtrade file and postprocesses it.

The matrix "data" below is the data captured from a COMTRADE "*.dat" file. To read in a data file remove the table currently at the top of the file. Then choose "Insert" ---> "Component".

- This will open a dialog box. **One option** is to choose "Input Table".
    - * Then select the first cell in the table and right click your mouse and choose "Import".
    - * Then browse to the "*.dat" COMTRADE file and select. This will fill in the data in the table. Then name the variable as "data"
- Another option is to choose "File Read or Write".
    - * This will open a dialog box, choose Text file
    - * Browse for file with extension .txt or .csv.
    - * Your assignments will tell you which files to open.
- The example below uses the File Read or Write option.

Read Comtrade File Data

1. Read Comtrade Configuration File: Example from EO lab 2

config :=

...\FDLGOPER.cfg

Right click on the floppy disk icon and select "Choose File" to open a file browser. Choose the *.cfg file from the contrade file (you will need to type the extension). MathCAD 13 or higher users, right click and select properties.

data :=

...\FDLGOPER.dat

Right click on the floppy disk icon and select "Choose File" to open a file browser. Choose the *.dat file from the contrade file (it should be an accepted file type)

COMTRADE configuration file format:
1. The first row (row 0) states how the file was created and the version of the standard
2. The second row (row 1) gives the total number of inputs (7 for these cases), number of analog inputs (7 here) and number of digital inputs (0 here)
3. Rows 2-8 are the analog inputs for relay 1 in this model, in the following order:
    In (referred to as residual current below)
    Ia
    Ib
    Ic
    Van at Bus 1
    Vbn
    Vcn
4. Data sampled 16 times per cycle (960 Hz)

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.

    $CTR := 1$ $PTR := 1$ Same for both relay models

    Sampling rate (samples/sec) $RS := 16$

Click on the Arrow to hide/unhide the digital filtering, angle calculations and symmterical components calculations

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)

	Relay 1			*Relay 1 Directional Elements*
E50P1_r1 := 1	E50P2_r1 := 1			E32P_r1 := 1
E50Q1_r1 := 1	E50Q2_r1 := 1			E32Q_r1 := 1
E50G1_r1 := 1	E50G2_r1 := 1			E32G_r1 := 1

*Relay Pickup Settings (*Relay 1 Overcurrent Settings. Phase element will overreach on 3 phase fault on level 1 and underreach on DLG fault on level 2.

Level_1_50P_r1 := 6.75	Level_2_50P_r1 := 5.07
Level_1_50Q_r1 := 3.48	Level_2_50Q_r1 := 2.53
Level_1_50G_r1 := 6.11	Level_2_50G_r1 := 4.01

<mark style="background:yellow">*Directional element settings for Relay 1*</mark>   <mark style="background:#90EE90">Quantities requiring setting have a green background</mark>

Default Line Impedance and angle Settings

<mark style="background:#90EE90">$Z1 := (0.05 + j \cdot 20) ohm$</mark>   <mark style="background:#90EE90">$Z0 := 3 \cdot Z1$</mark>   • Change to match this system

$Z1ANG := \arg(Z1)$

$Z0ANG := \arg(Z0)$ <mark style="background:#90EE90">$MTA_1 := Z1ANG$</mark> <mark style="background:#90EE90">$MTA_0 := Z0ANG$</mark>

Negative Sequence Directional Element

- Minimum Negative Sequence Current (as a percentage of I1) to Enable Directional Element.

  $a_2 := 0.001$ Default setting (set this to block false tripping on load current)

- Forward Threshhold (could be set at the negative of the source impedance, or perhaps minimum source impedance)

  $Z_{2Forward} := -0.25$ Default setting--captures most negative values

- Reverse Fault Threshhold (could be set at the total impedance looking into the line and the system behind it, or merely as a positive number)

  $Z_{2Reverse} := 0.25$ Default setting--captures most positive values

Zero Sequence Directional Element

- Minimum Zero Sequence Current (as a percentage of I1) to Enable Directional Element.

  $a_0 := 0.0001$ Default setting (set this to block false tripping on load current)

- Forward Threshhold (could be set at the negative of the source impedance, or perhaps minimum source impedance)

  $Z_{0Forward} := -0.1$ Default setting--captures most negative values

- Reverse Fault Threshhold (could be set at the total impedance looking into the line and the system behind it, or merely as a positive number)

  $Z_{0Reverse} := 0.1$ Default setting--captures most positive values

Torque Phase Directional Element

- Threshhold for three phase faults (torque based scheme used because these will have minimal I2 and I0)
- Torque threshhold

  $T_{Pforward} := 1$ Needs to be set high enough to not trip on load, but still respond to faults.

$$T_{Preverse} := -1$$

Level 2 Time Delays   Define   cycles := 1

$$T_{DelP\_r1} := 5 \text{cycles}$$

$$T_{DelQ\_r1} := 5 \text{cycles}$$

$$T_{DelG\_r1} := 5 \cdot \text{cycles}$$

- ### *Relay Element Pick Up Logic*

  *Initialize Relay Element Terms (use I2 and I0, not 3*I2 and 3*I0)*

  $$\text{Level1Q\_r1\_pu}_v := 0 \qquad \text{Level2Q\_r1\_pu}_v := 0$$

  $$\text{Level1G\_r1\_pu}_v := 0 \qquad \text{Level2G\_r1\_pu}_v := 0$$

  $$\text{Level1P\_r1\_pu}_v := 0 \qquad \text{Level2P\_r1\_pu}_v := 0$$

Relay 2 pickup logic and trip equations:

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

$$\text{Level1Q\_r1\_pu}_v := \begin{vmatrix} 1 & \text{if} & \left| \text{IA2\_r1}_v \right| \geq \text{Level\_1\_50Q\_r1} \\ 1 & \text{if} & \text{Level1Q\_r1\_pu}_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{vmatrix} \qquad \text{Level2Q\_r1\_pu}_v := \begin{vmatrix} 1 & \text{if} & \left| \text{IA2\_r1}_v \right| \geq \text{Level\_2\_50Q\_r1} \\ 1 & \text{if} & \text{Level2Q\_r1\_pu}_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{vmatrix}$$

Ground (zero sequence) element (using calculated instead of measured currents):

$$\text{Level1G\_r1\_pu}_v := \begin{vmatrix} 1 & \text{if} & 3 \left| \text{IA0\_r1}_v \right| \geq \text{Level\_1\_50G\_r1} \\ 1 & \text{if} & \text{Level1G\_r1\_pu}_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{vmatrix} \qquad \text{Level2G\_r1\_pu}_v := \begin{vmatrix} 1 & \text{if} & 3 \left| \text{IA0\_r1}_v \right| \geq \text{Level\_2\_50G\_r1} \\ 1 & \text{if} & \text{Level2G\_r1\_pu}_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{vmatrix}$$

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

$$\text{Level1P\_r1\_pu}_v := \begin{vmatrix} 1 & \text{if } \left|\text{IA\_r1cpx}_v\right| \geq \text{Level\_1\_50P\_r1} \\ 1 & \text{if } \left|\text{IB\_r1cpx}_v\right| \geq \text{Level\_1\_50P\_r1} \\ 1 & \text{if } \left|\text{IC\_r1cpx}_v\right| \geq \text{Level\_1\_50P\_r1} \\ 1 & \text{if } \text{Le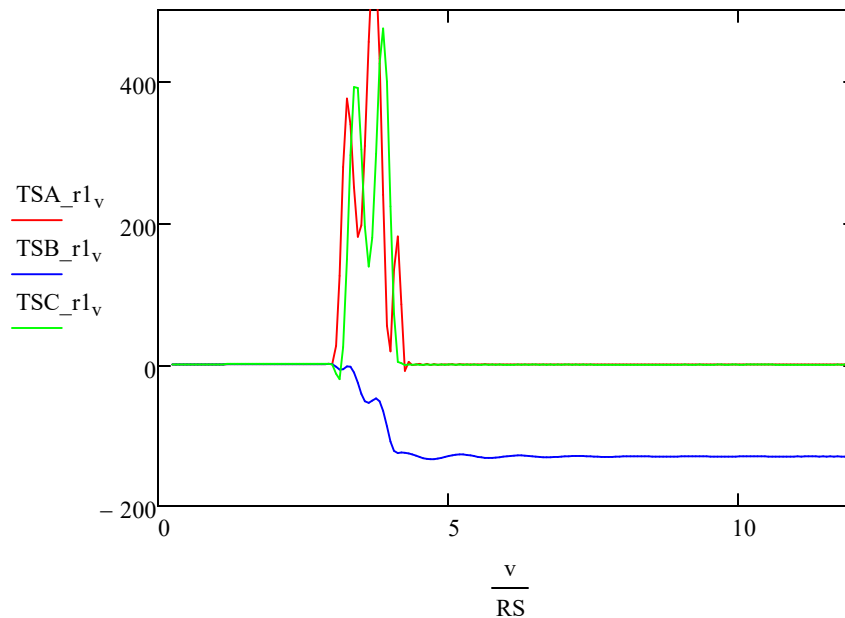vel1P\_r1\_pu}_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{vmatrix} \qquad \text{Level2P\_r1\_pu}_v := \begin{vmatrix} 1 & \text{if } \left|\text{IA\_r1cpx}_v\right| \geq \text{Level\_2\_50P\_r1} \\ 1 & \text{if } \left|\text{IB\_r1cpx}_v\right| \geq \text{Level\_2\_50P\_r1} \\ 1 & \text{if } \left|\text{IC\_r1cpx}_v\right| \geq \text{Level\_2\_50P\_r1} \\ 1 & \text{if } \text{Level2P\_r1\_pu}_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{vmatrix}$$

- Phase Torque Calculations

$$\text{TSA\_r1}_v := \left|\text{VA\_r1cpx}_v\right| \cdot \left|\text{IA\_r1cpx}_v\right| \cdot \cos\left[\theta_{\text{VA\_r1}_v} - \left(\theta_{\text{IA\_r1}_v} + \text{MTA}_1\right)\right]$$

$$\text{TSB\_r1}_v := \left|\text{VB\_r1cpx}_v\right| \cdot \left|\text{IB\_r1cpx}_v\right| \cdot \cos\left[\theta_{\text{VB\_r1}_v} - \left(\theta_{\text{IB\_r1}_v} + \text{MTA}_1\right)\right]$$

$$\text{TSC\_r1}_v := \left|\text{VC\_r1cpx}_v\right| \cdot \left|\text{IC\_r1cpx}_v\right| \cdot \cos\left[\theta_{\text{VC\_r1}_v} - \left(\theta_{\text{IC\_r1}_v} + \text{MTA}_1\right)\right]$$

- ***Relay 1 Directional Element Logic***

Torque Based Phase Direction Element:

$$A32F\_r1_v := TSA\_r1_v > T_{Pforward}$$
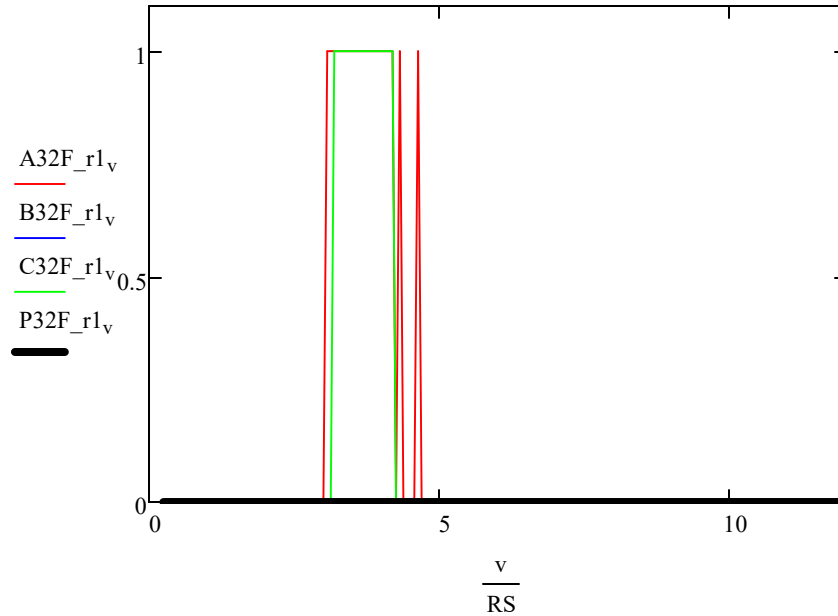
$$B32F\_r1_v := TSB\_r1_v > T_{Pforward}$$

$$C32F\_r1_v := TSC\_r1_v > T_{Pforward}$$

$$P32F\_r1_v := 0$$

$$P32F\_r1_v := \begin{cases} 1 & \text{if } \left(A32F\_r1_v \wedge B32F\_r1_v \wedge C32F\_r1_v\right) \\ 1 & \text{if } P32F\_r1_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

Note that this requires all three phases to be positive and relies on the negative or zero sequence elements for unbalanced faults. You can change this if desired.

The thick black line is the element that impacts the trip decision.

$A32F\_r1_v$

$B32F\_r1_v$

$C32F\_r1_v$

$P32F\_r1_v$

$$\frac{v}{RS}$$

Negative sequence and Zero sequence directional elements

Calculate negative sequence impedance and zero sequence impedance

$$Z2A\_r1_v := \frac{Re\left[VA2\_r1_v \cdot \left[\overline{\left[IA2\_r1_v \cdot \left(1 \cdot e^{j \cdot MTA_1}\right)\right]}\right]\right]}{\left(\left|IA2\_r1_v\right|\right)^2 + .00001}$$ Avoid divide by 0

$$Z0A\_r1_v := \frac{Re\left[VA0\_r1_v \cdot \left[\overline{\left[IA0\_r1_v \cdot \left(1 \cdot e^{j \cdot MTA_0}\right)\right]}\right]\right]}{\left(\left|IA0\_r1_v\right|\right)^2 + .00001}$$ Avoid divide by 0

$Z_{SOURCE2} := (0 + j \cdot 20)ohm$ $Z_{SOURCE0} := (0 + j \cdot 20)ohm$

$Z_{reverse2} := Z1$ $Z_{reverse0} := Z0$

$Z2A\_r1_v$

$-\left|Z_{SOURCE2}\right|$

$\left|Z_{reverse2}\right|$

$$\frac{v}{RS}$$
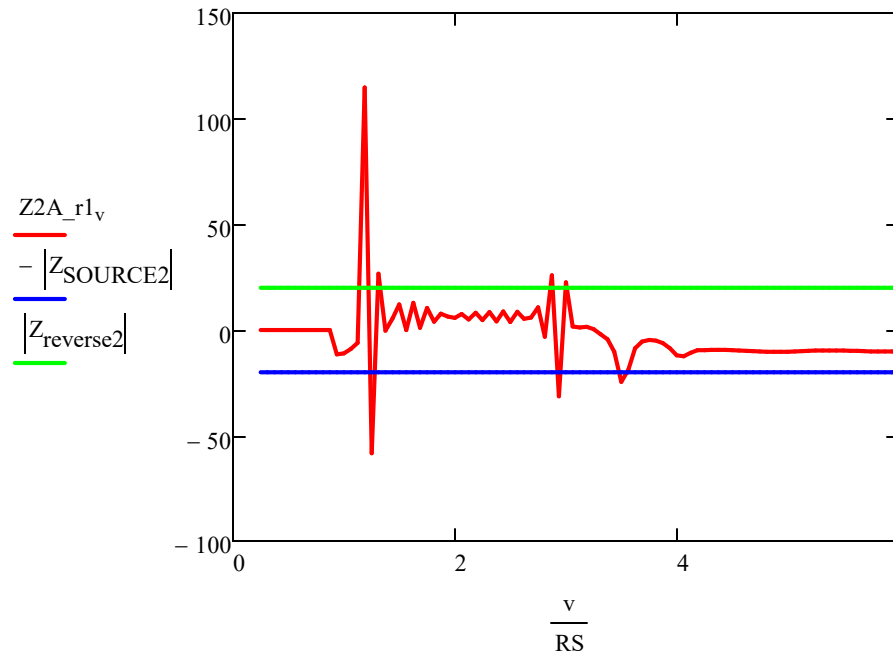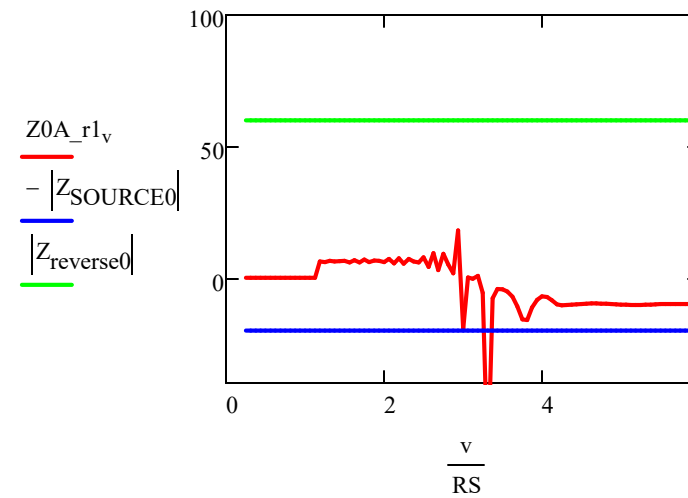
Negative and Zero Sequence Directional Element Logic

$$\text{F32Q\_r1}_v := \left(\text{Z2A\_r1}_v \leq \text{Z}_{2\text{Forward}} \right) \wedge \left(\left| \text{IA2\_r1}_v \right| \geq \text{a}_2 \cdot \left| \text{IA1\_r1}_v \right| \right)$$

$$\text{F32G\_r1}_v := \left(\text{Z0A\_r1}_v \leq \text{Z}_{0\text{Forward}} \right) \wedge \left(\left| \text{IA0\_r1}_v \right| \geq \text{a}_0 \cdot \left| \text{IA1\_r1}_v \right| \right)$$
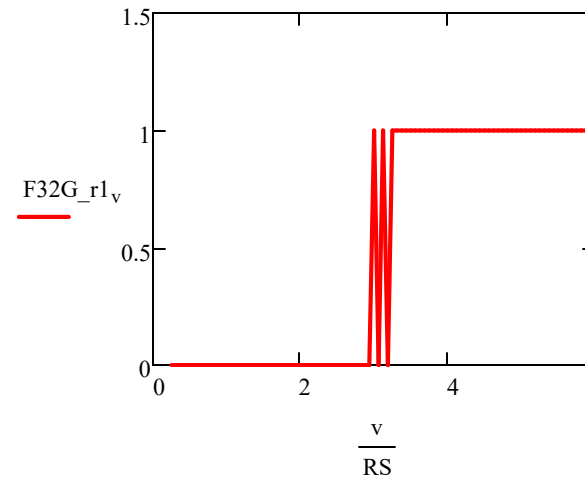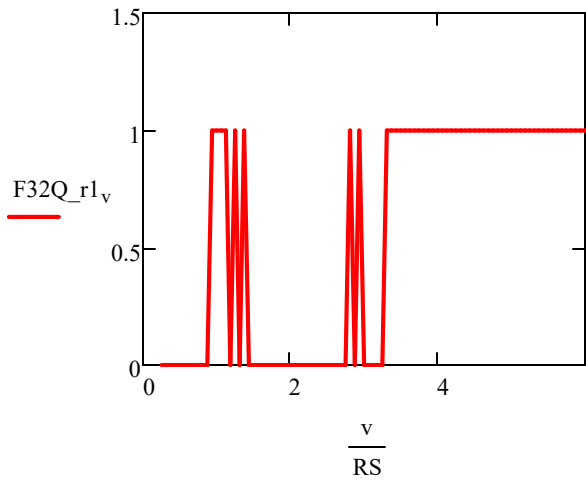
- ***Trip Logic***

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

  Overcurrent Elements:

  $TR50P1\_r1_v := E50P1\_r1 \wedge Level1P\_r1\_pu_v$

  $TR50P2\_r1_d := E50P2\_r1 \wedge Level2P\_r1\_pu_{d-T_{DelP\_r1}} RS$ Note that this includes the time delay for level 2

  $TR50P\_r1_v := TR50P1\_r1_v \vee TR50P2\_r1_v$

  $TR50Q1\_r1_v := E50Q1\_r1 \wedge Level1Q\_r1\_pu_v$

  $TR50Q2\_r1_d := E50Q2\_r1 \wedge Level2Q\_r1\_pu_{d-T_{DelQ\_r1}} RS$

  $TR50Q\_r1_v := TR50Q1\_r1_v \vee TR50Q2\_r1_v$

  $TR50G1\_r1_v := E50G1\_r1 \wedge Level1G\_r1\_pu_v$

  $TR50G2\_r1_d := E50G2\_r1 \wedge Level2G\_r1\_pu_{d-T_{DelG\_r1}} RS$

  $TR50G\_r1_v := TR50G1\_r1_v \vee TR50G2\_r1_v$

Directional Element Overall

- The phase element will pick up if any of the elements identify the fault as forward
- The negative sequence and ground elements only depend on the negative sequence and zero sequence direction element

$$T32P\_r1_v := \left(E32P\_r1 \wedge P32F\_r1_v\right) \vee \left(E32Q\_r1 \wedge F32Q\_r1_v\right) \vee \left(E32G\_r1 \wedge F32G\_r1_v\right)$$

$$T32Q\_r1_v := \left(E32Q\_r1 \wedge F32Q\_r1_v\right)$$

$$T32G\_r1_v := \left(E32G\_r1 \wedge F32G\_r1_v\right)$$

*Overcurrent elements with directio*n

$$TR67P\_r1_v := T32P\_r1_v \wedge TR50P\_r1_v$$

$$TR67Q\_r1_v := T32Q\_r1_v \wedge TR50Q\_r1_v$$

$$TR67G\_r1_v := T32G\_r1_v \wedge TR50G\_r1_v$$

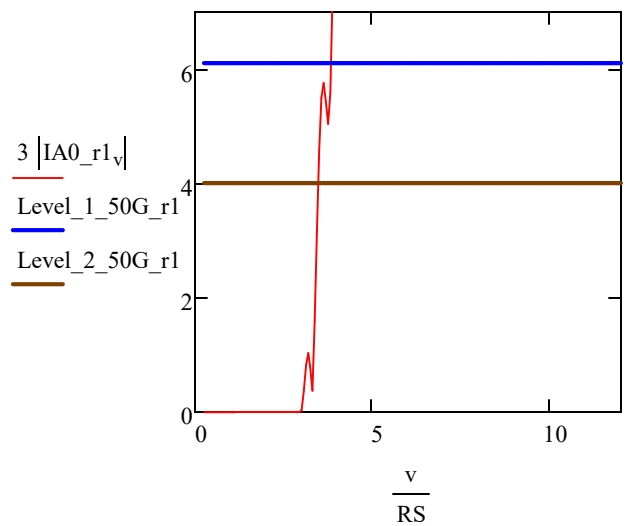$$Trip\_r1_v := TR67P\_r1_v \vee TR67Q\_r1_v \vee TR67G\_r1_v$$
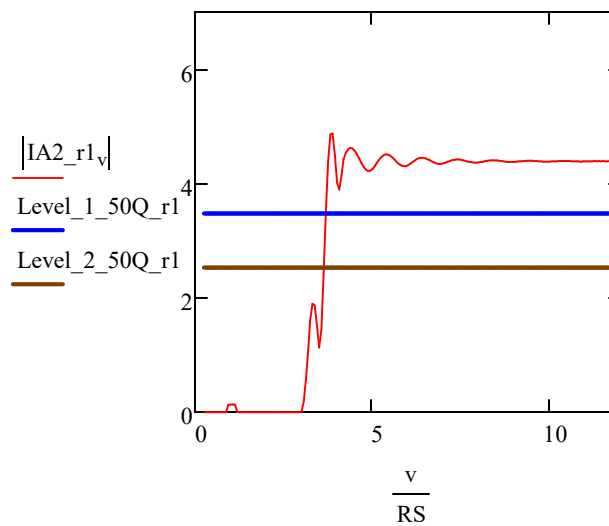
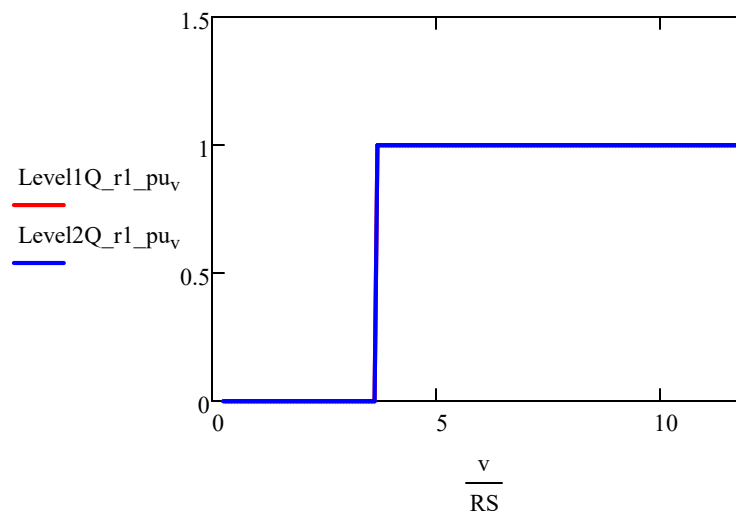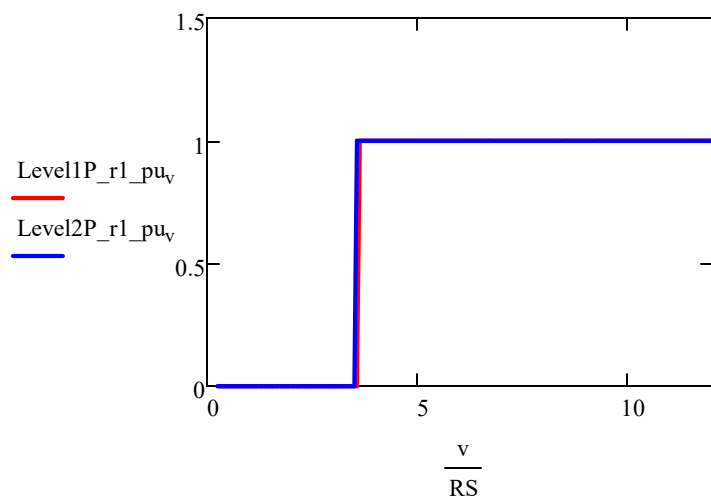- **Relay Response**

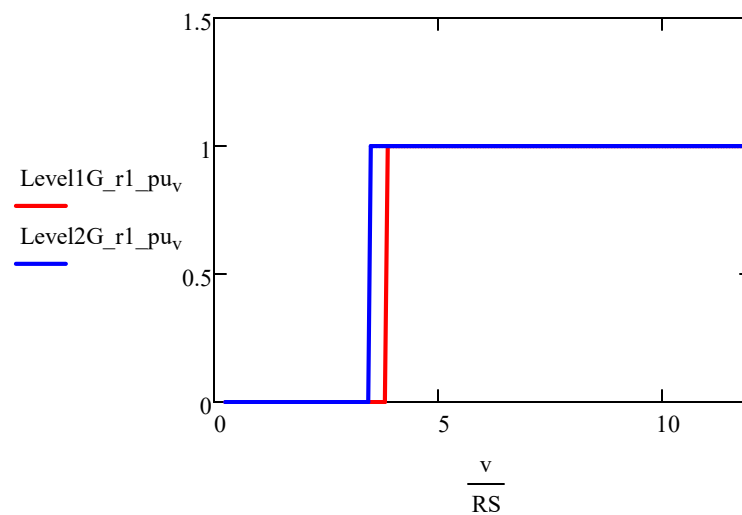 Overcurrent Elements:

  Phase Currents

Ground current

$3 \left| IA0\_r1_v \right|$

Level_1_50G_r1

Level_2_50G_r1

$\dfrac{v}{RS}$

Negative Sequence current

$\left| IA2\_r1_v \right|$

Level_1_50Q_r1

Level_2_50Q_r1

$\dfrac{v}{RS}$
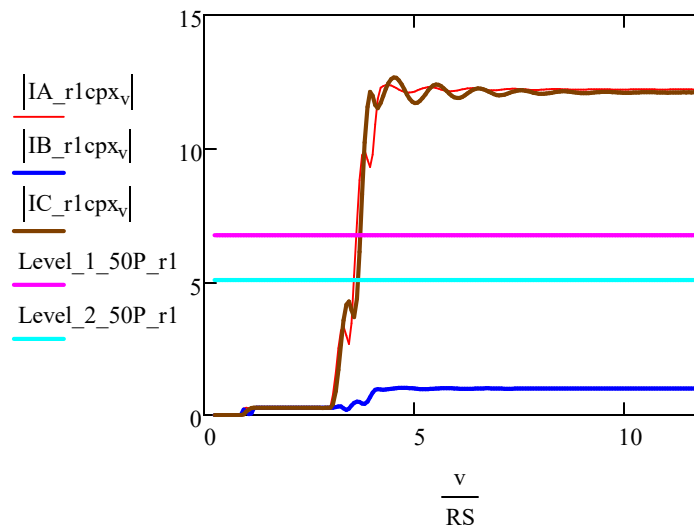
Overcurrent element pick up (without time delays)

$Level1P\_r1\_pu_v$

$Level2P\_r1\_pu_v$

$\dfrac{v}{RS}$

$Level1Q\_r1\_pu_v$

$Level2Q\_r1\_pu_v$

$\dfrac{v}{RS}$

Level1G_r1_pu$_v$

Level2G_r1_pu$_v$

$\dfrac{v}{RS}$

Trip equation response

TR50P_r1$_v$

TR50Q_r1$_v$

TR50G_r1$_v$

$\dfrac{v}{RS}$

TR67P_r1$_v$

TR67Q_r1$_v$

TR67G_r1$_v$

$\dfrac{v}{RS}$

Final trip equation:

Trip_r1_v

$$\frac{v}{RS}$$