Non-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:(this is using one of the files for the lab)

config := ...\FSLG75.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)

data := ...\FSLG75.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)

The COMTRADE file is actually threefiles. One has an extension "*.hdr". This file will be emtpy in this case. Another has the extension "*.dat". This has the actual numerical data in columns of numbers. The third file is a configuration file and has the extension "*.cfg" and this tells the program reading the numerical data what the columns represent. The configuration file provides scaling and offset information for each of the variables stored as vectors. Here is a typical entry:

```
1,IN,,,A,2.5162E-04,1.0045E00,0.0000E00,-32765,32765,1,1,P
```

Each data record starts entry number (1-7 here), the name for the measurements (for example "IN").

The number after the 4 commas (column 5 starting numbering with 0) is a scale factor. The next number (column 6) is an offset factor. If you don't change the scaling and offset factors, the waveforms you evaluate won't be correct. The MathCAD sheet has further instructions.

COMTRADE configuration file format:

1. The first fow states how the file was created and the version of the standard
2. The second row 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 3 - 10 are the analog inputs, in the following order:
   - In (referred to as residual current below)
   - Ia
   - Ib
   - Ic
   - Vag
   - Vbg
   - Vcg
4. Data sampled 16 times per cycle (960 Hz)

```
1,CT01A,,,,0.00132089,-28.689,0,0,65535,1.0,1.0,P
```

Scaling and Offset Data from Comtrade CFG file

- Read individual cells (scale from column 5, offset from column 6)
- Remember row and column indices start at 0:

$Ir_{scale} := config_{2,5}$	$Ir_{scale} = 2.6609 \times 10^{-4}$	$Ir_{offset} := config_{2,6}$	$Ir_{offset} = 1.0496$
$Ia_{scale} := config_{3,5}$	$Ia_{scale} = 2.6665 \times 10^{-4}$	$Ia_{offset} := config_{3,6}$	$Ia_{offset} = -1.0566$
$Ib_{scale} := config_{4,5}$	$Ib_{scale} = 3.425 \times 10^{-5}$	$Ib_{offset} := config_{4,6}$	$Ib_{offset} = 0.01$
$Ic_{scale} := config_{5,5}$	$Ic_{scale} = 3.4478 \times 10^{-5}$	$Ic_{offset} := config_{5,6}$	$Ic_{offset} = -2.257 \times 10^{-3}$
$Va_{scale} := config_{6,5}$	$Va_{scale} = 5.4237 \times 10^{-3}$	$Va_{offset} := config_{6,6}$	$Va_{offset} = -7.4183$
$Vb_{scale} := config_{7,5}$	$Vb_{scale} = 5.4198 \times 10^{-3}$	$Vb_{offset} := config_{7,6}$	$Vb_{offset} = 4.4338$
$Vc_{scale} := config_{8,5}$	$Vc_{scale} = 5.2139 \times 10^{-3}$	$Vc_{offset} := config_{8,6}$	$Vc_{offset} = -0.0296$

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.

$a := 1 \cdot e^{j \cdot 120deg}$

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)

$i := 0 .. rows(data) - 1$

$v := \frac{RS}{4} .. rows(data) - 1$ Offset samples by 1/4 cycles for phasor calculation

$d := 5 \cdot RS .. rows(data) - 1$ Offset samples by 5 cycles for trip calculation

$If := RS - 1 .. rows(data) - 1$

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.

  $CTR := 1$ $PTR := 1$

- Relay Settings

  Moved later in the file close to the relay model and plots.

Read Data From Comtrade File:

- The data from the COMTRADE file is now read into vectors for MathCAD to use.
- Note that these vectors are assuming that IA, IB, etc are in certain columns in the table. The numbers below assume that the data is assigned as described in the other handout. Columns 0 and 1 of the COMTRADE file do not store data, so Column 2 is the first one of interest.
- Since the neutral current I_N was measured, that will be used for the residual current (IR = 3I0).

$$IR := \left(\frac{data^{\langle 2\rangle}}{CTR}\right)\cdot Ir_{scale} + Ir_{offset}$$

$$VA := \left(\frac{data^{\langle 6\rangle}}{PTR}\right)\cdot Va_{scale} + Va_{offset}$$

$$IA := \left(\frac{data^{\langle 3\rangle}}{CTR}\right)\cdot Ia_{scale} + Ia_{offset}$$

$$VB := \left(\frac{data^{\langle 7\rangle}}{PTR}\right)\cdot Vb_{scale} + Vb_{offset}$$

$$IB := \left(\frac{data^{\langle 4\rangle}}{CTR}\right)\cdot Ib_{scale} + Ib_{offset}$$

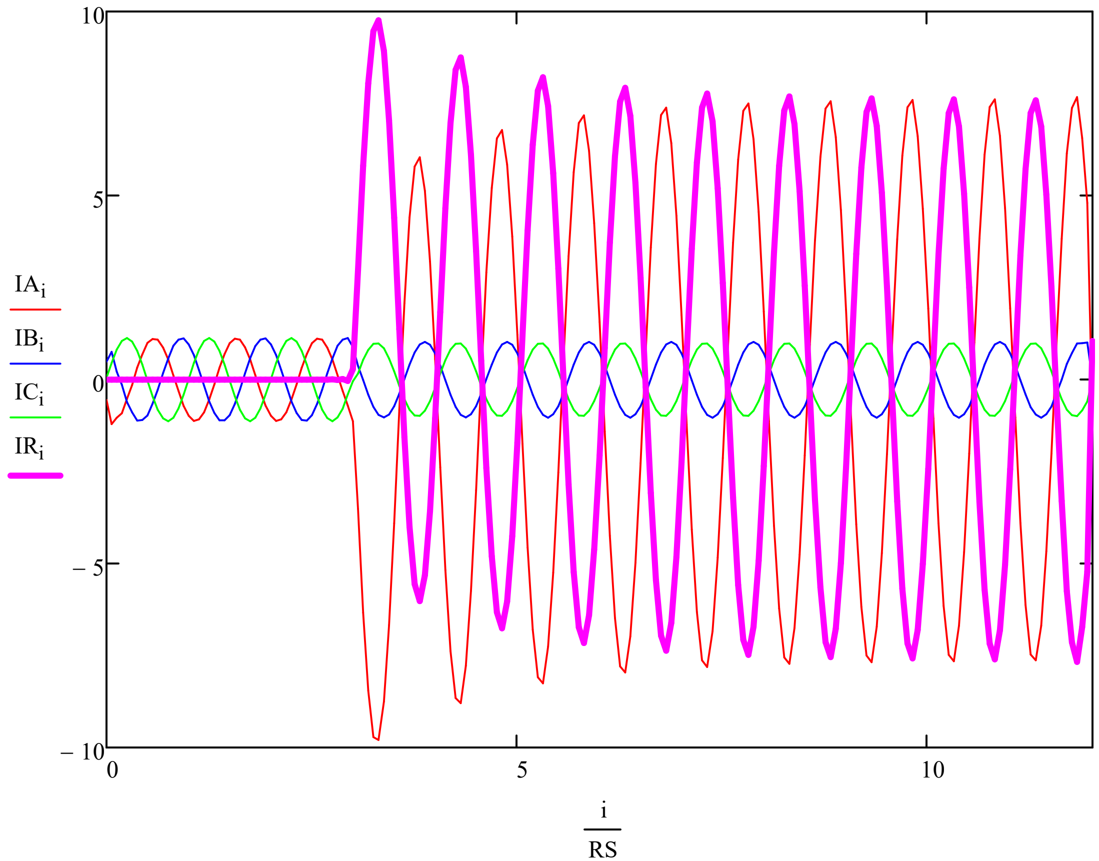
$$VC := \left(\frac{data^{\langle 8\rangle}}{PTR}\right)\cdot Vc_{scale} + Vc_{offset}$$

$$IC := \left(\frac{data^{\langle 5\rangle}}{CTR}\right)\cdot Ic_{scale} + Ic_{offset}$$

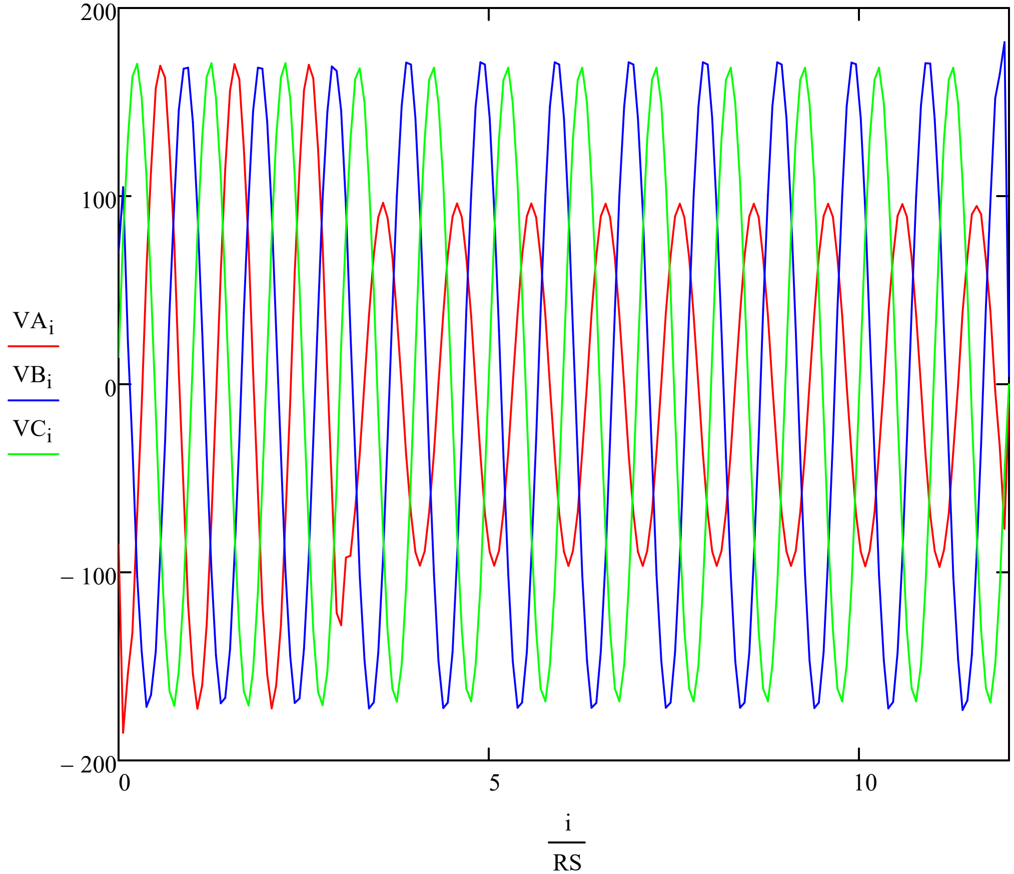
Now plot the currents and voltages. These should be sinusoidal. Note that the horizontal axis is in the number of cycles since the i/RS is sample number divided by sampling rate.

- As a check, the prefault data should be balanced three phase

Phase currents and residual current



Line to ground voltages:



Digital Filter Stages:

- Now the data is run through a digital cosine filter as a first step in calculating magnitude and phase. Normally the first step would be to perform a low pass filtering operation on the data, but since ATP Analyzer already did this, we can skip that step.

$$Ia_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot IA_{[If-(RS-1)]+k} \right]$$

$$Va_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot VA_{[If-(RS-1)]+k} \right]$$

$$Ib_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot IB_{[If-(RS-1)]+k} \right]$$

$$Vb_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot VB_{[If-(RS-1)]+k} \right]$$

$$Ic_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot IC_{[If-(RS-1)]+k} \right]$$

$$Vc_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot VC_{[If-(RS-1)]+k} \right]$$

$$Ir_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot IR_{[If-(RS-1)]+k} \right]$$

Now create phasors.

- To create a phasor we need a real and an imaginary part. If one uses Euler's identity, we need: cos(A) + j sin(A). The cosine filter output gives us the cosine part. Rather than implementing a sine filter (which doesn't reject decaying DC offsets), create the sine term by delaying the cosine terms by 90 degress (1/4 cycle-- or 4 samples when sampling at 16 samples per cycle). Also divide by SQRT(2) to get RMS phasors

$$IAcpx_v := \frac{1}{\sqrt{2}}\left(Ia_v + j \cdot Ia_{v-\frac{RS}{4}}\right)$$

$$IBcpx_v := \frac{1}{\sqrt{2}}\left(Ib_v + j \cdot Ib_{v-\frac{RS}{4}}\right)$$

$$ICcpx_v := \frac{1}{\sqrt{2}}\left(Ic_v + j \cdot Ic_{v-\frac{RS}{4}}\right)$$

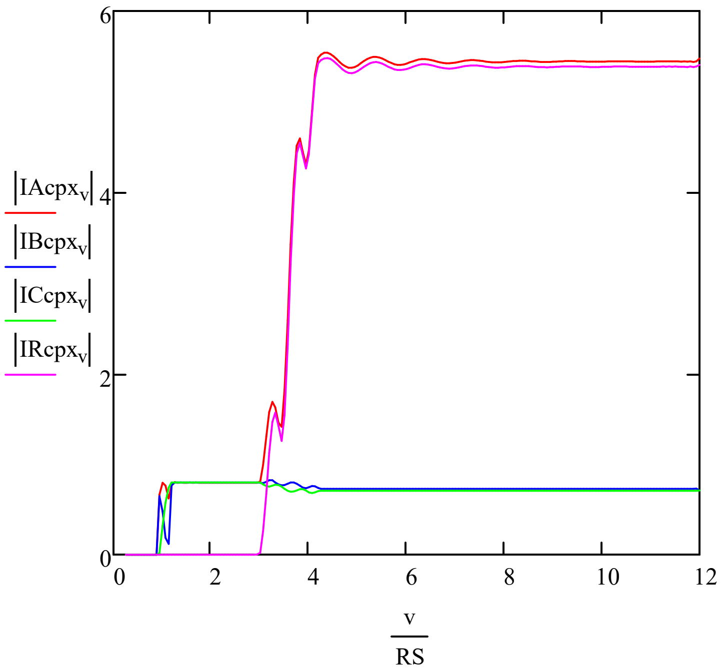
$$IRcpx_v := \frac{1}{\sqrt{2}}\left(Ir_v + j \cdot Ir_{v-\frac{RS}{4}}\right)$$

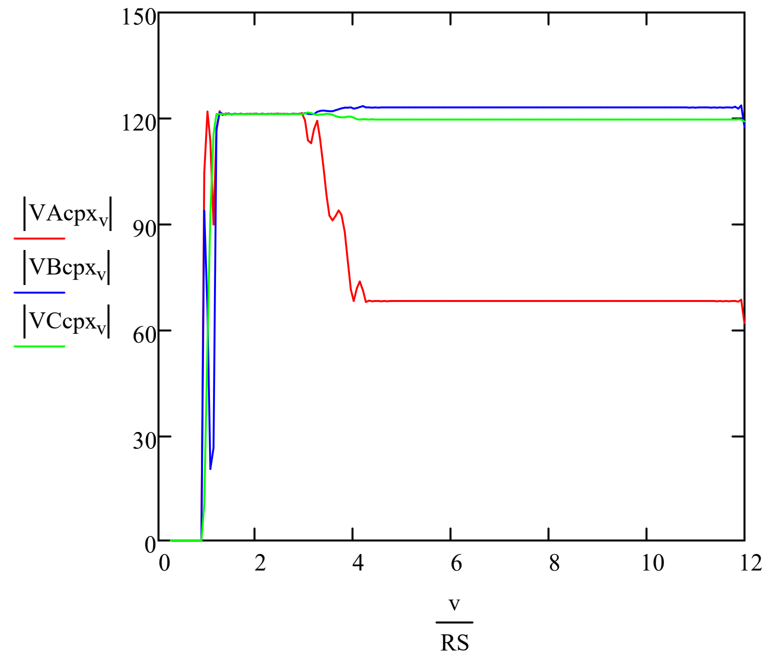
$$VAcpx_v := \frac{1}{\sqrt{2}}\left(Va_v + j \cdot Va_{v-\frac{RS}{4}}\right)$$

$$VBcpx_v := \frac{1}{\sqrt{2}}\left(Vb_v + j \cdot Vb_{v-\frac{RS}{4}}\right)$$

$$VCcpx_v := \frac{1}{\sqrt{2}}\left(Vc_v + j \cdot Vc_{v-\frac{RS}{4}}\right)$$

- Each of these terms is a phasor with magnitude and phase (we are only uses magnitude for now).

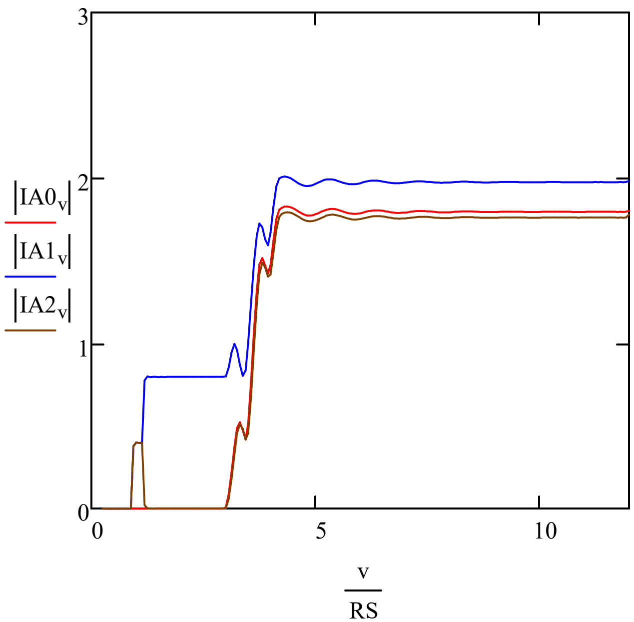


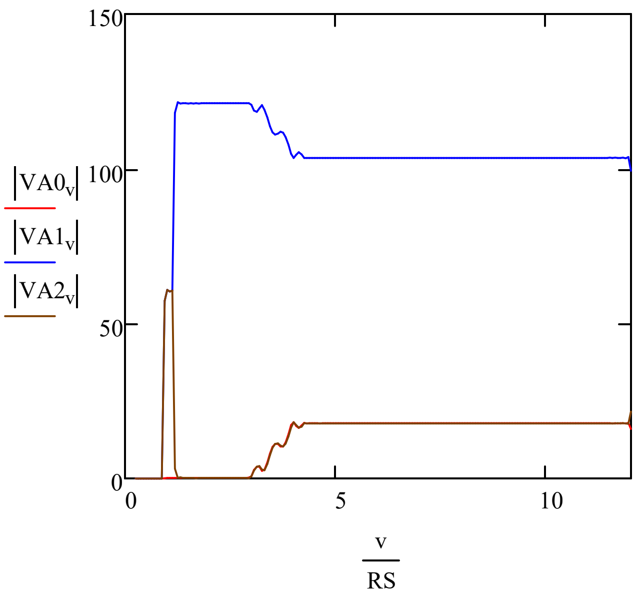


Create symmetrical components:

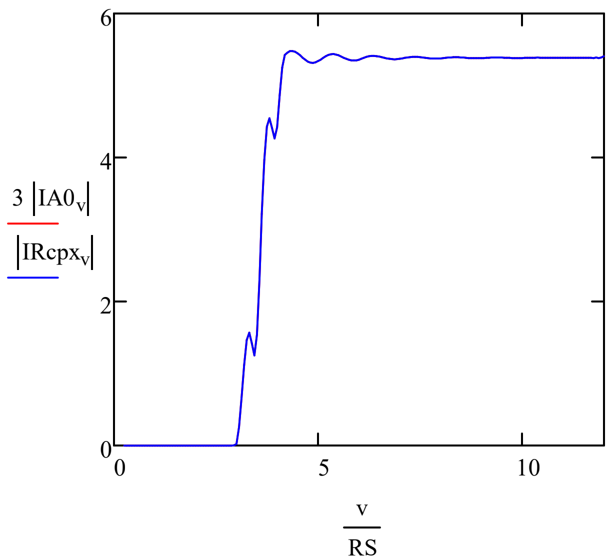
Phase A Components:

$$\begin{pmatrix} IA0_v \\ IA1_v \\ IA2_v \end{pmatrix} := A_{012}^{-1} \cdot \begin{pmatrix} IAcpx_v \\ IBcpx_v \\ ICcpx_v \end{pmatrix} \qquad \begin{pmatrix} VA0_v \\ VA1_v \\ VA2_v \end{pmatrix} := A_{012}^{-1} \cdot \begin{pmatrix} VAcpx_v \\ VBcpx_v \\ VCcpx_v \end{pmatrix}$$





Compare 3I0 to measured residual (ground current)



Phase B Components

$$\begin{pmatrix} IB0_v \\ IB1_v \\ IB2_v \end{pmatrix} := B_{012}^{-1} \cdot \begin{pmatrix} IAcpx_v \\ IBcpx_v \\ ICcpx_v \end{pmatrix}$$

$$\begin{pmatrix} VB0_v \\ VB1_v \\ VB2_v \end{pmatrix} := B_{012}^{-1} \cdot \begin{pmatrix} VAcpx_v \\ VBcpx_v \\ VCcpx_v \end{pmatrix}$$

Phase C Components:

$$\begin{pmatrix} IC0_v \\ IC1_v \\ IC2_v \end{pmatrix} := C_{012}^{-1} \cdot \begin{pmatrix} IAcpx_v \\ IBcpx_v \\ ICcpx_v \end{pmatrix}$$

$$\begin{pmatrix} VC0_v \\ VC1_v \\ VC2_v \end{pmatrix} := C_{012}^{-1} \cdot \begin{pmatrix} VAcpx_v \\ VBcpx_v \\ VCcpx_v \end{pmatrix}$$

The magnitudes for the phase A, B and C symmterical 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)

$Level\_1\_50P := 5$ $Level\_2\_50P := 2.5$

$Level\_1\_50Q := 5$ $Level\_2\_50Q := 2.5$

$Level\_1\_50G := 5$ $Level\_2\_50G := 2.5$

Level 2 Time Delays Define $cycles := 1$

$T_{DelP} := 5cycles$ default at 5 cycles

$T_{DelQ} := 5cycles$

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

- ***Relay Element Pick Up Logic***

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

Initialize arrays with all zeros: $Level1Q\_pu_v := 0$ $Level2Q\_pu_v := 0$

$$Level1Q\_pu_v := \begin{vmatrix} 1 & \text{if } \left|IA2_v\right| \geq Level\_1\_50Q \\ 1 & \text{if } Level1Q\_pu_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{vmatrix}$$

$$Level2Q\_pu_v := \begin{vmatrix} 1 & \text{if } \left|IA2_v\right| \geq Level\_2\_50Q \\ 1 & \text{if } Level2Q\_pu_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{vmatrix}$$

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

Initialize arrays with all zeros: $Level1G\_pu_v := 0$ $Level2G\_pu_v := 0$

$$Level1G\_pu_v := \begin{cases} 1 & \text{if } 3\left|IA0_v\right| \geq Level\_1\_50G \\ 1 & \text{if } Level1G\_pu_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

$$Level2G\_pu_v := \begin{cases} 1 & \text{if } 3\left|IA0_v\right| \geq Level\_2\_50G \\ 1 & \text{if } Level2G\_pu_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

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

Initialize arrays with all zeros: $Level1P\_pu_v := 0$ $Level2P\_pu_v := 0$

$$Level1P\_pu_v := \begin{cases} 1 & \text{if } \left|IAcpx_v\right| \geq Level\_1\_50P \\ 1 & \text{if } \left|IBcpx_v\right| \geq Level\_1\_50P \\ 1 & \text{if } \left|ICcpx_v\right| \geq Level\_1\_50P \\ 1 & \text{if } Level1P\_pu_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

$$Level2P\_pu_v := \begin{cases} 1 & \text{if } \left|IAcpx_v\right| \geq Level\_2\_50P \\ 1 & \text{if } \left|IBcpx_v\right| \geq Level\_2\_50P \\ 1 & \text{if } \left|ICcpx_v\right| \geq Level\_2\_50P \\ 1 & \text{if } Level2P\_pu_{v-1} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

- ***Trip Logic***

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

$$TR50P1_v := E50P1 \wedge Level1P\_pu_v$$

$$TR50P2_d := E50P2 \wedge Level2P\_pu_{d-T_{DelP}RS}$$

Note that this includes the time delay for level 2

$$TR50P_v := TR50P1_v \vee TR50P2_v$$

$$TR50Q_d := E50Q1 \wedge Level1Q\_pu_d \vee E50Q2 \wedge Level2Q\_pu_{d-T_{DelQ}}RS$$

$$TR50Q1_v := E50Q1 \wedge Level1Q\_pu_v$$

$$TR50Q2_d := E50Q2 \wedge Level2Q\_pu_{d-T_{DelQ}}RS$$

$$TR50Q_v := TR50Q1_v \vee TR50Q2_v$$

$$TR50G1_v := E50G1 \wedge Level1G\_pu_v$$

$$TR50G2_d := E50G2 \wedge Level2G\_pu_{d-T_{DelG}}RS$$

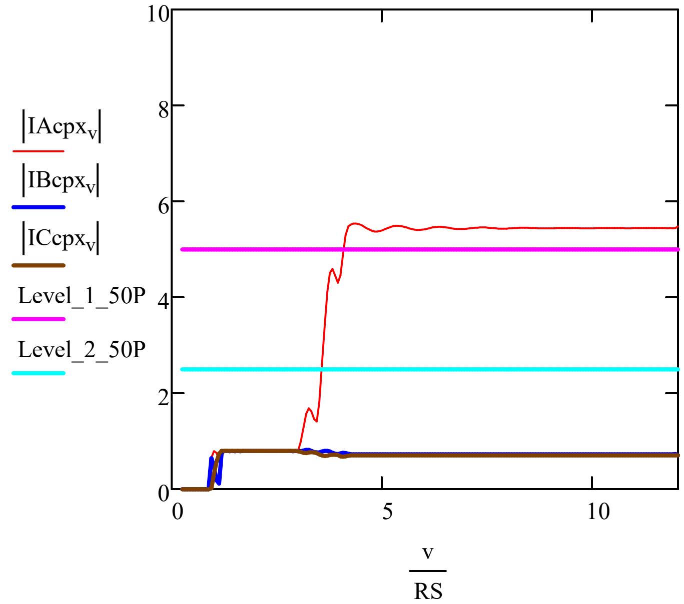
$$TR50G_v := TR50G1_v \vee TR50G2_v$$

Overall Trip Equation:

$$Trip_v := TR50P_v \vee TR50Q_v \vee TR50G_v$$

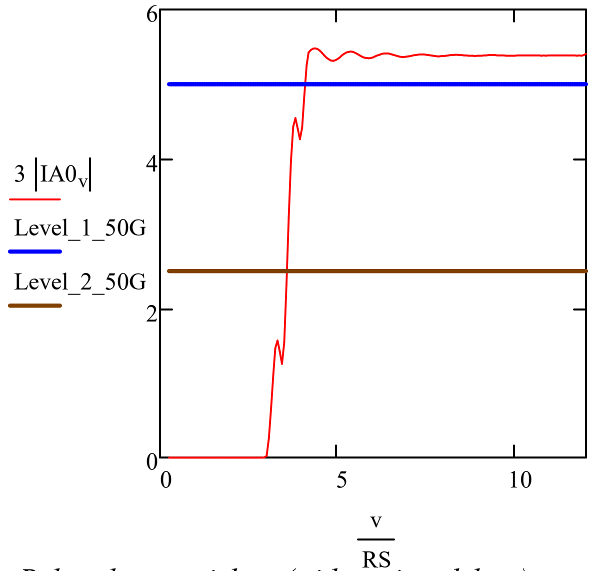
- ***Relay Response***

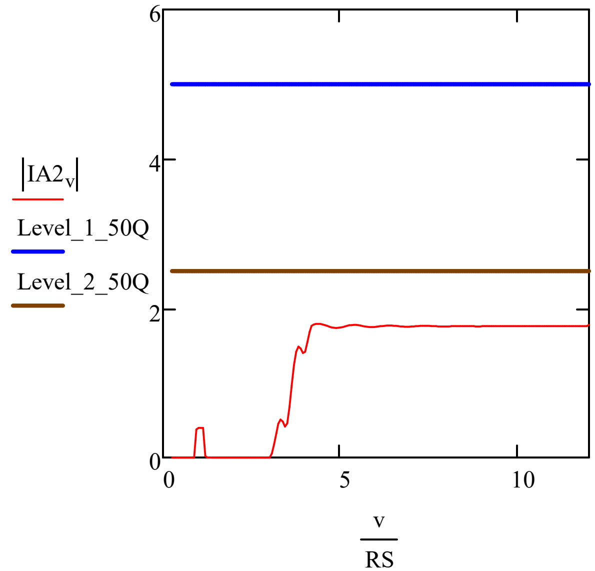
Phase Currents



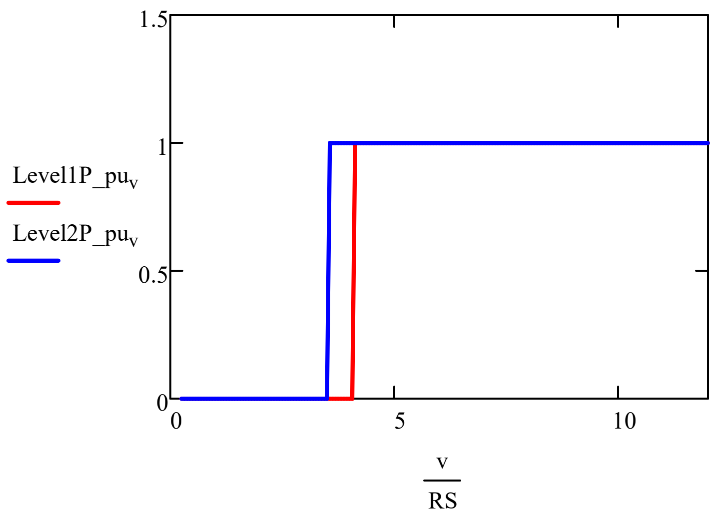
Ground current

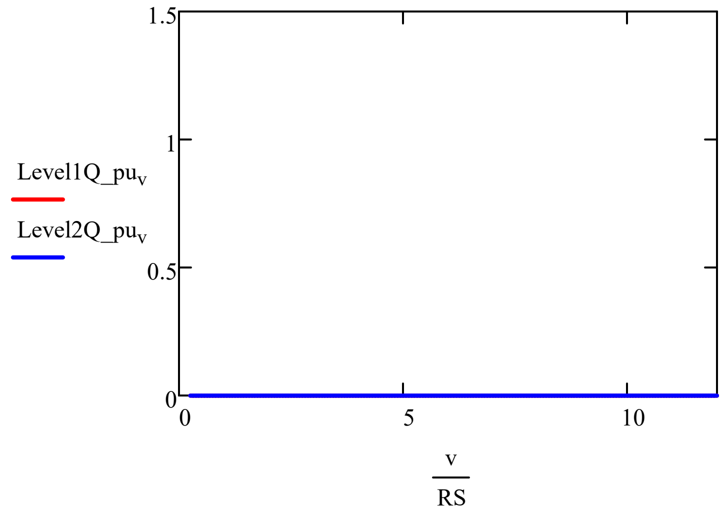
Negative Sequence current

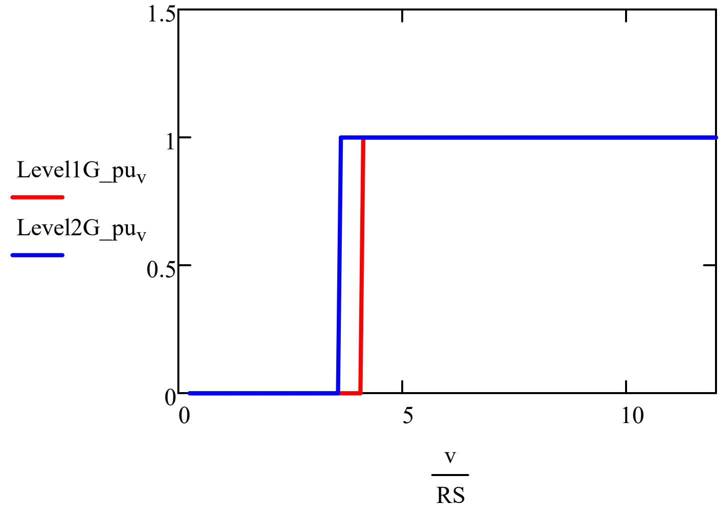




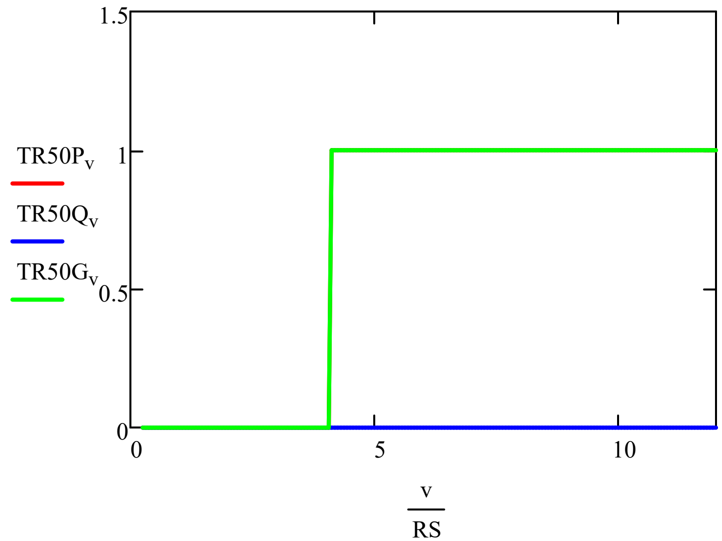
Relay element pick up (without time delays)







Trip equation response



Final trip equation: