Restrained Current Differential Relay Model

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

Read Comtrade File Data

1. Read Comtrade Configuration File

config :=

...\dlg_int.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 :=

...\dlg_int.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 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:
     I1a (feeder one, phase A)
     I2a (feeder two, phase A)
     I3a (feeder three, phase A)
     I4a (feeder four, phase A)
     Van
     Vbn
     Vcn
4. Data sampled 16 times per cycle (960 Hz)

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:

$$I1a_{scale} := config_{2,5} \qquad I1a_{scale} = 6.7049 \times 10^{-4} \qquad I1a_{offset} := config_{2,6} \qquad I1a_{offset} = 0.0889$$

$$I2a_{scale} := config_{3,5} \qquad I2a_{scale} = 6.7049 \times 10^{-4} \qquad I2a_{offset} := config_{3,6} \qquad I2a_{offset} = 0.0889$$

$$I3a_{scale} := config_{4,5} \qquad I3a_{scale} = 1.6971 \times 10^{-3} \qquad I3a_{offset} := config_{4,6} \qquad I3a_{offset} = -4.8923$$

$$I4a_{scale} := config_{5,5} \qquad I4a_{scale} = 8.1594 \times 10^{-5} \qquad I4a_{offset} := config_{5,6} \qquad I4a_{offset} = 5.4505 \times 10^{-3}$$

$$Va_{scale} := config_{6,5} \qquad Va_{scale} = 3.3747 \qquad Va_{offset} := config_{6,6} \qquad Va_{offset} = 101.45$$

$$Vb_{scale} := config_{7,5} \qquad Vb_{scale} = 3.3506 \qquad Vb_{offset} := config_{7,6} \qquad Vb_{offset} = 1.2985 \times 10^{3}$$

$$Vc_{scale} := config_{8,5} \qquad Vc_{scale} = 3.8577 \qquad Vc_{offset} := config_{8,6} \qquad Vc_{offset} = 813.4$$

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.

	Phase A symmetrical components transform	Phase B symmetrical components transform	Phase C symmetrical components transform

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

$$A_{012} := \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix} \qquad B_{012} := \begin{pmatrix} 1 & a & a^2 \\ 1 & 1 & 1 \\ 1 & a^2 & a \end{pmatrix} \qquad C_{012} := \begin{pmatrix} 1 & a^2 & a \\ 1 & a & a^2 \\ 1 & 1 & 1 \end{pmatrix}$$

$$RS := 16$$

Enter vector indices for filter and relay calculations (do not change these)

$$i := 0 \, .. \, \text{rows}(data) - 1$$

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

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

$$If := RS - 1 \, .. \, \text{rows}(data) - 1$$

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.

$$CTR := 1 \qquad VTR := \frac{230 kV}{120 V}$$

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).

$$I1A := \left(\frac{data^{\langle 2 \rangle}}{CTR} \right) \cdot I1a_{scale} + \frac{I1a_{offset}}{CTR} \qquad VA := \left(\frac{data^{\langle 6 \rangle}}{VTR} \right) \cdot Va_{scale} + \frac{Va_{offset}}{VTR}$$

$$I2A := \left(\frac{data^{\langle 3 \rangle}}{CTR} \right) \cdot I2a_{scale} + \frac{I2a_{offset}}{CTR} \qquad VB := \left(\frac{data^{\langle 7 \rangle}}{VTR} \right) \cdot Vb_{scale} + \frac{Vb_{offset}}{VTR}$$

$$I3A := \left(\frac{data^{\langle 4 \rangle}}{CTR} \right) \cdot I3a_{scale} + \frac{I3a_{offset}}{CTR} \qquad VC := \left(\frac{data^{\langle 8 \rangle}}{VTR} \right) \cdot Vc_{scale} + \frac{Vc_{offset}}{VTR}$$

$$I4A := \left(\frac{data^{\langle 5 \rangle}}{CTR} \right) \cdot I4a_{scale} + \frac{I4a_{offset}}{CTR}$$
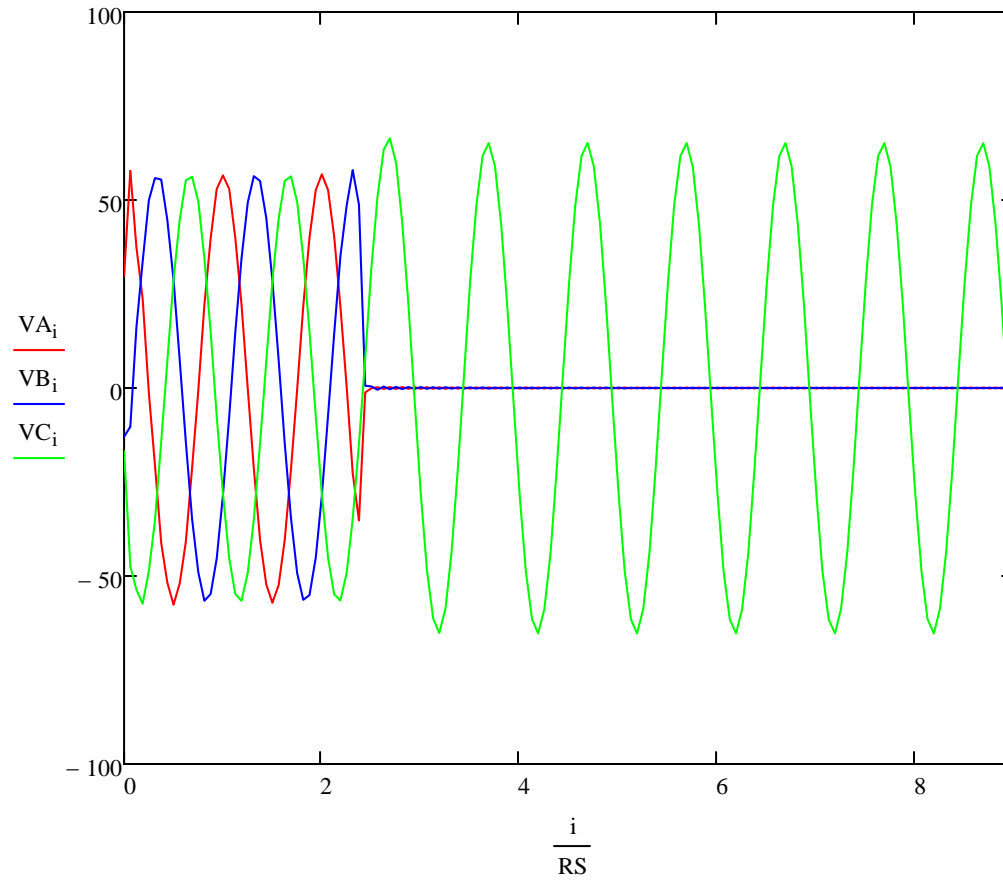
Now plot the currents and voltages. These should be sinusoidal. Note that the horizontal axis is in the number of cycles since the i/RS is sample number divided by sampling rate.

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

Phase currents
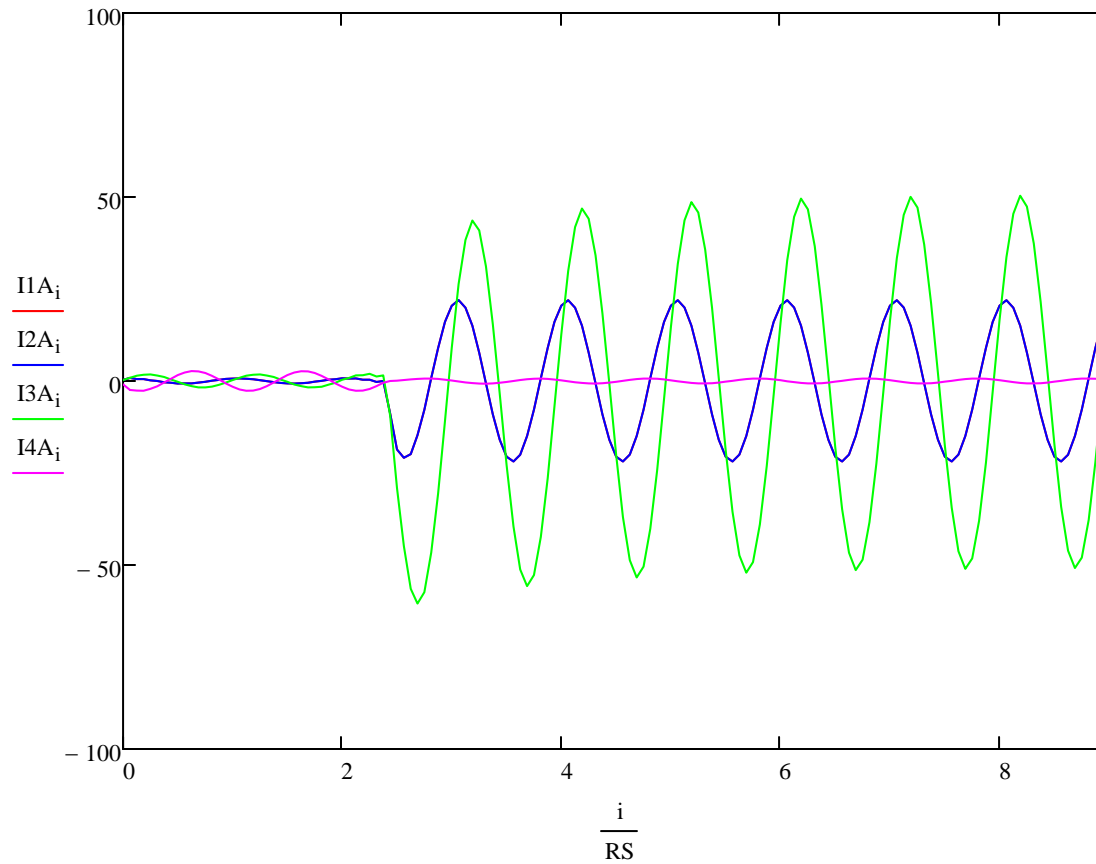
Line to ground voltages:

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.

$$I1a_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot I1A_{[If-(RS-1)]+k} \right]$$

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

$$I2a_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot I2A_{[If-(RS-1)]+k} \right]$$

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

$$I3a_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot I3A_{[If-(RS-1)]+k} \right]$$

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

$$I4a_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot I4A_{[If-(RS-1)]+k} \right]$$

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

$$I1Acpx_v := \frac{1}{\sqrt{2}}\left(I1a_v + j \cdot I1a_{v-\frac{RS}{4}}\right)$$

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

$$I2Acpx_v := \frac{1}{\sqrt{2}}\left(I2a_v + j \cdot I2a_{v-\frac{RS}{4}}\right)$$

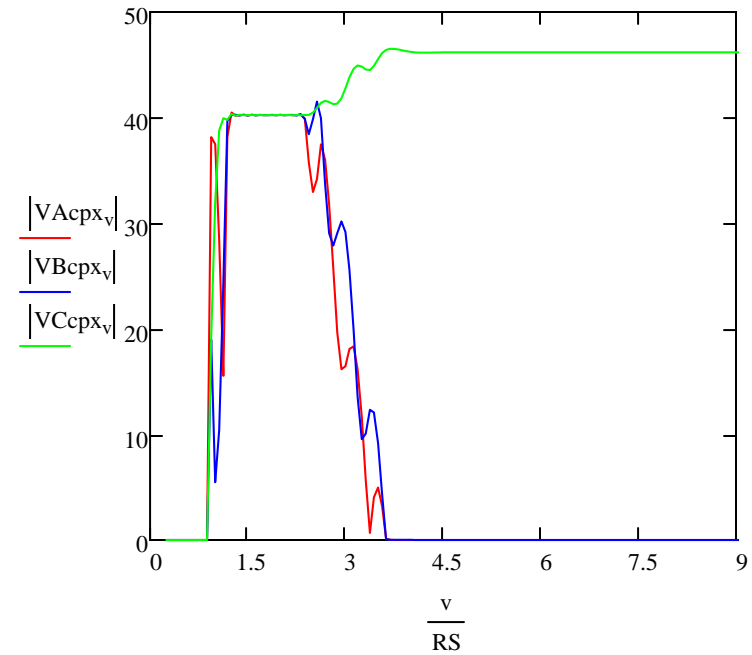$$VBcpx_v := \frac{1}{\sqrt{2}}\left(Vb_v + j \cdot Vb_{v-\frac{RS}{4}}\right)$$

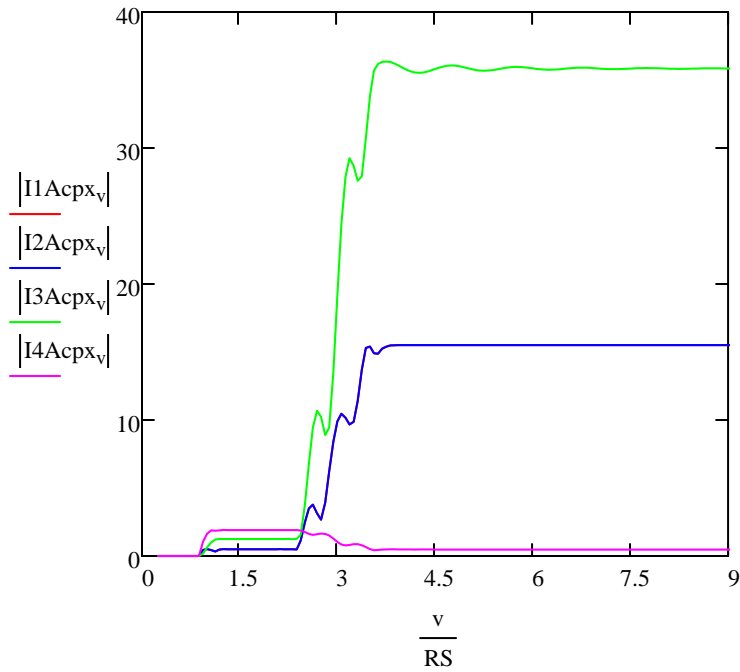$$I3Acpx_v := \frac{1}{\sqrt{2}}\left(I3a_v + j \cdot I3a_{v-\frac{RS}{4}}\right)$$

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

$$I4Acpx_v := \frac{1}{\sqrt{2}}\left(I4a_v + j \cdot I4a_{v-\frac{RS}{4}}\right)$$

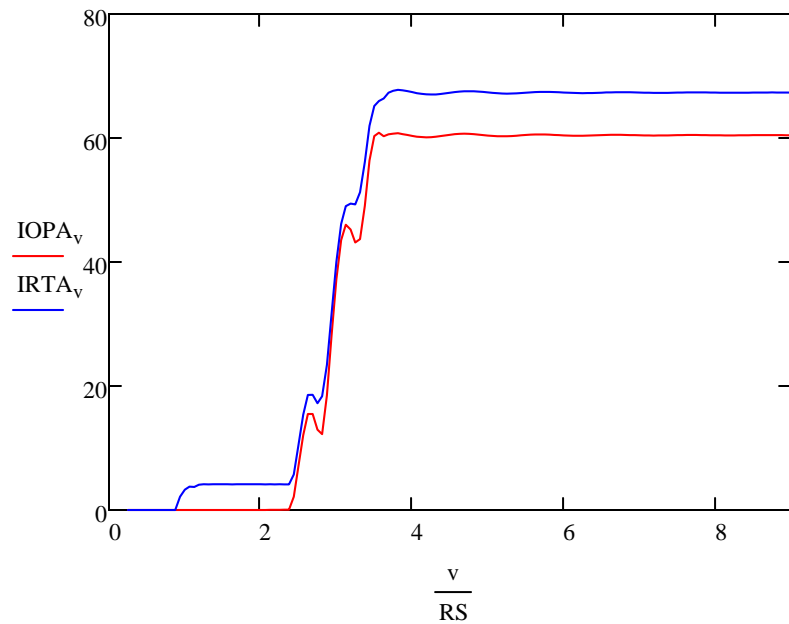- Each of these terms is a phasor with magnitude and phase (we are only uses magnitude for now).

$$\text{IOPA}_v := \left| \text{I1Acpx}_v + \text{I2Acpx}_v + \text{I3Acpx}_v + \text{I4Acpx}_v \right|$$

Operate Current

$$\text{IRTA}_v := \left| \text{I1Acpx}_v \right| + \left| \text{I2Acpx}_v \right| + \left| \text{I3Acpx}_v \right| + \left| \text{I4Acpx}_v \right|$$

Restraint Current

Relay Model:

- ### *Relay Settings*

Instantaneous differential 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)
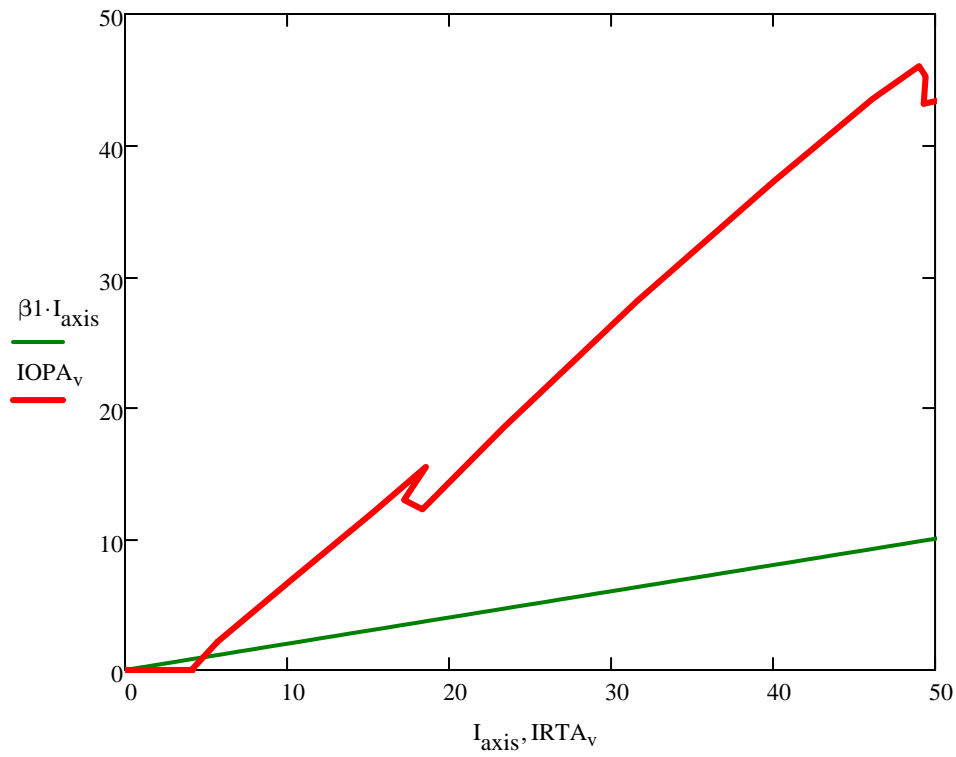
$E87\beta1 := 1$ $E87\beta2 := 1$

Relay restaint slopes

$\beta 1 := 0.2$ Enter your slope setting $I_{axis} := 0, 1 .. 300$

Relay Setting Slopes Plus IOP versus IRT

$\beta 1 \cdot I_{axis}$

$IOPA_v$

$I_{axis}, IRTA_v$

- ## *Relay Element Pick Up Logic*

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

$$Tr1_v := \begin{cases} 1 & \text{if } IOPA_v > \beta 1 \cdot IRTA_v \\ 0 & \text{otherwise} \end{cases}$$

- ## *Relay Response*