

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 :=

...\3PHINT.cfg

Right click on the floppy disk icon and select "Choose File" to open a file browser. Choose the *.cfg file from the comtrade file (you will need to type the extension)

data :=

...\3PHINT.dat

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

COMTRADE configuration file format:

1. The first row 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:

$$I1a_{scale} := \text{config}_{2,5} \quad I1a_{scale} = 0.5854 \quad I1a_{offset} := \text{config}_{2,6} \quad I1a_{offset} = -680.79$$

$$I2a_{scale} := \text{config}_{3,5} \quad I2a_{scale} = 0.7806 \quad I2a_{offset} := \text{config}_{3,6} \quad I2a_{offset} = -907.73$$

$$I3a_{scale} := \text{config}_{4,5} \quad I3a_{scale} = 1.1708 \quad I3a_{offset} := \text{config}_{4,6} \quad I3a_{offset} = -1.3616 \times 10^3$$

$$I4a_{scale} := \text{config}_{5,5} \quad I4a_{scale} = 0.0188 \quad I4a_{offset} := \text{config}_{5,6} \quad I4a_{offset} = -0.0282$$

$$Va_{scale} := \text{config}_{6,5} \quad Va_{scale} = 5.7782 \quad Va_{offset} := \text{config}_{6,6} \quad Va_{offset} = 101.2$$

$$Vb_{scale} := \text{config}_{7,5} \quad Vb_{scale} = 5.676 \quad Vb_{offset} := \text{config}_{7,6} \quad Vb_{offset} = -1.9996 \times 10^3$$

$$Vc_{scale} := \text{config}_{8,5} \quad Vc_{scale} = 5.675 \quad Vc_{offset} := \text{config}_{8,6} \quad Vc_{offset} = -2.0049 \times 10^3$$

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)

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

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

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

$$lf := RS - 1 \dots \text{rows}(\text{data}) - 1$$

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.

$$CTR := \frac{1000}{5} \quad VTR := \frac{230\text{kV}}{120\text{V}}$$

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 ($IR = 3I_0$).

$$I1A := \left(\frac{\text{data}^{\langle 2 \rangle}}{\text{CTR}} \right) \cdot I1a_{\text{scale}} + \frac{I1a_{\text{offset}}}{\text{CTR}} \quad V_A := \left(\frac{\text{data}^{\langle 6 \rangle}}{\text{VTR}} \right) \cdot V_{a_{\text{scale}}} + \frac{V_{a_{\text{offset}}}}{\text{VTR}}$$

$$I2A := \left(\frac{\text{data}^{\langle 3 \rangle}}{\text{CTR}} \right) \cdot I2a_{\text{scale}} + \frac{I2a_{\text{offset}}}{\text{CTR}} \quad V_B := \left(\frac{\text{data}^{\langle 7 \rangle}}{\text{VTR}} \right) \cdot V_{b_{\text{scale}}} + \frac{V_{b_{\text{offset}}}}{\text{VTR}}$$

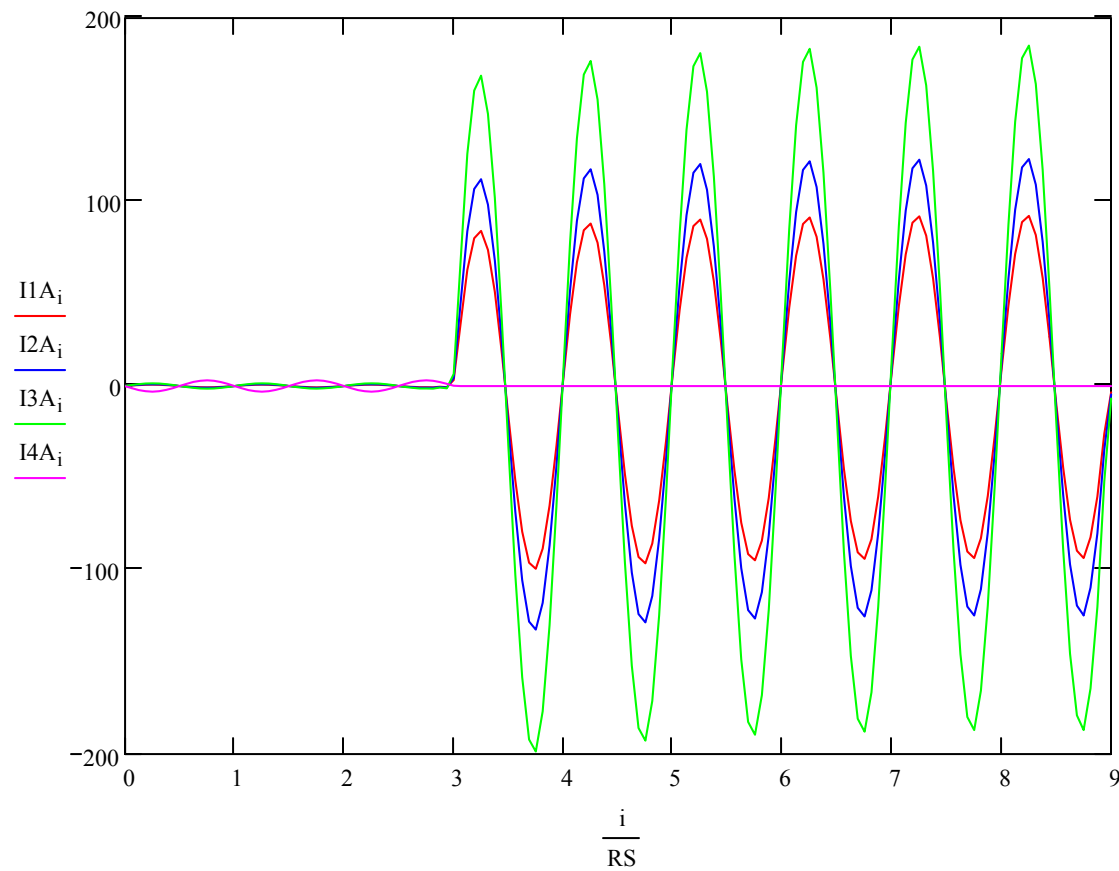
$$I3A := \left(\frac{\text{data}^{\langle 4 \rangle}}{\text{CTR}} \right) \cdot I3a_{\text{scale}} + \frac{I3a_{\text{offset}}}{\text{CTR}} \quad V_C := \left(\frac{\text{data}^{\langle 8 \rangle}}{\text{VTR}} \right) \cdot V_{c_{\text{scale}}} + \frac{V_{c_{\text{offset}}}}{\text{VTR}}$$

$$I4A := \left(\frac{\text{data}^{\langle 5 \rangle}}{\text{CTR}} \right) \cdot I4a_{\text{scale}} + \frac{I4a_{\text{offset}}}{\text{CTR}}$$

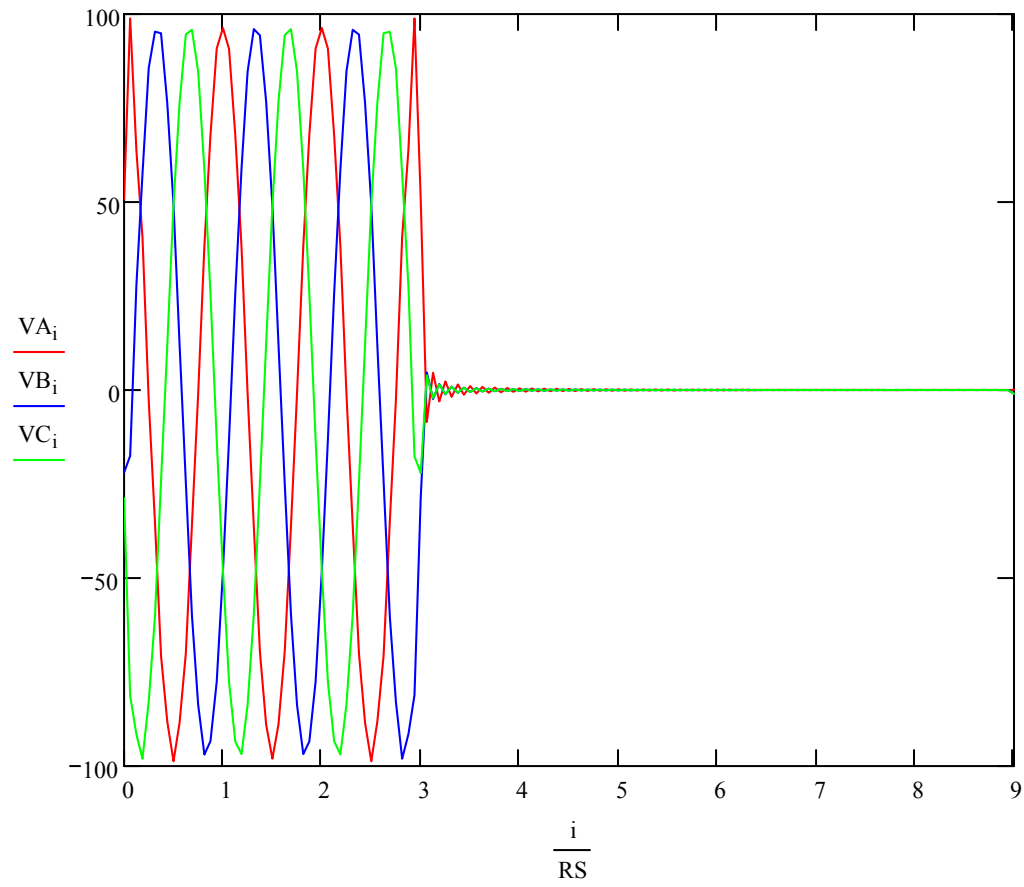
Now plot the currents and voltages. These should be sinusoidal. Note that the horizontal axis is in the number of cycles since the i/RS is sample number divided by sampling rate.

- As a check, the pre-fault 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.

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

$$V1a_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot V1A_{[If-(RS-1)]+k} \right]$$

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

$$V2a_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot V2A_{[If-(RS-1)]+k} \right]$$

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

$$V3a_{If} := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[\cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right) \cdot V3A_{[If-(RS-1)]+k} \right]$$

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

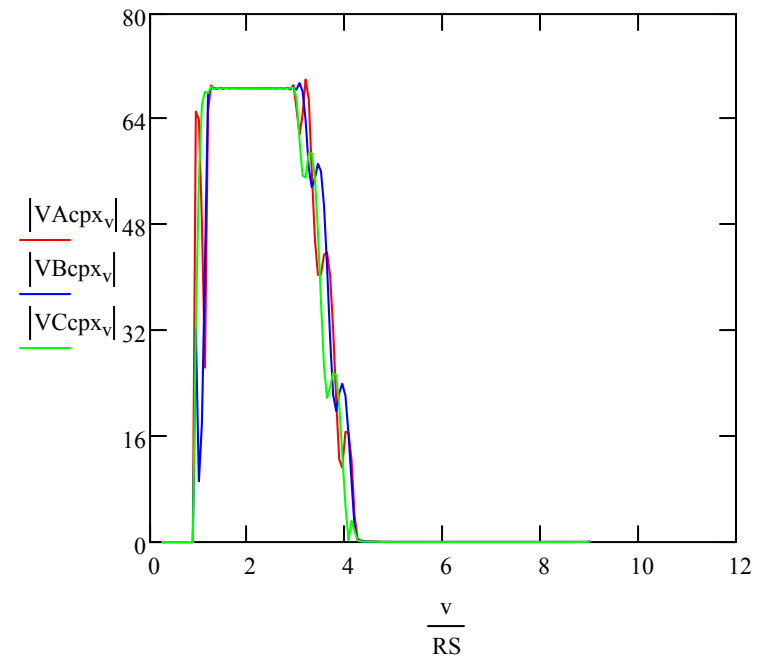
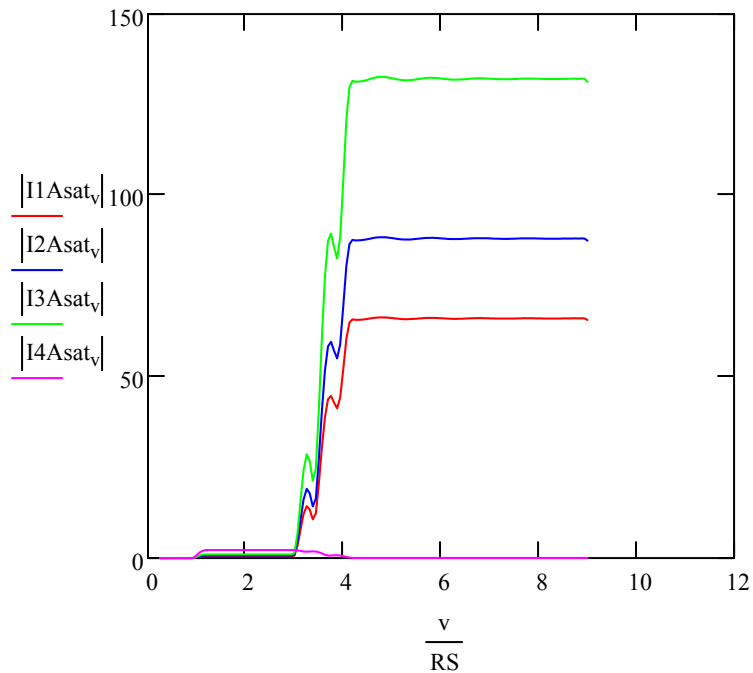
$$I1Asat_v := (1 - CT1sat) \cdot I1Acp_x_v$$

$$I3Asat_v := (1 - CT3sat) \cdot I3Acp_x_v$$

$$I2Asat_v := (1 - CT2sat) \cdot I2Acp_x_v$$

$$I4Asat_v := (1 - CT4sat) \cdot I4Acp_x_v$$

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

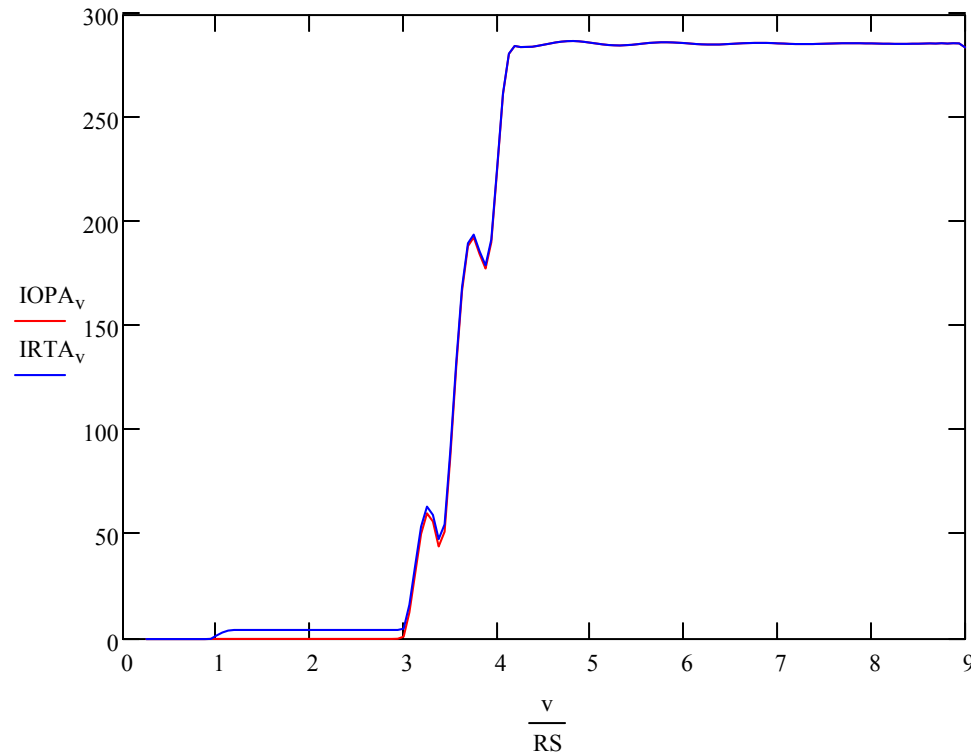


$$IOPA_v := |I1Asat_v + I2Asat_v + I3Asat_v + I4Asat_v|$$

Operate Current

$$IRTA_v := |I1Asat_v| + |I2Asat_v| + |I3Asat_v| + |I4Asat_v|$$

Restraint Current



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)

E87 β 1 := 1

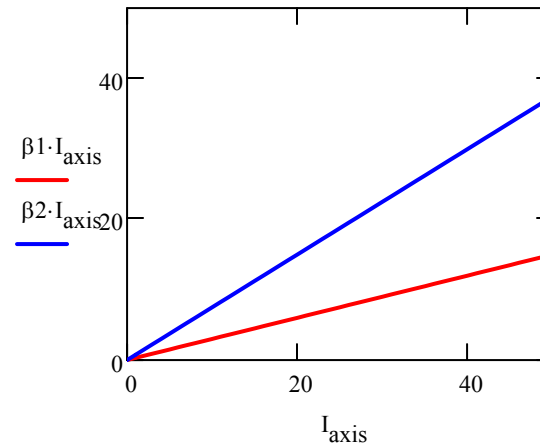
E87 β 2 := 1

Relay restraint slopes

$\beta_1 := 0.3$ Sensitive restraint slope

$I_{axis} := 0, 1 \dots 300$

$\beta_2 := 0.75$ More secure slope



• **Relay Element Pick Up Logic**

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

$$Tr1_v := \begin{cases} 1 & \text{if } IOPA_v > \beta_1 \cdot IRTA_v \\ 0 & \text{otherwise} \end{cases}$$

$$Tr2_v := \begin{cases} 1 & \text{if } IOPA_v > \beta_2 \cdot IRTA_v \\ 0 & \text{otherwise} \end{cases}$$

- **Relay Response**

