Lab 2A: Inverse Time 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 := ...\FDLG50.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 := ..\FDLG50.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)

Inverse Time Overcurrent Element

- Enable Inverse Time Overcurrent Elements

$E51P_{B3} := 1$ $E51P_{B2} := 1$

$E51G_{B3} := 1$ $E51G_{B2} := 1$

$E51Q_{B3} := 1$ $E51Q_{B2} := 1$

- Relay Element Settings for Relay controlling Breaker B3:

$I_{pu\_P\_B3} := 1$ $TD_{B3\_P} := 0.5$

$I_{pu\_G\_B3} := 0.1$ $TD_{B3\_G} := 0.5$

$I_{pu\_Q\_B3} := 0.1$ $TD_{B3\_Q} := 0.5$

Default settings -- Change based on your calculations

- Relay Element Settings for Relay controlling Breaker B2:

$I_{pu\_P\_B2} := 2$ $TD_{B2\_P} := 1$

$I_{pu\_G\_B2} := 0.2$ $TD_{B2\_G} := 1$

$I_{pu\_Q\_B2} := 0.2$ $TD_{B2\_Q} := 1$

Default settings -- Change based on your calculations

- Very Inverse Characteristic (U3)

$A_{VI} := 3.88$ $B_{VI} := 0.0963$ $p_{VI} := 2$ $C_{VI} := 3.88$

Model for Relay Controlling B3:

- Current Ratios

$$MB3_{phA_v} := \frac{\left|IA2cpx_v\right|}{I_{pu\_P\_B3}} \qquad MB3_{G_v} := \frac{3\left|IA20_v\right|}{I_{pu\_G\_B3}}$$

$$MB3_{phB_v} := \frac{\left|IB2cpx_v\right|}{I_{pu\_P\_B3}} \qquad MB3_{Q_v} := \frac{3\left|IA22_v\right|}{I_{pu\_Q\_B3}}$$

$$MB3_{phC_v} := \frac{\left|IC2cpx_v\right|}{I_{pu\_P\_B3}}$$

- Initialize angle history to 0:

$$\theta B3_{PA_v} := 0sec$$

$$\theta B3_{PB_v} := 0sec$$

$$\theta B3_{PC_v} := 0sec$$

$$\theta B3_{G_v} := 0sec$$

$$\theta B3_{Q_v} := 0sec$$

$$\theta B3_{PA_v} := \begin{cases} \left[\frac{\left[\left(MB3_{phA}\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB3_{phA_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{PA_{v-1}} & \text{if } MB3_{phA_v} \geq 1 \\ -\left[\frac{1 - \left(MB3_{phA_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{PA_{v-1}} & \text{if } MB3_{phA_v} < 1 \\ 0 & \text{if } \left(MB3_{phA_v} < 1\right) \wedge \left(\theta B3_{PA_{v-1}} \leq 0\right) \\ 0 & \text{otherwise} \end{cases}$$

"Rotate disk" toward trip

"Reset disk

$$\theta B3_{PB_v} := \begin{cases} \left[\frac{\left[\left(MB3_{phB}\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB3_{phB_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{PB_{v-1}} & \text{if } MB3_{phB_v} \geq 1 \\ -\left[\frac{1 - \left(MB3_{phB_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{PB_{v-1}} & \text{if } MB3_{phB_v} < 1 \\ 0 & \text{if } \left(MB3_{phB_v} < 1\right) \wedge \left(\theta B3_{PB_{v-1}} \leq 0\right) \\ 0 & \text{otherwise} \end{cases}$$

$$\theta B3_{PC_v} := \begin{cases} \left[\frac{\left[\left(MB3_{phC}\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB3_{phC_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{PC_{v-1}} & \text{if } MB3_{phC_v} \geq 1 \\ -\left[\frac{1 - \left(MB3_{phC_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{PC_{v-1}} & \text{if } MB3_{phC_v} < 1 \\ 0 & \text{if } \left(MB3_{phC_v} < 1\right) \wedge \left(\theta B3_{PC_{v-1}} \leq 0\right) \\ 0 & \text{otherwise} \end{cases}$$

$$\theta B3_{G_v} := \begin{cases} \left[\frac{\left[\left(MB3_G\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB3_{G_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{G_{v-1}} & \text{if } MB3_{G_v} \geq 1 \\ -\left[\frac{1 - \left(MB3_{G_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{G_{v-1}} & \text{if } MB3_{G_v} < 1 \\ 0 \quad \text{if } \left(MB3_{G_v} < 1\right) \wedge \left(\theta B3_{G_{v-1}} \leq 0\right) & \\ 0 \quad \text{otherwise} & \end{cases}$$

$$\theta B3_{Q_v} := \begin{cases} \left[\frac{\left[\left(MB3_Q\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB3_{Q_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{Q_{v-1}} & \text{if } MB3_{Q_v} \geq 1 \\ -\left[\frac{1 - \left(MB3_{Q_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B3_{Q_{v-1}} & \text{if } MB3_{Q_v} < 1 \\ 0 \quad \text{if } \left(MB3_{Q_v} < 1\right) \wedge \left(\theta B3_{Q_{v-1}} \leq 0\right) & \\ 0 \quad \text{otherwise} & \end{cases}$$

- ***B3 Relay Element Pick Up Logic***
  - Ground element (modified to latch and stay one, no drop out for now)

Initialize arrays with all zeros: $pu\_51G_{B3_v} := 0$

$$pu\_51G_{B3_v} := \begin{cases} 1 & \text{if } \left|\theta B3_{G_v}\right| \geq TD_{B3\_G} \\ 1 & \text{if } pu\_51G_{B3_{v-1}} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

  - Negative sequence element:

Initialize arrays with all zeros: $pu\_51Q_{B3_v} := 0$

$$pu\_51Q_{B3_v} := \begin{cases} 1 & \text{if } \left|\theta B3_{Q_v}\right| \geq TD_{B3\_Q} \\ 1 & \text{if } pu\_51Q_{B3_{v-1}} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

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

Initialize arrays with all zeros: $pu\_51P_{B3_v} := 0$

$$pu\_51P_{B3_v} := \begin{cases} 1 & \text{if } \theta B3_{PA_v} \geq TD_{B3\_P} \\ 1 & \text{if } \theta B3_{PB_v} \geq TD_{B3\_P} \\ 1 & \text{if } \theta B3_{PC_v} \geq TD_{B3\_P} \\ 1 & \text{if } pu\_51P_{B3_{v-1}} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

- ***Trip Logic***

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

$$TR51P_{B3_v} := E51P_{B3} \wedge pu\_51P_{B3_v}$$

$$TR51G_{B3_v} := E51G_{B3} \wedge pu\_51G_{B3_v}$$

$$TR51Q_{B3_v} := E51Q_{B3} \wedge pu\_51Q_{B3_v}$$

Overall Trip Equation:

$$Trip_{B3_v} := TR51P_{B3_v} \vee TR51G_{B3_v} \vee TR51Q_{B3_v}$$

Model for Relay Controlling B2:

- Current Ratios

$$MB2_{phA_v} := \frac{\left|IA1cpx_v\right|}{I_{pu\_P\_B2}} \qquad MB2_{G_v} := \frac{3\left|IA10_v\right|}{I_{pu\_G\_B2}}$$

- Initialize angle history to 0:

$$\theta B2_{PA_v} := 0sec$$

$$\theta B2_{PB_v} := 0sec$$

$$MB2_{phB_v} := \frac{\left|IB1cpx_v\right|}{I_{pu\_P\_B2}} \qquad MB2_{Q_v} := \frac{3\left|IA12_v\right|}{I_{pu\_Q\_B2}} \qquad \theta B2_{PC_v} := 0sec$$

$$\theta B2_{G_v} := 0sec$$

$$MB2_{phC_v} := \frac{\left|IC1cpx_v\right|}{I_{pu\_P\_B2}} \qquad \theta B2_{Q_v} := 0sec$$

$$\theta B2_{PA_v} := \begin{cases} \left[\frac{\left[\left(MB2_{phA}\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB2_{phA_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{PA_{v-1}} & \text{if } MB2_{phA_v} \geq 1 \\ -\left[\frac{1 - \left(MB2_{phA_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{PA_{v-1}} & \text{if } MB2_{phA_v} < 1 \\ 0 & \text{if } \left(MB2_{phA_v} < 1\right) \wedge \left(\theta B2_{PA_{v-1}} \leq 0\right) \\ 0 & \text{otherwise} \end{cases}$$

$$\theta B2_{PB_v} := \begin{cases} \left[\frac{\left[\left(MB2_{phB}\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB2_{phB_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{PB_{v-1}} & \text{if } MB2_{phB_v} \geq 1 \\ -\left[\frac{1 - \left(MB2_{phB_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{PB_{v-1}} & \text{if } MB2_{phB_v} < 1 \\ 0 & \text{if } \left(MB2_{phB_v} < 1\right) \wedge \left(\theta B2_{PB_{v-1}} \leq 0\right) \\ 0 & \text{otherwise} \end{cases}$$

$$\theta B2_{PC_v} := \begin{cases} \left[\frac{\left[\left(MB2_{phC}\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB2_{phC_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{PC_{v-1}} & \text{if } MB2_{phC_v} \geq 1 \\ -\left[\frac{1 - \left(MB2_{phC_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{PC_{v-1}} & \text{if } MB2_{phC_v} < 1 \\ 0 & \text{if } \left(MB2_{phC_v} < 1\right) \wedge \left(\theta B2_{PC_{v-1}} \leq 0\right) \\ 0 & \text{otherwise} \end{cases}$$

$$\theta B2_{G_v} := \begin{cases} \left[\frac{\left[\left(MB2_G\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB2_{G_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{G_{v-1}} & \text{if } MB2_{G_v} \geq 1 \\ -\left[\frac{1 - \left(MB2_{G_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{G_{v-1}} & \text{if } MB2_{G_v} < 1 \\ 0 & \text{if } \left(MB2_{G_v} < 1\right) \wedge \left(\theta B2_{G_{v-1}} \leq 0\right) \\ 0 & \text{otherwise} \end{cases}$$

$$\theta B2_{Q_v} := \begin{cases} \left(\frac{1}{TD_{B2\_Q}}\right)\cdot\left[\frac{\left[\left(MB2_Q\right)_v\right]^{p_{VI}} - 1}{B_{VI}\cdot\left[\left(MB2_{Q_v}\right)^{p_{VI}} - 1\right] + A_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{Q_{v-1}} & \text{if } MB2_{Q_v} \geq 1 \\ -\left[\frac{1 - \left(MB2_{Q_v}\right)^{p_{VI}}}{C_{VI}}\right]\cdot\left(\frac{1}{RS\cdot 60}\right) + \theta B2_{Q_{v-1}} & \text{if } MB2_{Q_v} < 1 \\ 0 & \text{if } \left(MB2_{Q_v} < 1\right) \wedge \left(\theta B2_{Q_{v-1}} \leq 0\right) \\ 0 & \text{otherwise} \end{cases}$$

- ***B2 Relay Element Pick Up Logic***

  - Ground element (modified to latch and stay one, no drop out for now)

    Initialize arrays with all zeros: $pu\_51G_{B2_v} := 0$

$$pu\_51G_{B2_v} := \begin{cases} 1 & \text{if } \left|\theta B2G_v\right| \geq TD_{B2\_G} \\ 1 & \text{if } pu\_51G_{B2_{v-1}} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

  - Negative sequence element:

    Initialize arrays with all zeros: $pu\_51Q_{B2_v} := 0$

$$pu\_51Q_{B2_v} := \begin{cases} 1 & \text{if } \left|\theta B2Q_v\right| \geq TD_{B2\_Q} \\ 1 & \text{if } pu\_51Q_{B2_{v-1}} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

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

Initialize arrays with all zeros: $pu\_51P_{B2_v} := 0$

$$pu\_51P_{B2_v} := \begin{cases} 1 & \text{if } \theta B2PA_v \geq TD_{B2\_P} \\ 1 & \text{if } \theta B2PB_v \geq TD_{B2\_P} \\ 1 & \text{if } \theta B2PC_v \geq TD_{B2\_P} \\ 1 & \text{if } pu\_51P_{B2_{v-1}} \geq 0.01 \\ 0 & \text{otherwise} \end{cases}$$

- ***Trip Logic***

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

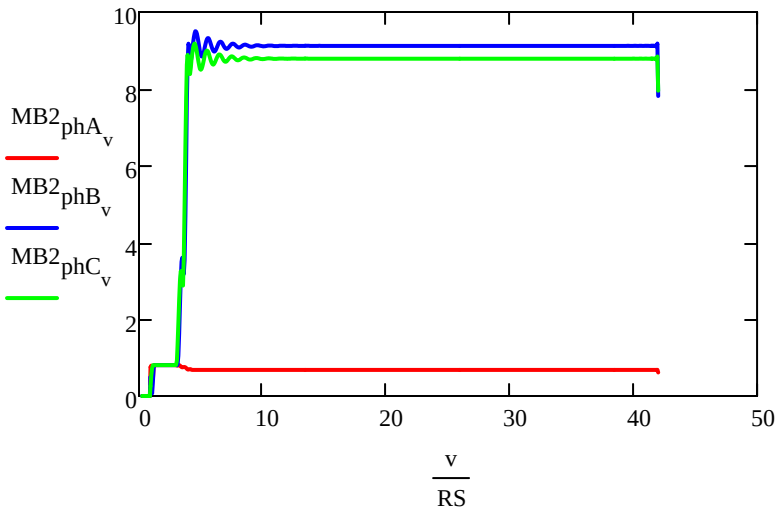
$$TR51P_{B2_v} := E51P_{B2} \wedge pu\_51P_{B2_v}$$

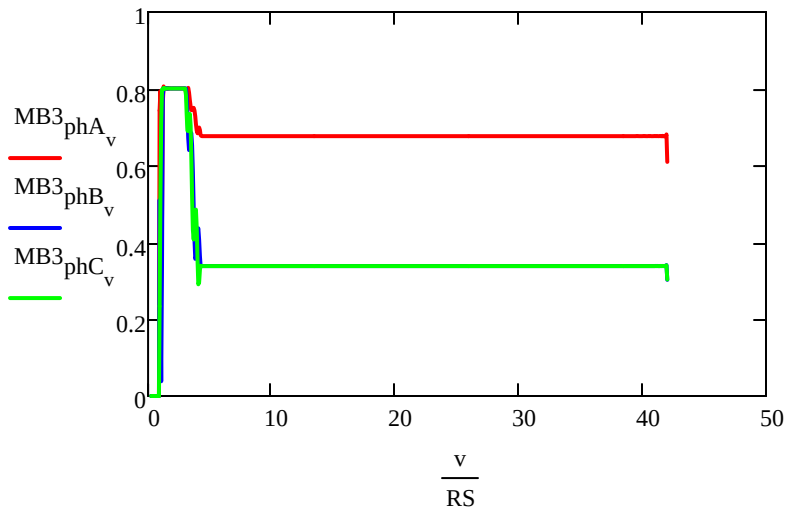
$$TR51G_{B2_v} := E51G_{B2} \wedge pu\_51G_{B2_v}$$

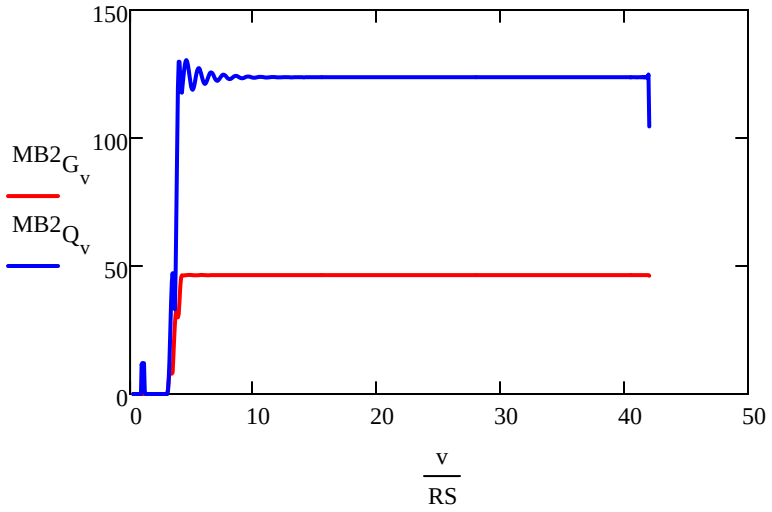
$$TR51Q_{B2_v} := E51Q_{B2} \wedge pu\_51Q_{B2_v}$$

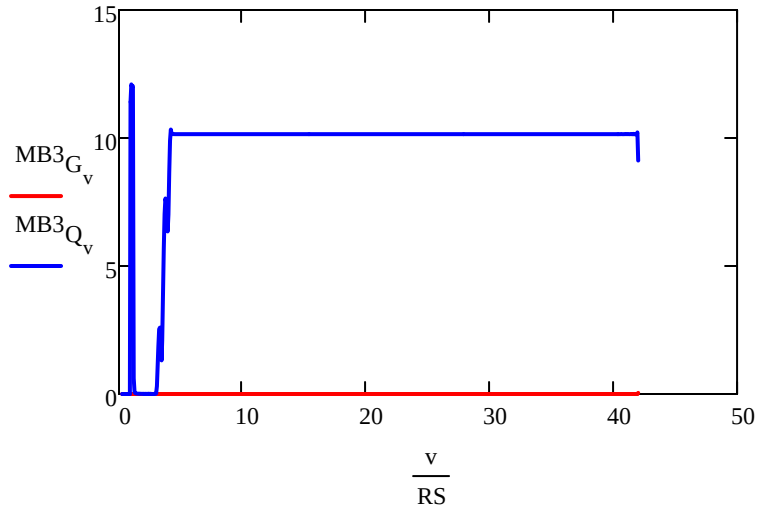
Overall Trip Equation:

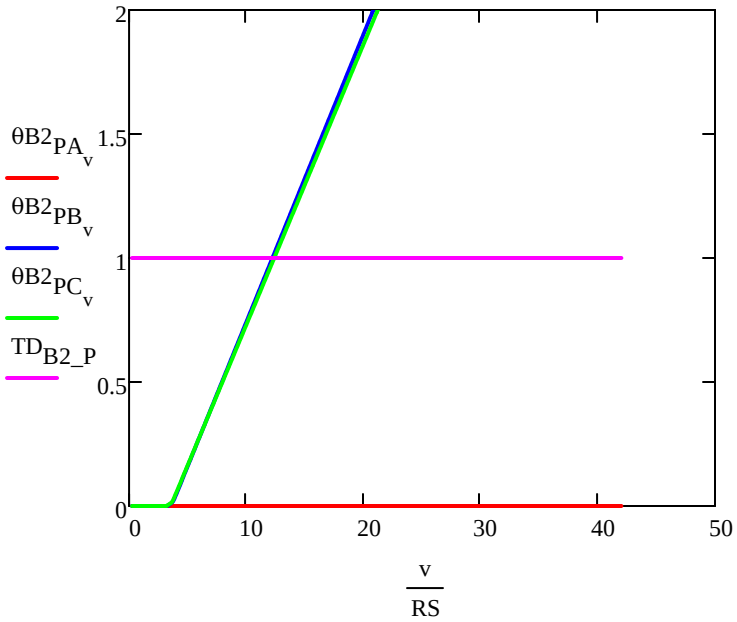
$$Trip_{B2_v} := \left(TR51P_{B2_v} \vee TR51G_{B2_v} \vee TR51Q_{B2_v}\right)$$

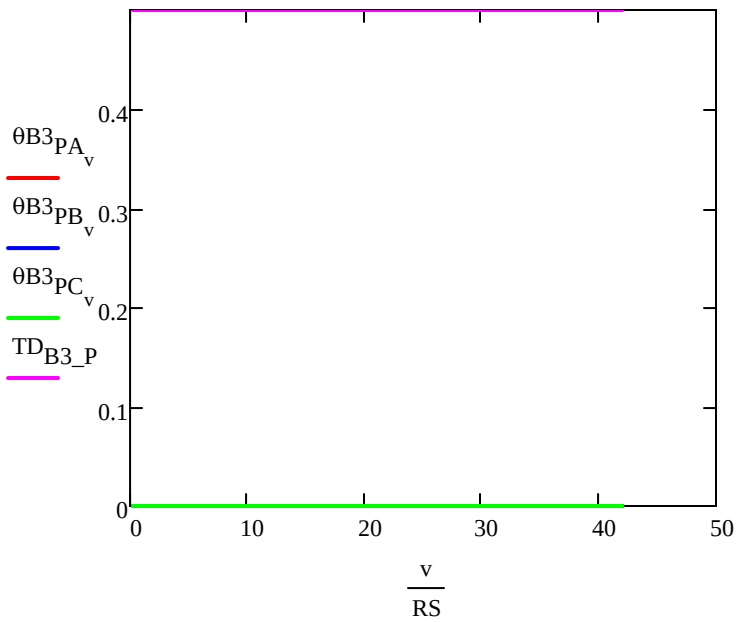

MB2phA_v
MB2phB_v
MB2phC_v
10
8
6
4
2
0
0
10
20
30
40
50
v
RS

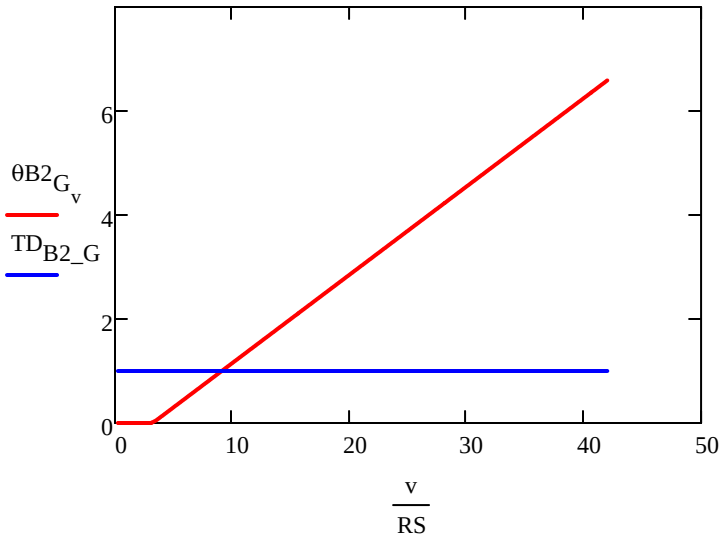

MB3phA_v
MB3phB_v
MB3phC_v
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
v
RS

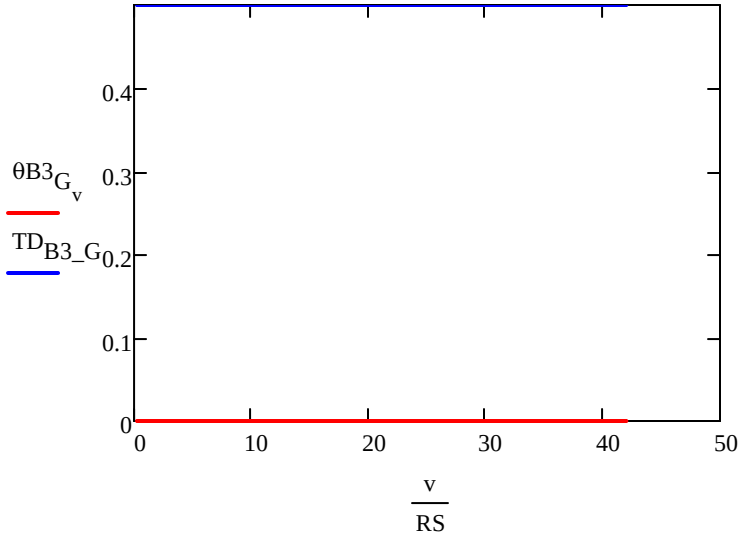

MB2G_v
MB2Q_v
150
100
50
0
0
10
20
30
40
50
v
RS

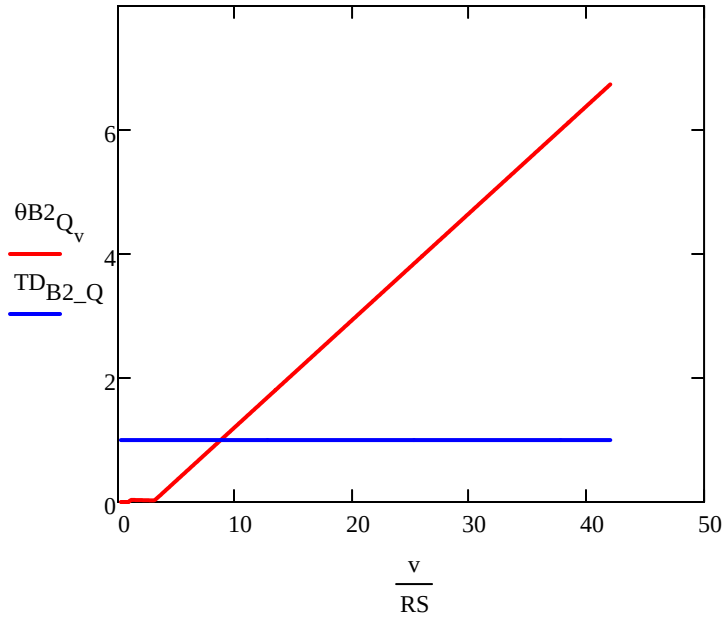

MB3G_v
MB3Q_v
15
10
5
0
0
10
20
30
40
50
v
RS

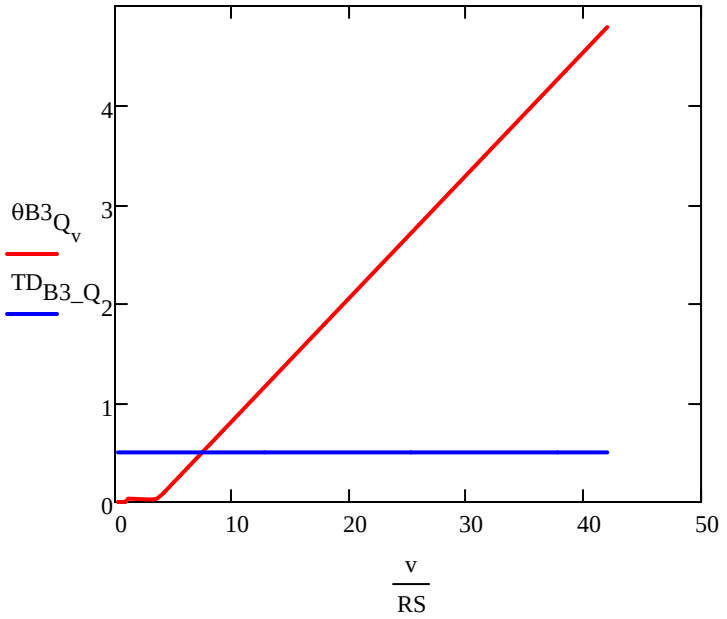

θB2PA_v
θB2PB_v
θB2PC_v
TDB2_P
2
1.5
1
0.5
0
0
10
20
30
40
50
v
RS


θB3PA_v
θB3PB_v
θB3PC_v
TDB3_P
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
v
RS


θB2G_v
TDB2_G
6
4
2
0
0
10
20
30
40
50
v
RS


θB3G_v
TDB3_G
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
v
RS


θB2Q_v
TD_B2_Q
6
4
2
0
0
10
20
30
40
50
v
RS


θB3Q_v
TD_B3_Q
4
3
2
1
0
0
10
20
30
40
50
v
RS

- ***Relay Response*** *Relay element pick up (without time delays)*