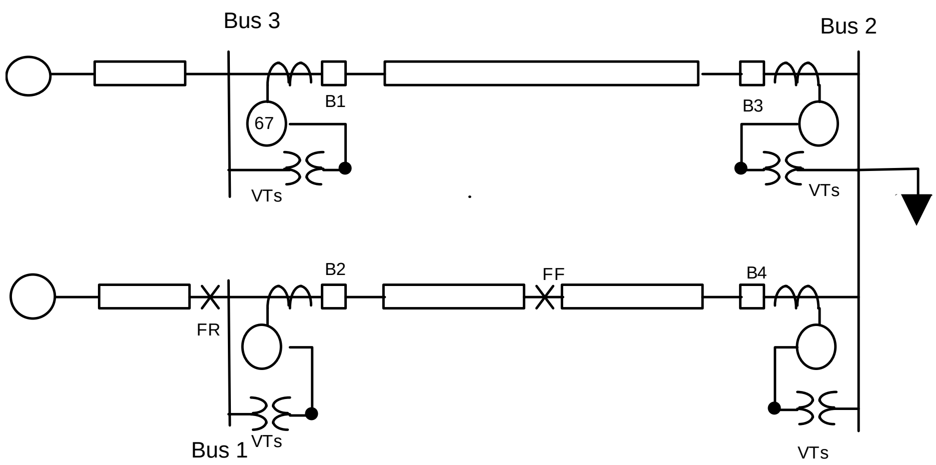
Directional Determination



Torque Calculation

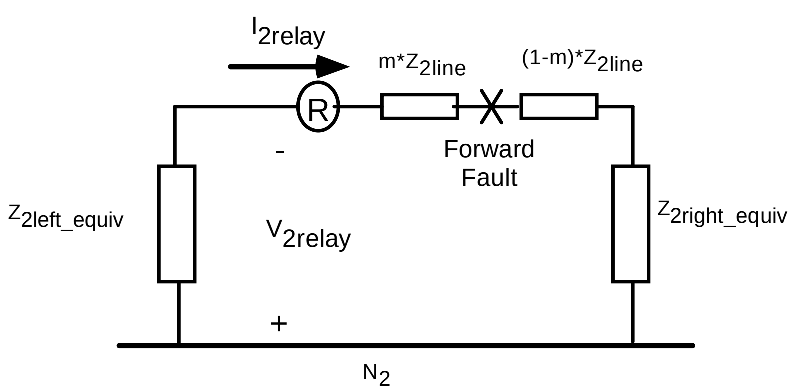
$MTA := Z1ANG$

$$TSA_v := \left|VAcpx_v\right| \cdot \left|IAcpx_v\right| \cdot \cos\left[\theta_{VA_v} - \left(\theta_{IA_v} + MTA\right)\right]$$

$$TSB_v := \left|VBcpx_v\right| \cdot \left|IBcpx_v\right| \cdot \cos\left[\theta_{VB_v} - \left(\theta_{IB_v} + MTA\right)\right]$$

$$TSC_v := \left|VCcpx_v\right| \cdot \left|ICcpx_v\right| \cdot \cos\left[\theta_{VC_v} - \left(\theta_{IC_v} + MTA\right)\right]$$

Negative Sequence Impedance for Forward Fault

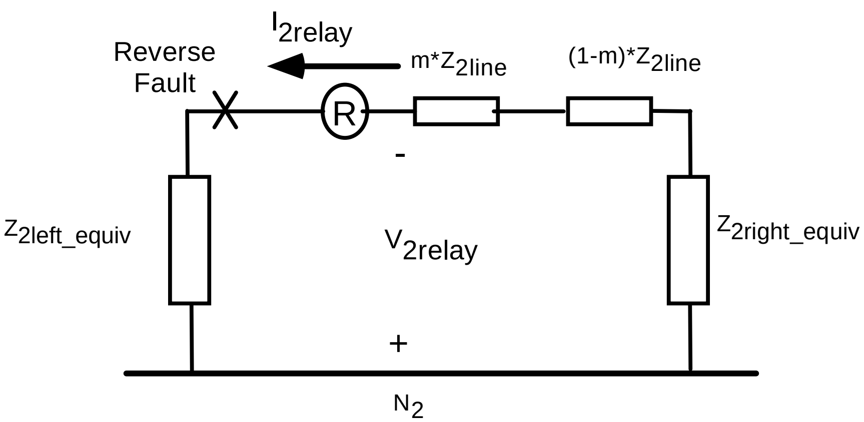


- The fault current seen by the relay flows to the fault from the left side, through the equivalent source impedance.
- The negative voltage to neutral reference (N2) at the relay location is the voltage drop due to the current passing through the impedance behind relay.
- Current feeding the fault from the right does not pass through the relay location and does not impact the negative sequence voltage at the relay.

So the relay calculates the following impedance:

$$Z_{2Relay} = \frac{V_{2relay}}{I_{2relay}} = \frac{-I_{2relay} \cdot Z_{2left\_equiv}}{I_{2relay}} = -Z_{2left\_equiv}$$

Negative Sequence Impedance for Reverse Fault



- Now the fault current is negative compared to what the relay sees as positive polarity
- The negative voltage to neutral reference (N2) at the relay location is the voltage drop due to the current passing through the impedance in front of the relay (line impedance plus the source impedance beyond the line
- Current feeding the fault from the left does not pass through the relay location and does not impact the negative sequence voltage at the relay.

So the relay calculates the following impedance:

$$Z_{2Relay} = \frac{V_{2relay}}{-I_{2relay}} = \frac{-I_{2relay} \cdot \left(Z_{2line} + Z_{2right\_equiv}\right)}{-I_{2relay}} = Z_{2line} + Z_{2right\_equiv}$$

- So the forward fault find a negative impedance (the magnitude of the impedance is less important than the fact that it is negative.
- Applying the analysis for reverse fault calculates a positive effective impedance.

- To confuse things (or to avoid confusion depending on your point of view), some vendors add a negative sign to the Z2 calculation so a forward fault has positive Z2 and a reverse fault has a negative Z2.

More secure calculation:

$$Z_2 = \frac{\mathrm{Re}\left[V2 \cdot \left(\overline{\left[I2 \cdot \left(1 \cdot e^{j \cdot Z1ANG}\right)\right]}\right)\right]}{\left(|I2|\right)^2 + .00001}$$

Effectively:

$$Z = \frac{S}{I^2}$$

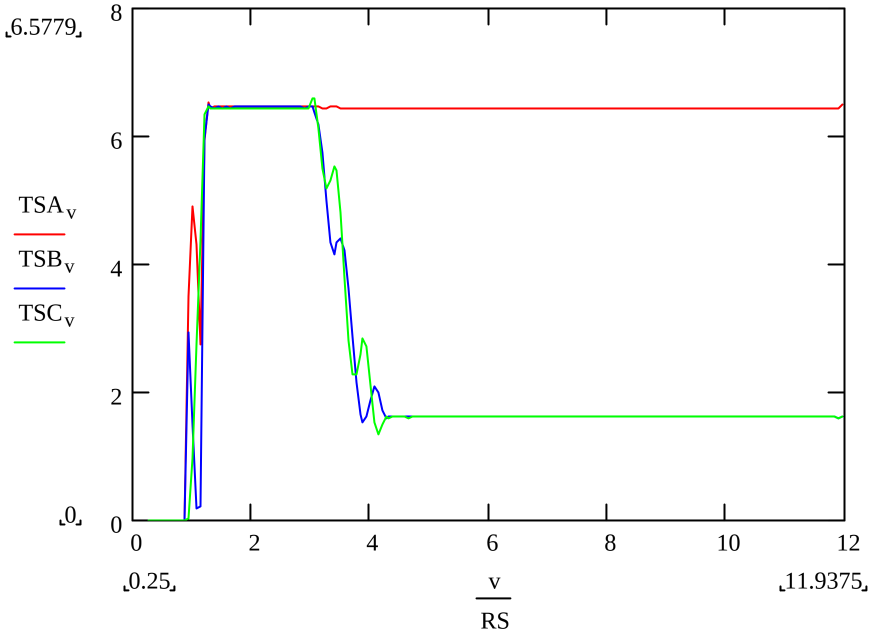
Settings for the element:

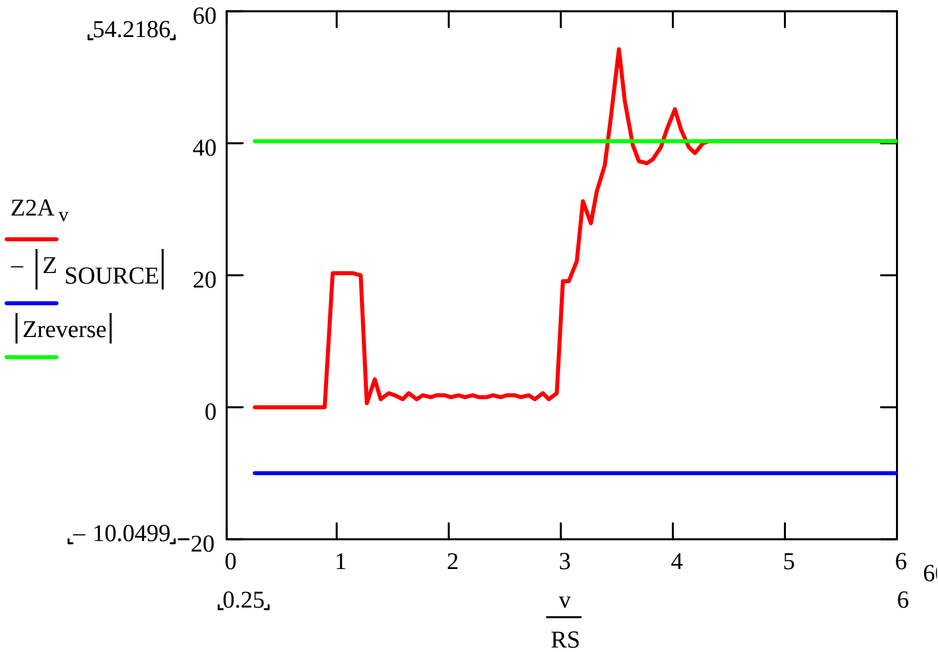
- Need to determine if there is sufficient negative sequence imbalance
- Need to set forward and reverse thresholds

Zero Sequence Element

- Behavior similar to negative sequence element
- Doesn’t cover as many faults
- Mutual coupling issues

Simulation Results—Reverse Fault

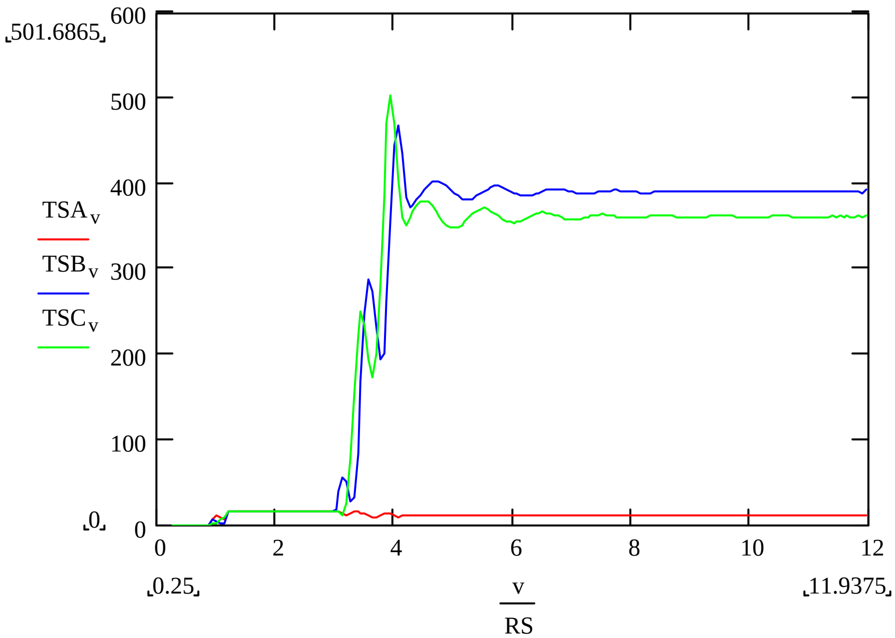


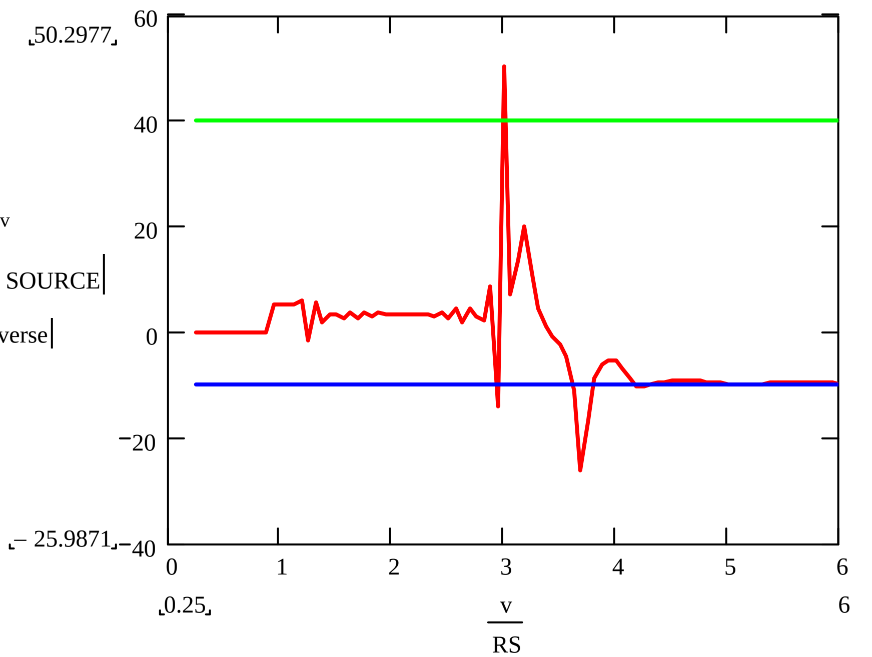


$Z_{SOURCE} := (1 + j\cdot 10)ohm$ $\quad$ $Zreverse := 2Z_{SOURCE} + 2\cdot Z1$

2 Zsource because fault current to 2 paths......

Simulation Results—Forward Fault





Alternate Three Phase Fault

An alternate approach instead of the torque equation is to compare the angle single phase impedance calculated from measurements to thresholds

$$-90\deg + Z1ANG < \theta_{Z1} < 90\deg + Z1ANG$$

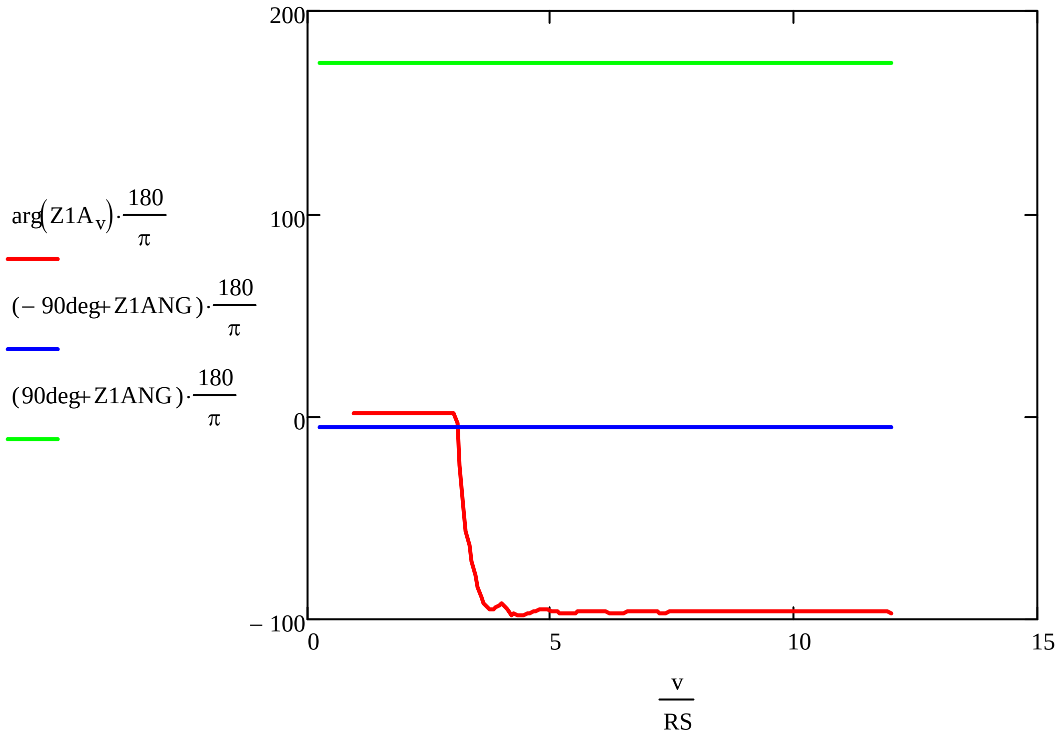
$$\theta_{V1_v} := \arg\left(VA1_v + 0.000001\right) \qquad \theta_{I1_v} := \arg\left[(IA1)_v + 0.000001\right]$$

$$Phase_{I1_v} := \begin{cases} \theta_{I1_v} - \theta_{V1_v} & \text{if } \left|\theta_{I1_v} - \theta_{V1_v}\right| < \pi \\ \left(\theta_{I1_v} - \theta_{V1_v} - 2\cdot\pi\right) & \text{if } \left(\theta_{I1_v} - \theta_{V1_v}\right) > \pi \\ \left(\theta_{I1_v} - \theta_{V1_v} + 2\cdot\pi\right) & \text{if } \theta_{I1_v} - \theta_{V1_v} < -(\pi) \end{cases}$$

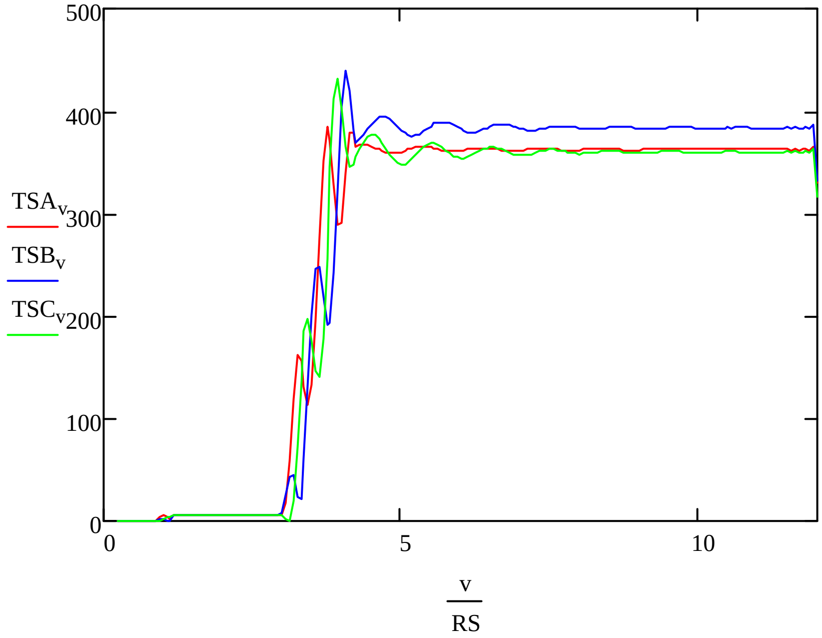
$$Phase_{V1_v} := \begin{cases} \theta_{V1_v} - \theta_{V1_v} & \text{if } \left|\theta_{V1_v} - \theta_{V1_v}\right| < \pi \\ \left(\theta_{V1_v} - \theta_{V1_v} - 2\cdot\pi\right) & \text{if } \left(\theta_{V1_v} - \theta_{V1_v}\right) > \pi \\ \left(\theta_{V1_v} - \theta_{V1_v} + 2\cdot\pi\right) & \text{if } \theta_{V1_v} - \theta_{V1_v} < -(\pi) \end{cases}$$

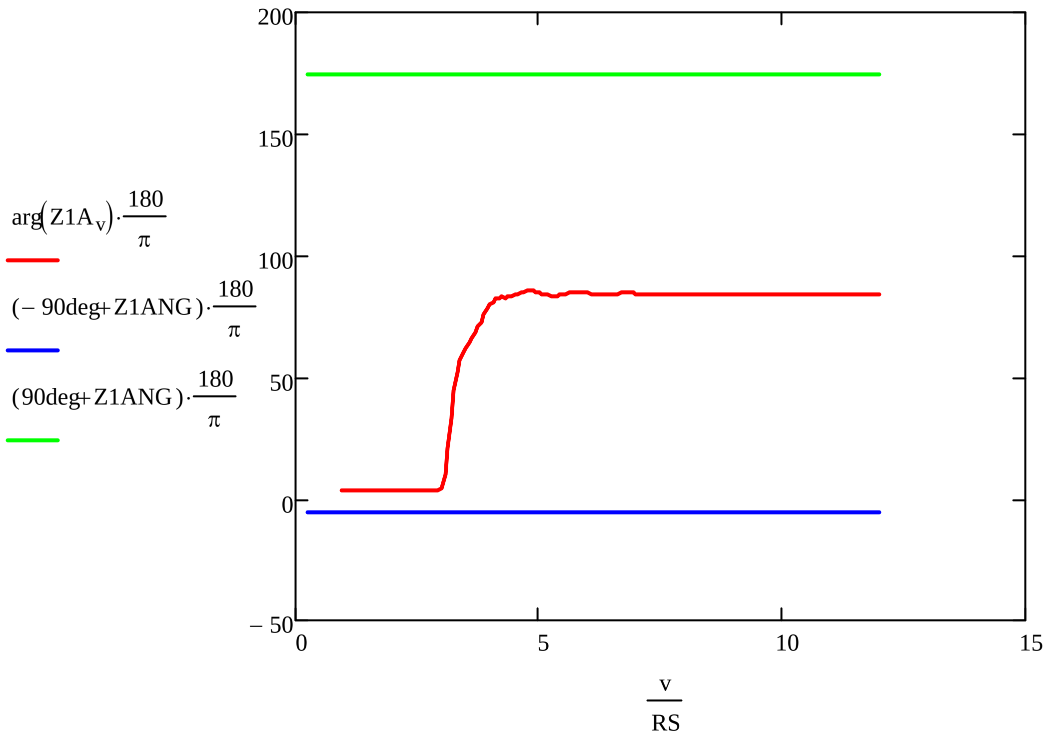
$$Z1A_v := \frac{\left|VA1_v\right|\cdot e^{j\cdot Phase_{V1_v}}}{\left|IA1_v\right|\cdot e^{j\cdot Phase_{I1_v}} + 0.00001}$$

Simulation Results—Reverse Fault

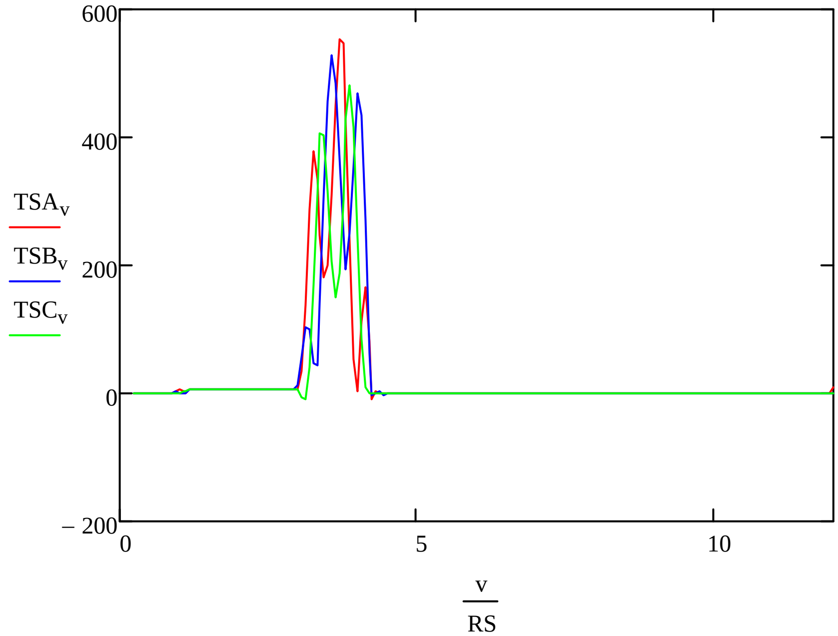


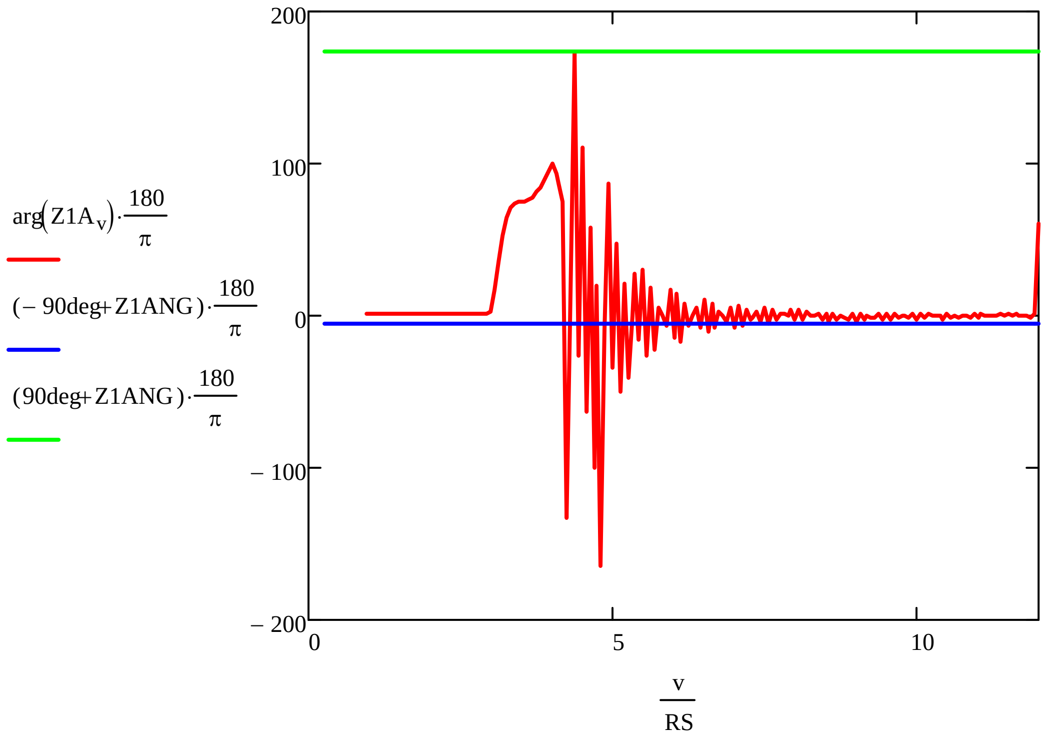
Simulation Results—Forward Fault





Simulation Results—Forward Fault Right at Breaker





Simulation Results—Reverse Fault Right at Breaker