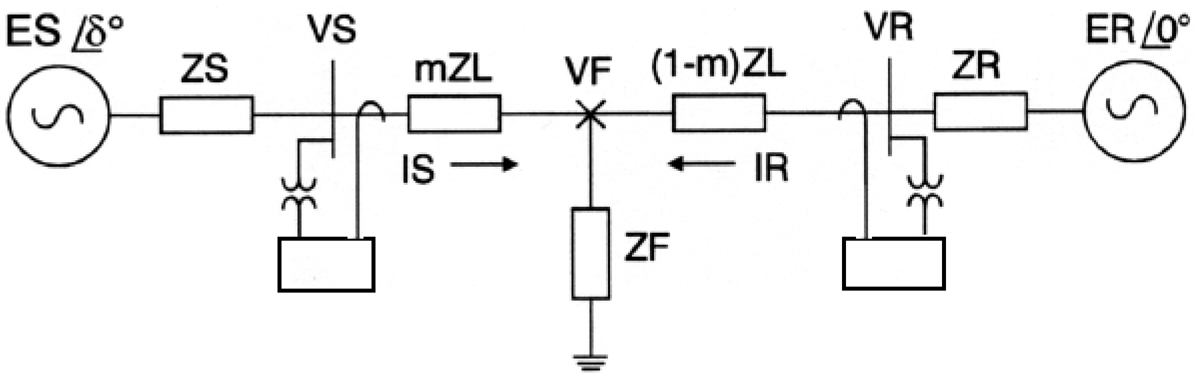
Patent number 3 made by Marko Pikkarainen



Fault Location

$d := 0.4653$

*Multiply factor to definition [0059] so that Iaf=multiply*Ia2 (original definition is that multiply=1)*

$multiply := 1$

$\delta := 0.1$ Voltage Phase Angle

$es := 12000 \cdot e^{j \cdot \delta \cdot deg}$ Source S Voltage $es = 1.2 \times 10^{4} + 20.944i$

$er := 11900$ $er = 1.19 \times 10^{4}$ Source R Voltage

$Ssir := .3 \cdot e^{j \cdot -5 \cdot deg}$ Source S SIR(Soure Impedance Ratio) $Ssir = 0.299 - 0.026i$

$Rsir := 0.2$ Source R SIR

$Z1L := 1.4 + 1.6i$ Positive Sequence Line Impedance

$Z0L := 3 \cdot Z1L$ Zero Sequence Line Impedance $INF := 10^{10}$ $Z1L = 1.4 + 1.6i$

$Z1S := Ssir \cdot Z1L$ Source S Positive Sequence Impedance $Z1S := 4.2 + 5.1i$

$Z0S := 5 \cdot e^{j \cdot -5 \cdot deg} \cdot Z1S$ Source S Zero Sequence Impedance $Z0S = 2.485 + 1.999i$

$Z1R := Z1S - Re(Z1S)$ Source R Positive Sequence Impedance

$Z0R := 3 \cdot Z1R$

First we generate voltages and currents in first case

$INF = 1 \times 10^{10}$

Fault Impedances (for AG fault case)

$ZFA := 0 + j \cdot 0 \qquad ZFB := INF + j \cdot 0 \qquad ZFC := INF + j \cdot 0$

Fault Resistance

$ZFG := 0$

CONSTANTS

$rad := 1 \qquad deg := \frac{\pi}{180} \cdot rad$

$a := -0.5 + j \cdot 0.8660254$

$$BAL := \begin{pmatrix} 1 \\ a^2 \\ a \end{pmatrix} \qquad one := \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad zero := \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Three phase voltages at S and R

$ES := es \cdot BAL$

$ER := er \cdot BAL$

$$ES = \begin{pmatrix} 1.2 \times 10^4 + 20.944i \\ -5.982 \times 10^3 - 1.04i \times 10^4 \\ -6.018 \times 10^3 + 1.038i \times 10^4 \end{pmatrix} \qquad ER = \begin{pmatrix} 1.19 \times 10^4 \\ -5.95 \times 10^3 - 1.031i \times 10^4 \\ -5.95 \times 10^3 + 1.031i \times 10^4 \end{pmatrix}$$

Coversion of positive sequence and zero sequence impedances to Self and Mutual impedances

$$zs(z0, z1) := \frac{2 \cdot z1 + z0}{3} \qquad zm(z0, z1) := \frac{z0 - z1}{3}$$

Conversion Matrix Format

$$Z(z0,z1) := \begin{pmatrix} zs(z0,z1) & zm(z0,z1) & zm(z0,z1) \\ zm(z0,z1) & zs(z0,z1) & zm(z0,z1) \\ zm(z0,z1) & zm(z0,z1) & zs(z0,z1) \end{pmatrix}$$

Now Conversion

$ZS := Z(Z0S, Z1S)$ $\quad ZL := Z(Z0L, Z1L)$ $\quad ZR := Z(Z0R, Z1R)$

$ZR_{0,1} := 0$ $\quad ZR_{0,2} := 0$ $\quad ZR_{2,1} := 0$ $\quad ZR_{1,0} := 0$ $\quad ZR_{1,2} := 0$ $\quad ZR_{2,0} := 0$

$$ZS = \begin{pmatrix} 1.135 + 0.961i & 0.675 + 0.519i & 0.675 + 0.519i \\ 0.675 + 0.519i & 1.135 + 0.961i & 0.675 + 0.519i \\ 0.675 + 0.519i & 0.675 + 0.519i & 1.135 + 0.961i \end{pmatrix} \qquad ZR = \begin{pmatrix} 0.736i & 0.294i & 0.294i \\ 0.294i & 0.736i & 0.294i \\ 0.294i & 0.294i & 0.736i \end{pmatrix}$$

Source and Line Impedances to the Fault

$$ZSS := ZS + d \cdot ZL \qquad ZSS = \begin{pmatrix} 2.221 + 2.201i & 1.109 + 1.015i & 1.109 + 1.015i \\ 1.109 + 1.015i & 2.221 + 2.201i & 1.109 + 1.015i \\ 1.109 + 1.015i & 1.109 + 1.015i & 2.221 + 2.201i \end{pmatrix}$$

$$ZL = \begin{pmatrix} 2.333 + 2.667i & 0.933 + 1.067i & 0.933 + 1.067i \\ 0.933 + 1.067i & 2.333 + 2.667i & 0.933 + 1.067i \\ 0.933 + 1.067i & 0.933 + 1.067i & 2.333 + 2.667i \end{pmatrix}$$

$$ZRR := ZR + (1 - d) \cdot ZL \qquad ZRR = \begin{pmatrix} 1.248 + 2.162i & 0.499 + 0.865i & 0.499 + 0.865i \\ 0.499 + 0.865i & 1.248 + 2.162i & 0.499 + 0.865i \\ 0.499 + 0.865i & 0.499 + 0.865i & 1.248 + 2.162i \end{pmatrix}$$

Build System Part of the Impedance Matrix ---see (2) of page 3 in the paper.

$$ZTOP := augment(augment(ZSS, zero), one)$$

$$ZTOP = \begin{pmatrix} 2.221 + 2.201i & 1.109 + 1.015i & 1.109 + 1.015i & 0 & 0 & 0 & 1 & 0 & 0 \\ 1.109 + 1.015i & 2.221 + 2.201i & 1.109 + 1.015i & 0 & 0 & 0 & 0 & 1 & 0 \\ 1.109 + 1.015i & 1.109 + 1.015i & 2.221 + 2.201i & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$ZMID := augment(augment(zero, ZRR), one)$$

$$ZMID = \begin{pmatrix} 0 & 0 & 0 & 1.248 + 2.162i & 0.499 + 0.865i & 0.499 + 0.865i & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.499 + 0.865i & 1.248 + 2.162i & 0.499 + 0.865i & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.499 + 0.865i & 0.499 + 0.865i & 1.248 + 2.162i & 0 & 0 & 1 \end{pmatrix}$$

$$ZSYS := stack(ZTOP, ZMID)$$

$$ZSYS = \begin{pmatrix} 2.221+2.201i & 1.109+1.015i & 1.109+1.015i & 0 & 0 & 0 & 1 & 0 & 0 \\ 1.109+1.015i & 2.221+2.201i & 1.109+1.015i & 0 & 0 & 0 & 0 & 1 & 0 \\ 1.109+1.015i & 1.109+1.015i & 2.221+2.201i & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1.248+2.162i & 0.499+0.865i & 0.499+0.865i & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.499+0.865i & 1.248+2.162i & 0.499+0.865i & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.499+0.865i & 0.499+0.865i & 1.248+2.162i & 0 & 0 & 1 \end{pmatrix}$$

Pre-fault conditions:

$$ZPRE := ZS + ZL + ZR$$

$$ZPRE = \begin{pmatrix} 3.468+4.363i & 1.608+1.88i & 1.608+1.88i \\ 1.608+1.88i & 3.468+4.363i & 1.608+1.88i \\ 1.608+1.88i & 1.608+1.88i & 3.468+4.363i \end{pmatrix}$$

$$IPRE := ZPRE^{-1} \cdot (ES - ER)$$

$$IPRE = \begin{pmatrix} 24.723-21.743i \\ -31.192-10.539i \\ 6.468+32.282i \end{pmatrix}$$

$$VSP := ES - ZS \cdot IPRE$$

Voltage at the relay near bus S? Yes, Prefault :

$$VSP = \begin{pmatrix} 1.198\times10^{4}+20.034i \\ -5.972\times10^{3}-1.038i\times10^{4} \\ -6.007\times10^{3}+1.036i\times10^{4} \end{pmatrix} \quad ES = \begin{pmatrix} 1.2\times10^{4}+20.944i \\ -5.982\times10^{3}-1.04i\times10^{4} \\ -6.018\times10^{3}+1.038i\times10^{4} \end{pmatrix}$$

Build the voltage Vector: Again, see (2) of page 3

$$null := (0 \quad 0 \quad 0)$$

$$E := stack\left(stack(ES, ER), null^T\right)$$

$$TS := augment(augment(one, zero), zero)$$

$$TR := augment(augment(zero, one), zero)$$

$$TVF := augment(augment(zero, zero), one)$$

$$E = \begin{pmatrix} 1.2 \times 10^4 + 20.944i \\ -5.982 \times 10^3 - 1.04i \times 10^4 \\ -6.018 \times 10^3 + 1.038i \times 10^4 \\ 1.19 \times 10^4 \\ -5.95 \times 10^3 - 1.031i \times 10^4 \\ -5.95 \times 10^3 + 1.031i \times 10^4 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

$$TS = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$TR = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{pmatrix}$$

$$TVF = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Building Fault Part of the Impedance Matrix:

$$ZFAG := ZFA + ZFG$$

$$ZFBG := ZFB + ZFG$$

$$ZFCG := ZFC + ZFG$$

$$ZF := \begin{pmatrix} ZFAG & ZFG & ZFG \\ ZFG & ZFBG & ZFG \\ ZFG & ZFG & ZFCG \end{pmatrix}$$

$$FABCG := augment(augment(-ZF, -ZF), one)$$

$$ZFAG = 0$$

$$ZFBG = 1 \times 10^{10}$$

$$ZF = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 \times 10^{10} & 0 \\ 0 & 0 & 1 \times 10^{10} \end{pmatrix}$$

$$FABCG = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & -1 \times 10^{10} & 0 & 0 & -1 \times 10^{10} & 0 & 0 & 1 & 0 \\ 0 & 0 & -1 \times 10^{10} & 0 & 0 & -1 \times 10^{10} & 0 & 0 & 1 \end{pmatrix}$$

$$ZABCG := \text{stack}(ZSYS, FABCG)$$

$$ZABCG = \begin{pmatrix} 2.221+2.201i & 1.109+1.015i & 1.109+1.015i & 0 & 0 & 0 & 1 & 0 & 0 \\ 1.109+1.015i & 2.221+2.201i & 1.109+1.015i & 0 & 0 & 0 & 0 & 1 & 0 \\ 1.109+1.015i & 1.109+1.015i & 2.221+2.201i & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1.248+2.162i & 0.499+0.865i & 0.499+0.865i & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.499+0.865i & 1.248+2.162i & 0.499+0.865i & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.499+0.865i & 0.499+0.865i & 1.248+2.162i & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & -1\times 10^{10} & 0 & 0 & -1\times 10^{10} & 0 & 0 & 1 & 0 \\ 0 & 0 & -1\times 10^{10} & 0 & 0 & -1\times 10^{10} & 0 & 0 & 1 \end{pmatrix}$$

$$YABCG := ZABCG^{-1}$$

Fault Currents:

$IABCG := YABCG \cdot E$

$$E = \begin{pmatrix} 1.2\times10^{4} + 20.944i \\ -5.982\times10^{3} - 1.04i\times10^{4} \\ -6.018\times10^{3} + 1.038i\times10^{4} \\ 1.19\times10^{4} \\ -5.95\times10^{3} - 1.031i\times10^{4} \\ -5.95\times10^{3} + 1.031i\times10^{4} \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad IABCG = \begin{pmatrix} 2.803\times10^{3} - 2.859i\times10^{3} \\ -101.291 + 143.563i \\ -63.631 + 186.385i \\ 2.317\times10^{3} - 3.997i\times10^{3} \\ 101.291 - 143.563i \\ 63.631 - 186.385i \\ 0 \\ -1.119\times10^{4} - 1.032i\times10^{4} \\ -1.122\times10^{4} + 1.038i\times10^{4} \end{pmatrix}$$

S - End Fault Currents:

$IS := TS \cdot IABCG$

R - End Fault Currents:

$IR := TR \cdot IABCG$

$$IS = \begin{pmatrix} 2.803\times10^{3} - 2.859i\times10^{3} \\ -101.291 + 143.563i \\ -63.631 + 186.385i \end{pmatrix} \quad IR = \begin{pmatrix} 2.317\times10^{3} - 3.997i\times10^{3} \\ 101.291 - 143.563i \\ 63.631 - 186.385i \end{pmatrix}$$

VF fault voltages:

$VF := TVF \cdot IABCG$

$$VF = \begin{pmatrix} 0 \\ -1.119\times10^{4} - 1.032i\times10^{4} \\ -1.122\times10^{4} + 1.038i\times10^{4} \end{pmatrix}$$

S - End Voltages

$VS := ES - ZS \cdot IS$

$$VS = \begin{pmatrix} 6.355\times10^{3} + 435.878i \\ -8.965\times10^{3} - 1.009i\times10^{4} \\ -9\times10^{3} + 1.066i\times10^{4} \end{pmatrix}$$

Line Prefault Load Currents from S Bus

$Ia := IPRE_0 \qquad |Ia| = 32.924 \qquad \frac{arg(Ia)}{deg} = -41.33 \qquad 0.32\cdot\frac{180}{3.14} = 18.344$

$Ib := IPRE_1 \qquad |Ib| = 32.924 \qquad \frac{arg(Ib)}{deg} = -161.33$

$$IPRE = \begin{pmatrix} 24.723 - 21.743i \\ -31.192 - 10.539i \\ 6.468 + 32.282i \end{pmatrix}$$

$Ic := IPRE_2 \qquad |Ic| = 32.924 \qquad \frac{arg(Ic)}{deg} = 78.67$

Line Prefault Voltages at S Bus

$Va := VSP_0 \qquad |Va| = 1.198 \times 10^4 \qquad \frac{arg(Va)}{deg} = 0.096$

$Vb := VSP_1 \qquad |Vb| = 1.198 \times 10^4 \qquad \frac{arg(Vb)}{deg} = -119.904$

$Vc := VSP_2 \qquad |Vc| = 1.198 \times 10^4 \qquad \frac{arg(Vc)}{deg} = 120.096$

$$VSP = \begin{pmatrix} 1.198 \times 10^4 + 20.034i \\ -5.972 \times 10^3 - 1.038i \times 10^4 \\ -6.007 \times 10^3 + 1.036i \times 10^4 \end{pmatrix}$$

Line Fault Currents from S Bus

$Iasf := IS_0 \qquad |Iasf| = 4.004 \times 10^3 \qquad \frac{arg(Iasf)}{deg} = -45.562$

$Ibsf := IS_1 \qquad |Ibsf| = 175.699 \qquad \frac{arg(Ibsf)}{deg} = 125.205$

$Icsf := IS_2 \qquad |Icsf| = 196.947 \qquad \frac{arg(Icsf)}{deg} = 108.85$

$$IS = \begin{pmatrix} 2.803 \times 10^3 - 2.859i \times 10^3 \\ -101.291 + 143.563i \\ -63.631 + 186.385i \end{pmatrix}$$

Line Fault Currents from R Bus

$Iarf := IR_0 \qquad |Iarf| = 4.62 \times 10^3 \qquad \frac{arg(Iarf)}{deg} = -59.9$

$Ibrf := IR_1 \qquad |Ibrf| = 175.699 \qquad \frac{arg(Ibrf)}{deg} = -54.795$

$Icrf := IR_2 \qquad |Icrf| = 196.947 \qquad \frac{arg(Icrf)}{deg} = -71.15$

$$IR = \begin{pmatrix} 2.317 \times 10^3 - 3.997i \times 10^3 \\ 101.291 - 143.563i \\ 63.631 - 186.385i \end{pmatrix}$$

Line Fault Voltages at S Bus

$$VSP = \begin{pmatrix} 1.198 \times 10^4 + 20.034i \\ -5.972 \times 10^3 - 1.038i \times 10^4 \\ -6.007 \times 10^3 + 1.036i \times 10^4 \end{pmatrix}$$

$Vaf := VS_0$ $\quad |Vaf| = 6.37 \times 10^3$ $\quad \frac{arg(Vaf)}{deg} = 3.924$

$Vbf := VS_1$ $\quad |Vbf| = 1.35 \times 10^4$ $\quad \frac{arg(Vbf)}{deg} = -131.629$

$$VS = \begin{pmatrix} 6.355 \times 10^3 + 435.878i \\ -8.965 \times 10^3 - 1.009i \times 10^4 \\ -9 \times 10^3 + 1.066i \times 10^4 \end{pmatrix}$$

$Vcf := VS_2$ $\quad |Vcf| = 1.395 \times 10^4$ $\quad \frac{arg(Vcf)}{deg} = 130.169$

$Ir := \sum_{mm=0}^{2} IS_{mm}$ $\quad Ir = 2.638 \times 10^3 - 2.529i \times 10^3$

$$IS = \begin{pmatrix} 2.803 \times 10^3 - 2.859i \times 10^3 \\ -101.291 + 143.563i \\ -63.631 + 186.385i \end{pmatrix}$$

$d = 0.465$

$$T1 := \frac{arg\left[\frac{Z0S + Z0R + Z0L}{Z0R + (1-d)Z0L}\right]}{deg} = -9.461 \qquad T1 = -9.461$$

$\left[\frac{Z0S + Z0R + Z0L}{Z0R + (1-d)Z0L}\right] = 2.31 - 0.385i$

$Z0S = 2.485 + 1.999i$

$Z0R = 1.325i$ $\quad Z0R = 1.325$ $\quad Z1R = 0.442i$

$Z0L = 4.2 + 4.8i$

$k0 := \frac{Z0L - Z1L}{3 \cdot Z1L}$ $\quad k0 = 0.667$

$e^{j \cdot T1} = -0.999 + 0.036i$ $\quad Z0S + Z0R + Z0L = 6.685 + 8.124i$

$Z0L = 4.2 + 4.8i$

distance L (which is supposed to be same as m)

$IPRE_0 = 24.723 - 21.743i$

$|IS_0| = 4.004 \times 10^3$

$IS_0 = 2.803 \times 10^3 - 2.859i \times 10^3$

$$L := \frac{Im\left[VS_0 \cdot \overline{\left(Ir \cdot e^{j \cdot T1 \cdot deg}\right)}\right]}{Im\left[Z1L \cdot (IS_0 + k0 \cdot Ir) \cdot \overline{\left(Ir \cdot e^{j \cdot T1 \cdot deg}\right)}\right]} \qquad L = 0.465$$

$VS_0 = 6.355 \times 10^3 + 435.878i$

$\frac{|IS_0|}{|IPRE_0|} = 121.598$

$VSP_0 = 1.198 \times 10^4 + 20.034i$

$e^{j \cdot T1} = -0.999 + 0.036i$

$\frac{VSP_0}{IPRE_0} - Z1L = 271.409 + 239.135i$

$VSP_0 = 1.198 \times 10^4 + 20.034i$ $\quad VS_0 = 6.355 \times 10^3 + 435.878i$

$\left|VSP_0\right| = 1.198 \times$ $\frac{\arg(VSP_0)}{deg} = 0.096$

$\left|VS_0\right| = 6.37 \times 10^3$ $\frac{\arg(VS_0)}{deg} = 3.924$

$\frac{VS_0 - VSP_0}{IS_0 - IPRE_0} = -1.066 - 0.939i$

So How do I generate digital signals of Voltage and Current of the Simulation 4 Cycles

$\left|VS_1\right| = 1.35 \times 10^4$

$\left|VS_2\right| = 1.395 \times 10^4$

$k := 0..511$

$delT := 0.0001302$

$e^{j \cdot T1} = -0.999 + 0.036i$

$Van_k := \left|VSP_0\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(VSP_0))$

$t1_k := k \cdot delT$

$t2_k := 512 \cdot delT + k \cdot delT$

$t3_k := 1024 \cdot delT + k \cdot delT$

$Vbn_k := \left|VSP_1\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(VSP_1))$

$Vcn_k := \left|VSP_2\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(VSP_2))$

$Vaf_k := \left|VS_0\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(VS_0))$

$Vbf_k := \left|VS_1\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(VS_1))$

$Vcf_k := \left|VS_2\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(VS_2))$

$Ian_k := \left|IPRE_0\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(IPRE_0))$

$Ibn_k := \left|IPRE_1\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(IPRE_1))$

$Icn_k := \left|IPRE_2\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(IPRE_2))$

$Iaf_k := \left|IS_0\right| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(IS_0))$

$$Ibf_k := \left|IS_1\right| \cdot \sin\left(2\cdot\pi\cdot 60\cdot k\cdot delT + \arg\left(IS_1\right)\right)$$

$$Icf_k := \left|IS_2\right| \cdot \sin\left(2\cdot\pi\cdot 60\cdot k\cdot delT + \arg\left(IS_2\right)\right)$$

$\min(t1) = 0$ $\max(t1) = 0.067$

$\min(t2) = 0.067$ $\max(t2) = 0.133$

$\min(t3) = 0.133$ $\max(t3) = 0.2$

$$\frac{\frac{1}{60}}{128} = 1.302 \times 10^{-4}$$

$t1_{511} = 0.067$ $t2_0 = 0.067$

$t2_0 - t1_{511} = 1.302 \times 10^{-4}$

$t3_0 - t2_{511} = 1.302 \times 10^{-4}$

Seg1 := augment(t1, Ian, Ibn, Icn, Van, Vbn, Vcn)

Seg2 := augment(t2, Iaf, Ibf, Icf, Vaf, Vbf, Vcf)

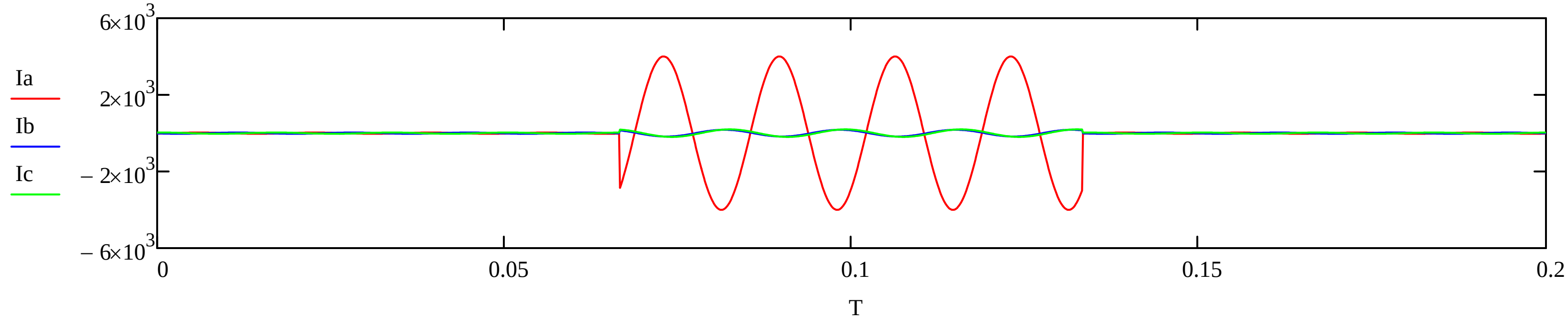
Seg3 := augment(t3, Ian, Ibn, Icn, Van, Vbn, Vcn)

Final := stack(Seg1, Seg2, Seg3)

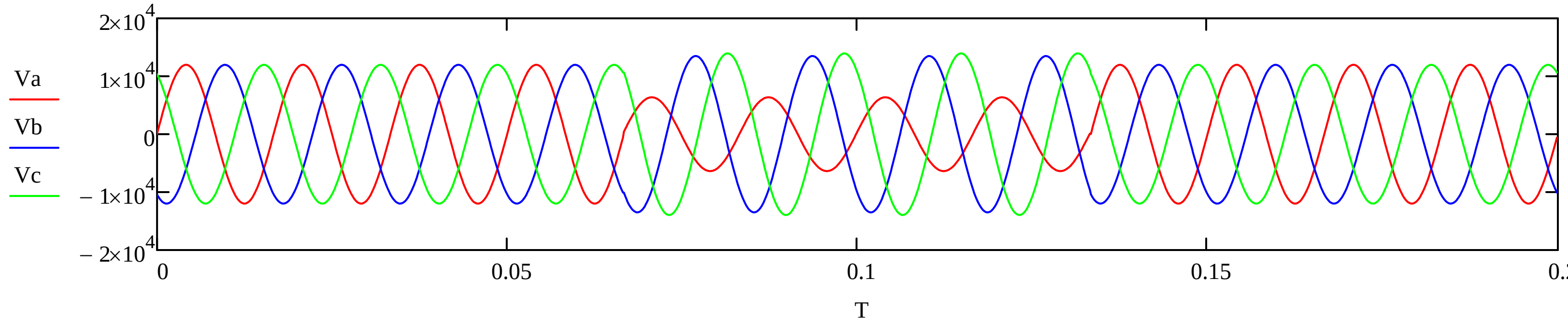
$T := Final^{\langle 0\rangle}$ $Ia := Final^{\langle 1\rangle}$ $Ib := Final^{\langle 2\rangle}$ $Ic := Final^{\langle 3\rangle}$ $Va := Final^{\langle 4\rangle}$ $Vb := Final^{\langle 5\rangle}$ $Vc := Final^{\langle 6\rangle}$

$Ir := Ia + Ib + Ic$

Generated phase currents



Generated phase voltages



$m := \text{length}(Va)$ $\quad m = 1.536 \times 10^3$

$Ko := .3$ $\quad Ko := \dfrac{1}{1 + 3 \cdot k0}$

$window := 128$

$wind := window - 1$

Isa on sama kuin (Ia +k*Ir)

$Isa := Ia$ $\quad Isb := Ib$ $\quad Isc := Ic$ $\quad k0 = 0.667$

$dd := 0 .. \dfrac{m}{window} - 1$

$kk := 0 .. m - window$

$k := 0 .. \frac{m - window}{8}$ $\frac{m - window}{8} = 176$

$Ua_k := submatrix(Va, k \cdot 8, k \cdot 8 + wind, 0, 0)$ $Ub_k := submatrix(Vb, k \cdot 8, k \cdot 8 + wind, 0, 0)$ $Uc_k := submatrix(Vc, k \cdot 8, k \cdot 8 + wind, 0, 0)$

$Ao_k := submatrix(Ir, k \cdot 8, k \cdot 8 + wind, 0, 0)$

$Aa_k := submatrix(Isa, k \cdot 8, k \cdot 8 + wind, 0, 0)$ $Ab_k := submatrix(Isb, k \cdot 8, k \cdot 8 + wind, 0, 0)$ $Ac_k := submatrix(Isc, k \cdot 8, k \cdot 8 + wind, 0, 0)$

Now we take FFT from voltages and currents so we get complex values for voltages and currents

$Fa_k := FFT\left(\left(Aa_k\right)\right)$ $Fb_k := FFT\left(Ab_k\right)$ $Fc_k := FFT\left(Ac_k\right)$

$Pa_k := FFT\left(Ua_k\right)$ $Pb_k := FFT\left(Ub_k\right)$ $Pc_k := FFT\left(Uc_k\right)$ $Fo_k := FFT\left(Ao_k\right)$

Line impedances (zero, positive and negative sequence) and α-factor

$Z0Fd := Z0L$

$Z1Fd := Z1L$

$Z2Fd := Z1L$

$alph := \exp\left(\pi \cdot j \cdot \frac{120}{180}\right) = -0.5 + 0.866i$

Sequence components of voltages and currents

$$Ia1_k := \frac{\left[\left(Fa_k\right)_{1,0} + alph \cdot \left(Fb_k\right)_{1,0} + alph^2 \cdot \left(Fc_k\right)_{1,0}\right]}{3}$$

$$Ua1_k := \frac{\left(Pa_k\right)_{1,0} + alph \cdot \left(Pb_k\right)_{1,0} + alph^2 \cdot \left(Pc_k\right)_{1,0}}{3}$$

$$Ia2_k := \frac{\left[\left(Fa_k\right)_{1,0} + alph^2 \cdot \left(Fb_k\right)_{1,0} + alph \cdot \left(Fc_k\right)_{1,0}\right]}{3}$$

$$Ia0_k := \frac{\left[\left(Fa_k\right)_{1,0} + \left(Fb_k\right)_{1,0} + \left(Fc_k\right)_{1,0}\right]}{3}$$

$$I0aFd_k := Ia2_k - Ia0_k$$

$$Ifa_k := \left(\text{multiply}\ Ia2_k\right)$$

$$Ua2_k := \frac{\left(Pa_k\right)_{1,0} + alph^2 \cdot \left(Pb_k\right)_{1,0} + alph \cdot \left(Pc_k\right)_{1,0}}{3}$$

$$Ua0_k := \frac{\left(Pa_k\right)_{1,0} + \left(Pb_k\right)_{1,0} + \left(Pc_k\right)_{1,0}}{3}$$

$$UaL_k := Ua1_k + Ua2_k + Ua0_k$$

Here are equations of patent. We are assuming that I0Fd is dependent on d so we are using here assumption [0048] and [0049].

Here s=0

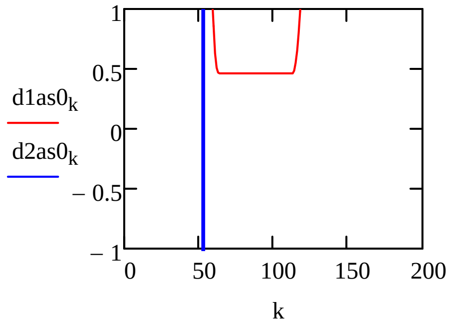
$$A1_k := -Re\left(Z0Fd \cdot I0aFd_k\right) \cdot Im\left(Ifa_k\right) + Im\left(Z0Fd \cdot I0aFd_k\right) Re\left(Ifa_k\right)$$

$$B1_k := -2\,Re\left(Z0Fd \cdot Ia0_k\right) \cdot Im\left(Ifa_k\right) + 2\,Im\left(Z0Fd \cdot Ia0_k\right) \cdot Re\left(Ifa_k\right) + \left(-2\,Re\left(Z1Fd \cdot Ifa_k\right) \cdot Im\left(Ifa_k\right) + 2\,Im\left(Z1Fd \cdot Ifa_k\right) \cdot Re\left(Ifa_k\right)\right) + \left(-2\,Re\left(Z2Fd \cdot Ifa_k\right) \cdot Im\left(Ifa_k\right) + 2\,Im\left(Z2Fd \cdot Ifa_k\right) \cdot Re\left(Ifa_k\right)\right)$$

$$Ca1_k := 2 \cdot Re\left(UaL_k\right) \cdot Im\left(Ifa_k\right) - 2 \cdot Im\left(UaL_k\right) \cdot Re\left(Ifa_k\right)$$

$$d1as0_k := \frac{-B1_k + \sqrt{B1_k \cdot B1_k - 4\,A1_k \cdot Ca1_k}}{2\,A1_k}$$

$$d2as0_k := \frac{-B1_k - \sqrt{B1_k \cdot B1_k - 4\,A1_k \cdot Ca1_k}}{2\,A1_k}$$



$d1as0_{90} = 0.462$

This is ds0a

$d2as0_{100} = -39.67$

$D1s0Final := d1as0_{90} = 0.462$

$\underline{C}=2*im(\underline{I}_F)*re(\underline{U}_L)-2*im(\underline{I}_F)*re(Z_{1Fd}*\underline{I}_1)-2*im(Z_{2Fd}*\underline{I}_F)*re(\underline{I}_F)$

$+2*im(\underline{I}_F)*re(Z_{1Fd}*\underline{I}_F)-2*im(\underline{I}_F)*re(Z_{1Fd}*\underline{I}_2)-2*re(\underline{I}_F)*im(\underline{U}_L)$

$+2*im(\underline{I}_F)*re(Z_{2Fd}*\underline{I}_F)-2*re(\underline{I}_F)*im(Z_{1Fd}*\underline{I}_F)$

$+2*im(Z_{2Fd}*\underline{I}_2)*re(\underline{I}_F)+2*im(Z_{1Fd}*\underline{I}_1)*re(\underline{I}_F)$

$d1(s=1)=(-B+sqrt(B*B-4*A*\underline{C}))/(2*A)$

$d2(s=1)=(-B-sqrt(B*B-4*A*\underline{C}))/(2*A)$

$$\begin{aligned}C2 &= 2*re(\underline{U}_L)*im(\underline{I}_F)-2*im(\underline{U}_L)*re(\underline{I}_F)\\ &-2*re(\underline{Z}_{1Fd}\underline{I}_1)*im(\underline{I}_F)+2*im(\underline{Z}_{1Fd}\underline{I}_1)*re(\underline{I}_F)\\ &+2*re(\underline{Z}_{1Fd}\underline{I}_F)*im(\underline{I}_F)-2*im(\underline{Z}_{1Fd}\underline{I}_F)*re(\underline{I}_F)\\ &-2*re(\underline{Z}_{2Fd}\underline{I}_2)*im(\underline{I}_F)+2*im(\underline{Z}_{2Fd}\underline{I}_2)*re(\underline{I}_F)\\ &+2*re(\underline{Z}_{2Fd}\underline{I}_F)*im(\underline{I}_F)-2*im(\underline{Z}_{2Fd}\underline{I}_F)*re(\underline{I}_F)\end{aligned}$$

Here s=1

$A2_k := A1_k$

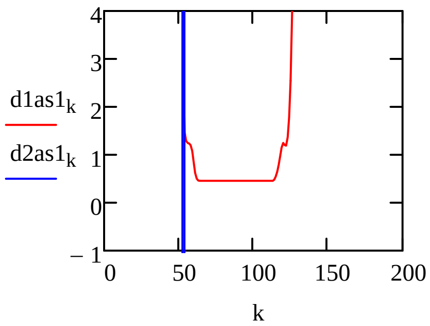
$B2_k := B1_k$

These are same in different s values

$C2_k := 2\cdot Re(UaL_k)\cdot Im(Ifa_k) - 2\cdot Im(UaL_k)\cdot Re(Ifa_k) + (-2\cdot Re(Z1Fd\cdot Ia1_k)\cdot Im(Ifa_k) + 2\cdot Im(Z1Fd\cdot Ia1_k)\cdot Re(Ifa_k) + 2\cdot Re(Z1Fd\cdot Ifa_k)\cdot Im(Ifa_k) - 2\cdot Im(Z1Fd\cdot Ifa_k)\cdot Re(Ifa_k) - 2\cdot Re(Z2F($

$$d1as1_k := \frac{-B2_k + \sqrt{B2_k\cdot B2_k - 4\,A2_k\cdot(C2_k)}}{2\,A2_k}$$

$$d2as1_k := \frac{-B2_k - \sqrt{B2_k\cdot B2_k - 4\,A2_k\cdot C2_k}}{2\,A2_k}$$



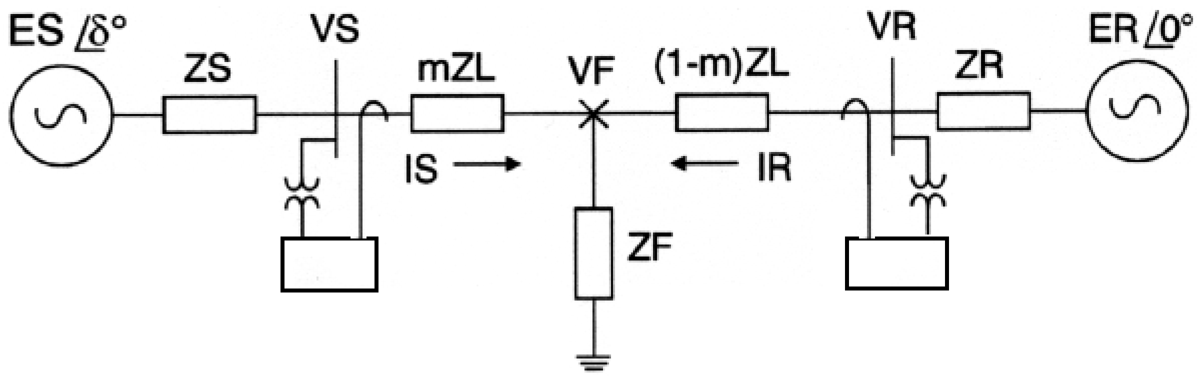
$d1as1_{90} = 0.457$

This is ds1a

$d2as1_{100} = -39.665$

$D2s1Final := d1as1_{90} = 0.457$

Now we change switching state of network and ratio of load current and fault current by changing δ



$\delta := 1$ Voltage Phase Angle

$es := 12000 \cdot e^{j \cdot \delta \cdot deg}$ Source S Voltage $es = 1.2 \times 10^{4} + 209.429i$

$er := 11900$ $er = 1.19 \times 10^{4}$ Source R Voltage

CONSTANTS

$rad := 1$ $deg := \frac{\pi}{180} \cdot rad$

$a := -0.5 + j \cdot 0.8660254$

$BAL := \begin{pmatrix} 1 \\ a^2 \\ a \end{pmatrix}$ $one := \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$ $zero := \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$

Three phase voltages at S and R

$ES := es \cdot BAL$

$ER := er \cdot BAL$

$$ES = \begin{pmatrix} 1.2\times 10^4 + 209.429i \\ -5.818\times 10^3 - 1.05i\times 10^4 \\ -6.18\times 10^3 + 1.029i\times 10^4 \end{pmatrix} \quad ER = \begin{pmatrix} 1.19\times 10^4 \\ -5.95\times 10^3 - 1.031i\times 10^4 \\ -5.95\times 10^3 + 1.031i\times 10^4 \end{pmatrix}$$

Coversion of positive sequence and zero sequence impedances to Self and Mutual impedances

$$zs(z0,z1) := \frac{2\cdot z1 + z0}{3} \qquad zm(z0,z1) := \frac{z0 - z1}{3}$$

Conversion Matrix Format

$$Z(z0,z1) := \begin{pmatrix} zs(z0,z1) & zm(z0,z1) & zm(z0,z1) \\ zm(z0,z1) & zs(z0,z1) & zm(z0,z1) \\ zm(z0,z1) & zm(z0,z1) & zs(z0,z1) \end{pmatrix}$$

Now Conversion

$ZS := Z(Z0S,Z1S)$ $\quad ZL := Z(Z0L,Z1L)$ $\quad ZR := Z(Z0R,Z1R)$

$ZR_{2,1} := 0$ $\quad ZR_{0,1} := 0$ $\quad ZR_{0,2} := 0$ $\quad ZR_{1,0} := 0$ $\quad ZR_{1,2} := 0$ $\quad ZR_{2,}$

$$ZS = \begin{pmatrix} 1.135 + 0.961i & 0.675 + 0.519i & 0.675 + 0.519i \\ 0.675 + 0.519i & 1.135 + 0.961i & 0.675 + 0.519i \\ 0.675 + 0.519i & 0.675 + 0.519i & 1.135 + 0.961i \end{pmatrix} \qquad ZR = \begin{pmatrix} 0.736i & 0.294i & 0.294i \\ 0.294i & 0.736i & 0.294i \\ 0.294i & 0.294i & 0.736i \end{pmatrix}$$

Source and Line Impedances to the Fault

$ZSS := ZS + d\cdot ZL$

$$ZSS = \begin{pmatrix} 2.221 + 2.201i & 1.109 + 1.015i & 1.109 + 1.015i \\ 1.109 + 1.015i & 2.221 + 2.201i & 1.109 + 1.015i \\ 1.109 + 1.015i & 1.109 + 1.015i & 2.221 + 2.201i \end{pmatrix}$$

$ZRR := ZR + (1 - d)\cdot ZL$

$$ZRR = \begin{pmatrix} 1.248 + 2.162i & 0.499 + 0.865i & 0.499 + 0.86 \\ 0.499 + 0.865i & 1.248 + 2.162i & 0.499 + 0.86 \\ 0.499 + 0.865i & 0.499 + 0.865i & 1.248 + 2.16 \end{pmatrix} \quad ZL = \begin{pmatrix} 2.333 + 2.667i & 0.933 + 1.067i & 0.933 + 1.067 \\ 0.933 + 1.067i & 2.333 + 2.667i & 0.933 + 1.067 \\ 0.933 + 1.067i & 0.933 + 1.067i & 2.333 + 2.667 \end{pmatrix}$$

Build System Part of the Impedance Matrix ---see (2) of page 3 in the paper.

$ZTOP := augment(augment(ZSS, zero), one)$

$$ZTOP = \begin{pmatrix} 2.221+2.201i & 1.109+1.015i & 1.109+1.015i & 0 & 0 & 0 & 1 & 0 & 0 \\ 1.109+1.015i & 2.221+2.201i & 1.109+1.015i & 0 & 0 & 0 & 0 & 1 & 0 \\ 1.109+1.015i & 1.109+1.015i & 2.221+2.201i & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$ZMID := augment(augment(zero, ZRR), one)$

$$ZMID = \begin{pmatrix} 0 & 0 & 0 & 1.248+2.162i & 0.499+0.865i & 0.499+0.865i & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.499+0.865i & 1.248+2.162i & 0.499+0.865i & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.499+0.865i & 0.499+0.865i & 1.248+2.162i & 0 & 0 & 1 \end{pmatrix}$$

$ZSYS := stack(ZTOP, ZMID)$

$$ZSYS = \begin{pmatrix} 2.221+2.201i & 1.109+1.015i & 1.109+1.015i & 0 & 0 & 0 & 1 \\ 1.109+1.015i & 2.221+2.201i & 1.109+1.015i & 0 & 0 & 0 & 0 \\ 1.109+1.015i & 1.109+1.015i & 2.221+2.201i & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.248+2.162i & 0.499+0.865i & 0.499+0.865i & 1 \\ 0 & 0 & 0 & 0.499+0.865i & 1.248+2.162i & 0.499+0.865i & 0 \\ 0 & 0 & 0 & 0.499+0.865i & 0.499+0.865i & 1.248+2.162i & 0 \end{pmatrix}$$

Pre-fault conditions:

$ZPRE := ZS + ZL + ZR$

$$ZPRE = \begin{pmatrix} 3.468+4.363i & 1.608+1.88i & 1.608+1.88i \\ 1.608+1.88i & 3.468+4.363i & 1.608+1.88i \\ 1.608+1.88i & 1.608+1.88i & 3.468+4.363i \end{pmatrix}$$

$IPRE := ZPRE^{-1} \cdot (ES - ER)$

$$IPRE = \begin{pmatrix} 72.993+15.147i \\ -23.379-70.787i \\ -49.614+55.64i \end{pmatrix}$$

$VSP := ES - ZS \cdot IPRE$

$$VSP = \begin{pmatrix} 1.197\times10^{4}+170.226i \\ -5.838\times10^{3}-1.045i\times10^{4} \\ -6.133\times10^{3}+1.028i\times10^{4} \end{pmatrix} \qquad ES = \begin{pmatrix} 1.2\times10^{4}+209.429i \\ -5.818\times10^{3}-1.05i\times10^{4} \\ -6.18\times10^{3}+1.029i\times10^{4} \end{pmatrix}$$

Voltage at the relay near bus S? Yes, Prefault :

$(Aoang_k)_{1,0} =$

Build the voltage Vector: Again, see (2) of page 3

$$null := (0 \quad 0 \quad 0)$$

$$E := stack\left(stack(ES, ER), null^T\right)$$

$$TS := augment(augment(one, zero), zero)$$

$$TR := augment(augment(zero, one), zero)$$

$$TVF := augment(augment(zero, zero), one)$$

$$E = \begin{pmatrix} 1.2 \times 10^4 + 209.429i \\ -5.818 \times 10^3 - 1.05i \times 10^4 \\ -6.18 \times 10^3 + 1.029i \times 10^4 \\ 1.19 \times 10^4 \\ -5.95 \times 10^3 - 1.031i \times 10^4 \\ -5.95 \times 10^3 + 1.031i \times 10^4 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

$$TS = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$TR = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{pmatrix}$$

$$TVF = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Building Fault Part of the Impedance Matrix:

$$ZFAG := ZFA + ZFG$$

$$ZFBG := ZFB + ZFG$$

$$ZFCG := ZFC + ZFG$$

$$ZF := \begin{pmatrix} ZFAG & ZFG & ZFG \\ ZFG & ZFBG & ZFG \\ ZFG & ZFG & ZFCG \end{pmatrix}$$

$$FABCG := augment(augment(-ZF, -ZF), one)$$

$$ZFAG = 0$$

$$ZFBG = 1 \times 10^{10}$$

$$ZF = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 \times 10^{10} & 0 \\ 0 & 0 & 1 \times 10^{10} \end{pmatrix}$$

$$FABCG = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & -1 \times 10^{10} & 0 & 0 & -1 \times 10^{10} & 0 & 0 & 1 & 0 \\ 0 & 0 & -1 \times 10^{10} & 0 & 0 & -1 \times 10^{10} & 0 & 0 & 1 \end{pmatrix}$$

$$ZABCG := \mathrm{stack}(ZSYS, FABCG)$$

$$ZABCG = \begin{pmatrix} 2.221+2.201i & 1.109+1.015i & 1.109+1.015i & 0 & 0 & 0 & 1 & 0 \\ 1.109+1.015i & 2.221+2.201i & 1.109+1.015i & 0 & 0 & 0 & 0 & 1 \\ 1.109+1.015i & 1.109+1.015i & 2.221+2.201i & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.248+2.162i & 0.499+0.865i & 0.499+0.865i & 1 & 0 \\ 0 & 0 & 0 & 0.499+0.865i & 1.248+2.162i & 0.499+0.865i & 0 & 1 \\ 0 & 0 & 0 & 0.499+0.865i & 0.499+0.865i & 1.248+2.162i & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1\times10^{10} & 0 & 0 & -1\times10^{10} & 0 & 0 & 1 \\ 0 & 0 & -1\times10^{10} & 0 & 0 & -1\times10^{10} & 0 & 0 \end{pmatrix}$$

$$YABCG := ZABCG^{-1}$$

Fault Currents:

$IABCG := YABCG \cdot E$

$$E = \begin{pmatrix} 1.2 \times 10^4 + 209.429i \\ -5.818 \times 10^3 - 1.05i \times 10^4 \\ -6.18 \times 10^3 + 1.029i \times 10^4 \\ 1.19 \times 10^4 \\ -5.95 \times 10^3 - 1.031i \times 10^4 \\ -5.95 \times 10^3 + 1.031i \times 10^4 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad IABCG = \begin{pmatrix} 2.87 \times 10^3 - 2.798i \times 10^3 \\ -94.574 + 82.636i \\ -120.81 + 209.064i \\ 2.297 \times 10^3 - 4.013i \times 10^3 \\ 94.574 - 82.636i \\ 120.81 - 209.064i \\ 0 \\ -1.11 \times 10^4 - 1.039i \times 10^4 \\ -1.129 \times 10^4 + 1.028i \times 10^4 \end{pmatrix}$$

S - End Fault Currents:

$IS := TS \cdot IABCG$

$$IS = \begin{pmatrix} 2.87 \times 10^3 - 2.798i \times 10^3 \\ -94.574 + 82.636i \\ -120.81 + 209.064i \end{pmatrix}$$

R - End Fault Currents:

$IR := TR \cdot IABCG$

$$IR = \begin{pmatrix} 2.297 \times 10^3 - 4.013i \times 10^3 \\ 94.574 - 82.636i \\ 120.81 - 209.064i \end{pmatrix}$$

VF fault voltages:

$VF := TVF \cdot IABCG$

$$VF = \begin{pmatrix} 0 \\ -1.11 \times 10^4 - 1.039i \times 10^4 \\ -1.129 \times 10^4 + 1.028i \times 10^4 \end{pmatrix}$$

S - End Voltages

$VS := ES - ZS \cdot IS$

$$VS = \begin{pmatrix} 6.349 \times 10^3 + 543.183i \\ -8.83 \times 10^3 - 1.018i \times 10^4 \\ -9.125 \times 10^3 + 1.056i \times 10^4 \end{pmatrix}$$

Line Prefault Load Currents from S Bus

$Ia := IPRE_0 \qquad |Ia| = 74.548 \qquad \frac{arg(Ia)}{deg} = 11.723 \qquad 0.32 \cdot \frac{180}{3.14} = 18.344$

$Ib := IPRE_1 \qquad |Ib| = 74.548 \qquad \frac{arg(Ib)}{deg} = -108.277$

$$IPRE = \begin{pmatrix} 72.993 + 15.147i \\ -23.379 - 70.787i \\ -49.614 + 55.64i \end{pmatrix}$$

$Ic := IPRE_2$ $\quad |Ic| = 74.548$ $\quad \frac{arg(Ic)}{deg} = 131.723$

Line Prefault Voltages at S Bus

$Va := VSP_0$ $\quad |Va| = 1.197 \times 10^4$ $\quad \frac{arg(Va)}{deg} = 0.815$

$$VSP = \begin{pmatrix} 1.197 \times 10^4 + 170.226i \\ -5.838 \times 10^3 - 1.045i \times 10^4 \\ -6.133 \times 10^3 + 1.028i \times 10^4 \end{pmatrix}$$

$Vb := VSP_1$ $\quad |Vb| = 1.197 \times 10^4$ $\quad \frac{arg(Vb)}{deg} = -119.185$

$Vc := VSP_2$ $\quad |Vc| = 1.197 \times 10^4$ $\quad \frac{arg(Vc)}{deg} = 120.815$

Line Fault Currents from S Bus

$Iasf := IS_0$ $\quad |Iasf| = 4.008 \times 10^3$ $\quad \frac{arg(Iasf)}{deg} = -44.271$

$$IS = \begin{pmatrix} 2.87 \times 10^3 - 2.798i \times 10^3 \\ -94.574 + 82.636i \\ -120.81 + 209.064i \end{pmatrix}$$

$Ibsf := IS_1$ $\quad |Ibsf| = 125.591$ $\quad \frac{arg(Ibsf)}{deg} = 138.854$

$Icsf := IS_2$ $\quad |Icsf| = 241.459$ $\quad \frac{arg(Icsf)}{deg} = 120.022$

Line Fault Currents from R Bus

$$IR = \begin{pmatrix} 2.297 \times 10^3 - 4.013i \times 10^3 \\ 94.574 - 82.636i \\ 120.81 - 209.064i \end{pmatrix}$$

$Iarf := IR_0$ $\quad |Iarf| = 4.624 \times 10^3$ $\quad \frac{arg(Iarf)}{deg} = -60.212$

$Ibrf := IR_1$ $\quad |Ibrf| = 125.591$ $\quad \frac{arg(Ibrf)}{deg} = -41.146$

$Icrf := IR_2$ $\quad |Icrf| = 241.459$ $\quad \frac{arg(Icrf)}{deg} = -59.978$

Line Fault Voltages at S Bus

$$VSP = \begin{pmatrix} 1.197\times10^4 + 170.226i \\ -5.838\times10^3 - 1.045i\times10^4 \\ -6.133\times10^3 + 1.028i\times10^4 \end{pmatrix}$$

$Vaf := VS_0$ $\quad |Vaf| = 6.372\times10^3$ $\quad \frac{\arg(Vaf)}{deg} = 4.89$

$Vbf := VS_1$ $\quad |Vbf| = 1.347\times10^4$ $\quad \frac{\arg(Vbf)}{deg} = -130.943$

$$VS = \begin{pmatrix} 6.349\times10^3 + 543.183i \\ -8.83\times10^3 - 1.018i\times10^4 \\ -9.125\times10^3 + 1.056i\times10^4 \end{pmatrix}$$

$Vcf := VS_2$ $\quad |Vcf| = 1.395\times10^4$ $\quad \frac{\arg(Vcf)}{deg} = 130.84$

$Ir := \sum_{mm=0}^{2} IS_{mm}$ $\quad Ir = 2.655\times10^3 - 2.506i\times10^3$

$$IS = \begin{pmatrix} 2.87\times10^3 - 2.798i\times10^3 \\ -94.574 + 82.636i \\ -120.81 + 209.064i \end{pmatrix}$$

$d = 0.465$

$T1 := \dfrac{\arg\left[\dfrac{Z0S + Z0R + Z0L}{Z0R + (1-d)Z0L}\right]}{deg} = -9.461$ $\quad T1 = -9.461$

$\left[\dfrac{Z0S + Z0R + Z0L}{Z0R + (1-d)Z0L}\right] = 2.31 - 0.385i$

$Z0S = 2.485 + 1.999i$

$Z0R = 1.325i$ $\quad Z0R = 1.325$ $\quad Z1R = 0.442i$

$k0 := \dfrac{Z0L - Z1L}{3\cdot Z1L}$ $\quad k0 = 0.667$

$Z0L = 4.2 + 4.8i$

$e^{j\cdot T1} = -0.999 + 0.036i$ $\quad Z0S + Z0R + Z0L = 6.685 + 8.124i$

$Z0L = 4.2 + 4.8i$

distance L (which is supposed to be same as m)

$IPRE_0 = 72.993 + 15.147i$

$IS_0 = 2.87\times10^3 - 2.798i\times10^3$ $\quad |IS_0| = 4.008\times10$

$$L := \frac{\mathrm{Im}\left[VS_0\cdot\overline{\left(Ir\cdot e^{j\cdot T1\cdot deg}\right)}\right]}{\mathrm{Im}\left[Z1L\cdot\left(IS_0 + k0\cdot Ir\right)\cdot\overline{\left(Ir\cdot e^{j\cdot T1\cdot deg}\right)}\right]}$$

$L = 0.465$

$\dfrac{|IS_0|}{|IPRE_0|} = 53.766$

$VS_0 = 6.349\times10^3 + 543.183i$

$VSP_0 = 1.197\times10^4 + 170.226i$

$e^{j\cdot T1} = -0.999 + 0.036i$

$\dfrac{VSP_0}{IPRE_0} - Z1L = 156.299 - 31.992i$

$VSP_0 = 1.197\times10^4 + 170.226i$ $\quad VS_0 = 6.349\times10^3 + 543.183i$

$|VSP_0| = 1.197\times$ $\quad \dfrac{\arg(VSP_0)}{deg} = 0.815$

$|VS_0| = 6.372\times10^3$ $\quad \dfrac{\arg(VS_0)}{deg} = 4.89$ $\quad \dfrac{VS_0 - VSP_0}{IS_0 - IPRE_0} = -1.066 - 0.939i$

So How do I generate digital signals of Voltage and Current of the Simulation 4 Cycles

$$\left|VS_1\right| = 1.347 \times 10^4$$

$$\left|VS_2\right| = 1.395 \times 10^4$$

$$k := 0..511$$

$$delT := 0.0001302$$

$$e^{j \cdot T1} = -0.999 + 0.036i$$

$$Van_k := \left|VSP_0\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(VSP_0\right)\right)$$

$$t1_k := k \cdot delT$$

$$t2_k := 512 \cdot delT + k \cdot delT$$

$$t3_k := 1024 \cdot delT + k \cdot delT$$

$$Vbn_k := \left|VSP_1\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(VSP_1\right)\right)$$

$$Vcn_k := \left|VSP_2\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(VSP_2\right)\right)$$

$$Vaf_k := \left|VS_0\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(VS_0\right)\right)$$

$$Vbf_k := \left|VS_1\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(VS_1\right)\right)$$

$$Vcf_k := \left|VS_2\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(VS_2\right)\right)$$

$$Ian_k := \left|IPRE_0\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(IPRE_0\right)\right)$$

$$Ibn_k := \left|IPRE_1\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(IPRE_1\right)\right)$$

$$Icn_k := \left|IPRE_2\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(IPRE_2\right)\right)$$

$$Iaf_k := \left|IS_0\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(IS_0\right)\right)$$

$$Ibf_k := \left|IS_1\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(IS_1\right)\right)$$

$$Icf_k := \left|IS_2\right| \cdot \sin\left(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg\left(IS_2\right)\right)$$

$\min(t1) = 0$ $\max(t1) = 0.067$

$\min(t2) = 0.067$ $\max(t2) = 0.133$

$\min(t3) = 0.133$ $\max(t3) = 0.2$

$$\frac{\frac{1}{60}}{128} = 1.302 \times 10^{-4}$$

$t1_{511} = 0.067$ $t2_{0} = 0.067$

$t2_{0} - t1_{511} = 1.302 \times 10^{-4}$

$t3_{0} - t2_{511} = 1.302 \times 10^{-4}$

$Seg1 := augment(t1, Ian, Ibn, Icn, Van, Vbn, Vcn)$

$Seg2 := augment(t2, Iaf, Ibf, Icf, Vaf, Vbf, Vcf)$

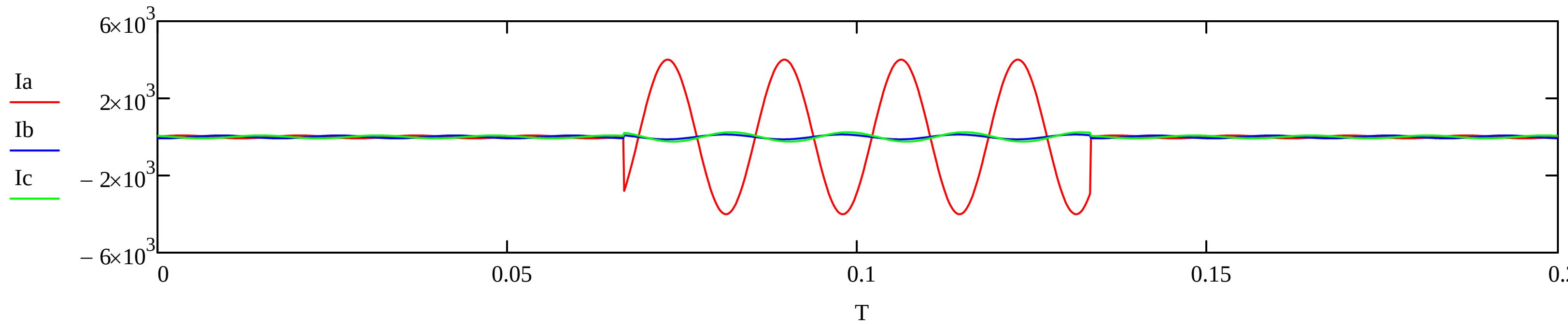
$Seg3 := augment(t3, Ian, Ibn, Icn, Van, Vbn, Vcn)$

$Final := stack(Seg1, Seg2, Seg3)$

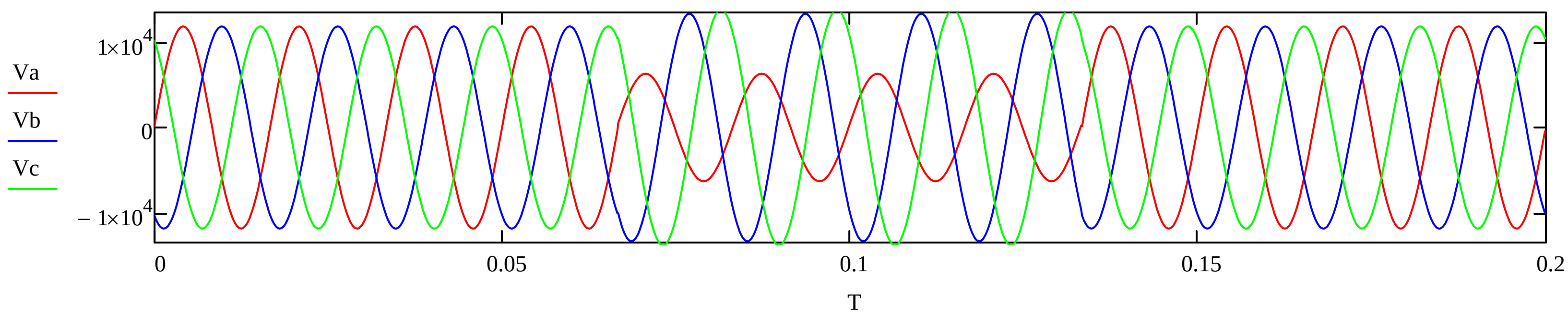
$T := Final^{\langle 0 \rangle}$ $Ia := Final^{\langle 1 \rangle}$ $Ib := Final^{\langle 2 \rangle}$ $Ic := Final^{\langle 3 \rangle}$ $Va := Final^{\langle 4 \rangle}$ $Vb := Final^{\langle 5 \rangle}$ $Vc := Final^{\langle 6 \rangle}$

$Ir := Ia + Ib + Ic$

Generated phase currents



Generated phase voltages



$m = 1.536 \times 10^{3}$

$Isa := Ia$ $Isb := Ib$ $Isc := Ic$ $k0 = 0.667$

$dd := 0 .. \frac{m}{window} - 1$

$kk := 0 .. m - window$

$k := 0 .. \frac{m - window}{8}$ $\frac{m - window}{8} = 176$

$Ua_k := submatrix(Va, k \cdot 8, k \cdot 8 + wind, 0, 0)$ $Ub_k := submatrix(Vb, k \cdot 8, k \cdot 8 + wind, 0, 0)$ $Uc_k := submatrix(Vc, k \cdot 8, k \cdot 8 + wind, 0, 0)$

$Ao_k := submatrix(Ir, k \cdot 8, k \cdot 8 + wind, 0, 0)$

$Aa_k := \text{submatrix}(Isa, k\cdot 8, k\cdot 8 + wind, 0, 0)$ $Ab_k := \text{submatrix}(Isb, k\cdot 8, k\cdot 8 + wind, 0, 0)$ $Ac_k := \text{submatrix}(Isc, k\cdot 8, k\cdot 8 + wind, 0, 0)$

Now we take FFT from voltages and currents so we get complex values for voltages and currents

$Fa_k := \text{FFT}\left(\left(Aa_k\right)\right)$ $Fb_k := \text{FFT}\left(Ab_k\right)$ $Fc_k := \text{FFT}\left(Ac_k\right)$

$Pa_k := \text{FFT}\left(Ua_k\right)$ $Pb_k := \text{FFT}\left(Ub_k\right)$ $Pc_k := \text{FFT}\left(Uc_k\right)$ $Fo_k := \text{FFT}\left(Ao_k\right)$

Line impedances (zero, positive and negative sequence) and α-factor

$Z0Fd := Z0L$

$Z1Fd := Z1L$

$Z2Fd := Z1L$

$alph := \exp\left(\pi\cdot j\cdot\frac{120}{180}\right) = -0.5 + 0.866i$

Sequence components of voltages and currents

$$Ia1_k := \frac{\left[\left(Fa_k\right)_{1,0} + alph\cdot\left(Fb_k\right)_{1,0} + alph^2\cdot\left(Fc_k\right)_{1,0}\right]}{3}$$

$$Ua11_k := \frac{\left(Pa_k\right)_{1,0} + alph\cdot\left(Pb_k\right)_{1,0} + alph^2\cdot\left(Pc_k\right)_{1,0}}{3}$$

$$Ia2_k := \frac{\left[\left(Fa_k\right)_{1,0} + alph^2\cdot\left(Fb_k\right)_{1,0} + alph\cdot\left(Fc_k\right)_{1,0}\right]}{3}$$

$$Ua2_k := \frac{\left(Pa_k\right)_{1,0} + alph^2\cdot\left(Pb_k\right)_{1,0} + alph\cdot\left(Pc_k\right)_{1,0}}{3}$$

$$Ia0_k := \frac{\left[\left(Fa_k\right)_{1,0} + \left(Fb_k\right)_{1,0} + \left(Fc_k\right)_{1,0}\right]}{3}$$

$$Ua0_k := \frac{\left(Pa_k\right)_{1,0} + \left(Pb_k\right)_{1,0} + \left(Pc_k\right)_{1,0}}{3}$$

$I0aFd_k := Ia2_k - Ia0_k$ This is defined in [0060]

$Ual_k := Ua11_k + Ua2_k + Ua0_k$

$Ifa_k := \text{multiply}\ Ia2_k$ This is defined in [0059]

Here are equations of patent. We are assuming that I0Fd is dependent on d so we are using here assumption [0048] and [0049].

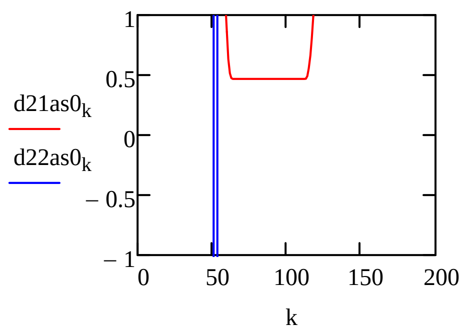
Here s=0

$A1_k := -Re\left(Z0Fd \cdot I0aFd_k\right) \cdot Im\left(Ifa_k\right) + Im\left(Z0Fd \cdot I0aFd_k\right) Re\left(Ifa_k\right)$

$B1_k := -2\,Re\left(Z0Fd \cdot Ia0_k\right) \cdot Im\left(Ifa_k\right) + 2\,Im\left(Z0Fd \cdot Ia0_k\right) \cdot Re\left(Ifa_k\right) + \left(-2\,Re\left(Z1Fd \cdot Ifa_k\right) \cdot Im\left(Ifa_k\right) + 2\,Im\left(Z1Fd \cdot Ifa_k\right) \cdot Re\left(Ifa_k\right)\right) + \left(-2\,Re\left(Z2Fd \cdot Ifa_k\right) \cdot Im\left(Ifa_k\right) + 2\,Im\left(Z2Fd \cdot Ifa_k\right) \cdot Re(\right.$

$Ca1_k := 2 \cdot Re\left(Ual_k\right) \cdot Im\left(Ifa_k\right) - 2 \cdot Im\left(Ual_k\right) \cdot Re\left(Ifa_k\right)$

$d21as0_k := \dfrac{-B1_k + \sqrt{B1_k \cdot B1_k - 4\,A1_k \cdot Ca1_k}}{2\,A1_k}$ $d22as0_k := \dfrac{-B1_k - \sqrt{B1_k \cdot B1_k - 4\,A1_k \cdot Ca1_k}}{2\,A1_k}$



$d21as0_{90} = 0.466$ This is ds0b

$(d22as0)_{100} = -39.675$

$\underline{C}=2*im(\underline{I}_F)*re(\underline{U}_L)-2*im(\underline{I}_F)*re(Z_{1Fd}*\underline{I}_1)-2*im(Z_{2Fd}*\underline{I}_F)*re(\underline{I}_F)$

$+2*im(\underline{I}_F)*re(Z_{1Fd}*\underline{I}_F)-2*im(\underline{I}_F)*re(Z_{1Fd}*\underline{I}_2)-2*re(\underline{I}_F)*im(\underline{U}_L)$

Here s=1

$+2*im(\underline{I}_F)*re(Z_{2Fd}*\underline{I}_F)-2*re(\underline{I}_F)*im(Z_{1Fd}*\underline{I}_F)$

$+2*im(Z_{2Fd}*\underline{I}_2)*re(\underline{I}_F)+2*im(Z_{1Fd}*\underline{I}_1)*re(\underline{I}_F)$

$A2_k := A1_k$

These are same in different s values

$d1(s=1)=(-B+sqrt(B*B-4*A*\underline{C}))/(2*A)$

$B2_k := B1_k$

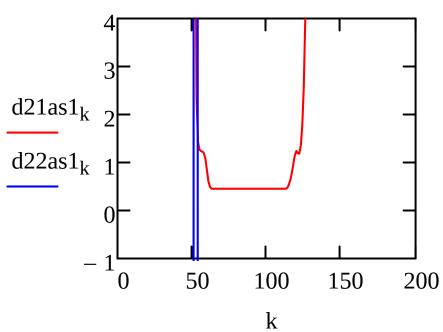
$d2(s=1)=(-B-sqrt(B*B-4*A*\underline{C}))/(2*A)$

$$C2 = 2*re(\underline{U}_L)*im(\underline{I}_F)-2*im(\underline{U}_L)*re(\underline{I}_F)$$
$$-2*re(\underline{Z}_{1Fd}\underline{I}_1)*im(\underline{I}_F)+2*im(\underline{Z}_{1Fd}\underline{I}_1)*re(\underline{I}_F)$$
$$+2*re(\underline{Z}_{1Fd}\underline{I}_F)*im(\underline{I}_F)-2*im(\underline{Z}_{1Fd}\underline{I}_F)*re(\underline{I}_F)$$
$$-2*re(\underline{Z}_{2Fd}\underline{I}_2)*im(\underline{I}_F)+2*im(\underline{Z}_{2Fd}\underline{I}_2)*re(\underline{I}_F)$$
$$+2*re(\underline{Z}_{2Fd}\underline{I}_F)*im(\underline{I}_F)-2*im(\underline{Z}_{2Fd}\underline{I}_F)*re(\underline{I}_F)$$

$$C2_k := 2\cdot Re(Ual_k)\cdot Im(Ifa_k) - 2\cdot Im(Ual_k)\cdot Re(Ifa_k) + (-2\cdot Re(Z1Fd\cdot Ia1_k)\cdot Im(Ifa_k) + 2\cdot Im(Z1Fd\cdot Ia1_k)\cdot Re(Ifa_k) + 2\cdot Re(Z1Fd\cdot Ifa_k)\cdot Im(Ifa_k) - 2\cdot Im(Z1Fd\cdot Ifa_k)\cdot Re(Ifa_k) - 2\cdot Re(Z2F$$

$$d21as1_k := \frac{-B2_k + \sqrt{B2_k\cdot B2_k - 4\,A2_k\cdot(C2_k)}}{2\,A2_k}$$

$$d22as1_k := \frac{-B2_k - \sqrt{B2_k\cdot B2_k - 4\,A2_k\cdot C2_k}}{2\,A2_k}$$



$d21as1_{90} = 0.452$

This is ds1b

$d22as1_{100} = -39.661$

$$line2 := \begin{pmatrix} d21as0_{90} \\ d21as1_{90} \end{pmatrix} = \begin{pmatrix} 0.466 \\ 0.452 \end{pmatrix}$$

$$line1 := \begin{pmatrix} D1s0Final \\ D2s1Final \end{pmatrix} = \begin{pmatrix} 0.462 \\ 0.457 \end{pmatrix}$$

$$ds0a := D1s0Final = 0.462$$

$$ds0b := d21as0_{90} = 0.466$$

$$ds1a := D2s1Final = 0.457$$

$$ds1b := d21as1_{90} = 0.452$$

Final Result

$$result := \frac{[ds0a \cdot (ds1b - ds0b) - ds0b \cdot (ds1a - ds0a)]}{ds1b - ds0b - ds1a + ds0a} = 0.46$$

$$d\cdot Ia2_{k}\Big)\cdot Im\Big(Ifa_{k}\Big) + 2\cdot Im\Big(Z2Fd\cdot Ia2_{k}\Big)\cdot Re\Big(Ifa_{k}\Big) + 2\cdot Re\Big(Z2Fd\cdot Ifa_{k}\Big)\cdot Im\Big(Ifa_{k}\Big) - 2\cdot Im\Big(Z2Fd\cdot Ifa_{k}\Big)\cdot Re\Big(Ifa_{k}\Big)\Big) = ...$$

$_0 := 0$

$$\begin{pmatrix} i \\ i \\ i \end{pmatrix}$$

$$\begin{matrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{matrix}\right)$$

$)^3$

$\left(\text{Ifa}_k\right)\Big)$

$$d\cdot Ia2_k)\cdot Im(Ifa_k) + 2\cdot Im(Z2Fd\cdot Ia2_k)\cdot Re(Ifa_k) + 2\cdot Re(Z2Fd\cdot Ifa_k)\cdot Im(Ifa_k) - 2\cdot Im(Z2Fd\cdot Ifa_k)\cdot Re(Ifa_k)) = ...$$