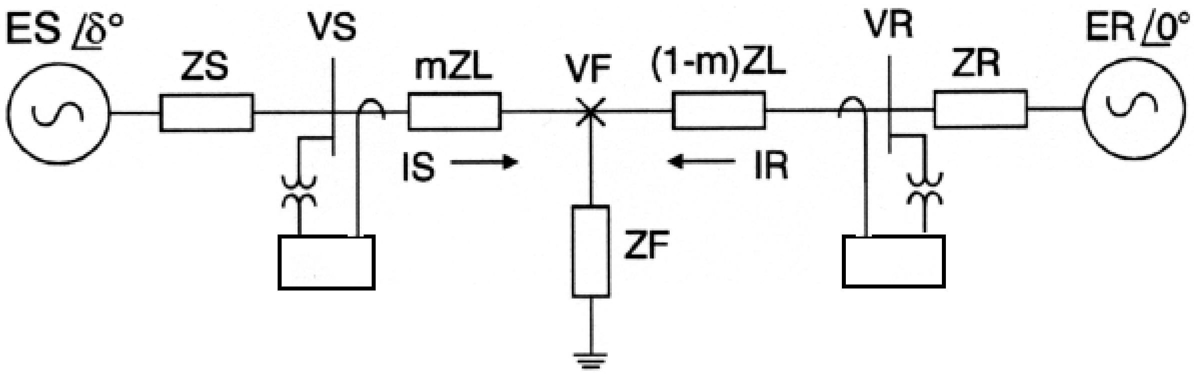
ALgorithm Test

NOTE:Some parameter values are changed

May 2010 @TKK REVISED



Fault Location $d := 0.95$

$\delta := 0.001$ **Voltage Phase Angle**

$es := 12000 \cdot e^{j \cdot \delta \cdot deg}$ **Source S Voltage**

$er := 12000$ $er := 0$ $es = 1.2 \times 10^{4} + 0.209i$

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

$Rsir := 0.2$ **Source R SIR**

$Z1L := 4 \cdot e^{j \cdot 1 \cdot deg}$ **Positive Sequence Line Impedance**

$Z1L := 1.4 + 1.6i$ $Z1L = 1.4 + 1.6i$ $INF := 10^{10}$

$Z0L := 3 \cdot Z1L$ **Zero Sequence Line Impedance**

$Z1S := Ssir \cdot Z1L$ **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** $Z1R = 0.442i$

$Z0R := 3 \cdot Z1R$ $Z1R := 20Z1S$

Source S Zero Sequence Impedance $Z0R = 1.325i$ $Z0R = 1.325i$

Creelman

$Z1L := 10 + 13i$ $Z0L := 30 + 39i$ $Z1S := 0.042 + 0.513i$ $Z0S := 0.013 + 1.225i$

$Z1R := 0.42 + 0.5i$

$Z0R := 0$ $Z1R := 4.2 + 5i$

$Z1R := 0$ $Z0R := 3 \cdot Z1R$

$INF = 1 \times 10^{10}$ $Z1R := 400 + .01i$

Fault Impedances (for AG fault case) $Z0R := 0.42 + 0.5i$ $Z1R := 0$

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

Fault Resistance

$ZFG := 0.85 + j \cdot 0$ $ZFG := 30 + j \cdot 0$ $ZFG := 1$

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

$ES := es \cdot BAL$ $ES = \begin{pmatrix} 1.2 \times 10^4 + 0.209i \\ -6 \times 10^3 - 1.039i \times 10^4 \\ -6 \times 10^3 + 1.039i \times 10^4 \end{pmatrix}$

$ER := er \cdot BAL$ $ER = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$

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

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

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

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

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

$$ZS = \begin{pmatrix} 0.032 + 0.75i & -9.667 \times 10^{-3} + 0.237i & -9.667 \times 10^{-3} + 0.237i \\ -9.667 \times 10^{-3} + 0.237i & 0.032 + 0.75i & -9.667 \times 10^{-3} + 0.237i \\ -9.667 \times 10^{-3} + 0.237i & -9.667 \times 10^{-3} + 0.237i & 0.032 + 0.75i \end{pmatrix}$$

$$ZR = \begin{pmatrix} 0.28 + 0.333i & -0.14 - 0.167i & -0.14 - 0.167i \\ -0.14 - 0.167i & 0.28 + 0.333i & -0.14 - 0.167i \\ -0.14 - 0.167i & -0.14 - 0.167i & 0.28 + 0.333i \end{pmatrix}$$

Source and Line Impedances to the Fault

$ZSS := ZS + d \cdot ZL$

$$ZSS = \begin{pmatrix} 15.866 + 21.334i & 6.324 + 8.471i & 6.324 + 8.471i \\ 6.324 + 8.471i & 15.866 + 21.334i & 6.324 + 8.471i \\ 6.324 + 8.471i & 6.324 + 8.471i & 15.866 + 21.334i \end{pmatrix}$$

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

$$ZRR = \begin{pmatrix} 1.113 + 1.417i & 0.193 + 0.267i & 0.193 + 0.267i \\ 0.193 + 0.267i & 1.113 + 1.417i & 0.193 + 0.267i \\ 0.193 + 0.267i & 0.193 + 0.267i & 1.113 + 1.417i \end{pmatrix}$$

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

$ZTOP := \text{augment}(\text{augment}(ZSS, \text{zero}), \text{one})$

$$ZTOP = \begin{pmatrix} 15.866 + 21.334i & 6.324 + 8.471i & 6.324 + 8.471i & 0 & 0 & 0 & 1 & 0 & 0 \\ 6.324 + 8.471i & 15.866 + 21.334i & 6.324 + 8.471i & 0 & 0 & 0 & 0 & 1 & 0 \\ 6.324 + 8.471i & 6.324 + 8.471i & 15.866 + 21.334i & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$ZMID := \text{augment}(\text{augment}(\text{zero}, ZRR), \text{one})$

$$ZMID = \begin{pmatrix} 0 & 0 & 0 & 1.113 + 1.417i & 0.193 + 0.267i & 0.193 + 0.267i & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.193 + 0.267i & 1.113 + 1.417i & 0.193 + 0.267i & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.193 + 0.267i & 0.193 + 0.267i & 1.113 + 1.417i & 0 & 0 & 1 \end{pmatrix}$$

$ZSYS := \text{stack}(ZTOP, ZMID)$

$$ZSYS = \begin{pmatrix} 15.866 + 21.334i & 6.324 + 8.471i & 6.324 + 8.471i & 0 & 0 & 0 & 1 & 0 \\ 6.324 + 8.471i & 15.866 + 21.334i & 6.324 + 8.471i & 0 & 0 & 0 & 0 & 1 \\ 6.324 + 8.471i & 6.324 + 8.471i & 15.866 + 21.334i & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.113 + 1.417i & 0.193 + 0.267i & 0.193 + 0.267i & 1 & 0 \\ 0 & 0 & 0 & 0.193 + 0.267i & 1.113 + 1.417i & 0.193 + 0.267i & 0 & 1 \\ 0 & 0 & 0 & 0.193 + 0.267i & 0.193 + 0.267i & 1.113 + 1.417i & 0 & 0 \end{pmatrix}$$

Pre-fault conditions:

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

$$ZPRE = \begin{pmatrix} 16.979 + 22.75i & 6.517 + 8.737i & 6.517 + 8.737i \\ 6.517 + 8.737i & 16.979 + 22.75i & 6.517 + 8.737i \\ 6.517 + 8.737i & 6.517 + 8.737i & 16.979 + 22.75i \end{pmatrix}$$

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

$$IPRE = \begin{pmatrix} 410.529 - 549.85i \\ -681.448 - 80.603i \\ 270.92 + 630.453i \end{pmatrix}$$

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

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

$$VSP = \begin{pmatrix} 1.17 \times 10^{4} - 187.298i \\ -6.013 \times 10^{3} - 1.004i \times 10^{4} \\ -5.688 \times 10^{3} + 1.023i \times 10^{4} \end{pmatrix} \qquad ES = \begin{pmatrix} 1.2 \times 10^{4} + 0.209i \\ -6 \times 10^{3} - 1.039i \times 10^{4} \\ -6 \times 10^{3} + 1.039i \times 10^{4} \end{pmatrix}$$

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

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

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

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

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

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

$$E = \begin{pmatrix} 1.2 \times 10^{4} + 0.209i \\ -6 \times 10^{3} - 1.039i \times 10^{4} \\ -6 \times 10^{3} + 1.039i \times 10^{4} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

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

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

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

Building Fault Part of the Impedance Matrix:

$$ZFAG := ZFA + ZFG$$

$$ZFBG := ZFB + ZFG$$

$$ZFCG := ZFC + ZFG$$

$$ZFAG = 30$$

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

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

$$ZF = \begin{pmatrix} 30 & 30 & 30 \\ 30 & 1 \times 10^{10} & 30 \\ 30 & 30 & 1 \times 10^{10} \end{pmatrix}$$

$$FABCG := \text{augment}(\text{augment}(-ZF, -ZF), \text{one})$$

$$FABCG = \begin{pmatrix} -30 & -30 & -30 & -30 & -30 & -30 & 1 & 0 & 0 \\ -30 & -1 \times 10^{10} & -30 & -30 & -1 \times 10^{10} & -30 & 0 & 1 & 0 \\ -30 & -30 & -1 \times 10^{10} & -30 & -30 & -1 \times 10^{10} & 0 & 0 & 1 \end{pmatrix}$$

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

$$ZABCG = \begin{pmatrix} 15.866 + 21.334i & 6.324 + 8.471i & 6.324 + 8.471i & 0 & 0 & 0 & 1 & 0 & 0 \\ 6.324 + 8.471i & 15.866 + 21.334i & 6.324 + 8.471i & 0 & 0 & 0 & 0 & 1 & 0 \\ 6.324 + 8.471i & 6.324 + 8.471i & 15.866 + 21.334i & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1.113 + 1.417i & 0.193 + 0.267i & 0.193 + 0.267i & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.193 + 0.267i & 1.113 + 1.417i & 0.193 + 0.267i & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.193 + 0.267i & 0.193 + 0.267i & 1.113 + 1.417i & 0 & 0 & 1 \\ -30 & -30 & -30 & -30 & -30 & -30 & 1 & 0 & 0 \\ -30 & -1 \times 10^{10} & -30 & -30 & -1 \times 10^{10} & -30 & 0 & 1 & 0 \\ -30 & -30 & -1 \times 10^{10} & -30 & -30 & -1 \times 10^{10} & 0 & 0 & 1 \end{pmatrix}$$

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

Fault Current: $IABCG := YABCG \cdot E$

$$E = \begin{pmatrix} 1.2\times 10^{4} + 0.209i \\ -6\times 10^{3} - 1.039i\times 10^{4} \\ -6\times 10^{3} + 1.039i\times 10^{4} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad IABCG = \begin{pmatrix} 412.874 - 550.098i \\ -681.827 - 80.552i \\ 270.541 + 630.505i \\ -380.434 + 547.628i \\ 681.827 + 80.552i \\ -270.541 - 630.505i \\ 973.187 - 74.096i \\ -541.231 - 865.986i \\ -482.767 + 883.41i \end{pmatrix}$$

S - End Fault Currents: $IS := TS \cdot IABCG$

$$IS = \begin{pmatrix} 412.874 - 550.098i \\ -681.827 - 80.552i \\ 270.541 + 630.505i \end{pmatrix}$$

R - End Fault Currents: $IR := TR \cdot IABCG$

$$IR = \begin{pmatrix} -380.434 + 547.628i \\ 681.827 + 80.552i \\ -270.541 - 630.505i \end{pmatrix}$$

VF fault voltages:

$VF := TVF \cdot IABCG$

$$VF = \begin{pmatrix} 973.187 - 74.096i \\ -541.231 - 865.986i \\ -482.767 + 883.41i \end{pmatrix}$$

S - End Voltages

$VS := ES - ZS \cdot IS$

$$VS = \begin{pmatrix} 1.17\times 10^{4} - 188.869i \\ -6.013\times 10^{3} - 1.004i\times 10^{4} \\ -5.688\times 10^{3} + 1.023i\times 10^{4} \end{pmatrix}$$

Line Prefault Load Currents from S Bus

$Ia := IPRE_0 \qquad |Ia| = 686.199 \qquad \frac{arg(Ia)}{deg} = -53.254 \qquad 0.32 \cdot \frac{180}{3.14} = 18.344$

$Ib := IPRE_1 \qquad |Ib| = 686.199 \qquad \frac{arg(Ib)}{deg} = -173.254$

$Ic := IPRE_2 \qquad |Ic| = 686.199 \qquad \frac{arg(Ic)}{deg} = 66.746$

$$IPRE = \begin{pmatrix} 410.529 - 549.85i \\ -681.448 - 80.603i \\ 270.92 + 630.453i \end{pmatrix}$$

Line Prefault Voltages at S Bus

$$VSP = \begin{pmatrix} 1.17 \times 10^{4} - 187.298i \\ -6.013 \times 10^{3} - 1.004i \times 10^{4} \\ -5.688 \times 10^{3} + 1.023i \times 10^{4} \end{pmatrix}$$

$Va := VSP_0 \qquad |Va| = 1.17 \times 10^{4} \qquad \dfrac{arg(Va)}{deg} = -0.917$

$Vb := VSP_1 \qquad |Vb| = 1.17 \times 10^{4} \qquad \dfrac{arg(Vb)}{deg} = -120.917$

$Vc := VSP_2 \qquad |Vc| = 1.17 \times 10^{4} \qquad \dfrac{arg(Vc)}{deg} = 119.083$

Line Fault Currents from S Bus

$$IS = \begin{pmatrix} 412.874 - 550.098i \\ -681.827 - 80.552i \\ 270.541 + 630.505i \end{pmatrix}$$

$Iasf := IS_0 \qquad |Iasf| = 687.802 \qquad \dfrac{arg(Iasf)}{deg} = -53.11$

$Ibsf := IS_1 \qquad |Ibsf| = 686.569 \qquad \dfrac{arg(Ibsf)}{deg} = -173.262$

$Icsf := IS_2 \qquad |Icsf| = 686.097 \qquad \dfrac{arg(Icsf)}{deg} = 66.776$

Line Fault Currents from R Bus

$$IR = \begin{pmatrix} -380.434 + 547.628i \\ 681.827 + 80.552i \\ -270.541 - 630.505i \end{pmatrix}$$

$Iarf := IR_0 \qquad |Iarf| = 666.803 \qquad \dfrac{arg(Iarf)}{deg} = 124.788$

$Ibrf := IR_1 \qquad |Ibrf| = 686.569 \qquad \dfrac{arg(Ibrf)}{deg} = 6.738$

$Icrf := IR_2 \qquad |Icrf| = 686.097 \qquad \dfrac{arg(Icrf)}{deg} = -113.224$

Line Fault Voltages at S Bus

$$VSP = \begin{pmatrix} 1.17\times10^{4} - 187.298i \\ -6.013\times10^{3} - 1.004i\times10^{4} \\ -5.688\times10^{3} + 1.023i\times10^{4} \end{pmatrix}$$

$Vaf := VS_0$ $\quad |Vaf| = 1.17\times10^{4}$ $\quad \frac{arg(Vaf)}{deg} = -0.925$

$Vbf := VS_1$ $\quad |Vbf| = 1.17\times10^{4}$ $\quad \frac{arg(Vbf)}{deg} = -120.917$

$$VS = \begin{pmatrix} 1.17\times10^{4} - 188.869i \\ -6.013\times10^{3} - 1.004i\times10^{4} \\ -5.688\times10^{3} + 1.023i\times10^{4} \end{pmatrix}$$

$Vcf := VS_2$ $\quad |Vcf| = 1.17\times10^{4}$ $\quad \frac{arg(Vcf)}{deg} = 119.083$

$Ir := \sum_{mm=0}^{2} IS_{mm}$ $\quad Ir = 1.588 - 0.144i$

$$IS = \begin{pmatrix} 412.874 - 550.098i \\ -681.827 - 80.552i \\ 270.541 + 630.505i \end{pmatrix}$$

$d = 0.95$

$$T1 := \frac{arg\left[\frac{Z0S + Z0R + Z0L}{Z0R + (1-d)Z0L}\right]}{deg} = 0.841$$

$T1 = 0.841$

$Z0S = 0.013 + 1.225i$

$\left[\frac{Z0S + Z0R + Z0L}{Z0R + (1-d)Z0L}\right] = 20.398 + 0.299i$

$Z0R = 0$ $\quad Z0R = 0$ $\quad Z1R = 0.42 + 0.5i$

$Z0L = 30 + 39i$

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

$e^{j\cdot T1} = 0.667 + 0.745i$

$Z0S + Z0R + Z0L = 30.013 + 40.225i$

$Z0L = 30 + 39i$

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

$IPRE_0 = 410.529 - 549.85i$

$|IS_0| = 687.802$

$IS_0 = 412.874 - 550.098i$

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

$L = 0.95$

$\frac{|IS_0|}{|IPRE_0|} = 1.002$

$VS_0 = 1.17\times10^{4} - 188.869i$

$VSP_0 = 1.17\times10^{4} - 187.298i$

$e^{j\cdot T1} = 0.667 + 0.745i$

$\frac{VSP_0}{IPRE_0} - Z1L = 0.42 + 0.5i$

$VSP_0 = 1.17\times10^{4} - 187.298i$ $\quad VS_0 = 1.17\times10^{4} - 188.869i$

$|VSP_0| = 1.17\times1$ $\quad \frac{arg(VSP_0)}{deg} = -0.917$

$|VS_0| = 1.17\times10^{4}$ $\quad \frac{arg(VS_0)}{deg} = -0.925$

$\frac{VS_0 - VSP_0}{IS_0 - IPRE_0} = -0.033 - 0.673i$

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

$|VS_1| = 1.17\times10^{4}$

$k := 0 .. 511$

$delT := 0.0001302$

$e^{j \cdot T1} = 0.667 + 0.745i$

$|VS_2| = 1.17 \times 10^4$

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

$t1_k := k \cdot delT$

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

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

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

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

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

$T1_k =$

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

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

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

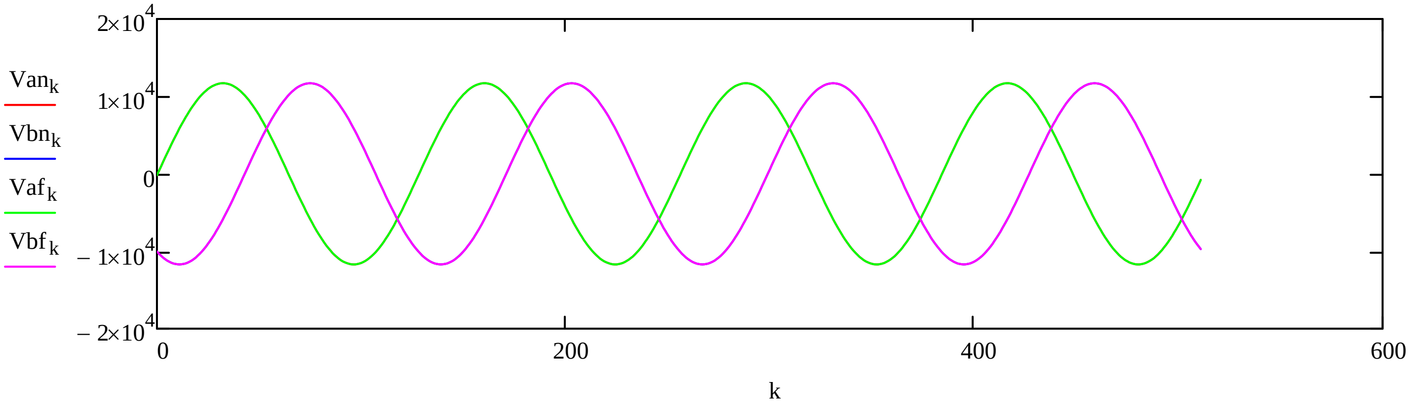
$Ibn_k := |IPRE_1| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(IPRE_1))$

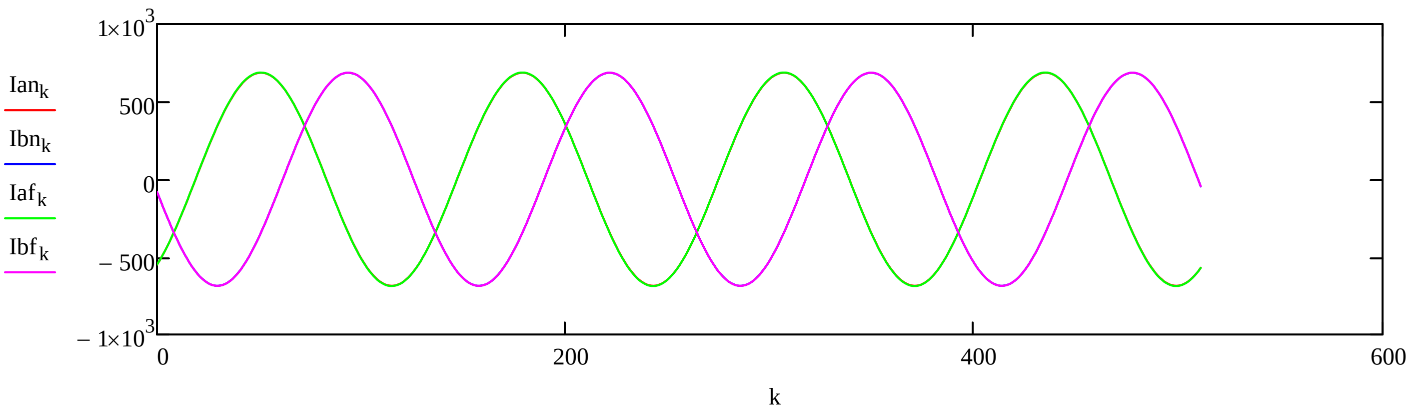
$Icn_k := |IPRE_2| \cdot \sin(2 \cdot \pi \cdot 60 \cdot k \cdot delT + \arg(IPRE_2))$

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

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

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





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

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

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

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

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

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

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

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

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

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

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

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

$Ir := Ia + Ib + Ic$

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

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

$window := 128$

$wind := window - 1$

End of waveform creation

EXAM WORK STARTS HERE

The exam task is based on US Patent No 4559491 (Saha) - Method and Device for Locating a Fault Point on a Three-Phase Power Transmission Line

The solution, that will provide us the fault location in the network, is presented in column "9" on the patent

$$K_1 = \frac{U_A}{I_A \times Z_L} + 1 + \frac{Z_B}{Z_L}$$

$$K_2 = \frac{U_A}{I_A \times Z_L}\left(\frac{Z_B}{Z_L} + 1\right) \qquad (41)$$

$$K_3 = \frac{I_{FA}}{I_A \times Z_L}\left[\frac{Z_A + Z_B}{Z_L} + 1\right]$$

Where UA - Voltage at source observed (faulty phase) during fault
IA - Current at source observed (faulty phase) during fault

ZL - Impedance of the faulty section

ZA - Source impedance of the first end (observing)

ZB - Source impedance of the second end (not observing)

IFA - Current change at point A during fault

In this model, the corresponding variables are:

ZA --> ZS

ZB --> ZR

This basically is pretty much the same as Novosel -patent algorithm

$$k_1 = \frac{v_{sf}}{I_{sf} Z_{L1}} + \frac{Z_{load}}{z_{L1}} + 1$$

$$k_2 = \frac{v_{sf}}{I_{sf} Z_{L1}}\left(\frac{Z_{load}}{Z_{L1}} + 1\right)$$

$$k_3 = \frac{\Delta I_s}{I_{sf} Z_{L1}}\left(\frac{Z_s + Z_{load}}{Z_{L1}} + 1\right)$$

Novosel algorithm is very straightforward when coming to distance solutions

Whereas the "exam" patent solution is given by

$$m = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

where:

$$a = 1$$

$$b = -\left(Re(k_1) - \frac{Im(k_1) \times Re(k_3)}{Im(k_3)} \right)$$

$$c = Re(k_2) - \frac{Im(k_2) \times Re(k_3)}{Im(k_3)}$$

$$n^2 + B \times n + C = 0$$

where

$$B = \frac{K_{1V} \times K_{3H} - K_{1H} \times K_{3V}}{K_{3V}} \text{ and}$$

$$C = \frac{K_{2H} \times K_{3V} - K_{2V} \times K_{3H}}{K_{3V}}$$

In "exam" patent the "n" is the relative distance

It turns out that these 2 methods for the fault location ARE identical !!

This brings me to the next issue : what is the point of having the same methods in different patents, filed at different times?

My first guess is that the competition is tough and forces to find alternative methods to describe the solution. I do not know the patent law very deep, but it seems to me by this case, that when one could propose a different approach to the same calculation, it could be a different patent?

OK then, on to the trials of the algorithm.

In calculations, only the basic 50 Hz harmonics are used, all others rejected. Thus first FFT algorithms have to be used for extracting the first harmonic.

I am using the formulas provided in the course example

$window := 128$

$wind := window - 1$

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

$Isa := Ia + k0 \cdot Ir$ $\quad Isb := Ib + k0 \cdot Ir$ $\quad Isc := Ic + k0 \cdot Ir$

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

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

$Pa_k := FFT(Ua_k)$ $\quad Pb_k := FFT(Ub_k)$ $\quad Pc_k := FFT(Uc_k)$

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

Algorithm constants k1, k2, k3 for the 3 phases

$$ka1_k := \frac{\left(Pa_k\right)_{1,0}}{\left(Fa_k\right)_{1,0} \cdot Z1L} + \frac{Z1R}{Z1L} + 1 \qquad kb1_k := \frac{\left(Pb_k\right)_{1,0}}{\left(Fb_k\right)_{1,0} \cdot Z1L} + \frac{Z1R}{Z1L} + 1 \qquad kc1_k := \frac{\left(Pc_k\right)_{1,0}}{\left(Fc_k\right)_{1,0} \cdot Z1L} + \frac{Z1R}{Z1L} + 1$$

$$ka2_k := \frac{\left(Pa_k\right)_{1,0}}{\left(Fa_k\right)_{1,0} \cdot Z1L} \cdot \left(\frac{Z1R}{Z1L} + 1\right) \qquad kb2_k := \frac{\left(Pb_k\right)_{1,0}}{\left(Fb_k\right)_{1,0} \cdot Z1L} \cdot \left(\frac{Z1R}{Z1L} + 1\right) \qquad kc2_k := \frac{\left(Pc_k\right)_{1,0}}{\left(Fc_k\right)_{1,0} \cdot Z1L} \cdot \left(\frac{Z1R}{Z1L} + 1\right)$$

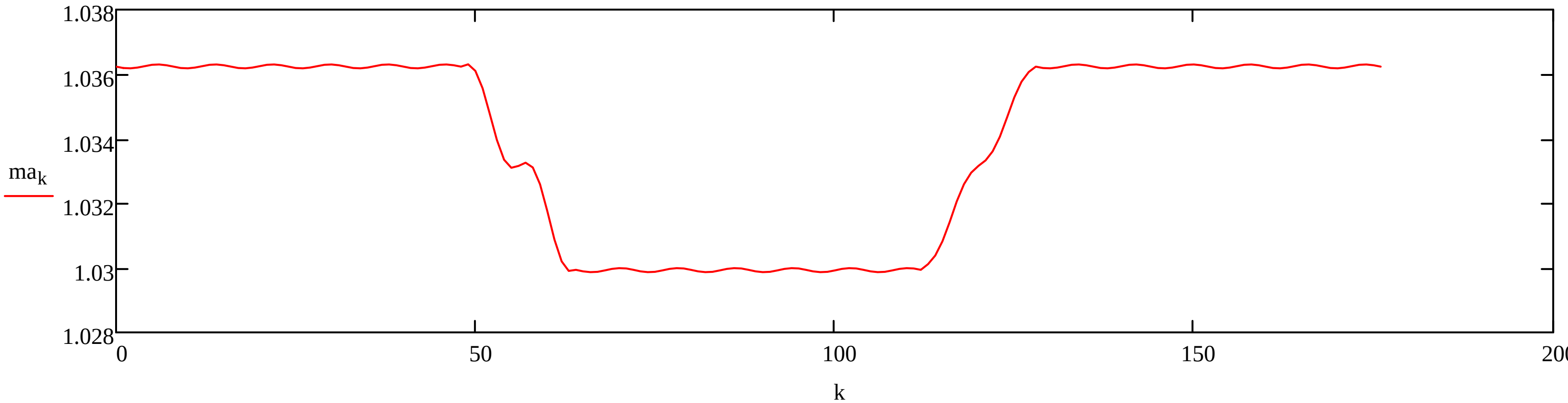
$$ka3_k := \frac{\left(Fa_k\right)_{1,0}}{\left(Fa_k\right)_{1,0} \cdot Z1L} \cdot \left(\frac{Z1S + Z1R}{Z1L} + 1\right) \qquad kb3_k := \frac{\left(Fb_k\right)_{1,0}}{\left(Fb_k\right)_{1,0} \cdot Z1L} \cdot \left(\frac{Z1S + Z1R}{Z1L} + 1\right) \qquad kc3_k := \frac{\left(Fc_k\right)_{1,0}}{\left(Fc_k\right)_{1,0} \cdot Z1L} \cdot \left(\frac{Z1S + Z1R}{Z1L} + 1\right)$$

$$ba_k := -\left(\mathrm{Re}\left(ka1_k\right) - \frac{\mathrm{Im}\left(ka1_k\right) \cdot \mathrm{Re}\left(ka3_k\right)}{\mathrm{Im}\left(ka3_k\right)}\right) \qquad bb_k := -\left(\mathrm{Re}\left(kb1_k\right) - \frac{\mathrm{Im}\left(kb1_k\right) \cdot \mathrm{Re}\left(kb3_k\right)}{\mathrm{Im}\left(kb3_k\right)}\right) \qquad bc_k := -\left(\mathrm{Re}\left(kc1_k\right) - \frac{\mathrm{Im}\left(kc1_k\right) \cdot \mathrm{Re}\left(kc3_k\right)}{\mathrm{Im}\left(kc3_k\right)}\right)$$

$$ca_k := \mathrm{Re}\left(ka2_k\right) - \frac{\mathrm{Im}\left(ka2_k\right) \mathrm{Re}\left(ka3_k\right)}{\mathrm{Im}\left(ka3_k\right)} \qquad cb_k := \mathrm{Re}\left(ka2_k\right) - \frac{\mathrm{Im}\left(kb2_k\right) \mathrm{Re}\left(kb3_k\right)}{\mathrm{Im}\left(kb3_k\right)} \qquad cc_k := \mathrm{Re}\left(kc2_k\right) - \frac{\mathrm{Im}\left(kc2_k\right) \mathrm{Re}\left(kc3_k\right)}{\mathrm{Im}\left(kc3_k\right)}$$

$$ma_k := \frac{-ba_k - \sqrt{\left(ba_k \cdot ba_k - 4 \cdot 1 \cdot ca_k\right)}}{2 \cdot 1} \qquad mb_k := \frac{-bb_k - \sqrt{\left(bb_k \cdot bb_k - 4 \cdot 1 \cdot cb_k\right)}}{2 \cdot 1} \qquad mc_k := \frac{-bc_k - \sqrt{\left(bc_k \cdot bc_k - 4 \cdot 1 \cdot cc_k\right)}}{2 \cdot 1}$$

$ma_{80} = 1.03$



This is pretty much as expected and as seen from the Novosel algorithm trials in class.

This method seems to perform even with 5% of the span to fault distance quite accurately, at 95% of the distance the accyracy is slightly more off. This is for the zero-resistance fault.

Of course it fails more with fault resistance not being zero. Here is an example of 30-ohm fault, witch is quite common in MV distribution. Error is around 8% of the span. This though is still quite close, but it is also ideal conditions here!