United States Patent

Yang

ONE-TERMINAL FAULT LOCATION SYSTEM THAT CORRECTS FOR FAULT RESISTANCE EFFECT

written in Mathcad by PhD student
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INPUT DATA

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

$es := 70 \cdot e^{j \cdot \delta \cdot deg}$ **Source S Voltage** $es = 70 + 1.222i \times 10^{-3}$

$er := 70$ **Source R Voltage**

$Z1S := 4.104 + j \cdot 11.276$ **Source S Positive Sequence Impedance**

$Z0S := 25.357 + j \cdot 54.378$ **Source S Zero Sequence Impedance**

$Z1R := 0.518 + j \cdot 1.932$ **Source R Positive Sequence Impedance**

$Z0R := 3 \cdot Z1R$ **Source S Zero Sequence Impedance**

$Z1L := 1.035 + j \cdot 3.864$ **Positive Sequence Line Impedance**

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

Fault Location

$m := 0.5$

Fault Impedances (for AG fault case) $INF := 10^{10}$

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

Fault Resistance

$ZFG := 0.1 + j \cdot 0$

CONSTANTS

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

Operator

$a := e^{j \cdot 120 \cdot deg} \qquad a = -0.5 + 0.866i$

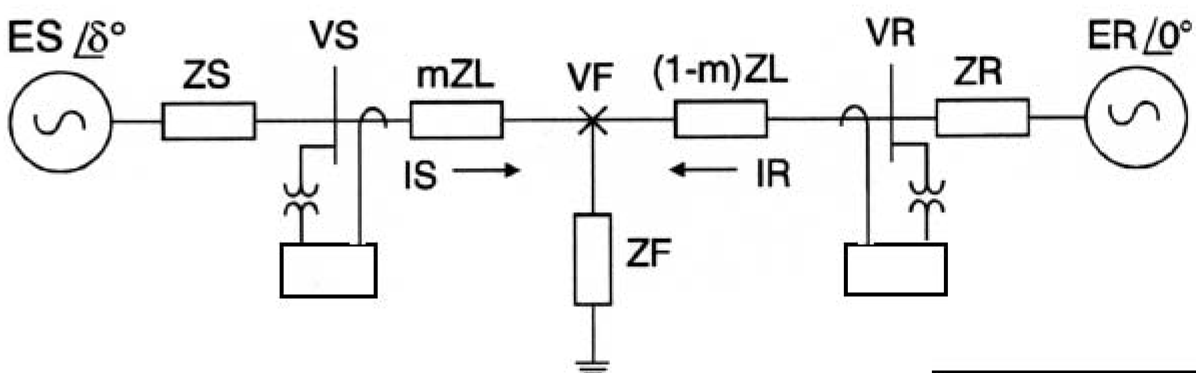
$$BAL := \begin{pmatrix} 1 \\ a^2 \\ a \end{pmatrix} \qquad one := \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad zero := \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Three phase voltages at S and R

$ES := es \cdot BAL \qquad ES = \begin{pmatrix} 70 + 1.222i \times 10^{-3} \\ -34.999 - 60.622i \\ -35.001 + 60.621i \end{pmatrix}$

$ER := er \cdot BAL \qquad ER = \begin{pmatrix} 70 \\ -35 - 60.622i \\ -35 + 60.622i \end{pmatrix}$

CIRCUIT EQUATION



$$\begin{aligned} ES &= [ZS + m \cdot ZL] \cdot IS + 0 + VF \\ ER &= +0 + [ZR + (1-m) \cdot ZL] \cdot IR + VF \\ 0 &= -ZF \cdot IS - ZF \cdot IR + VF \end{aligned}$$

→

$$\begin{aligned} ES &= ZSS \cdot IS + 0 + VF \\ ER &= +0 + ZRR \cdot IR + VF \\ 0 &= -ZF \cdot IS - ZF \cdot IR + VF \end{aligned}$$

$ZSS = [ZS + m \cdot ZL]$

$ZRR = [ZR + (1-m) \cdot ZL]$

In 3-phase matrix form, the equation looks like this:

$$\begin{bmatrix} ES \\ ER \\ null \end{bmatrix} = \begin{bmatrix} ZSS & zero & one \\ zero & ZRR & one \\ -ZF & -ZF & one \end{bmatrix} \begin{bmatrix} IS \\ IR \\ VF \end{bmatrix}$$

How do we form the soure impedance ZS and ZR?

Let us consider the link between 3-phase circuit and symmetrical components

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

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

$$ZS = \begin{pmatrix} 11.188 + 25.643i & 7.084 + 14.367i & 7.084 + 14.367i \\ 7.084 + 14.367i & 11.188 + 25.643i & 7.084 + 14.367i \\ 7.084 + 14.367i & 7.084 + 14.367i & 11.188 + 25.643i \end{pmatrix}$$

Source and Line Impedances to the Fault

$$ZSS := ZS + m\cdot ZL \qquad ZSS = \begin{pmatrix} 12.051 + 28.863i & 7.429 + 15.655i & 7.429 + 15.655i \\ 7.429 + 15.655i & 12.051 + 28.863i & 7.429 + 15.655i \\ 7.429 + 15.655i & 7.429 + 15.655i & 12.051 + 28.863i \end{pmatrix}$$

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

$$ZRR = \begin{pmatrix} 1.726 + 6.44i & 0.69 + 2.576i & 0.69 + 2.576i \\ 0.69 + 2.576i & 1.726 + 6.44i & 0.69 + 2.576i \\ 0.69 + 2.576i & 0.69 + 2.576i & 1.726 + 6.44i \end{pmatrix}$$

Build System Part of the Impedance Matrix

$$\begin{bmatrix} ES \\ ER \\ null \end{bmatrix} = \begin{bmatrix} ZSS & zero & one \\ zero & ZRR & one \\ -ZF & -ZF & one \end{bmatrix} \begin{bmatrix} IS \\ IR \\ VF \end{bmatrix}$$

$$ES = \begin{bmatrix} ES_a \\ ES_b \\ ES_c \end{bmatrix} \quad ER = \begin{bmatrix} ER_a \\ ER_b \\ ER_c \end{bmatrix} \quad VF = \begin{bmatrix} VF_a \\ VF_b \\ VF_c \end{bmatrix} \quad IS = \begin{bmatrix} IS_a \\ IS_b \\ IS_c \end{bmatrix} \quad IR = \begin{bmatrix} IR_a \\ IR_b \\ IR_c \end{bmatrix}$$

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

$$ZTOP = \begin{pmatrix} 12.051 + 28.863i & 7.429 + 15.655i & 7.429 + 15.655i & 0 & 0 & 0 & 1 & 0 & 0 \\ 7.429 + 15.655i & 12.051 + 28.863i & 7.429 + 15.655i & 0 & 0 & 0 & 0 & 1 & 0 \\ 7.429 + 15.655i & 7.429 + 15.655i & 12.051 + 28.863i & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

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

$$ZMID = \begin{pmatrix} 0 & 0 & 0 & 1.726 + 6.44i & 0.69 + 2.576i & 0.69 + 2.576i & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.69 + 2.576i & 1.726 + 6.44i & 0.69 + 2.576i & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.69 + 2.576i & 0.69 + 2.576i & 1.726 + 6.44i & 0 & 0 & 1 \end{pmatrix}$$

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

$$ZSYS = \begin{pmatrix} 12.051 + 28.863i & 7.429 + 15.655i & 7.429 + 15.655i & 0 & 0 & 0 & 1 & 0 & 0 \\ 7.429 + 15.655i & 12.051 + 28.863i & 7.429 + 15.655i & 0 & 0 & 0 & 0 & 1 & 0 \\ 7.429 + 15.655i & 7.429 + 15.655i & 12.051 + 28.863i & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1.726 + 6.44i & 0.69 + 2.576i & 0.69 + 2.576i & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.69 + 2.576i & 1.726 + 6.44i & 0.69 + 2.576i & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.69 + 2.576i & 0.69 + 2.576i & 1.726 + 6.44i & 0 & 0 & 1 \end{pmatrix}$$

Pre-fault conditions:

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

$$ZPRE = \begin{pmatrix} 13.777 + 35.303i & 8.12 + 18.231i & 8.12 + 18.231i \\ 8.12 + 18.231i & 13.777 + 35.303i & 8.12 + 18.231i \\ 8.12 + 18.231i & 8.12 + 18.231i & 13.777 + 35.303i \end{pmatrix}$$

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

$$IPRE = \begin{pmatrix} 6.448 \times 10^{-5} + 2.137i \times 10^{-5} \\ -1.374 \times 10^{-5} - 6.653i \times 10^{-5} \\ -5.075 \times 10^{-5} + 4.516i \times 10^{-5} \end{pmatrix}$$

Pre_fault voltage at S end

$VSP := ES - ZS \cdot IPRE$

$$VSP = \begin{pmatrix} 70 + 4.069i \times 10^{-4} \\ -35 - 60.622i \\ -35 + 60.622i \end{pmatrix} \qquad ES = \begin{pmatrix} 70 + 1.222i \times 10^{-3} \\ -34.999 - 60.622i \\ -35.001 + 60.621i \end{pmatrix}$$

Build the voltage Vector

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

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

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

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

$$E = \begin{pmatrix} 70 + 1.222i \times 10^{-3} \\ -34.999 - 60.622i \\ -35.001 + 60.621i \\ 70 \\ -35 - 60.622i \\ -35 + 60.622i \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

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

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

Building Fault Part of the Impedance Matrix:

- the fault impedance ZF
- voltage drop due to each phase current flowing individually in the phase-fault impedances (ZFA, ZFB, or ZFC) and mutually in the ground-fault impedance ZFG.

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

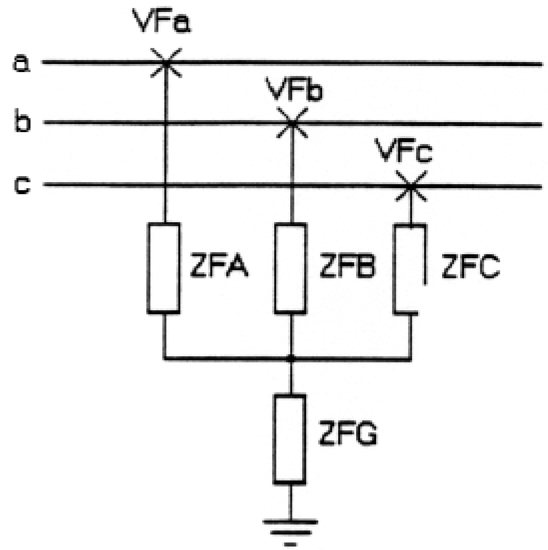
where:

$$\begin{cases} ZFAG = ZFA + ZFG \\ ZFBG = ZFB + ZFG \\ ZFCG = ZFC + ZFG \end{cases}$$

$ZFAG := ZFA + ZFG$

$ZFBG := ZFB + ZFG$

$ZFCG := ZFC + ZFG$



$ZFAG = 0.1$

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

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

$$ZF = \begin{pmatrix} 0.1 & 0.1 & 0.1 \\ 0.1 & 1 \times 10^{10} & 0.1 \\ 0.1 & 0.1 & 1 \times 10^{10} \end{pmatrix}$$

$$\begin{bmatrix} ES \\ ER \\ null \end{bmatrix} = \begin{bmatrix} ZSS & zero & one \\ zero & ZRR & one \\ -ZF & -ZF & one \end{bmatrix} \begin{bmatrix} IS \\ IR \\ VF \end{bmatrix}$$

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

$$FABCG = \begin{pmatrix} -0.1 & -0.1 & -0.1 & -0.1 & -0.1 & -0.1 & 1 & 0 & 0 \\ -0.1 & -1 \times 10^{10} & -0.1 & -0.1 & -1 \times 10^{10} & -0.1 & 0 & 1 & 0 \\ -0.1 & -0.1 & -1 \times 10^{10} & -0.1 & -0.1 & -1 \times 10^{10} & 0 & 0 & 1 \end{pmatrix}$$

FINAL Z MATRIX

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

$$ZABCG = \begin{pmatrix} 12.051 + 28.863i & 7.429 + 15.655i & 7.429 + 15.655i & 0 & 0 & 0 & 1 & 0 & 0 \\ 7.429 + 15.655i & 12.051 + 28.863i & 7.429 + 15.655i & 0 & 0 & 0 & 0 & 1 & 0 \\ 7.429 + 15.655i & 7.429 + 15.655i & 12.051 + 28.863i & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1.726 + 6.44i & 0.69 + 2.576i & 0.69 + 2.576i & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.69 + 2.576i & 1.726 + 6.44i & 0.69 + 2.576i & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.69 + 2.576i & 0.69 + 2.576i & 1.726 + 6.44i & 0 & 0 & 1 \\ -0.1 & -0.1 & -0.1 & -0.1 & -0.1 & -0.1 & 1 & 0 & 0 \\ -0.1 & -1 \times 10^{10} & -0.1 & -0.1 & -1 \times 10^{10} & -0.1 & 0 & 1 & 0 \\ -0.1 & -0.1 & -1 \times 10^{10} & -0.1 & -0.1 & -1 \times 10^{10} & 0 & 0 & 1 \end{pmatrix}$$

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

Fault Currents:

$$IABCG := YABCG \cdot E$$

$$E = \begin{pmatrix} 70 + 1.222i \times 10^{-3} \\ -34.999 - 60.622i \\ -35.001 + 60.621i \\ 70 \\ -35 - 60.622i \\ -35 + 60.622i \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad IABCG = \begin{pmatrix} 0.94 - 2.363i \\ -0.056 + 0.29i \\ -0.056 + 0.29i \\ 2.835 - 9.807i \\ 0.056 - 0.29i \\ 0.056 - 0.29i \\ 0.377 - 1.217i \\ -64.972 - 60.955i \\ -64.972 + 60.289i \end{pmatrix}$$

S - End Fault Currents:

$IS := TS \cdot IABCG$

$$IS = \begin{pmatrix} 0.94 - 2.363i \\ -0.056 + 0.29i \\ -0.056 + 0.29i \end{pmatrix}$$

R - End Fault Currents:

$IR := TR \cdot IABCG$

$$IR = \begin{pmatrix} 2.835 - 9.807i \\ 0.056 - 0.29i \\ 0.056 - 0.29i \end{pmatrix}$$

S - End Voltages

$VS := ES - ZS \cdot IS$

$$VS = \begin{pmatrix} 8.012 - 0.172i \\ -62.979 - 60.46i \\ -62.98 + 60.783i \end{pmatrix}$$

Line Prefault Load Currents from S Bus

$Ia := IPRE_0$ $\quad |Ia| = 6.793 \times 10^{-5}$ $\quad \frac{arg(Ia)}{deg} = 18.334$ $\quad 0.32 \cdot \frac{180}{3.14} = 18.344$

$Ib := IPRE_1$ $\quad |Ib| = 6.793 \times 10^{-5}$ $\quad \frac{arg(Ib)}{deg} = -101.666$

$Ic := IPRE_2$ $\quad |Ic| = 6.793 \times 10^{-5}$ $\quad \frac{arg(Ic)}{deg} = 138.334$

$$IPRE = \begin{pmatrix} 6.448 \times 10^{-5} + 2.137i \times 10^{-5} \\ -1.374 \times 10^{-5} - 6.653i \times 10^{-5} \\ -5.075 \times 10^{-5} + 4.516i \times 10^{-5} \end{pmatrix}$$

Line Prefault Voltages at S Bus

$Va := VSP_0$ $\quad |Va| = 70$ $\quad \frac{arg(Va)}{deg} = 3.331 \times 10^{-4}$

$$VSP = \begin{pmatrix} 70 + 4.069i \times 10^{-4} \\ -35 - 60.622i \\ -35 + 60.622i \end{pmatrix}$$

$Vb := VSP_1$ $\quad |Vb| = 70$ $\quad \frac{arg(Vb)}{deg} = -120$

$Vc := VSP_2$ $\quad |Vc| = 70$ $\quad \frac{arg(Vc)}{deg} = 120$

Line Fault Currents from S Bus

$Iasf := IS_0$ $\quad |Iasf| = 2.543$ $\quad \frac{arg(Iasf)}{deg} = -68.312$

$Ibsf := IS_1$ $\quad |Ibsf| = 0.296$ $\quad \frac{arg(Ibsf)}{deg} = 100.858$

$Icsf := IS_2$ $\quad |Icsf| = 0.296$ $\quad \frac{arg(Icsf)}{deg} = 100.861$

$$IS = \begin{pmatrix} 0.94 - 2.363i \\ -0.056 + 0.29i \\ -0.056 + 0.29i \end{pmatrix}$$

Line Fault Currents from R Bus

$Iarf := IR_0$ $\quad |Iarf| = 10.209$ $\quad \frac{arg(Iarf)}{deg} = -73.878$

$Ibrf := IR_1$ $\quad |Ibrf| = 0.296$ $\quad \frac{arg(Ibrf)}{deg} = -79.142$

$Icrf := IR_2$ $\quad |Icrf| = 0.296$ $\quad \frac{arg(Icrf)}{deg} = -79.139$

$$IR = \begin{pmatrix} 2.835 - 9.807i \\ 0.056 - 0.29i \\ 0.056 - 0.29i \end{pmatrix}$$

$$VSP = \begin{pmatrix} 70 + 4.069i \times 10^{-4} \\ -35 - 60.622i \\ -35 + 60.622i \end{pmatrix}$$

Line Fault Voltages at S Bus

$Vaf := VS_0$ $\quad |Vaf| = 8.014$ $\quad \frac{arg(Vaf)}{deg} = -1.231$

$Vbf := VS_1$ $\quad |Vbf| = 87.303$ $\quad \frac{arg(Vbf)}{deg} = -136.169$

$Vcf := VS_2$ $\quad |Vcf| = 87.528$ $\quad \frac{arg(Vcf)}{deg} = 136.017$

$$VS = \begin{pmatrix} 8.012 - 0.172i \\ -62.979 - 60.46i \\ -62.98 + 60.783i \end{pmatrix}$$

Residual Current Ir

$$Ir := \sum_{j=0}^{2} IS_j \qquad Ir = 0.829 - 1.783i$$

$$IS = \begin{pmatrix} 0.94 - 2.363i \\ -0.056 + 0.29i \\ -0.056 + 0.29i \end{pmatrix}$$

$$IrPRE := \sum_{j=0}^{2} IPRE_j = 0$$

Phase A SLG Fault

$$Va = m \cdot Z1L \cdot (Ia + k_0 \cdot Ir) + R_F \cdot I_F$$

$$m = \frac{Va - R_F \cdot I_F}{Z1L \cdot (Ia + k_0 \cdot Ir)}$$

$Vaf = 8.012 - 0.172i$ $\quad Z1L = 1.035 + 3.864i$

$Iasf = 0.94 - 2.363i$

$Rf := Re(ZFAG)$

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

$Rf = 0.1$

$Ir = 0.829 - 1.783i$

$If := Iasf + Iarf = 3.775 - 12.17i$

Fault Current

Impedance to the Fault

$$mCalc := \frac{(Vaf - Rf \cdot If)}{(Iasf + k0 \cdot Ir) \cdot Z1L} = 0.5$$

Fault Distance

$|mCalc| = 0.5$

$m = 0.5$

$|Z1L| = 4$

Line Length

$$Ds := \frac{Iasf}{If}$$ **Distrbution Factor**

$$Ns := \frac{Iasf}{Iasf - IPRE_0} = 1 + 2.666i \times 10^{-5}$$

Loading Factor

$m = 0.5$

$$mCalc2 := \frac{1}{Z1L} \cdot \left(\frac{Vaf}{Iasf + k0 \cdot Ir} - \frac{Rf}{Ds \cdot Ns} \right) = 0.491 + 0.042i$$

Fault Distance

$|mCalc2| = 0.492$

Zero Sequence Current Distribution Factor, Dn

$$d_s = \frac{Z_H + (1-m)Z_L}{Z_G + Z_H + Z_L}$$

$arg(Ds) = 0.078$

$$Ds := \frac{Z0R + (1 - m) \cdot Z0L}{Z0S + Z0R + Z0L} = 0.153 + 0.021i$$

$beta := arg(Ds) = 0.134$

$theta := -beta = -0.134$

distance L (which is supposed to be same as m) by [modified] Takagi Method

$$L := \frac{\mathrm{Im}\left[\mathrm{Vaf}\,\overline{\left(\mathrm{Ir}\cdot e^{j\cdot \mathrm{theta}}\right)}\right]}{\mathrm{Im}\left[\mathrm{Z1L}\cdot(\mathrm{Iasf} + \mathrm{k0}\cdot\mathrm{Ir})\cdot\overline{\left(\mathrm{Ir}\cdot e^{j\cdot \mathrm{theta}}\right)}\right]}$$

$$L = 0.5$$

>>>>>>>>>>>>>> SKIP ABOVE <<<<<<<<<<<<<<<<<<<<<

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written in Mathcad by PhD student

Andrey Lana

United States Patent

Yang

ONE-TERMINAL FAULT LOCATION SYSTEM THAT CORRECTS FOR FAULT RESISTANCE EFFECT

BEGIN

100. SET VALUES Zi1,Zi0

$Z10 := Z0L = 3.105 + 11.592i$

$Z11 := Z1L = 1.035 + 3.864i$

110. DETERMINE K, X11 and R11

$$K := \frac{Z10 - Z11}{Z11} = 2$$

$X11 := \mathrm{Im}(Z11) = 3.864$

$R11 := \mathrm{Re}(Z11) = 1.035$

Z10 - line zero sequence impedance
Z11- line positive sequence impedance
"K factor" to compensate cross coupling

120. MONITOR LINES Va, Vb, Vc, Ia, Ib, Ic

8 samples per cycle, if no fault then saved as load values

On fault two sets are available: saved load values and post fault values

140. FAULT

150. MULTI-PHASE OR SINGLE PHASE

START IF

160. IF SINGLE DETERMINE SEQUENCE CURRENTS AND VOLTAGES

$Z2L := Z1L$

$$I012_1 := \frac{VS}{Z0L + Z1L + Z2L + 3 \cdot ZFG} = \begin{pmatrix} 0.101 - 0.386i \\ -3.752 + 2.197i \\ 2.057 + 3.843i \end{pmatrix}$$

$I012_2 := I012_1$

$I012_0 := I012_1$

165. IF SINGLE CALCULATE COMPENSATE CURRENT I'x

$$Ic := IS + K \cdot I012_0 = \begin{pmatrix} 1.141 - 3.136i \\ -7.559 + 4.683i \\ 4.059 + 7.976i \end{pmatrix}$$

162. IF MULTI-PHASE DERIVE Vx, Ix and dIx

a-b or a-b-G	**fault type 1**	**ft=1**
b-c or b-c-G	**fault type 2**	**ft=2**
c-a or c-a-G	**fault type 3**	**ft=3**

$ft := 1$

a-b-c or a-b-c-Gotherwise **ft=4**

$$Vx(ft) := \begin{cases} (VS_0 - VS_1) & \text{if } ft = 1 \\ (VS_1 - VS_2) & \text{if } ft = 2 \\ (VS_2 - VS_0) & \text{if } ft = 3 \\ (VS_0 - VS_1) & \text{otherwise} \end{cases}$$

$$Ix(ft) := \begin{cases} (IS_0 - IS_1) & \text{if } ft = 1 \\ (IS_1 - IS_2) & \text{if } ft = 2 \\ (IS_2 - IS_0) & \text{if } ft = 3 \\ (IS_0 - IS_1) & \text{otherwise} \end{cases}$$

$$deltaIx(ft) := \begin{cases} Ix(ft) - (IPRE_0 - IPRE_1) & \text{if } ft = 1 \\ Ix(ft) - (IPRE_1 - IPRE_2) & \text{if } ft = 2 \\ Ix(ft) - (IPRE_2 - IPRE_0) & \text{if } ft = 3 \\ Ix(ft) - (IPRE_0 - IPRE_1) & \text{otherwise} \end{cases}$$

$Vx(ft) = 70.991 + 60.288i$ $Ix(ft) = 0.996 - 2.654i$ $deltaIx(ft) = 0.995 - 2.654i$

$$\alpha mpf := \arg(Ix(ft)) - \arg(deltaIx(ft)) = 3.673 \times 10^{-5}$$

$$Zmpf := \frac{VS}{Ix(ft)} = \begin{pmatrix} 1.05 + 2.625i \\ 12.167 - 28.299i \\ -27.885 - 13.272i \end{pmatrix}$$

END IF

170. DERIVE Zx, Xx & Rx

$$Zabc := \frac{VS}{Ic} = \begin{pmatrix} 0.869 + 2.239i \\ 2.44 + 9.509i \\ 2.862 + 9.352i \end{pmatrix} \quad X := Im(Zabc) = \begin{pmatrix} 2.239 \\ 9.509 \\ 9.352 \end{pmatrix} \quad R := Re(Zabc) = \begin{pmatrix} 0.869 \\ 2.44 \\ 2.862 \end{pmatrix}$$

180. DERIVE 00

$$\alpha := \arg(Ic) - \arg(I012_2) = \begin{pmatrix} 0.094 \\ -0.025 \\ 0.021 \end{pmatrix} \quad \arg(Ic) = \begin{pmatrix} -1.222 \\ 2.587 \\ 1.1 \end{pmatrix} \quad \arg(I012_2) = \begin{pmatrix} -1.316 \\ 2.612 \\ 1.079 \end{pmatrix}$$

Fault Distance is set to:

$m = 0.5$

190. DETERMINE m

RESULTS FOR SINGLE PHASE FAULT:

$$ma := \frac{Im(Zabc_0) + Re(Zabc_0)\cdot\tan(\alpha_0)}{X11 + R11\cdot\tan(\alpha_0)} = 0.586 \quad mb := \frac{Im(Zabc_1) + Re(Zabc_1)\cdot\tan(\alpha_1)}{X11 + R11\cdot\tan(\alpha_1)} = 2.462 \quad mc := \frac{Im(Zabc_2) + Re(Zabc_2)\cdot\tan(\alpha_2)}{X11 + R11\cdot\tan(\alpha_2)} = 2.422$$

RESULT FOR MULTI-PHASE FAULT:

$$mmpf := \frac{Im(Zmpf) + Re(Zmpf) \cdot \tan(\alpha mpf)}{X11 + R11 \cdot \tan(\alpha mpf)} = \begin{pmatrix} 0.679 \\ -7.323 \\ -3.435 \end{pmatrix}$$

DETECTION ERROR, %

$$DEa := |m - ma| \cdot 100 = 8.58$$

200. FIND FAULT IN UNITS

END

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CONCLUSION AND RESULT:

ALGORITHM IS SIMPLE AND EASY TO IMPLEMENT.
ITS PERFORM WELL AS FOR SINGLE PHASE FAULT AS FOR 2- AND 3- PHASE FAULTS.