Digital Technique of fault study of power system

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Abstract - *In huge complex power system networks, faults are inevitable. It's very important to analyze the fault level for avoiding the severe consequences and proving the conditions thus quality power supply need not to face any kind of discontinuity. The objective of this paper is to study the common fault types which are balanced and unbalanced fault of transmission line in power system using a systematic procedure of digital techniques and to perform the analysis and obtain the result from simulation on that type of fault using MATLAB.*

***Key Words*:Power system fault analysis, Asymmetrical fault, Symmetrical components, MATLAB, Z-parameters.**

1.INTRODUCTION

Power system works in normal balanced condition but whenever some fault arises it becomes unbalanced. Any unexpected disturbance in the normal working condition is termed as fault. Fault may arise due to various factors such as Lightening stroke, high wind which leads to falling of trees on line, wind and ice loading resulting in failure of insulators. Fault can be symmetrical or unsymmetrical, when the fault occurs at all the three phases at a time, it is said to be symmetrical fault and where one or more phases may be involved is unsymmetrical fault. Though the symmetric fault is rare, but this type of faults shows most severe effects to our power systems. Unsymmetrical fault can be treated as a regular problem of the power system and has to be analyzed more preciously thus the system can remain in its stable condition and can lead its operation without breaking continuity. The point at which the fault occurs behaves as sink point and the voltage at that point tends to become zero. Thus all the points have potential higher than faulty point starts to send current to these faulty point and thus the fault level rises to very higher magnitude than normal operating level. Therefore, it is important to determine the values of system voltage and current during fault conditions so that the protective devices may be set to detect the fault and isolate the faulty portion of the system.

1.1 Faults in Three phase system

1. Symmetrical three-phase fault
2. Single line-to-ground fault
3. Line-to-line fault
4. Double line-to-ground fault

Symmetrical fault is defined as the simultaneous short circuit across all the three phases. It is most infrequent fault but the most severe type of fault encountered. Symmetrical fault is the rarest one and calculation of fault level is much simpler, but in case of unsymmetrical symmetry faulted power system does not have three phase symmetry, so it cannot be solved by per phase analysis. To find fault current and voltage, it is first transformed into their symmetrical component, use of which help to reduce the complexity of transmission line and components are by large and symmetrical, although the fault may be unsymmetrical .This can be done by replacing three phase fault current by the sum of three phases zero sequence sources, a three phase positive sequence source, a three phase negative sequence.

1.2 BUS IMPEDENCE CALCULATION

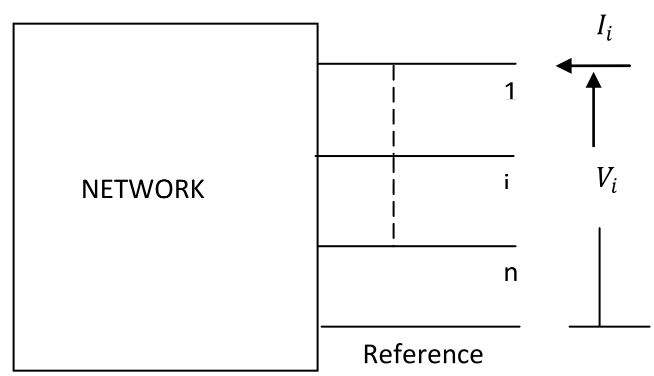


Fig. 1 General n port network

Fig.1 shows an n bus passive linear network. The voltage of the ith bus (with respect to reference) is V_i and the current entering the ith bus isI_i . The knowledge of network theory tells us that this network can be described by

$$[V_{bus}]_{n\times1} = [Z_{bus}]_{n\times n}[I_{bus}]_{n\times1}$$

Where V_{bus} is the bus voltage matrix, I_{bus} is the bus current matrix and Z_{bus} is the bus impedance matrix. The general entry Z_{ik} of Z_{bus} can be obtained

$$Z_{ik} = \frac{V_i}{I_k}$$

I_1=I_2.......=I_n=0

$I_k \neq 0$

When an existing Z_{bus} is added with new element having self-impedance Z_s, a new bus may be created or a new bus may not be created. This leads to the addition of Z_s in the following ways:

1. Injection of Z_s from a new bus to reference.
2. Injection of Z_s from a new bus to old bus.
3. Injection of Z_s from an old bus to reference
4. Injection of Z_s between two old buses.

TYPE 1 MODIFICATION

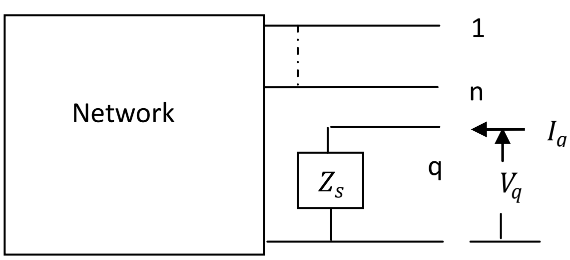


Fig. 2 Type 1 modification

Fig. 2 shows a branch Z_s connected between reference bus and a new bus q. For this new branch we can write

$$V_q = z_s I_q$$

$$\begin{bmatrix} V_1 \\ \vdots \\ V_i \\ \vdots \\ V_n \\ V_q \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & \cdots & Z_{1n} & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ Z_{i1} & Z_{i2} & \cdots & \cdots & Z_{in} & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ Z_{n1} & Z_{n2} & \cdots & \cdots & Z_{nn} & 0 \\ 0 & 0 & \cdots & \cdots & 0 & z_s \end{bmatrix} \begin{bmatrix} I_1 \\ \vdots \\ I_i \\ \vdots \\ I_n \\ I_q \end{bmatrix}$$

$$\text{Or } [Z_{bus}]_{new} = \left[\begin{array}{c:c} [Z_{bus}]_{old} & \begin{matrix} 0 \\ \vdots \\ 0 \end{matrix} \\ \hdashline 0 \quad \cdots \quad 0 & z_s \end{array}\right]$$

TYPE 2 MODIFICTION

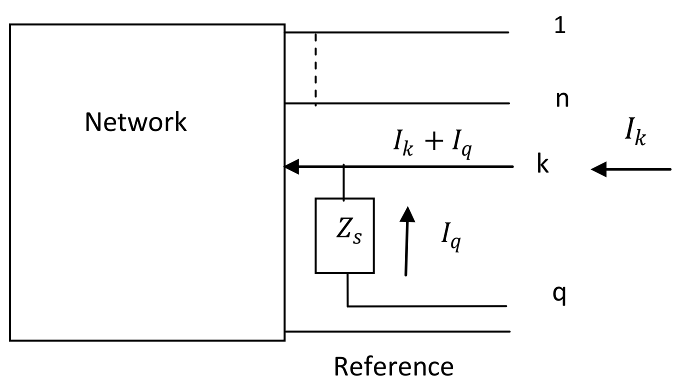


Fig. 3 Type 2 modification

$$V_q = z_s I_q + V_k$$

$$= Z_{k1}I_1 + Z_{k2}I_2 + \ldots\ldots\ldots + Z_{kk}I_k + \ldots\ldots\ldots + Z_{kn}I_n + (Z_{kk}+z_s)I_q$$

The equation for V_1 can be written by considering that new current at kth bus is $I_k + I_q$.

$$V_1 = Z_{11}I_1 + Z_{12}I_2 + \ldots\ldots\ldots + Z_{1k}I_k + \ldots\ldots\ldots + Z_{1n}I_n + Z_{1k}I_q$$

The equations for $V_2, V_3 \ldots\ldots V_n$ also get modified in a similar manner and is given by

$$\begin{bmatrix} V_1\\ V_2\\ \vdots\\ V_k\\ \vdots\\ V_n\\ V_q\end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \dots & Z_{1k} & \dots & Z_{1n} & Z_{1k}\\ Z_{21} & Z_{22} & \dots & Z_{2k} & \dots & Z_{2n} & Z_{2k}\\ \dots & \dots & \dots & \dots & \dots & \dots & \dots\\ Z_{k1} & Z_{k2} & \dots & Z_{kk} & \dots & Z_{kn} & Z_{kk}\\ \dots & \dots & \dots & \dots & \dots & \dots & \dots\\ Z_{n1} & Z_{n2} & \dots & Z_{nk} & \dots & Z_{nn} & Z_{nk}\\ Z_{k1} & Z_{k2} & \dots & Z_{kk} & \dots & Z_{kn} & (Z_{kk}+z_s)\end{bmatrix} \begin{bmatrix} I_1\\ I_2\\ \vdots\\ I_k\\ \vdots\\ I_n\\ I_q\end{bmatrix}$$

TYPE 3 MODIFICATION

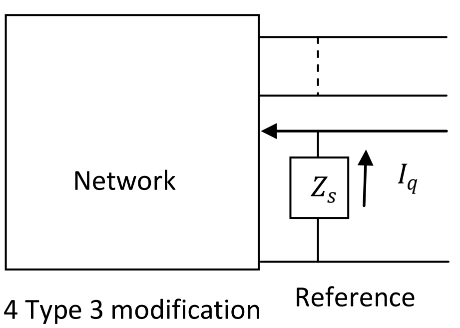


Fig. 4 Type 3 modification

The new set of the equation is

$$\begin{bmatrix} V_1\\ V_2\\ \vdots\\ \vdots\\ V_n\\ \hline 0\end{bmatrix} = \left[\begin{array}{c|c} [Z_{bus}]_{old} & \begin{matrix} Z_{1k}\\ Z_{2k}\\ \vdots\\ Z_{nk}\end{matrix}\\ \hline Z_{k1} \quad Z_{k2} \quad \dots \quad Z_{kn} & Z_{kk}+z_s\end{array}\right] \begin{bmatrix} I_1\\ I_2\\ \vdots\\ \vdots\\ I_n\\ \hline I_q\end{bmatrix}$$

$$or[Z_{bus}]_{new} = [Z_{bus}]_{old} - \frac{1}{Z_{kk}+z_s}\begin{bmatrix} Z_{1k}\\ Z_{2k}\\ \vdots\\ Z_{nk}\end{bmatrix}\begin{bmatrix} Z_{k1} & Z_{k2} & \dots & Z_{kn}\end{bmatrix}$$

TYPE 4 MODIFICATION

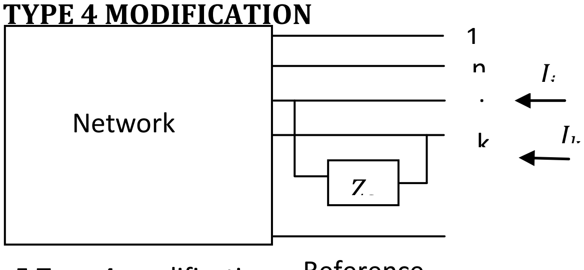


Fig. 5 Type 4 modification

$V_K = Z_s + V_i$

Or $= z_s I_q + Z_{i1} I_1 + Z_{i2} I_2 + \dots + Z_{ii}(I_i + I_q) + \quad Z_{ij} I_j + Z_{ik}(I_k - I_q) + \dots$

Rearranging

$0 = (Z_{i1} - Z_{k1})I_1 + \dots + (Z_{ii} - Z_{ki})I_i + (Z_{ij} - Z_{kj})I_j + (Z_{ik} - Z_{kk})I_k + \dots + (z_s + Z_{ii} - Z_{ik} - Z_{ki} + Z_{kk})$

Equations $V_1, V_2, V_3 \dots \dots \dots V_n$ can be written in the following form:

$$\begin{bmatrix} V_1\\ V_2\\ \vdots\\ \vdots\\ V_n\\ \hline 0\end{bmatrix} = \left[\begin{array}{c|c} [Z_{bus}]_{old} & \begin{matrix} Z_{1i}-Z_{1k}\\ Z_{2i}-Z_{2k}\\ \vdots\end{matrix}\\ \hline Z_{i1}-Z_{k1} & z_s+Z_{ii}+Z_{kk}-2Z_{ik}\end{array}\right] \begin{bmatrix} I_1\\ I_2\\ \vdots\\ \vdots\\ I_n\\ \hline I_q\end{bmatrix}$$

Or $$[Z_{bus}]_{new} = [Z_{bus}]_{old} - \frac{1}{Z_s + Z_{ii} + Z_{kk} - 2Z_{ik}}\begin{bmatrix} Z_{1i} - Z_{1k}\\ Z_{2i} - Z_{2k}\\ \vdots\\ \vdots\\ Z_{ni} - Z_{nk}\end{bmatrix}[(Z_{i1} - Z_{k1}) \quad \dots\dots \quad (Z_{in} - Z_{kn})]$$

1.3 SEQUENCE MATRICES

The sequence impedance matrices required for the short circuit studies are:

$[Z_{0-bus}]$ = zero sequence bus impedance matrix (n$\times n$),generally entry Z_{ik0}

$[Z_{1-bus}]$ = positive sequence bus impedance matrix (n$\times n$),generally entry Z_{ik1}

$[Z_{2-bus}]$ = negative sequence bus impedance matrix (n$\times n$),generally entry Z_{ik2}

The equations relating the sequence quantities are:

$V_{0-bus} = -[Z_{0-bus}]I_{0-bus}$

$V_{1-bus} = E_{bus} - [Z_{1-bus}]I_{1-bus}$

$V_{2-bus} = -[Z_{2-bus}]I_{2-bus}$

The prefault currents are neglected, vector E contains $1\angle 0$ in all entries. The currents are all zero till the network is terminated externally . At a time only one bus(i.e. faulted bus k) is terminated. Thus, only I_{k0}, I_{k1}, I_{k2} have non-zero entry

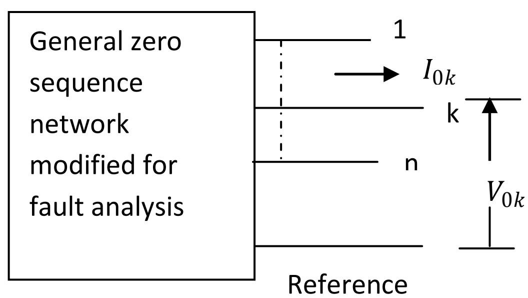


Fig. 6(a) system zero sequence network

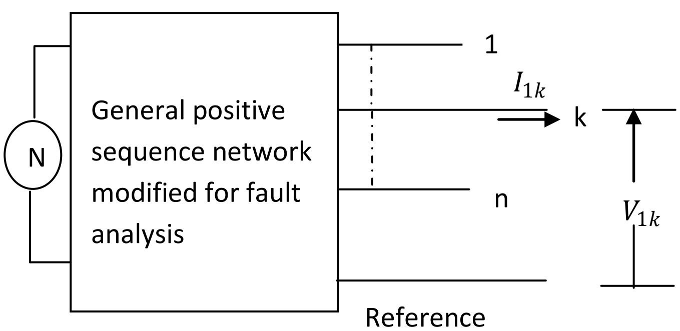


Fig. 6(b) system positive sequence network

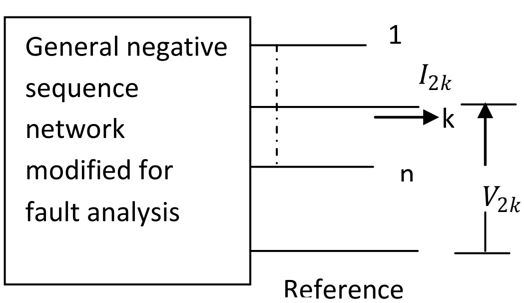


Fig. 6(c) system negative sequence network

1.4 SHORT CIRCUIT STUDIES

Symmetrical fault :-For a symmetrical fault the negative sequence and zero sequence are absent, i.e.,V_{0-bus} ,V_{2-bus} ,I_{0-bus} and I_{2-bus} are zero.

$$V_{k1} = E-(Z_{k11}I_{11} + Z_{k21}I_{21} + \cdots + Z_{kk1}I_{k1} + \cdots + Z_{kn1}I_{n1}) \quad (1)$$

But all the currents except the current at the faulted bus, i.e., I_{k1} are zero. Therefore,

$$V_{k1} = E-Z_{kk1}I_{k1} \quad (2)$$

If Z_f is the fault impedance

$$V_{k1} = I_{k1}Z_f \quad (3)$$

From (2 and 3)

$$I_{k1} = \frac{E}{Z_{kk1}+Z_f} \quad (4)$$

The voltage at ith bus is

$$V_{i1} = E - Z_{ik1}I_{k1} = E\left(1-\frac{Z_{ik1}}{Z_{kk1}+Z_f}\right) \quad (5)$$

For i = 1, 2 .... n

Single Line to Ground Fault

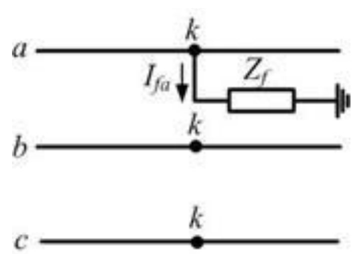


Fig. 7: - Single Line-to-ground fault.

Assuming that fault current I_f occurred on the phase with fault impedance Z_f . The boundary conditions are:

$V_{ag} = Z_f I_a$

$I_b = 0, I_C = 0$

The symmetrical component of current are, with $I_b = I_C = 0$:

$$\begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a = I_f \\ 0 \\ 0 \end{bmatrix}$$

$I_{a_0} = I_{a_1} = I_{a_2} = \frac{I_f}{3}$

$I_f = I_a = I_{a_0} + I_{a_1} + I_{a_2} = \frac{3V_f}{Z_0 + Z_1 + Z_2 + 3Z_f}$

Where, Z_0, Z_1, Z_2 is a zero, positive, negative sequence impedance.

Using Z-parameters analysis (Digital approach)

We know that

$\boldsymbol{I_{i0} = I_{i1} = I_{i2} = 0}$ **For i = 1, 2 ...... n** (6a)

i≠ K **(**6b)

And $I_{k0} = I_{k1} = I_{k2}$

$V_{k0} + V_{k1} + V_{k2}$ **=** $3Z_f I_{k1}$ (7)

Also $V_{k0} = -Z_{kk0} I_{k0}$

$V_{k1} = E - Z_{kk1} I_{k1}$ (8)

$V_{k2} = -Z_{kk2} I_{k2}$

Combining equation (6, 7 and 8)

$I_{k1} = \frac{E}{Z_{kk0} + Z_{kk1} + Z_{kk2} + 3Z_f}$ (9)

The sequence components of bus voltages at ith bus (i = 1, 2, 3 ..... n) are

$V_{i0} = -Z_{ik0} I_{k0} = -Z_{ik0} I_{k1}$ (10a)

$= \frac{-Z_{ik0} E}{Z_{kk0} + Z_{kk1} + Z_{kk2} + 3Z_f}$ (10b)

$V_{i1} = E - Z_{ik1} I_{k1}$ (11a)

$= E\left[1 - \frac{Z_{ik1}}{Z_{kk0} + Z_{kk1} + Z_{kk2} + 3Z_f}\right]$ (11b)

$= E\left[\frac{Z_{kk0} + Z_{kk1} + Z_{kk2} + 3Z_f - Z_{ik1}}{Z_{kk0} + Z_{kk1} + Z_{kk2} + 3Z_f}\right]$ (11c)

$V_{i2} = -Z_{ik2} I_{k2} = -Z_{ik2} I_{k1}$ (12a)

$= \frac{-Z_{ik2} E}{Z_{kk0} + Z_{kk1} + Z_{kk2} + 3Z_f}$ (12b)

Line to Line Fault

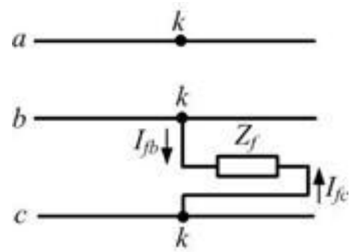


Fig.8: Line-to-Line fault

Line-to-Line fault takes place on phase b and c. The boundary conditions are:

$I_a = 0$

$I_b + I_C = 0$

$V_b = V_c$

The symmetrical component of current are:

$$\begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 0 \\ I_b \\ -I_b \end{bmatrix}$$

$$\begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix} = \begin{bmatrix} 0 \\ \frac{1}{3}(a - a^2) I_b \\ -\frac{1}{3}(a - a^2) I_b \end{bmatrix}$$

Therefore, $I_{a_1} = -I_{a_2}$

Also $V_{a1} = V_{a2}$

Or $I_{a_1} = \frac{V_f}{Z_1 + Z_2}$

Where, Z_1, Z_2 is positive, negative sequence impedances.

Using Z-parameters analysis (Digital approach)

For a line to line fault

$V_{0-bus} = I_{0-bus} = 0$ (13)

(6a and 8) are still valid

$V_{k1} = V_{k2} + I_{k1}Z_f$ (14)

Substituting the values for V_{k1} and V_{k2} from (7) into (13)

$E - Z_{kk1}I_{k1} = -Z_{kk2}I_{k2} + I_{k1}Z_f$ (15)

We know that for a line to line fault I_{k2} = -I_{k1}. Making this substitution in (14)

$E - Z_{kk1}I_{k1} = Z_{kk2}I_{k1} + I_{k1}Z_f$

Or $I_{k1} = \frac{E}{Z_{kk1}+Z_{kk2}+Z_f}$ (16)

The positive and negative sequence voltages at ith bus (i = 1, 2 ...... n) are

V_{i1} = E-$Z_{ik1}I_{k1}$ (17a)

= E-$Z_{ik1}\frac{E}{Z_{kk1}+Z_{kk2}+Z_f}$ (17b)

= E$\left[\frac{Z_{kk1}+Z_{kk2}+Z_f-Z_{ik1}}{Z_{kk1}+Z_{kk2}+Z_f}\right]$ (17c)

V_{i2} = -$Z_{ik2}I_{k2}$ (18a)

= +$Z_{ik2}I_{k1}$ (18b)

= $\frac{Z_{ik2}E}{Z_{kk1}+Z_{kk2}+Z_f}$ (18c)

Double Line to Ground Fault

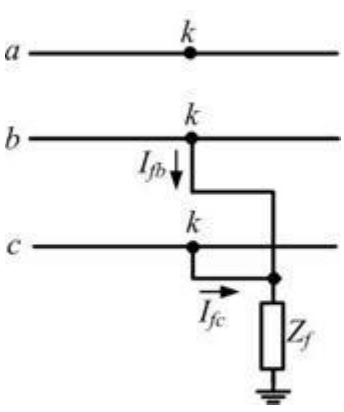


Fig. 9: - Double-line-to-ground fault

The boundary conditions for Double Line-to-Ground:

$I_a = 0$

$V_b = V_c = (I_b + I_c)Z_f$

The symmetrical components of voltage are:

$$\begin{bmatrix} V_{a_0} \\ V_{a_1} \\ V_{a_2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

Also V_{a_1}=V_{a_2}=V_{a_0}-3$Z_f I_{a_0}$

And Since $I_a = 0$

Therefore, $I_{a_0} + I_{a_1} + I_{a_2} = 0$

Or $I_{a_1} = \frac{V_f}{Z_1 + \frac{Z_2(Z_0+3Z_f)}{Z_2+Z_0+3Z_f}}$

Where, Z_0, Z_1, Z_2 is a Zero, positive, negative sequence impedance.

Using Z-parameters analysis (Digital approach)

We know $V_{k1} = V_{k2}$ (19a)

V_{k0} -V_{k1} = 3$I_{k0}Z_f$ (19b)

And $I_{k0} + I_{k1} + I_{k2} = 0$ (20)

Equations (6a and 8) are still valid. From (8, 19 and 20)

$I_{k1} = \frac{E-V_{k1}}{Z_{kk1}}$ (21a)

$I_{k2} = \frac{-V_{k2}}{Z_{kk2}} = -\frac{V_{k1}}{Z_{kk2}}$ (21b)

$I_{k0} = -\frac{V_{k0}}{Z_{kk0}} = \frac{-V_{k1}}{Z_{kk0}+3Z_f}$ (21c)

Substituting (21) into (20) we have

$-\frac{V_{k1}}{Z_{kk0}+3Z_f} + \frac{E-V_{k1}}{Z_{kk1}} - \frac{V_{k1}}{Z_{kk2}} = 0$

Or $V_{k1} = \frac{E(Z_{kk0}+3Z_f)Z_{kk2}}{Z_{kk1}(Z_{kk2}+Z_{kk0}+3Z_f)+Z_{kk2}(Z_{kk0}+3Z_f)}$ (22)

$Z_{kk1}(Z_{kk2} + Z_{kk0} + 3Z_f) + Z_{kk2}(Z_{kk0} + 3Z_f) = \Delta$ (23)

From (21)

$I_{k1} = (Z_{kk2} + Z_{kk0} + 3Z_f)$ E/Δ (24a)

I_{k2} = -E$(Z_{kk0} + 3Z_f)/\Delta$ (24b)

$I_{k0} = -EZ_{kk2}/\Delta$ (24c)

The sequence components of voltages at ith bus (i = 1, 2 … n) are

$V_{i0} = -Z_{ik0}I_{k0} = EZ_{ik0}Z_{kk2}/\Delta$ (25a)

$V_{i1} = E - Z_{ik1}I_{k1} = E\,[\Delta - Z_{ik1}(Z_{kk2}Z_{kk0} + 3Z_f)]/\Delta$ (25b)

$V_{i2} = -Z_{ik2}I_{k2} = Z_{ik2}[Z_{kk0} + 3Z_f)]\,E/\Delta$ (25c)

Test Problem

A 3-phase fault occurs at the bus 2 of the system shown in fig. below. Find (a) sequence current and voltage (b) fault current of each phases (c) fault voltage (line to neutral) of each phases at bus 3. Assume that prefault voltages at all buses are 1 p.u. Given:-

$[Z_{1-bus}]$ =

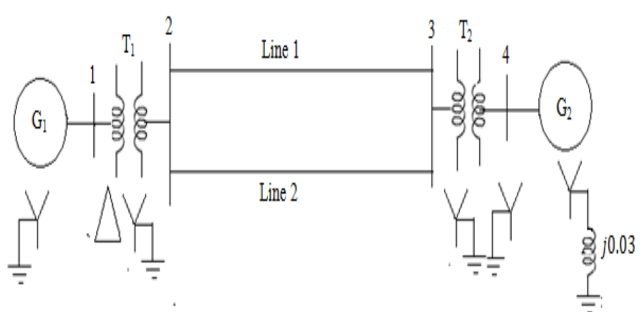
$$\begin{bmatrix} j0.1507937 & j0.1269841 & j0.1071429 & j0.0793651 \\ j0.1269841 & j0.1574603 & j0.1328571 & j0.0984127 \\ j0.1071429 & j0.1328571 & j0.1542857 & j0.1142857 \\ j0.0793651 & j0.0984127 & j0.1142857 & j0.1365079 \end{bmatrix}$$

Since all the negative sequence reactance are the same as the positive sequence reactance,

$[Z_{1-bus}] = [Z_{2-bus}]$.

and $[Z_{0-bus}]$ =

$$\begin{bmatrix} j0.05 & 0 & 0 & 0 \\ 0 & j0.0514286 & j0.03 & j0.02 \\ 0 & j0.03 & j0.105 & j0.07 \\ 0 & j0.02 & j0.07 & j0.0933333 \end{bmatrix}$$



RESULT

Using MATLAB tools, the result of the problem is

Parameters of justification	For symmetrical fault	For single line-to-ground fault	For line-to-line fault	For double line-to-ground fault
I_{a0}	0 amp.	0-j716.36 amp.	0 amp.	0+J3.8415amp.
I_{a1}	0-j1666.7 amp.	0-j716.36 amp.	0-j3.1754 amp.	0-j5.0961 amp.
I_{a2}	0 amp.	0-j716.36 amp.	j3.1754 amp.	j1.2547 amp.
I_a	0-j1666.7 amp.	0-j2149.1 amp.	0 amp.	0 amp.
Parameters of justification	For symmetrical fault	For single line-to-ground fault	For line-to-line fault	For double line-to-ground fault
I_b	(-1443.3+j833.25) amp.	0-j0.0315 amp.	(-5.4998-j0.0001) amp.	(-5.4998+j5.7620) amp.
I_c	1443.3+j833.33 amp.	0-j0.0315amp.	5.4998+j0.0001amp.	5.4998+j5.7622 amp.
V_{a0}	19.8464 KV	0-0.0819 KV	0 KV	0.1152 KV
V_{a1}	0 KV	0.6373 KV	0.4219 KV	1.0000-j0.0262 KV
V_{a2}	0 KV	-0.3627	0.4219 KV	1.0000-j0.0262

		KV		KV
V_a	19.8464 KV	24.4906 KV	0.8437 KV	2.1152-j0.0525 KV
V_b	(-9.9223-j17.1870) KV	(-27.844-j110.00) KV	-0.4219 KV	0 KV
V_c	(-9.9223+j17.1870) KV	(-27.848+j110.00) KV	-0.4219 KV	0 KV

RESULT ANALYSIS

It is evident from the result that a 3-phase fault is the most dangerous one and it has larger magnitude of current than other types of fault. Also among the unsymmetrical, line-to-line fault because of absence of zero sequence network as there is no path to ground ,it has higher magnitude of current with respect to single line-to-ground fault and double line-to-ground fault. This could be matched with theoretical equation (16) as well, where zero sequence networks is not there in denominator. The magnitude of Double line-to-ground fault lies between single line-to-ground fault and line –to-line fault i.e. less than line-to-line fault and more than single line-to-ground fault. As far as voltage is concerned line-to-line voltage has least voltage among the unsymmetrical faults.

Also, data and analysis came same when the fault occurred at bus 3 and parameters calculated at bus 2.

CONCLUSION

This paper is basically related with finding the fault that occurs in power system using digital approach and through MATLAB programming and it is concluded that the evaluation of fault is very important part of power system analysis for stable and economic operations of power system network and also because it provide data such as voltage and currents which are necessary in designing the protective schemes of power system. The calculations are done theoretically and also by MATLAB programming. Both results are found equal, so this type of digital fault calculation is very useful.

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