



# **Short Circuit Study of a Balanced 3 Phase System Using p-inverse**

A Thesis submitted to the  
Dept. of Electrical & Electronics Engineering, BRAC University  
in partial fulfillment of the requirements for the  
Bachelor of Science degree in Electrical & Electronics Engineering

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## Declaration

We to hereby declare that the thesis titled "Short Circuit Study of a Balanced 3 Phase System using p-inverse function" is submitted to the Department of Electrical & Electronics Engineering of BRAC University in partial fulfillment of the Bachelor of Science in Electrical & Electronics Engineering. This is our original work and was not submitted elsewhere for the award of any other degree or any other publications.

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Hasan MuhommodSabbir

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## *Abstract*

Power system fault analysis is the process of determining the bus voltages and line currents during the occurrence of various types of faults. Faults on power systems can be divided into three-phase balanced faults and unbalanced faults. Three types of unbalanced fault occurrence on power system transmission lines are single line to ground faults, line to line faults, and double line to ground faults. Fault studies are used to select and set the proper protective devices and switchgears. The determination of the bus voltages and line currents is very important in the fault analysis of power system. The process consists of various methods of mathematical calculation which is difficult to perform by hand. The calculation can be easily done by computer which is generated by a program developed using MATLAB. However, in the conventional short circuit study there arise an error while doing Y-bus to Z-bus inversion for a big bus system. To minimize the error, this paper provides a solution which is solved through **MATLAB**, using p-inverse methodology.

# *Chapter - 1*

## INTRODUCTION

### **1.1 Background**

This project is focusing on the development of a method for power system fault analysis using MATLAB. Power system fault analysis is the process of determining the magnitude of voltages and line currents during the occurrence of various types of faults. The magnitude of these currents depends on the internal impedance of the generators plus the impedance of the intervening circuit. It can be of the order of tens of thousands of amperes. Faults on power systems can be divided into three-phase balanced faults and unbalanced faults. Three types of unbalanced fault occurrence on power system transmission lines are single line-to-ground faults, line-to-line faults, and double line-to-ground faults. The magnitude of the fault current must be accurately calculated in order that mechanical and thermal stresses on equipment may be estimated. Fault studies are used to select and set the proper protective devices and switchgears.

The determination of the bus voltages and line currents is very important in the fault analysis of power system. The process consists of various methods of mathematical calculation which includes loads of formula and matrix approach to determine the magnitude of the voltage and current. The calculation may form a large rows and columns of matrix depending on the number of busses. The calculation is possible when dealing with small number of busses. However, it is difficult to perform by hand when dealing with large number of busses. We will discuss the method of analysis in the methodology.

Hence, the development of this project will ease user to perform the calculations of fault analysis despite encountering large number of buses with less errors. The calculation can be easily done by computer which is generated by a program developed using MATLAB. The program will simulate the input data keyed in by the user.

## **1.2 Short circuit analyses**

Short Circuit analysis is required to ensure the existing and new equipment ratings are sufficient at each point in the electrical system. A Short Circuit Analysis will help to ensure that equipment are protected by establishing proper interrupting ratings of protective devices (e.g. circuit breaker and fuses). If an electrical fault exceeds the interrupting rating of the protective device, the consequences can be devastating. It can be a serious threat to human life and is capable of causing injury, extensive equipment damage, and costly. On large systems, short circuit analysis is required to determine both the switchgear ratings and the relay settings. No substation equipment can be installed without knowledge of the complete short circuit values for the entire power distribution system. The short circuit calculations must be maintained and periodically updated to protect the equipment and the lives. It is not safe to assume that new equipment is properly rated.



## **1.2.1 Benefits of a Short Circuit Analysis**

Performing a Short Circuit Study provides the following benefits:

- Reduces the risk a facility could face and help avoid catastrophic losses.
- Increases the safety and reliability of the power system and related equipment.
- Evaluates the application of protective devices and equipment.
- Identifies problem areas in the system.
- Identifies recommended solutions to existing problems.

## **1.3 Literature Review-Power Flow**

Before entering to the fault analysis first, we need to keep in mind the power-flow study, or load-flow study, which is a numerical analysis of the flow of electric power in an interconnected system. A power-flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various aspects of AC power parameters, such as voltages, voltage angles, real power and reactive power. It analyzes the power systems in normal steady-state operation. Power-flow or load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. Commercial power systems are usually too complex to allow for hand solution of the power flow whereas special

purpose network analyzers were built digital computers replaced the analog methods with numerical solutions.

In addition to a power-flow study, computer programs perform related calculations such as **short-circuit fault analysis**, stability studies, unit commitment and economic dispatch. In particular, some programs use linear programming to find the optimal power flow, the conditions which give the lowest cost per kilowatt hour delivered.

### **1.3.1 Power-flow problem formulation**

The objective of a power-flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions. Once this information is known, real and reactive power flow on each branch as well as generator reactive power output can be analytically determined.

The solution to the power-flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus. A bus without any generators connected to it is called a **Load Bus**. With one exception, a bus with at least one generator connected to it is called a **Generator Bus**. The exception is one arbitrarily selected bus that has a generator. This bus is referred to as the **Slack Bus**.

There are several methods for solving the power flow problem. They are as follows-

### 1.3.1.1 Newton–Raphson solution method

There are several different methods of solving the resulting nonlinear system of equations. The most popular is known as the Newton–Raphson method. This method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses). Next, a Taylor Series is written, with the higher order terms ignored, for each of the power balance equations included in the system of equations. The result is a linear system of equations that can be expressed as:

$$\begin{bmatrix} \Delta\theta \\ \Delta|V| \end{bmatrix} = -J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

where  $\Delta P$  and  $\Delta Q$  are called the mismatch equations:

$$\Delta P_i = -P_i + \sum_{k=1}^N |V_i||V_k|(G_{ik} \cos \theta_{ik} + B_{ik} \sin \theta_{ik})$$

$$\Delta Q_i = -Q_i + \sum_{k=1}^N |V_i||V_k|(G_{ik} \sin \theta_{ik} - B_{ik} \cos \theta_{ik})$$

and  $J$  is a matrix of partial derivatives known as a Jacobian:

$$J = \begin{bmatrix} \frac{\partial \Delta P}{\partial \theta} & \frac{\partial \Delta P}{\partial |V|} \\ \frac{\partial \Delta Q}{\partial \theta} & \frac{\partial \Delta Q}{\partial |V|} \end{bmatrix}$$

The linearized system of equations is solved to determine the next guess ( $m + 1$ ) of voltage magnitude and angles based on:

$$\theta^{m+1} = \theta^m + \Delta\theta$$

$$|V|^{m+1} = |V|^m + \Delta|V|$$

The process continues until a stopping condition is met.

### **1.3.1.2 Gauss–Seidel method**

This is the earliest devised method. It shows slower rates of convergence compared to other iterative methods, but it uses very little memory and does not need to solve a matrix system. In numerical linear algebra, the Gauss–Seidel method, also known as the Liebmann method or the method of successive displacement, is an iterative method used to solve a linear system of equations.

The Gauss–Seidel method is an iterative technique for solving a square system of  $n$  linear equations with unknown  $\mathbf{x}$ :

$$A\mathbf{x} = \mathbf{b}.$$

It is defined by the iteration

$$L_*\mathbf{x}^{(k+1)} = \mathbf{b} - U\mathbf{x}^{(k)},$$

where the matrix  $A$  is decomposed into a lower triangular component  $L_*$ , and a strictly upper triangular component  $U$ :  $A = L_* + U$ . In more detail, write out  $A$ ,  $\mathbf{x}$  and  $\mathbf{b}$  in their components:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad \mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}, \quad \mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}.$$

Then the decomposition of  $A$  into its lower triangular component and its strictly upper triangular component is given by:

$$A = L_* + U \quad \text{where} \quad L_* = \begin{bmatrix} a_{11} & 0 & \cdots & 0 \\ a_{21} & a_{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad U = \begin{bmatrix} 0 & a_{12} & \cdots & a_{1n} \\ 0 & 0 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 \end{bmatrix}.$$

The system of linear equations may be rewritten as:

$$L_* \mathbf{x} = \mathbf{b} - U \mathbf{x}$$

The Gauss–Seidel method now solves the left hand side of this expression for  $\mathbf{x}$ , using previous value for  $\mathbf{x}$  on the right hand side. Analytically, this may be written as:

$$\mathbf{x}^{(k+1)} = L_*^{-1}(\mathbf{b} - U \mathbf{x}^{(k)}).$$

However, by taking advantage of the triangular form of  $L_*$ , the elements of  $\mathbf{x}^{(k+1)}$  can be computed sequentially using forward substitution:

$$x_i^{(k+1)} = \frac{1}{a_{ii}} \left( b_i - \sum_{j<i} a_{ij} x_j^{(k+1)} - \sum_{j>i} a_{ij} x_j^{(k)} \right), \quad i, j = 1, 2, \dots, n.$$

The procedure is generally continued until the changes made by an iteration.

### **1.3.1.3 Fast-decoupled-load-flow method**

This is a variation on Newton-Raphson that develops the approximate decoupling of active and reactive flows in well-behaved power networks, and additionally fixes the value of the Jacobian during the iteration in order to avoid costly matrix decompositions. Also referred to as "fixed-slope, decoupled Newton Raphson". Within the algorithm, the Jacobian matrix is inverted only once, and there are three assumptions. *Firstly*, the conductance between the buses is zero. *Secondly*, the magnitude of the bus voltage is one per unit. *Thirdly*, the sine of phases between buses is zero. Fast decoupled load flow can return the answer within seconds whereas the Newton Raphson method takes much longer. This is useful for real-time management of power grids.

### **1.3.1.4 Holomorphic embedding load flow method**

A recently developed method based on advanced techniques of complex analysis. It is direct and guarantees the calculation of the correct (operative) branch, out of the multiple solutions present in the power flow equations.

∅ A rough outline of solution of the power-flow problem is:

1. Make an initial guess of all unknown voltage magnitudes and angles. It is common to use a "flat start" in which all voltage angles are set to zero and all voltage magnitudes are set to 1.0 p.u.
2. Solve the power balance equations using the most recent voltage angle and magnitude values.
3. Linearize the system around the most recent voltage angle and magnitude values
4. Solve for the change in voltage angle and magnitude
5. Update the voltage magnitude and angles
6. Check the stopping conditions, if met then terminate, else go to step 2.

## 1.4 Literature Review of Fault

In an electric power system, a **fault** is unusual electric current. A short circuit is also considered as a fault in which current bypasses the normal load. An open-circuit fault occurs if a circuit is interrupted by some failure. In three-phase systems, a fault may involve one or more phases and ground, or may occur only between phases. In a "ground fault" or "earth fault", charge flows into the earth. The prospective short circuit current of a fault can be calculated for power systems. In power systems, protective devices detect fault conditions and operate circuit breakers and other devices to limit the loss of service due to a failure.

## 1.4.1 Types of Faults

### 1.4.1.1 Transient fault

A **transient fault** is a fault that is no longer present if power is disconnected for a short time and then restored. Many faults in overhead power lines are transient in nature. When a fault occurs, equipment used for power system protection operate to isolate the area of the fault. A transient fault will then clear and the power-line can be returned to service. Typical examples of transient faults include:

- Momentary tree contact
- Bird or other animal contact
- Lightning strike
- Conductor clashing

### 1.4.1.2 Persistent fault

A **persistent fault** does not disappear when power is disconnected. Faults in underground power cables are most often persistent due to mechanical damage to the cable, but are sometimes transient in nature due to lightning.



### 1.4.1.3 Symmetric fault

A **symmetric** or **balanced fault** affects each of the three phases equally. In transmission line faults, roughly 5% are symmetric. This is in contrast to an asymmetrical fault, where the three phases are not affected equally.

### 1.4.1.4 Asymmetric fault

An **asymmetric** or **unbalanced fault** does not affect each of the three phases equally. Common types of asymmetric faults, and their causes:

*line-to-line* - a short circuit between lines, caused by ionization of air, or when lines come into physical contact, for example due to a broken insulator.

*line-to-ground* - a short circuit between one line and ground, very often caused by physical contact, for example due to lightning or other storm damage

*double line-to-ground* - two lines come into contact with the ground also commonly due to storm damage.

### 1.4.1.5 Bolted fault

One extreme is where the fault has zero impedance, giving the maximum prospective short-circuit current. Notionally, all the conductors are considered connected to ground as if by a metallic conductor; this is called a "bolted fault". It would be unusual in a well-designed power

system to have a metallic short circuit to ground but such faults can occur by mischance. In one type of transmission line protection, a "bolted fault" is deliberately introduced to speed up operation of protective devices.

#### **1.4.1.6 Realistic faults**

Realistically, the resistance in a fault can be from close to zero to fairly high. A large amount of power may be consumed in the fault, compared with the zero-impedance case where the power is zero. Also, arcs are highly non-linear, so a simple resistance is not a good model. All possible cases need to be considered for a good analysis.

#### **1.4.1.7 Arcing fault**

Where the system voltage is high enough, an electric arc may form between power system conductors and ground. Such an arc can have a relatively high impedance and can be difficult to detect by simple over current protection. For example, an arc of several hundred amperes on a circuit normally carrying a thousand amperes may not trip over current circuit breakers but can do enormous damage to bus bars or cables before it becomes a complete short circuit. Utility, industrial, and commercial power systems have additional protection devices to detect relatively small but undesired currents escaping to ground. In residential wiring, electrical regulations may now require Arc-fault circuit interrupters on building wiring circuits, to detect small arcs before they cause damage or a fire.

## 1.4.2 Transmission line fault

In the transmission line, the common types of fault occurrence are:

- i. Balanced three-phase fault
- ii. Single line-to-ground fault
- iii. Line-to-line fault
- iv. Double line-to-ground fault

Figure 1.4.2 shows a graphical view of fault respectively.

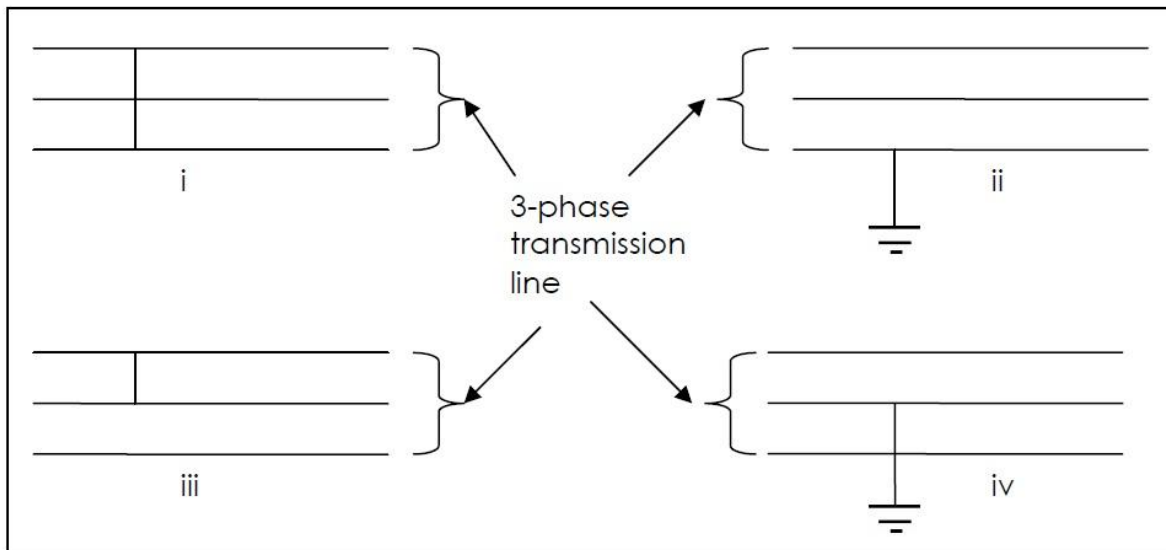


Figure 1.4.2 Four different types of transmission fault

In theory, solving transmission lines fault problems requires a circuit analysis approach and mathematical skills. Terms like Thevenin theorem, mesh analysis, nodal analysis or any other method learnt in the basic circuit analysis should be considered while mathematical skills

required for forming a Bus Impedance Matrix (Zbus) in order to put them in matrix outline. In general, the analysis of any fault condition is performed in the following order:

i. Represent the given power system by its positive, negative and zero-sequence networks. This representation requires the calculation of per unit (p.u.) impedances for generators, transformers, lines, cables and other elements of the power system.

ii. Reduce each of the sequence networks to its simplest form. The equivalent positive, negative and zero-sequence networks are represented as a series and series-parallel combinations of the p.u. impedances. These are replaced by the single equivalent impedance for each sequence network. It may also involve the use of the delta-star or star-delta transformations.

iii. Use the appropriate symmetrical-component equations to find the phase sequence components of the current in fault under the particular short-circuit condition.

iv. Determine the required p.u. phase-current values at the point of fault.

v. Finally, calculate the actual values of the phase-currents by multiplying obtained p.u. values by the base current at the point of fault.

The procedure outlined above provides a complete analysis of the given power system for the specified fault condition and can be easily implemented in computer aided tutorials.

In a poly phase system, a fault may affect all phases equally which is known as "symmetrical fault". If only some phases are affected, the situation is known as "asymmetrical fault." In real power engineering world asymmetrical fault becomes more complicated to analyze due to the simplifying assumption of equal current magnitude in all phases which is not longer applicable.

The analysis of this type of fault is often simplified by using methods such as symmetrical components.

### **1.5 Objectives of Project**

The objective of this project is to study the common fault type which is balance fault of the transmission line in the power system. Secondly is to perform the analysis and obtain the results from simulation on those types of fault using MATLAB. Lastly is to develop a toolbox for power system fault analysis for educational and training purposes.

## *Chapter - 2*

# Fault Calculation

### 2.1 Balanced 3-phase short circuit Analysis

#### Theory

During a three-phase fault, the impedance of a generator is a time varying quantity. It is  $X_d''$  in the sub-transient period (one to four cycles),  $X_d'$  in the transient period (about 30 cycles), and the synchronous reactance  $X_d$  after that. The sub-transient currents can be very large due to the small size of  $X_d''$ . Due to symmetry, the three phase currents during a symmetrical fault can be solved using ordinary circuit theory. In this case, Thevenin's theorem is being used for simple and small power circuits only to analyze the fault. If the fault has zero impedance to ground, it is called a **solid fault** or **bolted fault** (all three lines shorted to ground with zero impedance). However, it is impractical for a real large power system. A systematic method is presented in this section which applies to power systems of any size. The method can also be programmed on a computer shows in figure 2.1 (a).

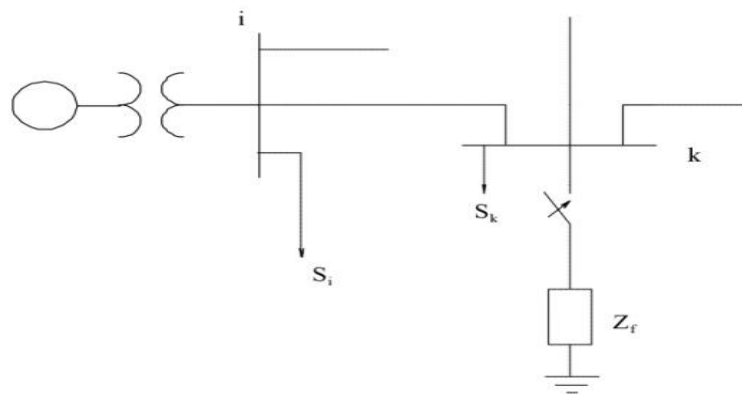


Figure2.1 (a) Single line diagram of a three bus system

power flow solution and represented by the vector

$$V_{bus}(0) = \begin{bmatrix} V_1(0) \\ \vdots \\ V_k(0) \\ \vdots \\ V_n(0) \end{bmatrix} \quad (1.1)$$

Generally, the short circuit currents are so large compared to the steady state loads, the loads may be neglected. However, the loads can be represented as impedances using the above voltages for example, the load  $S_i$  may be approximated by the impedance

$$Z_i = \frac{|V_i(0)|^2}{S_i^*} \quad (1.2)$$

The changes in network voltage due to the fault are found from the system with all voltages shorted to ground and the pre-fault voltage  $V_k(0)$  applied as shown in the figure 2.1 (b) below:

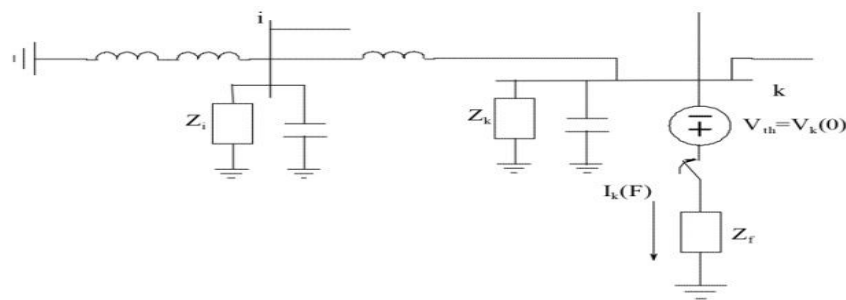


Figure 2.1 (b) shows the changes in network voltage

Note the capacitors for the pi equivalent of line  $ik$ . Also note the loads are replaced by the approximation of impedances. The voltage source at  $i$  is grounded and its impedance remains as shown above. The column vector represents the bus voltage changes caused by the fault in this circuit

$$\Delta V_{bus} = \begin{bmatrix} \Delta V_1 \\ \vdots \\ \Delta V_k \\ \vdots \\ \Delta V_n \end{bmatrix} \quad (1.3)$$

From Thevenin's theorem the voltages during the fault are found from

$$V_{bus}(F) = V_{bus}(0) + \Delta V_{bus} \quad (1.4)$$

We also know for the nodal equations that

$$I_{bus} = Y_{bus} V_{bus} \quad (1.5)$$

where  $I_{bus}$  is the bus current entering the bus and  $Y_{bus}$  is the bus admittance matrix. The diagonal elements of each bus is the sum of the admittances connected to that bus, i.e.

$$Y_{ii} = \sum_{j=0}^m y_{ij} \quad j \neq i \quad (1.6)$$

The off-diagonal element is equal to the negative of the admittance between the nodes, i.e.



$$Y_{ij} = Y_{ji} = -y_{ij} \quad (1.7)$$

where  $y_{ij}$  is the actual admittance between nodes  $i$  and  $j$ . For the Thevenin circuit above, the nodal equations are

$$\begin{bmatrix} 0 \\ \vdots \\ -I_k(F) \\ \vdots \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{11} & \cdots & Y_{1k} & \cdots & Y_{1n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ Y_{k1} & \cdots & Y_{kk} & \cdots & Y_{kn} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ Y_{n1} & \cdots & Y_{nk} & \cdots & Y_{nn} \end{bmatrix} \begin{bmatrix} \Delta V_1 \\ \vdots \\ \Delta V_k \\ \vdots \\ \Delta V_n \end{bmatrix} \quad (1.8)$$

Note that the minus sign is due to the fact the fault current is shown leaving node  $k$ . The above matrix equation can be written as

$$I_{bus}(F) = Y_{bus} \Delta V_{bus} \quad (1.9)$$

which can be solved for the voltage change thus

$$\Delta V_{bus} = Z_{bus} I_{bus}(F) \quad (1.10)$$

where  $Z_{bus} = Y_{bus}^{-1}$  is known as the *bus impedance matrix*. Using (1.10) in (1.4) we have:

$$V_{bus}(F) = V_{bus}(0) + Z_{bus} I_{bus}(F) \quad (1.11)$$

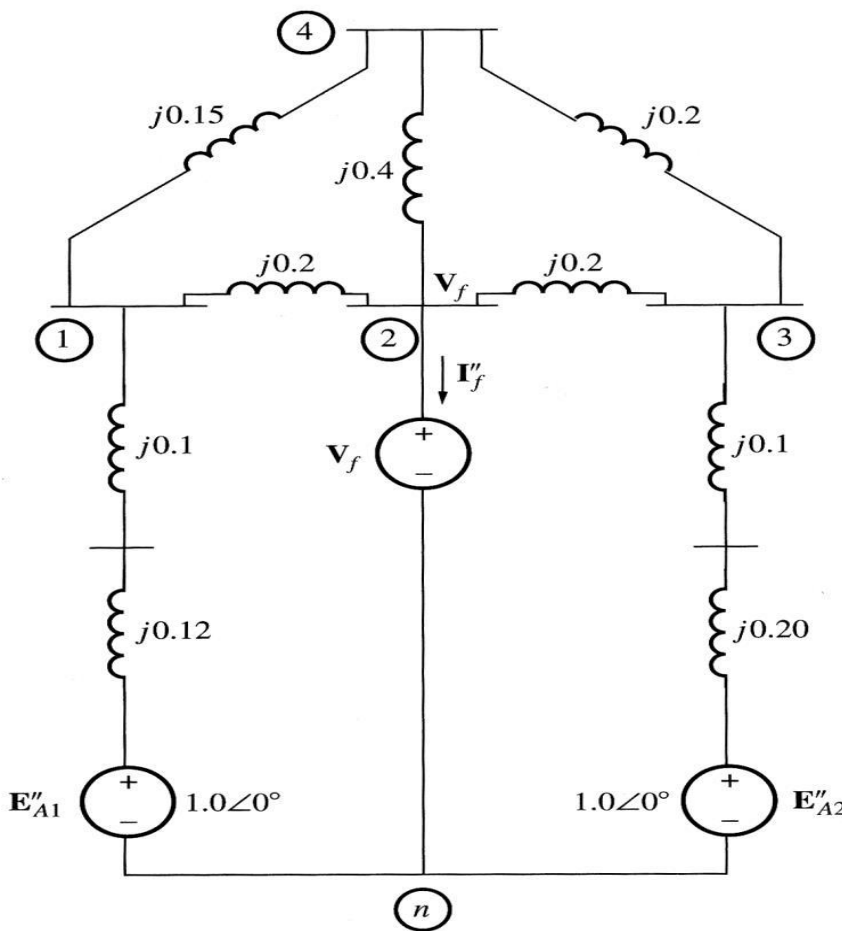
Which can be expanded into matrix form:

$$\begin{bmatrix} V_1(F) \\ \vdots \\ V_k(F) \\ \vdots \\ V_n(F) \end{bmatrix} = \begin{bmatrix} V_1(0) \\ \vdots \\ V_k(0) \\ \vdots \\ V_n(0) \end{bmatrix} + \begin{bmatrix} Z_{11} & \cdots & Z_{1k} & \cdots & Z_{1n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ Z_{k1} & \cdots & Z_{kk} & \cdots & Z_{kn} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ Z_{n1} & \cdots & Z_{nk} & \cdots & Z_{nn} \end{bmatrix} \begin{bmatrix} 0 \\ \vdots \\ -I_k(F) \\ \vdots \\ 0 \end{bmatrix} \quad (1.12)$$

### 2.1.1 Hand Calculation for 4 bus system

Before the fault, the voltage on bus 2 was  $V_f$ . After introducing a voltage source of value  $V_f$  between bus 2 and the neutral, nothing will change in the system. Since the system operates normally before the fault, there will be no current  $I_f''$  through that source.

Let, create a short circuit on bus 2, which forces the voltage on bus 2 to 0. This is equivalent to



inserting an additional voltage source of value  $-V_f$  in series with the existing voltage source. This later will make the total voltage at bus 2 become 0. With this additional voltage source, there will be a fault current  $I_f''$ , which is entirely due to the insertion of the new voltage source to the system. Therefore, we can

Figure 2.1.1 (a) shows creating a short circuit on bus 2

use superposition to analyze the effects of the new voltage source on the system. The resulting current  $\mathbf{I}_f''$  will be the current for the entire power system, since the other sources in the system produced a net zero current.

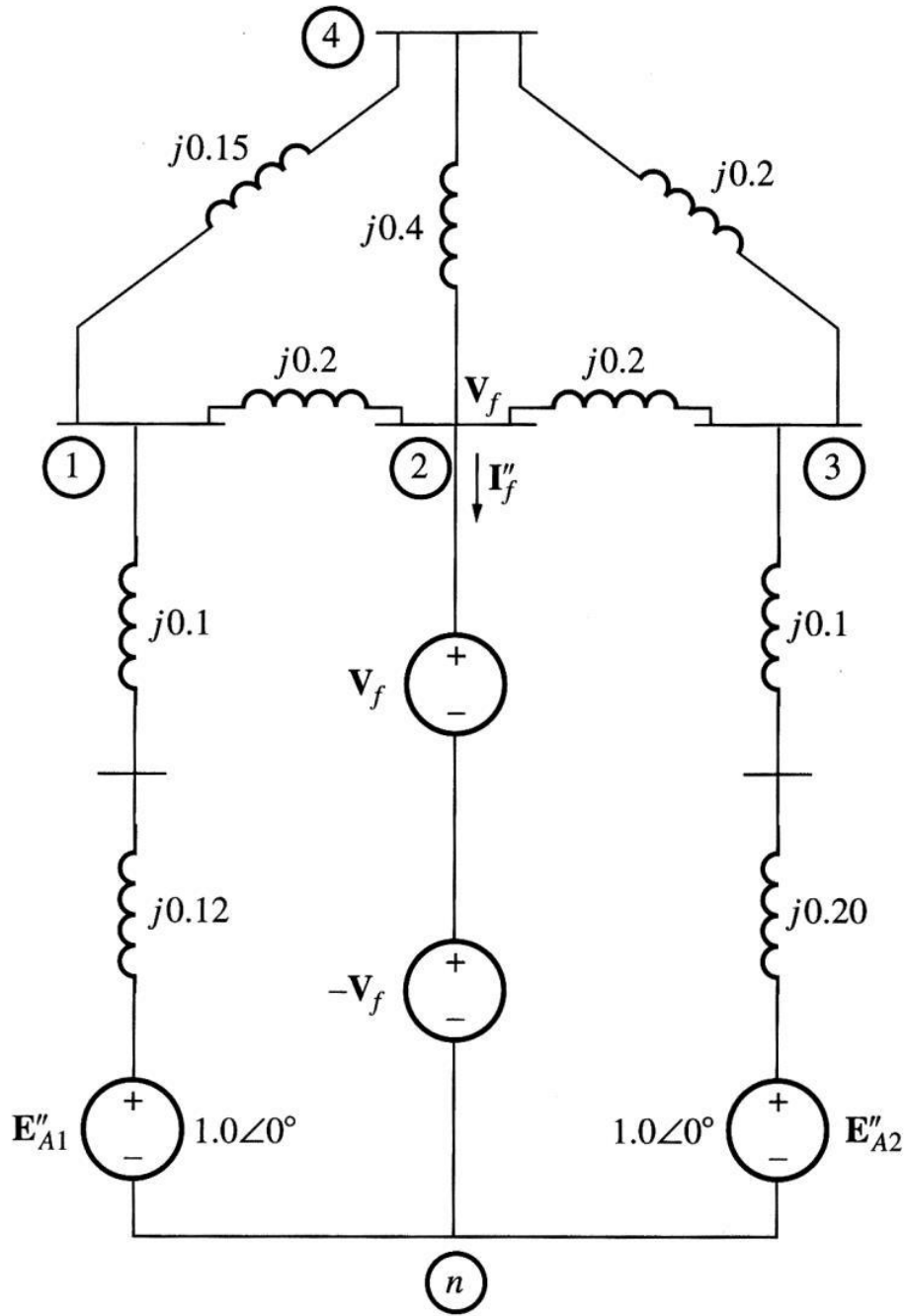


Figure 2.1.1 (b) shows inserting an additional  $-V_f$  voltage source

If all voltage sources except  $-V_f$  are set to zero and shorten the system, the system will appear as shown in Figure 2.1.1 (c):

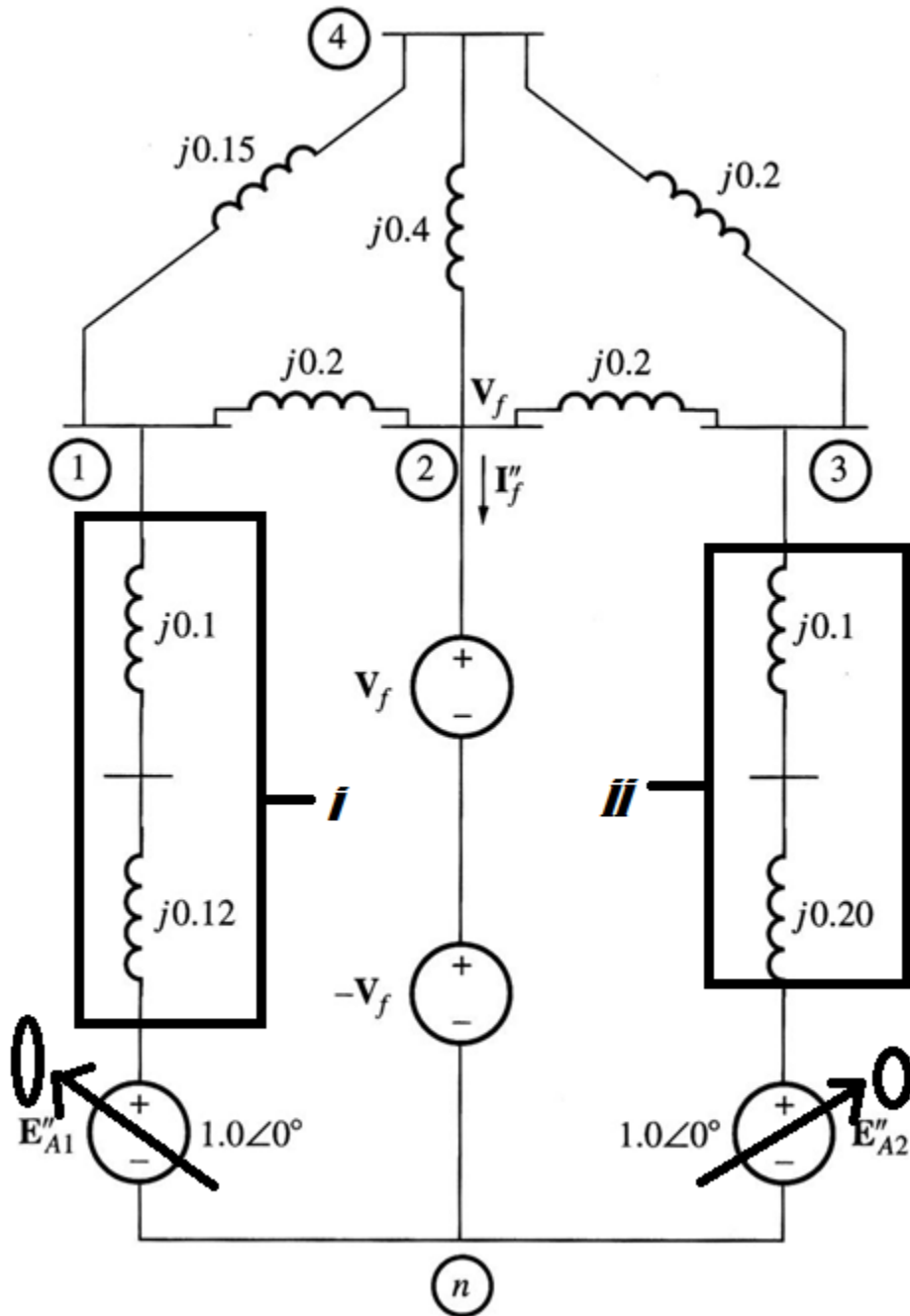


Figure 2.1.1 (c) shows all voltage sources except  $-V_f$  are set to zero

$$i = j 0.1 + j 0.12 = j 0.22$$

$$ii = j 0.1 + j 0.20 = j 0.30$$

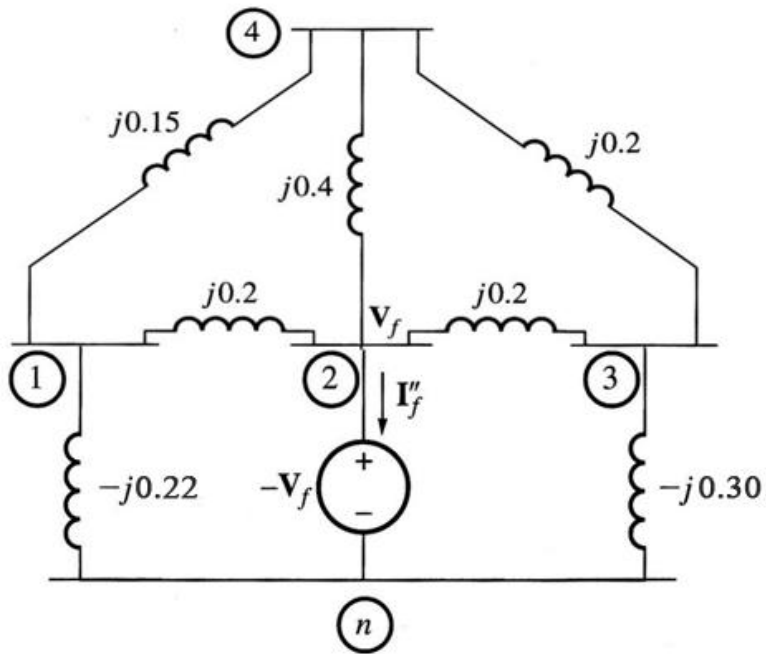


Figure 2.1.1 (d) shows the sum up of all impedance

The *impedances* are converted to *admittances*; the power system appears as shown Figure 2.1.1 (e), 2.1.1 (f):

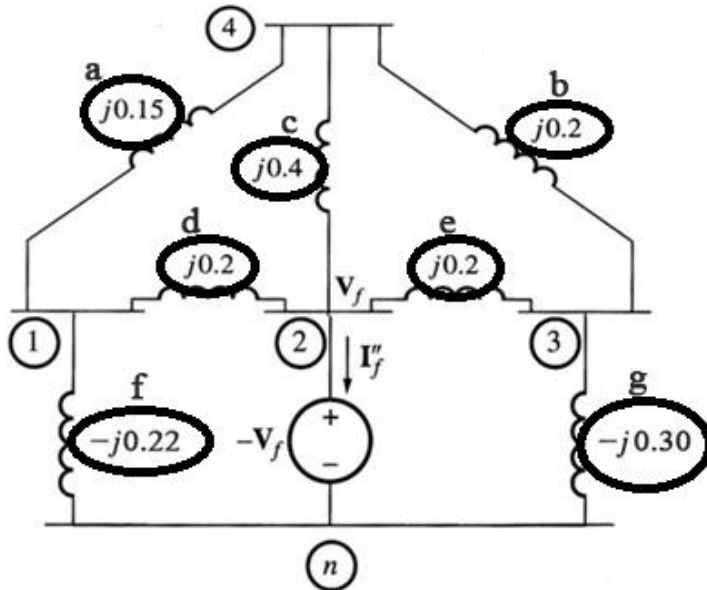


Figure 2.1.1 (e) shows the impedances are converted to admittances

$$\mathbf{a = 1 / j0.15 = -j 6.667}$$

$$\mathbf{b = 1 / j0.2 = -j 5.0}$$

$$\mathbf{c = 1 / j0.4 = -j 2.50}$$

$$\mathbf{d = 1 / j0.2 = -j 5.0}$$

$$\mathbf{e = 1 / j0.2 = -j 5.0}$$

$$\mathbf{f = 1 / j0.22 = -j 4.545}$$

$$\mathbf{g = 1 / j0.30 = -j 3.333}$$

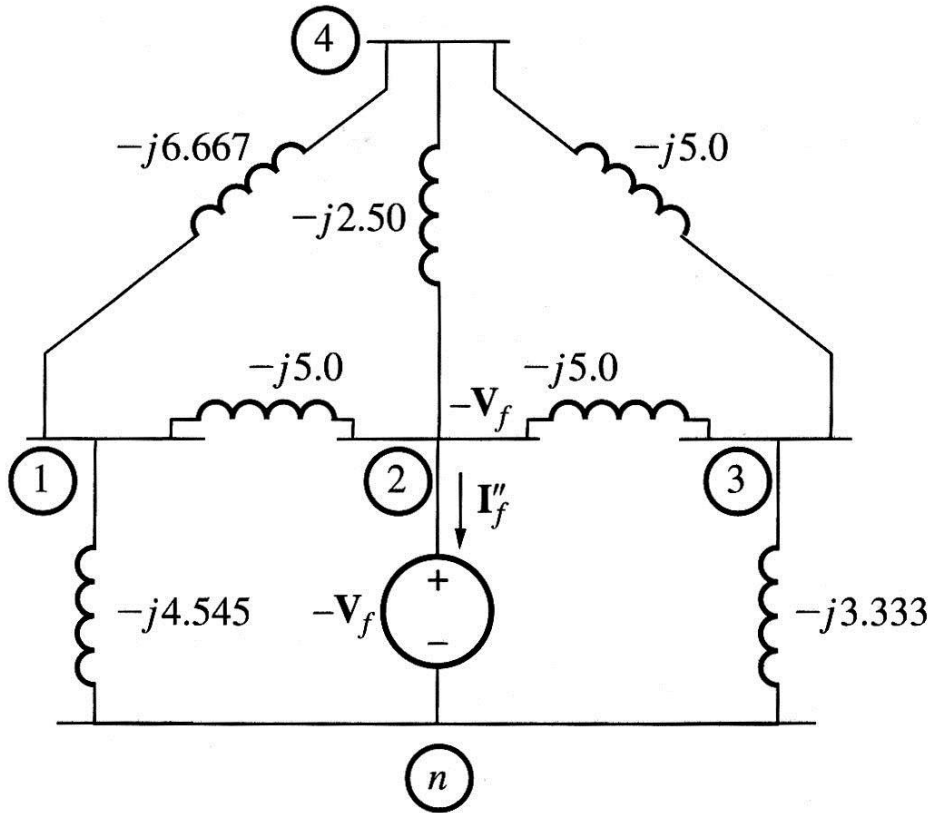


Figure 2.1.1 (f) shows admittance conversion result

The nodal equation describing this power system is

$$Y_{\text{bus}} \mathbf{V} = \mathbf{I}$$

With all other voltage sources set to zero, the voltage at bus 2 is  $-\mathbf{V}_f$ , and the current entering the bus 2 is  $-\mathbf{I}_f''$ . Therefore, the nodal equation becomes

$$\begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} \Delta V_1 \\ -V_f \\ \Delta V_3 \\ \Delta V_4 \end{bmatrix} = \begin{bmatrix} 0 \\ -I_f'' \\ 0 \\ 0 \end{bmatrix}$$

$Y_{11}$  = The Connection between Bus 1 and Bus 1

$Y_{12}$  = The Connection between Bus 1 and Bus 2

$Y_{13}$  = The Connection between Bus 1 and Bus 3

$Y_{14}$  = The Connection between Bus 1 and Bus 4

$Y_{21}$  = The Connection between Bus 2 and Bus 1

$Y_{22}$  = The Connection between Bus 2 and Bus 2

$Y_{23}$  = The Connection between Bus 2 and Bus 3

$Y_{24}$  = The Connection between Bus 2 and Bus 4

$Y_{31}$  = The Connection between Bus 3 and Bus 1

$Y_{32}$  = The Connection between Bus 3 and Bus 2



$Y_{33}$  = The Connection between Bus 3 and Bus 3

$Y_{34}$  = The Connection between Bus 3 and Bus 4

$Y_{41}$  = The Connection between Bus 4 and Bus 1

$Y_{42}$  = The Connection between Bus 4 and Bus 2

$Y_{43}$  = The Connection between Bus 4 and Bus 3

$Y_{44}$  = The Connection between Bus 4 and Bus 4

Where  $\Delta V_1$ ,  $\Delta V_2$ , and  $\Delta V_4$  are the changes in the voltages at those busses due to the current  $-I_f''$  injected at bus 2 by the fault.

The solution is found as

$$\mathbf{V} = \mathbf{Y}_{\text{bus}}^{-1} \mathbf{I} = \mathbf{Z}_{\text{bus}} \mathbf{I}$$

Which in the case considered, is

$$\begin{bmatrix} \Delta V_1 \\ -V_f \\ \Delta V_3 \\ \Delta V_4 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} \end{bmatrix} \begin{bmatrix} 0 \\ -I_f'' \\ 0 \\ 0 \end{bmatrix}$$

Where  $\mathbf{Z}_{\text{bus}} = \mathbf{Y}_{\text{bus}}^{-1}$ . Since only bus 2 has current injected at it, the system reduces to

$$\begin{aligned}\Delta V_1 &= -Z_{12}I_f'' \\ -V_f &= -Z_{22}I_f'' \\ \Delta V_3 &= -Z_{32}I_f'' \\ \Delta V_4 &= -Z_{42}I_f''\end{aligned}$$

Therefore, the fault current at bus 2 is just the prefault voltage  $V_f$  at bus 2 divided by  $Z_{22}$ , the driving point impedance at bus 2.

$$I_f'' = \frac{V_f}{Z_{22}}$$

The voltage differences at each of the nodes due to the fault current can be calculated by substitution:

$$\begin{aligned}\Delta V_1 &= -Z_{12}I_f'' = -\frac{Z_{12}}{Z_{22}}V_f \\ \Delta V_2 &= -V_f = -V_f \\ \Delta V_3 &= -Z_{32}I_f'' = -\frac{Z_{32}}{Z_{22}}V_f \\ \Delta V_4 &= -Z_{42}I_f'' = -\frac{Z_{42}}{Z_{22}}V_f\end{aligned}$$

Assuming that the power system was running at no load conditions before the fault, it is easy to calculate the voltages at every bus during the fault. At no load, the voltage will be the same on every bus in the power system, so the voltage on every bus in the system is  $V_f$ . The change in voltage on every bus caused by the fault current  $-I_f''$

so the total voltage during the fault is

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} V_f \\ V_f \\ V_f \\ V_f \end{bmatrix} + \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \Delta V_3 \\ \Delta V_4 \end{bmatrix} = \begin{bmatrix} V_f \\ V_f \\ V_f \\ V_f \end{bmatrix} + \begin{bmatrix} -\frac{Z_{12}}{Z_{22}} V_f \\ -V_f \\ -\frac{Z_{32}}{Z_{22}} V_f \\ -\frac{Z_{42}}{Z_{22}} V_f \end{bmatrix} = \begin{bmatrix} 1 - \frac{Z_{12}}{Z_{22}} \\ 0 \\ 1 - \frac{Z_{32}}{Z_{22}} \\ 1 - \frac{Z_{42}}{Z_{22}} \end{bmatrix} V_f$$

For this system, the bus admittance matrix is constructed as follows:

$$Y_{bus} = \begin{bmatrix} -j16.212 & j5.0 & 0 & j6.667 \\ j5.0 & -j12.5 & j5.0 & j2.5 \\ 0 & j5.0 & -j13.333 & j5.0 \\ j6.667 & j2.5 & j5.0 & -j14.167 \end{bmatrix}$$

$$Y_{11} = Y_{10} + Y_{12} + Y_{13} + Y_{14} = -j 4.545 - j 5.0 - 0 - j 6.667 = -j 16.212$$

$$Y_{12} = -Y_{12} = j 5.0$$

$$Y_{13} = 0$$

$$Y_{14} = -Y_{14} = j 6.667$$

$$Y_{21} = -Y_{21} = j 5.0$$

$$Y_{22} = Y_{20} + Y_{21} + Y_{23} + Y_{24} = 0 - j 5.0 - j 5.0 - 2.50 = -j 12.5$$

$$Y_{23} = -Y_{23} = j 5.0$$

$$Y_{24} = -Y_{24} = j 2.5$$

$$Y_{31} = 0$$

$$Y_{32} = -Y_{32} = j 5.0$$

$$Y_{33} = Y_{30} + Y_{31} + Y_{32} + Y_{34} = -j 3.333 - 0 - j 5.0 - j 5.0 = -j 13.333$$

$$Y_{34} = -Y_{34} = j 5.0$$

$$Y_{41} = -Y_{41} = j 6.667$$

$$Y_{42} = -Y_{42} = j 2.5$$

$$Y_{43} = -Y_{43} = j 5.0$$

$$Y_{44} = Y_{41} + Y_{42} + Y_{43} + Y_{40} = -j 6.667 - j 2.50 - j 5.0 = -j 14.167$$

The bus impedance matrix calculated using Matlab as the inverse of  $Y_{bus}$  is

$$Z_{bus} = \begin{bmatrix} 0 + j0.1515 & 0 + j0.1232 & 0 + j0.0934 & 0 + j0.1260 \\ 0 + j0.1232 & 0 + j0.2104 & 0 + j0.1321 & 0 + j0.1417 \\ 0 + j0.0934 & 0 + j0.1321 & 0 + j0.1726 & 0 + j0.1282 \\ 0 + j0.1260 & 0 + j0.1417 & 0 + j0.1282 & 0 + j0.2001 \end{bmatrix}$$

## 2.1.2 Result of Hand Calculation

For the given power system, the no-load voltage at every bus is equal to the pre-fault voltage at the bus that is

$$V_f = 1.00 \angle 0^\circ \text{ pu}$$

The current at the faulted bus is computed as

$$I''_{f,2} = \frac{V_f}{Z_{22}} = \frac{1.00 \angle 0^\circ}{j0.2104} = 4.753 \angle -90^\circ \text{ pu}$$

The voltage at bus  $j$  during a symmetrical 3 phase fault at bus  $I$  can be found as

$$V_1 = \left(1 - \frac{Z_{12}}{Z_{22}}\right) V_f = \left(1 - \frac{j0.1232}{j0.2104}\right) \cdot 1.0 \angle 0^\circ = 0.414 \angle 0^\circ \text{ pu}$$

$$V_2 = 0.0 \angle 0^\circ \text{ pu}$$

$$V_3 = \left(1 - \frac{Z_{32}}{Z_{22}}\right) V_f = \left(1 - \frac{j0.1321}{j0.2104}\right) \cdot 1.0 \angle 0^\circ = 0.372 \angle 0^\circ \text{ pu}$$

$$V_4 = \left(1 - \frac{Z_{42}}{Z_{22}}\right) V_f = \left(1 - \frac{j0.1417}{j0.2104}\right) \cdot 1.0 \angle 0^\circ = 0.327 \angle 0^\circ \text{ pu}$$

In this section we have implemented 3-phase balanced short circuit analysis using pinv() method. And we will compare our result with traditional hand calculation method discussed in chapter 2.1.

## 2.2 Matlab Implementation

### 2.2.1 Data format

In this paper we followed IEEE line data format for our matlab program where we have considered first four columns. in below IEEE data sample is given

From bus	To Bus	Resistance R(pu)	Reactance X (pu)	.....	
1	2	00.00	0.023		

**Table:** IEEE Line data format

### **2.2.2 Assumptions**

In This proposed method we have made some assumption .We neglected resistance from line data as it has minimum effect and we used pre fault voltage as 1 per unit for calculation case.

The following assumptions are also made:

1. Shunt capacitances are neglected and the system is considered on no-load.
2. All generators are running at their rated voltage and rated frequency with their emfs in phase

## 2.2.3 Major functions

To solve this problem we have created as one main class and 3 functions

- main.m
- BalancedFaultAnalysis.m
- buildYbus.m
- complexRuseltValue

### 2.2.3.1 main.m

Our main program is main.m where `lineData` will be stored. In `main.m` class first it calculates [1] maximum number of buses in the network. Here we assume the pre fault voltage ( $v_0$ ) [2] at each buses as 1 per unit (pu) for calculation purpose. It can be taken from user or can be taken from any power flow analysis prompt a GUI for take two inputs. First one is fault bus number (`fbusNo`) and other one is fault Impedance `zf`. After taking inputs it convert the taken value string to number and call our function `BalancedFaultAnalysis()`.

```
lineData=[
0 1 0 0.22
0 3 0 0.30
1 2 0 0.2
1 4 0 0.15
2 3 0 0.2
2 4 0 0.4
3 4 0 0.2
];

%1
NumberofBuses = max(max (lineData(:,1)),max(lineData(:,2)));

fprintf('You have %d busse in your Network ',NumberofBuses);
%2
```



```

preFaultVoltage=ones (NumberofBuses,1);
% [~,~,~,~,~,Ybus]=buildYbus(lineData);

%GUI INPUT

prompt={'Enter your The Fault Bus No:','Enter fault impedance
(R+j*X) Zero for Bolted:'};
% Create all your text fields with the questions specified by
the variable prompt.
title='3-Phase Balanced Short circuit Analysis ';
% The main title of your input dialog interface.
answer=inputdlg(prompt,title);
% Convert these values to a number using str2num.
fbusNo= str2num(answer{1});
zf = str2num(answer{2});
% %
% zf=0;
% fbusNo=4;

BalancedFaultAnalysis (lineData,preFaultVoltage,zf,fbusNo);

```

### 2.2.3.2 BalancedFaultAnalysis

This function takes four parameters `lineData`, `preFaultVoltage`, `zf`, `fbusNo` and it does not return anything. When this function is called from `main.m` class that class will give it all the four parameters it required to run. Then it calls `buildYbus()` and give it `lineData` as parameter and it returns Y-bus matrix (`Ybus`) and other data like `fromBus`, `toBus`, `NumberofBuses`, `NumberOfBranches`, `Z`. After that it inverts `Ybus` into `Zbus` using `pinv()` method what is built-in function of matlab. In next step it calculates fault current of given fault bus [4] and printed in rectangular form and then convert it

into polar format. Then its Prompt a GUI for taking input for viewing [5] different types of result. Input 1 for per unite polar form and 2 for rectangular form. Then it calculates fault voltages of each buses [6] and prints the result according to user defined view mode. At last it calculates and shows line to line current [7] after fault. It also invoked `complexResultValue` ( ) to view complex result format.

```
function BalancedFaultAnalysis(lineData, V0, Zf, fbusNo)

%[3]
[fromBus, toBus, NumberOfBuses, NumberOfBranches, Z, Ybus]=
buildYbus(lineData);
% making Zbus by Inverting Ybus

%yb=ybus4(lineData);
Zbus=inv(Ybus);
Ybus

Zbus=Zbus*(-1)
%Zbus=Zbus./(90.476/100);
%Calculating Fault-current
magVfault=0;

fprintf('Three-phase Balanced fault at bus No. %d\n\n\n      ' ,
fbusNo)

%[4]
IfaultCurrent = (V0(fbusNo))/(Zf + Zbus(fbusNo, fbusNo));
%Inpufaultcurrent
Ifault_m = abs(IfaultCurrent);
Ifault_mang=angle(IfaultCurrent)*180/pi;

%disp('      ## 3-Phase Balanced Fault Current      ##      ')
fprintf('|-----|\n')
IfaultCurrent
fprintf('|-----|\n\n\n')

%in pu
FaultCurrentMag = abs(IfaultCurrent)
FaultCurrentAng=angle(IfaultCurrent)*180/pi
```

```

%[5]
%GUI for choosing result mood
prompt={'Enter 1 For per Unit Output 2 For Rectangle Form
Output'};
% % Create all your text fields with the questions specified by
the variable prompt.
title='3-Phase Balanced Short circuit Analysis ';
% % The main title of your input dialog interface.
answer=inputdlg(prompt,title);
% % Convert these values to a number using str2num.
viewMode= str2num(answer{1});

viewMode =input('Enter 1 for per unit')

ifviewMode==1
% Start of 1st If
%preparing for printing results in pu
fprintf(' ##Balanced 3 Phase Bus Voltages during fault in per
unit \n\n')
fprintf(' |-----|-----|-----|\n')
fprintf(' | Bus | Voltage | Voltage Angle |\n')
fprintf(' | No. | Magnitude | degrees |\n')
fprintf(' |-----|-----|-----|\n')

else
%preparing for printing results in rectangler/complex form
fprintf(' ##Balanced 3 Phase Bus Voltages After fault \n\n')
fprintf(' |-----|-----|-----|\n')
fprintf(' | Bus | Voltage | Voltage |\n')
fprintf(' | No. | MW | Mvr |\n')
fprintf(' |-----|-----|-----|\n')

end%end of 1st if
%[6]
%calculating Vfault of each bus
for n = 1:NumberofBuses
%start of 1st For loop
if n==fbusNo
% at Fault Bus
Vfault(n) = (V0(fbusNo)*Zf )/(Zf + Zbus(fbusNo,fbusNo));

%converting topu
mVfault = abs(Vfault(n));

angVfault=angle(Vfault(n))*180/pi;
mVfaultReal=real(Vfault(n));
mVfaultImg=imag(Vfault(n));

```

```

else
%Vfault(n) = (V0(n) - (V0(n)*Zbus(n, fbusNo)))/(
Zbus(fbusNo, fbusNo) + Zf);
Vfault(n) = (V0(n) - (Zbus(n, fbusNo)*IfaultCurrent));
end
%converting topu
magVfault = abs(Vfault(n));
angVfault=angle(Vfault(n))*180/pi;
mVfaultReal=real(Vfault(n));
mVfaultImg=imag(Vfault(n));

ifviewMode==1
%preparing for printing results in pu
fprintf(' %5g', n)
%fprintf(' |\n')
fprintf('%17.5f', magVfault)
%fprintf(' |')
fprintf(' %15.5f\n', angVfault)
% fprintf(' |')
fprintf(' |-----|-----|-----|\n')

else
%preparing for printing results in rectangler/complex form
fprintf(' %4g', n)
%fprintf(' |\n')
fprintf('%17.4g', mVfaultReal)
%fprintf(' |')
fprintf(' %15.4g\n', mVfaultImg)
% fprintf(' |')
fprintf(' |-----|-----|-----|\n')
end

end%End of 1st for loop

% calculating Line_to Line Current
fprintf('\n\n')
%preparing for printing results in pu
ifviewMode==1

disp(' ## 3-Phase Balanced Line-to-Line Fault
Curren ## ')
disp(' |-----|')
-----|')
disp(' | Bus | Bus | current |
Current Angle |')

```

```

disp('      | to.      |      from      |      Magnitude      |
degrees      |')
disp('-----|')
-----|')

else
%preparing for printing results in rectangler/complex form
disp('          ## 3-Phase Balanced Line-to-Line Fault
Curren ##          ')
disp('-----|')
-----|')
disp('      | Bus      |      Bus      |      current      |
Current Angle |')
disp('      | to.      |      from      |      Real      |
Imagenary |')
disp('-----|')
-----|')

end
%[7]
fori=1:NumberOfBranches
iftoBus(i)>0 &&fromBus(i)>0
IfaultLine(toBus(i),fromBus(i))=(Vfault(toBus(i))-
Vfault(fromBus(i)))/(Z(i));% If(ij)=V0i-V0k/zik
Value=IfaultLine(toBus(i),fromBus(i));
ifviewMode==1
%converting to pu
mIfaultLine=abs(Value); %magnititude of
Line to Line fault current
angIfaultLine=angle(Value)*180/pi; %Angle of Line
to Line fault current

%preparing for printing results in pu
%formatting Table like output
fprintf('          %5g', fromBus(i))
fprintf('          %5g', toBus(i))
fprintf('          %13.4f', mIfaultLine)
fprintf('          %12.4f\n', angIfaultLine)

else
%preparing for printing results in rectangler/complex form
realIf=real(Value);
imgIf=imag(Value);
%this function is just for creating printing formate
complexRuseltValue(fromBus(i),toBus(i),realIf,imgIf);

```

```

end
end

end

end

```

### 2.2.3.3 buildYbus.m

This function is for building Ybus matrix from given data. We have modified buildYbus() and make it capable of returning fromBus, toBus, NumberofBuses, NumberOfBranches, Z, Ybus. It extracts the data from linedata create Ybus matrix. This function is following:

```

function[fromBus, toBus, NumberofBuses, NumberOfBranches, Z, Ybus]=bu
ildYbus(lineData)

%Line data should have follow IEEE standerd
%           |column 1|column 2| column 3 | column 4 | column5  | |
From |
%           To   |   R     |   X     |   B/2  | | Bus  | Bus
| pu
%           | pu     |   pu    |
%
% Extacinting Data from LineData
fromBus=lineData(:,1);
toBus= lineData(:,2);

R = lineData(:,3);           % Resistance, R
X = lineData(:,4);           % Reactance, X

NumberofBuses = max(max(fromBus),max(toBus));           % No. of
buses
NumberOfBranches = length(fromBus);           % No. of
branches

```

```

Z= R + 1i*X; % z matrix
yba= ones(NumberOfBranches,1)./Z; % branch
admittance

%innisialYbus

Ybus=zeros(NumberOfBuses,NumberOfBuses);

%Building off-Diagonal Elements of Y-Bus
for m=1:NumberOfBranches;
if fromBus(m)>0 &&toBus(m)>0
Ybus(fromBus(m),toBus(m))=-yba(m);
Ybus(toBus(m),fromBus(m))= Ybus(fromBus(m),toBus(m));
end
end

% Building of the diagonal elements of Y-Bus

for m=1:NumberOfBuses;
for n=1:NumberOfBranches
if fromBus(n)==m || toBus(n)==m
Ybus(m,m)=Ybus(m,m)+yba(n);
end
end

```

### 2.2.3.4 complexRuseltValue

This simple function is just for result representation purpose .It helps to create matlab output format on console. The function is following

```

function[] = complexRuseltValue(frbus,toBus,real,img)

%formating Table like output

```

```

fprintf('      %5g', frbus)
fprintf('      %5g', toBus)
fprintf('      %11.4g', real)
fprintf('      %12.4g\n', img)
end

```

### 2.3 Matlab Results

Following tables represents the output of the balanced 3 phased short circuit study of 4 bus system:

To Bus	From bus	Resistance(r)	Reactance(x)
0	1	0	0.22
0	3	0	0.30
1	2	0	0.2
1	4	0	0.15
2	3	0	0.2
2	4	0	0.4
3	4	0	0.2

**Table 2.4 a.** Line data (input)

Fault Bus No.	Fault current mag	Fault current Angle
2	4.7523	90.0000

**Table 2.4b :** Fault current at faulted bus

Bus No	Voltage magnitude	Voltage angle
1	0.41468	-0.00000
2	0.00000	0.00000
3	0.37248	-0.00000
4	0.32661	-0.00000

**Table 2.4c.** Balanced 3 Phase Bus Voltages during fault in per unit



<b>From Bus</b>	<b>To Bus</b>	<b>Current magnitude</b>	<b>Current Angle</b>
1	2	2.0734	90.0000
1	4	0.5872	90.0000
2	2	1.8624	-90.0000
2	4	0.8165	-90.0000
3	4	0.2294	90.0000

**Table 2.4d** . Balanced 3 Phase Bus Voltages during fault in per unit

## **2.4 Flow chart of execution**

This Chapter presents the methodology of this project. The methodology is divided into two parts, which is the simulation and analysis of fault in MATLAB and the development of the Fault Analysis program using MATLAB GUIDE. The work flow is shown as follows-

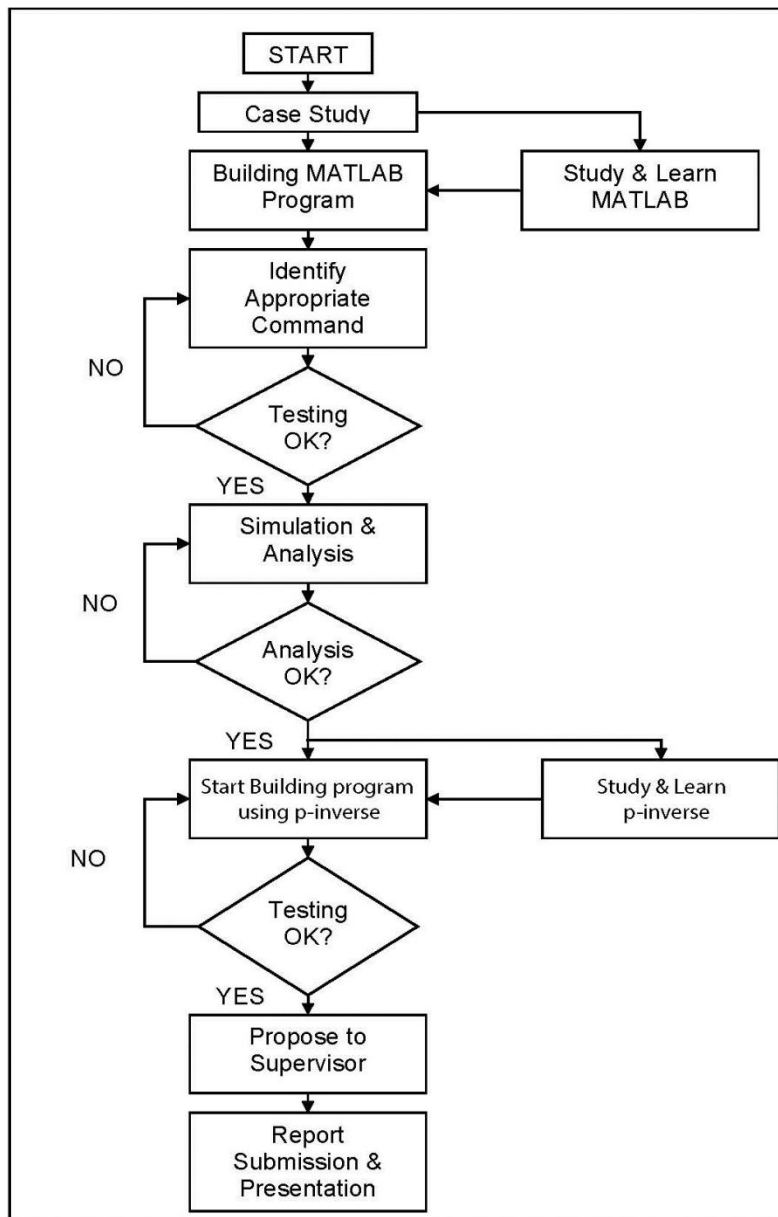


Figure 2.4 Shows work flow project

## *Chapter - 3*

### CONCLUSION

#### 3.1 Finale

Various methods for the calculation of short circuit currents have been developed and subsequently included in standards and in this “MATLAB using p-inverse” publication as well. A number of these methods were initially designed in such a way that short-circuit currents could be calculated by hand or using a small calculator. Over the years, the standards have been revised and the methods have often been modified to provide greater accuracy and a better representation of reality. However, in the process, they have become more complicated and time-consuming where hand calculations are possible only for the simplest cases. With the development of ever more sophisticated computerized calculations, electrical-installation designers have developed software meeting their particular needs. All computer programs designed to calculate short-circuit currents are predominantly concerned with:

- Determining the required breaking and making capacities of switchgear and the electromechanical withstand capabilities of equipment
- Determining the settings for protection relays and fuse ratings to ensure a high level of discrimination in the electrical network

Considering above our project will be helpful for calculating the big system with MATLAB using p-inverse programme. It will be easier for the user to handle and observe the hand calculation parallel to the MATLAB calculation of a big system's short circuit calculation.

### **3.2 Shortcoming**

In this project we are trying to solve the calculation of the short circuit fault current using MATLAB with the help of a pre designed function named ,p-inverse. We havetried our best to finish our project. Our project is worked in small bus system very efficiently. But while

performing in the big bus system there is some partial error which is considered as very few error. This error can be solved in future and higher optimization project.

### **3.3 Scopes of Project**

The scope of the project is to build a package to assist user to perform the fault analysis calculations with less errors. The targeted user is among trainee engineer and power system students which have less experience in computer programming or C language. In order to achieve the objectives of the project, some command in MATLAB program should be studied and understand so that the package would operate as desired.

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