Short-Circuit Fault Study Of Power System

A Thesis

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ABSTRACT

The fault analysis of a power system is required in order to provide information for the Selection of switchgear, setting of relays and stability of system operation. A power System is not static but changes during operation (switching on or off of generators and Transmission lines) and during planning (addition of generators and transmission lines).Thus fault studies need to be routinely performed by utility engineers (such as in the CEB). Faults usually occur in a power system due to either insulation failure, flashover, physical damage or human error. These faults, may either be three phase in nature involving all Three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved. Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases. Sometimes simultaneous faults may occur involving both short-circuit and broken conductor Faults (also known as open-circuit faults).Balanced three phase faults may be analyzed using an equivalent single phase circuit. With asymmetrical three phase faults, the use of symmetrical components help to reduce the complexity of the calculations as transmission lines and components are by and large symmetrical, although the fault may be asymmetrical. Fault analysis is usually carried out in per-unit quantities (similar to percentage quantities) as they give solutions which are somewhat consistent over different voltage and power Ratings, and operate on values of the order of unity. In the ensuing sections, we will derive expressions that may be used in computer simulations by the utility engineers.

NOTATIONS

SI.No.	Notation	Description
1	Eg	Per phase no load voltage (rms) of generator
2	Eg	voltage behind the transient reactance of generator
3	e	Induced Voltage of generator
4	Li	Normal load current of ith bus
5	i	No. of row, Bus number.
6	j	Operator, No. of column, Bus number.
7	n	No. of Bus
8	p	starting Bus.
9	q	Ending Bus.
10	SC MVA	Short circuit Mega-volt-Ampere
11	MV Abase	Base Mega-volt-Ampere
12	Vpq	Voltage between p & q Bus.
13	V_n^0	Pre-fault voltage of the nth Bus
14	v	Change in bus Voltage
15	Xd	Direct axis synchronous reactances
17	$Zbus$	Bus impedances matrix
18	Zb	Branch impedance.
19	Zpq	Transfer impedance between P&Q bus.
20	Zkk	self impedance of kth bus
21	Zf	fault impedance.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 THE STATEMENT OF PROBLEM

The statement of the problem of power system began in the U.S.A in 1885. The first transmission line was single phase and the energy consumed for lighting only. With the increase of demand the system becomes more and more complex as the different system were interconnected for the reliable power supply and the question of the protection of the system from different types of fault arises. Inter connection of the system brought many problems most of which have been solved satisfactory. Interconnection increase the amount of current which flows when a short circuit occurs on a system and required the installation of protective device to be able to interrupt large current. The disturbance caused by a short circuit on one system may spread to interconnected systems unless proper relays and circuit breakers are provided at different locations of the interconnected system.

1.2 PURPOSE OF FAULT ANALYSIS

The fault analysis of a power system is required in order to provide information for the Selection of switchgear, setting of relays and stability of system operation. A power System is not static but changes during operation (switching on or off of generators and Transmission lines) and during planning (addition of generators and transmission lines).Thus fault studies need to be routinely performed by utility engineers (such as in the CEB). Faults usually occur in a power system due to either insulation failure, flashover, physical damage or human error. These faults, may either be three phase in nature involving all Three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved. Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases. Sometimes simultaneous faults may occur involving both short-circuit and broken conductor Faults (also known as open-circuit faults).Balanced three phase faults may be analyzed using an equivalent single phase circuit. With asymmetrical three phase faults, the use of symmetrical components help to reduce the complexity of the calculations as transmission lines and components are by and large symmetrical, although the fault may be asymmetrical. Fault analysis is usually carried out in per-unit quantities (similar to percentage quantities) as they give solutions which are somewhat consistent over different voltage and power Ratings, and operate on values of the order of unity. In the ensuing sections, we will derive expressions that may be used in computer simulations by the utility engineers.

1.3 MOTIVATION

Short circuit calculation are provided current and voltage on a power system during fault condition. In different kinds of faults in a power system are

1. Three-phase fault 5%
2. Double line to ground fault 10%
3. Double line to line fault 15%
4. Single line to ground fault 70%

Though the symmetrical fault are rear, accounting for only about 5% of the total symmetrical fault analysis must be carried out as this type of fault generally leads to severe fault current. If is the least complex of all type of short circuit. Studies so for as the calculation are connected.

1.4 THESIS PREPARATION

The thesis organization is given on the following lines:

CHAPTER-1

Introduces the purpose of fault analysis.

CHAPTER-2

Introduces faults, causes of faults, types of faults e.t.c

CHAPTER-3

Introduces modelling of Z_{bus}, Z_{bus} building algorithm, and algorithm for short circuit calculations.

CHAPTER-4

Introduces computer simulation studies including short circuit calculation algorithm for formation of Z_{bus} and sample system studies.

CHAPTER-5

Formation of Y_{bus}.

CHAPTER-6

Introduces discussion and conclusions

CHAPTER 2

2.1 INTRODUCTION

- The fault analysis of a power system is required in order to provide information for the selection of switchgear, setting of relays and stability of system operation.
- A power system is not static but changes during operation (switching on or off of generators and transmission lines) and during planning (addition of generators and transmission lines). Thus fault studies need to be routinely performed by utility engineers.

2.2 CAUSES OF FAULT

Faults usually occur in a power system due to either insulation failure, flashover, physical damage or human error. These faults, may either be three phase in nature involving all three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved. Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases.

2.3 TYPES OF FAULTS

There are two main types of Faults.

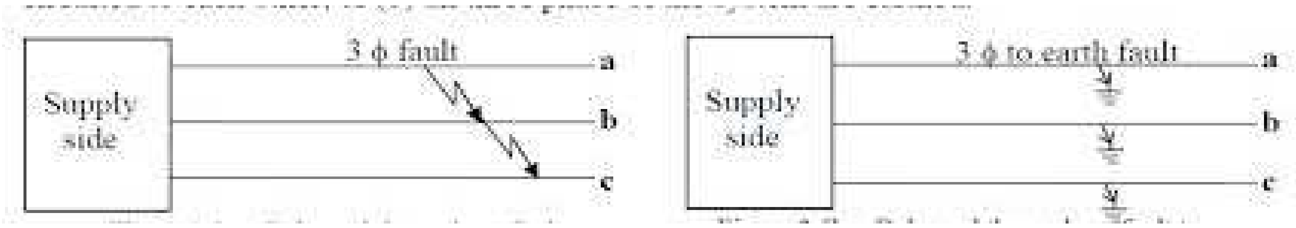
I. Symmetrical faults and

II. Unsymmetrical faults

2.3.1 SYMMETRICAL FAULTS

A three phase fault is a condition where either
(a) All three phases of the system are short-circuited to each other, or

(b) All three phase of the system are earthed.



(a) All three phases of the system are short-circuited to each other (b) All three phase of the system are earthed.

This is in general a balanced condition, and we need to only know the positive-sequence network to analyze faults. Further, the single line diagram can be used, as all three phases carry equal currents displaced by 120 degrees. Typically, only 5% of the initial faults in a power system, are three phase faults with or without earth. Of the unbalanced faults, 80 % are line-earth and 15% are double line faults with or without earth and which can often deteriorate to 3 phase fault. Broken conductor faults account for the rest.

2.3.2 ASSYMMETRICAL FAULTS

Assumptions Commonly Made in Three Phase Fault Studies

The following assumptions are usually made in fault analysis in three phase transmission
lines.

- All sources are balanced and equal in magnitude & phase
- Sources represented by the Thevenin's voltage prior to fault at the fault point
- Large systems may be represented by an infinite bus-bars
- Transformers are on nominal tap position
- Resistances are negligible compared to reactance
- Transmission lines are assumed fully transposed and all 3 phases have same Z
- Loads currents are negligible compared to fault currents
- Line charging currents can be completely neglected

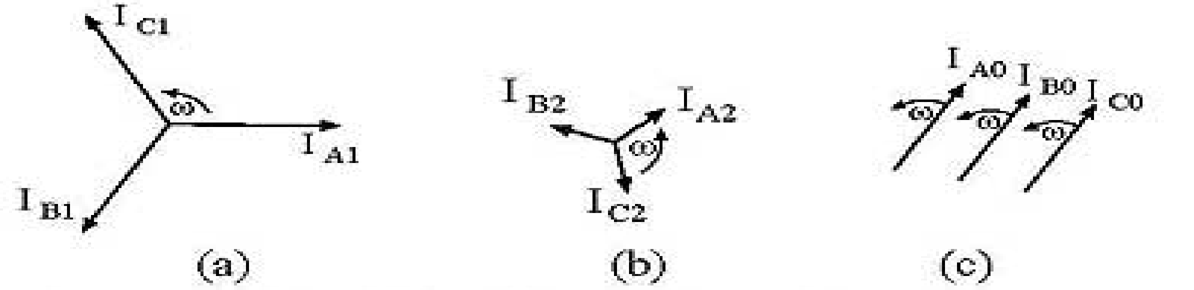
Balanced three phase faults may be analyzed using an equivalent single phase circuit. With asymmetrical three phase faults, the use of symmetrical components help to reduce the complexity of the calculations as transmission lines and components are by and large symmetrical, although the fault may be asymmetrical.

SYMMETRICAL COMPONENTS

The key idea of symmetrical component analysis is to decompose the system into three sequence networks. The networks are then coupled only at the point of the unbalance (i.e., the fault). The three sequence networks are known as the

(a) Positive sequence (this is the one we've been using). (b) Negative sequence.

(c) Zero sequence



(a) Positive, (b) Negative, and (c) Zero Sequence Components

Positive Sequence Sets

•The positive sequence sets have three phase currents/voltages with equal magnitude, with phase b lagging phase a by 120°, and phase c lagging phase b by 120°. We've been studying positive sequence sets.

Negative Sequence Sets

•The negative sequence sets have three phase currents/voltages with equal magnitude, with phase b leading phase a by 120°, and phase c leading phase b by 120°. Negative sequence sets are similar to positive sequence, except the phase order is reversed

Zero Sequence Sets

•Zero sequence sets have three values with equal magnitude and angle. Zero sequence sets have neutral current.

CHAPTER 3

3 DEVELOPMENT OF MATHEMATICAL MODEL FOR SHORT CIRCUIT STUDIES

3.1 modelling of Z_{bus}

Z_{bus} For a given system can be built by starting with a single line diagram of the system. The Bus are designated by a unique number usually the reference bus is number as zero. The following different method are available for the formation of Z_{bus}.

a) By inversion of Y_{bus}

b) Current injection technique

c) Z_{bus} Building Algorithm.

Among this methods only (i) is popular, it is also time consuming. The Z_{bus} building Algorithm has certain advantages, so we shall be using it. However both have been described below.

3.1.1 FORMATION OF Z_{bus} BY INVERSION OF Y_{bus}

To constant a Y_{bus} matrix let us consider the n number of bus in the system. Z

So we get,

$$Y_{BUS}=\begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \ldots\ldots Y_{1n} \\ Y_{21} & Y_{22} & Y_{23} \ldots\ldots Y_{2n} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \\ Y_{n1} & Y_{n2} & Y_{n3} \ldots\ldots Y_{nn} \end{bmatrix}$$

(3.1)

We know

$$[V] = [Y^{-1}][1] \ldots\ldots..$$

(3.2)

$$[V] = [Z][1] \ldots\ldots\ldots..$$

(3.3)

Where $Z_{bus} = Y_{BUS}^{-1}$ *and is given by*

$$Z_{BUS}=\begin{bmatrix} Z_{11} \dots \dots \dots Z_{1j} \dots \dots Z_{1n} \\ Z_{21} \dots \dots \dots Z_{2j} \dots \dots Z_{2n} \\ \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \\ Z_{i1} \dots \dots \dots Z_{ij} \dots \dots Z_{in} \\ \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \\ Z_{n1} \dots \dots \dots Z_{nj} \dots \dots Z_{nn} \end{bmatrix}$$

(3.4)

The impedance element of Z_{BUS} on the principle diagonal are called driving impedance of the bus and of diagonal element are called the transfer impedance of the bus. But element of Z_{BUS} matrix is not equal to the respective element of the Y_{BUS} matrix.

3.1.2 Z_{BUS} Building Algorithm

This is a very systematic way of forming Z_{BUS} and allow for easy implementation on the digital computer.

<u>Advantages</u>

1. Easy to implement

2. Avoids matrix inversion

3. It is easy to handle Z_{BUS} modifications due to line switching and changes in network topology.

<u>Basic Problem</u>

How to find the Z_{BUS} of a modified network

<u>Approach to the Solution</u>

- Network modifications can be described as adding a branch of impedance Z_b between Nodes.
- If there are several network changes, then the problem is one of successive branch additions.
- A given network can be visualized as being built from successive branch additions.

Problem Statement

Given a network with Z_{bus}^{old} (n×n matrix), find Z_{bus}^{new} when a branch of impedance $Z_b$is added to the network.

Solution

Notation

1. Z_{bus}^{old}→existing Zbus (n×nmatrix)
2. Z_{bus}^{new}→required Zbus(?matrix)
3. i, j, k →existing buses
4. p →a new bus (not in the original network)

$$V_p = Z_b I_p$$

3.2 ALGORITHM FOR SHORT CIRCUIT STUDIES

Short circuit calculation can be performed by the following four steps.

STEP-1: Steady state solution of the loaded system i.e the value of pre-fault voltage and current by the flow study are to be obtained.

STEP-2: Replace reactance of synchronous machines by their sub-transient transient values. Short circuit all emf sources. The result is the passive Thervenin network.

STEP-3: Excite the passive network of step-2 at the fault point by negative of pre-fault voltage inseries with the fault impedance. Compute voltages and currents at all points of interest.

STEP-4: Post-fault currents and voltages are obtained by adding results of step-1 and step-3

ASSUMPTIONS:

The following assumptions can be safely made in short circuit computations loading to considerably computational simplifications.

Assumptions-1:

All pre-fault voltage magnitudes are 1 pu

Assumption-2:

All pre-fault currents are zero.

The first assumption is quite close to actual conditions asunder normal operation all voltages (p.u.) are nearly unity.

Whenever we are dealing with short circuit of an inter-connected system, the synchronous machines (generators and motors) are replaced by their corresponding circuit models having voltage behind sub-transient (transient) reactance. The rest of the network being passive remains unchanged.

CHAPTER 4

4 COMPUTER SIMULATION STUDIES

4.1 INTRODUCTION

The element ofZ_{bus}. The short circuit current, short circuit MVA, post fault bus voltage and the line current are calculated by hand for sample test systems and are represented respectively.

Computer programs are developed for Z_{bus} formation and for the short circuit calculation and tested for in sample test systems and the result obtained from the computer printout are represented in this chapter.

4.2 ALGORITH FOR FORMULATION OF Z_{bus}

The steps of the computational algorithm for the Z_{bus} formation of large power systems are given below

I) read the no the buses, NB; no of the element, NE; type of elements NT YPE; bus code, p-q, impedance of element (Z_b) connected between buses p-q and type of sequence (NSEQ).

ii) for the first element set $Z_{pi} = 0$, where p is the reference bus and i-2,2….n

iii) Set k=1 for the first element

iv) test of the type of the connected element whether it is a link or branch.

v) for type-1 computer

$$Z_{qi} = Z_{pi} \; where \; i = 1,2,3 \ldots \ldots n \; i = q$$

$$Z_{qq} = Z_{pq} + Z_b(p.q)$$

vi) For the type-2, computer, $Z_{li} = Z_{pi} - Z_{qc}$

where 1=1,2,3,…n

i=1, $Z_{il} - Z_{pl} - Z_{ql} = Z_b\ (p, q)$

vii) For the type-2, modification is done using equation;

$$Z_{ij} = Z_{ij} - \frac{Z_{il} * Z_{jl}}{Z_{ll}}$$

Viiii) test for the element exhausted

ix) Repeat step 4 through 8 until all the element are considered. In each step k is increased by one.

x) Z_{bus}, thus for the is stored as ZI_{bus}

xi)Repeat step 1 through 9 using zero sequence network data

xii) store Z_{bus} thus formed as Z_{0bus}

xiii) print $ZI_{bus}\ and\ Zo_{bus}$

4.3 SAMPLE SYSTEM STUDIED

In this study we considered an 11-bus power system

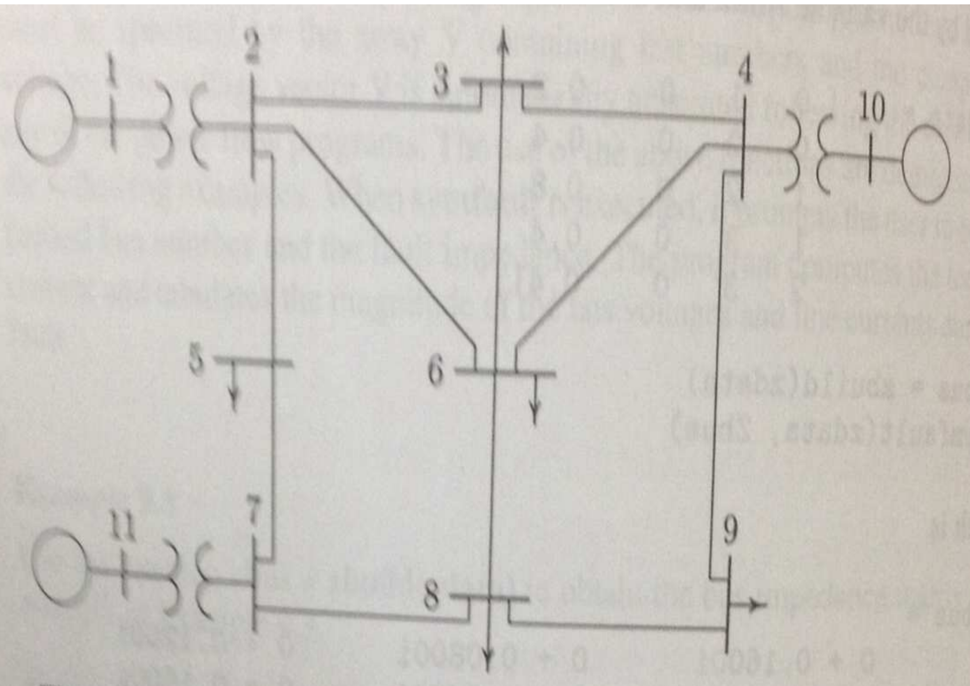


FIGURE 9.17
One-line diagram for Example 9.7

The transient impedance of the generators on a 100-MVA base are given below.

GEN. TRANSIENT IMPEDANCE PU		
Gen. No.	R_a	X'_d
1	0	0.20
10	0	0.15
11	0	0.25

The line and transformer data containing the series resistance and reactance in per unit, and one-half of the total capacitance in per unit susceptance on a 100-MVA base is tabulated below.

We run the matlab code below

```
clc
close all
clear all
zdata=[ 0  1  0.00  0.20
        0  10 0.00  0.15
        0  11 0.00  0.25
        1  2  0.00  0.06
        2  3  0.08  0.30
        2  5  0.04  0.15
        2  6  0.12  0.45
        3  4  0.10  0.40
        3  6  0.04  0.40
        4  6  0.15  0.60
        4  9  0.18  0.70
        4  10 0.00  0.08
        5  7  0.05  0.43
        6  8  0.06  0.48
        7  8  0.06  0.35
        7  11 0.00  0.10
        8  9  0.052 0.48];

    zbus= zbuild1(zdata)
    symfault2(zdata,zbus)
```

And here is our result

```
Zbus = zbuild(zdata)
symfault(zdata, Zbus)
```

The bus impedance matrix is displayed on the screen, and the three-phase short circuit result is

```
Enter Faulted Bus No. -> 8
Enter Fault Impedance Zf = R + j*X in
complex form (for bolted fault enter 0). Zf = 0
Balanced three-phase fault at bus No. 8
Total fault current =    3.3319 per unit

Bus Voltages during the fault in per unit
```

Bus No.	Voltage Magnitude	Angle Degree
1	0.8082	-1.8180
2	0.7508	-2.5443
3	0.6882	-1.5987
4	0.7491	-2.4902
5	0.7007	-2.3762
6	0.5454	-1.0194
7	0.5618	-3.8128
8	0.0000	0.0000
9	0.3008	2.4499
10	0.8362	-1.4547
11	0.6866	-2.2272

Line currents for fault at bus No. 8

From Bus	To Bus	Current Magnitude	Angle Degree
G	1	0.9697	-82.4034
1	2	0.9697	-82.4034
2	3	0.2053	-87.8751
2	5	0.3230	-79.9626
2	6	0.4427	-81.6497
3	6	0.3556	-88.0987
4	3	0.1503	-88.4042
4	6	0.3305	-82.3804
4	9	0.6229	-81.3672
5	7	0.3230	-79.9626
6	8	1.1274	-83.8944
7	8	1.5820	-84.0852
8	F	3.3319	-83.5126
9	8	0.6229	-81.3672
G	10	1.1029	-82.6275
10	4	1.1029	-82.6275
G	11	1.2601	-85.1410
11	7	1.2601	-85.1410

CHAPTER 5

5 Y_{BUS} FORMATION.

CHAPTER 6

6 DISCUSSION AND CONCLUSIONS

Faults usually occur in a power system due to either insulation failure, flashover, physical damage or human error. These faults, may either be three phase in nature involving all three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved.

Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases.

Sometimes simultaneous faults may occur involving both short-circuit and broken-conductor faults (also known as open-circuit faults). Balanced three phase faults may be analyzed using an equivalent single phase circuit. With asymmetrical three phase faults, the use of symmetrical components help to reduce the complexity of the calculations as transmission lines and components are by and large symmetrical, although the fault may be asymmetrical. Fault analysis is usually carried out in per-unit quantities (similar to percentage quantities) as they give solutions which are somewhat consistent over different voltage and power ratings, and operate on values of the order of unity. In the ensuing sections, we will derive expressions that may be used in computer simulations by the utility engineers.

Goal of fault analysis is to determine the magnitudes of the currents present during the fault.

• need to determine the maximum current to insure devices can survive the fault.

• need to determine the maximum current the circuit breakers (CBs) need to interrupt to correctly size the CBs

The different methods for short circuit calculations were discussed among the methods are Z_{bus} building Algorithm, which is an easy and very effective method, we used it. It is taken due to various computational aspects. Z_{bus} can be obtained by inversion of Y_{bus}, it is also a popular method.

The full Z_{bus} need to be calculated. So Z_{bus} algorithm takes the least time and is more economic than the inversion of Y_{bus}.

The results obtained from the computer simulations were compared with that obtained by hand calculations and also with the solutions given in reference books.

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