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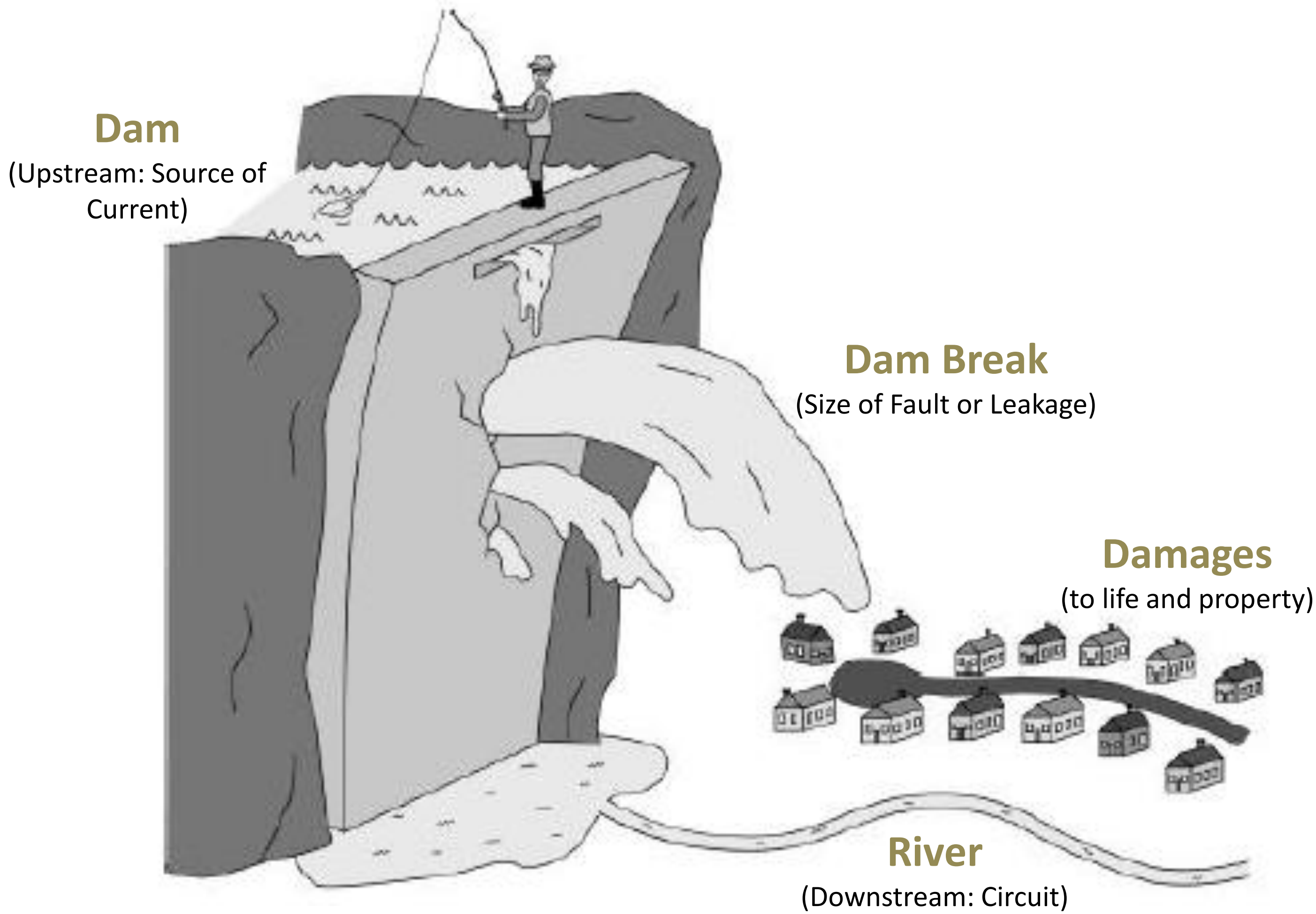
Objectives

- To understand the concepts of fault and fault current in distribution system
- To be able to perform fault current calculation

Content

1. Introduction
2. Assumptions
3. Sources of Fault Current
4. Fault Current Calculation
   a. Per Unit System
   b. Impedance Diagram
   c. Calculation

Story of a Dam and River



The needs to calculate maximum fault current (three phase short circuit)

- **The calculations related to short circuit conditions fall into three categories:**

  a) those which have to be undertaken to determine whether the associated **protective device** have **adequate breaking capacity** for compliance with IEC 60364-4- 43:2001

  b) those which have to be undertaken to determine whether the **conductors** of the circuits concerned are **protected thermally** for compliance with IEC60364-4-43:2001

  c) IEC 60364-5-53:2001 emphasize the importance of **selectivity** (discrimination) in low voltage networks.

- Proper **selection** of protection devices types and ratings is important in delivering a safe and reliable supply

- Thus, it is important to include **protection devices coordination** in the preliminary design (this require calculation of fault current).

WHY calculate maximum fault (three phase short circuit) current

The calculations related to short circuit conditions fall into three categories

(a) those which have to be undertaken to determine whether the associated **protective device have adequate breaking capacity** for compliance with **IEC 60364-4-43:2001**

(b) those which have to be undertaken to determine whether the conductors of the circuits concerned are protected thermally for compliance with **IEC 60364-4-43:2001**

Circuit conductors will meet the thermal requirements if compliance with the adiabatic equation is satisfied

$$k^2s^2 \geq I_f^2t$$

(c) **IEC 60364-5-53:2001** emphasize the importance of selectivity (discrimination) in low voltage networks.

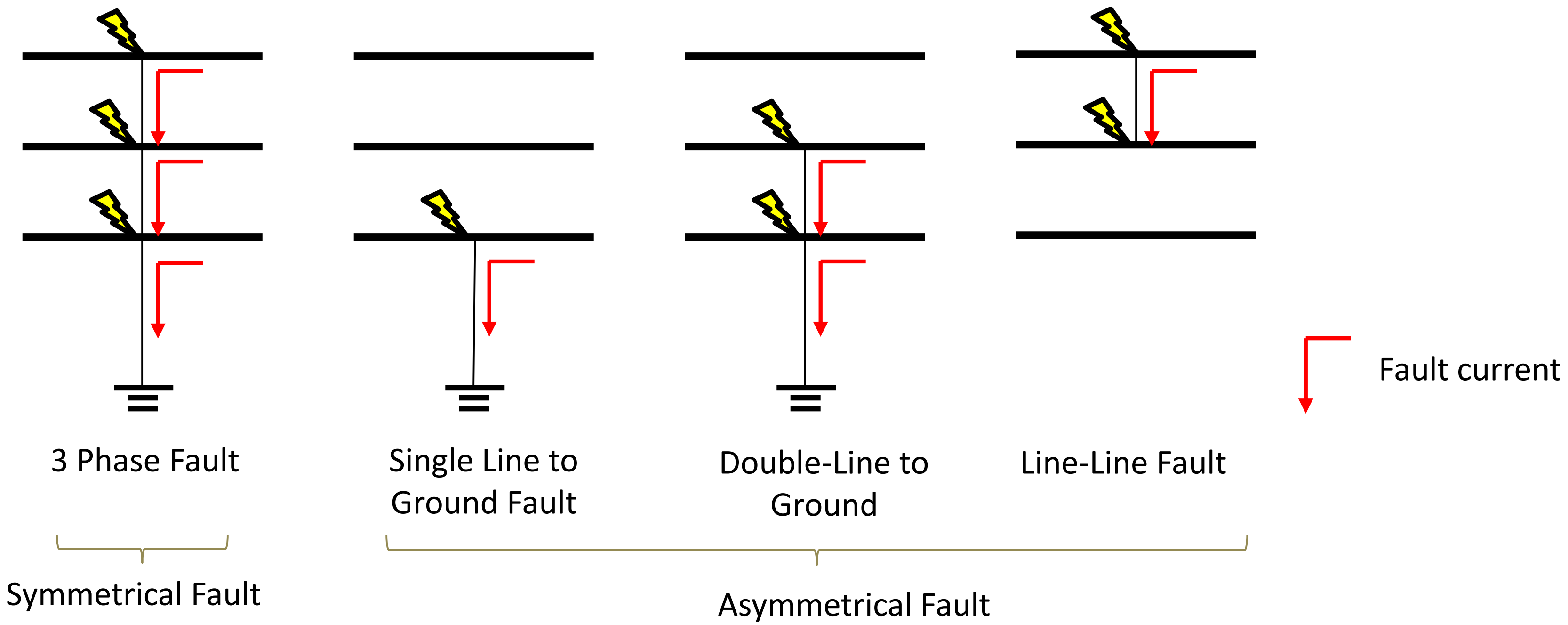
Proper selection of protection devices **types** and **ratings** is important in delivering a safe and reliable supply.

Thus, It is important to include protection devices **coordination** in the **preliminary** design (This required calculation of fault current)

Introduction

Fault occurs when an unintended low impedance is formed in the electrical system, causing large current to flow.

There are essentially four different types of faults:



Introduction

When a fault (short-circuit) occurs, the following things happens:

1. Short-circuit current flows from sources to the fault location.

2. Arcing and/or burning occurs at the location of fault.

3. All components carrying the large fault current are subjected to high thermal and mechanical stresses.

4. System voltages drop proportionally to the magnitude of the fault current.

EARTH FAULT & EARTH LEAKAGE

Earth fault protection is primarily used for Equipment protection

Earth leakage protection is primarily used to protect hazards to human beings due to accidental contact **with a** live conductor or due to small **leakage** currents due to insulation failure.

Assumptions

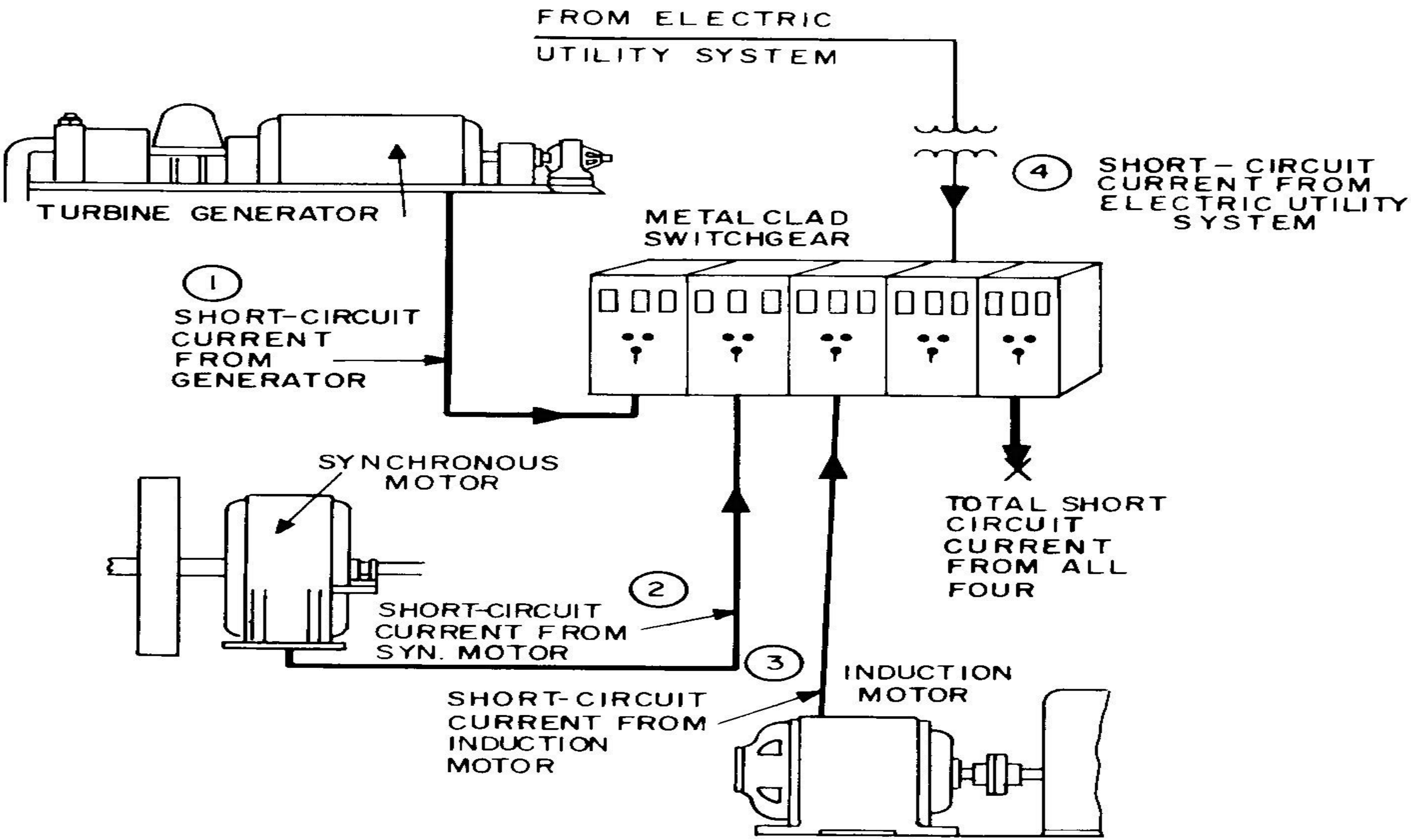
For **low voltage system**, simplifying assumptions can **be used to simplify short circuit current calculation**:

1. **The fault is shorted through a zero fault impedance.**

   This simplifies the calculation and also provides a safety factor, since zero fault impedance is the **worst case scenario**.

2. **The fault is a three-phase fault.**
   - This is again a worst case scenario, where the fault current is highest.
   - Line-to-line short circuit current is about 87% of the three-phase fault.
   - For system with solidly grounded neutral, line-to-earth gives around 60% to 125% of the three-phase short circuit current.
   - However, generally line-to-earth fault current is rarely larger than that of a three-phase fault.

Sources of Fault Current



Sources of Fault Current

1. **Utility Supplies**

   Utility supply is the main source of fault current. However, transmission and distribution lines and transformers introduce impedances between the utility generator and the low voltage system. As a result, the contribution of the these generators to the fault current is substantially reduced.

   The contribution of utility supply to fault current is generally expressed in terms of the fault level at the service entrance.

   The values of these fault levels should be normally obtained from the utility.

Short circuit rating by TNB ESAH

1.4 SHORT-CIRCUIT LEVELS

TNB network are design and operated in order to remain within the limits of short-circuit levels as in **Item 1.4.5 of Supply Application Section.** TNB equipment design is specified to the same Short Circuit rating. Consumer's equipment at the point of interface or part of the interconnection design shall also comply with the minimum Short Circuit rating. TNB may provide indicative or prospective fault level in terms of X/R at the interface point with consumer, if so required for detailed installation design.

	System	Short circuit rating
i.	500kV	50 kA, 1s
ii.	275kV	40 kA, 3s (50kA , 1s for substation adjacent to Power Station, or within 500kV substation)
iii.	132kV	31.5 kA, 3s (40kA, 3s for substation adjacent to Power Station, or within 500/275kV substation)
iv.	33kV	25 kA, 3s
v.	22kV	20 kA, 3s
vi.	11kV	20 kA, 3s
vii.	6.6kV	20 kA, 3s
viii.	400/230 V	31.5 kA, 3s

L-S1 | 2.1 Types of Switchboards

- **2.1.2** Unless otherwise specified elsewhere, the switchboards shall be capable of withstanding fault condition of not less 50kA at 415V for 1sec defined in MS IEC 60439-1

- *Prospective Short Circuit Current (PSCC):*
  The highest electric current which can exist in a particular electrical system under short circuit conditions. It is determined by the voltage and impedance of the supply system.

$$PSCC = \frac{\text{Transformer kVA} \times 100}{\text{Rated Secondary Voltage} \times \text{\% Impedance of Transformer} \times \sqrt{3}}$$

e.g.: $$PSCC = \frac{1000 \times 100}{\sqrt{3} \times 415 \times 5} = 27.86kA$$

Note: 50kA means the switchboard and its component shall withstand PSCC of 50kA at 415V for 1s.
For incoming supply from overhead lines or underground cable, the PSCC is 25kA at 415V for 1s.

Tx Rated Power (kVA)	Min. Short Circuit Impedance, Z (%) ,[L-S17]	PSCC (kA)
400	4	
500	4	
800	5	
1000	5	
1250	5	
1600	6	
2000	6	

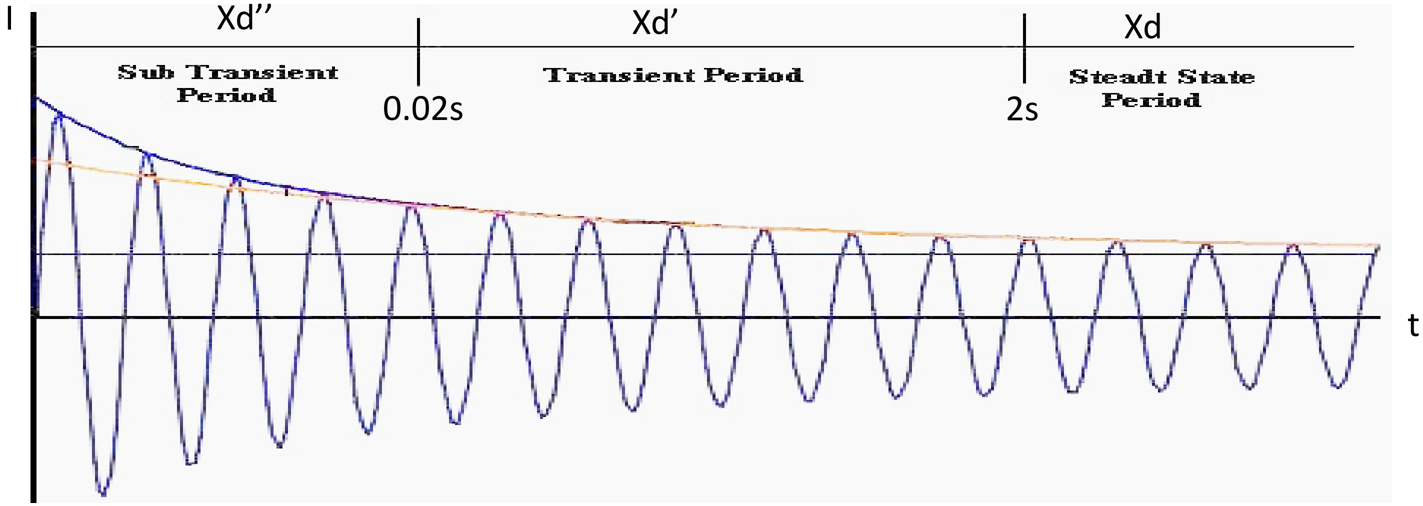
Sources of Fault Current

2. Local generator

- These are the generators located at the low voltage system, such as gen sets in factories.
- The fault current generated from a local generator decreases exponentially, from a high value to a small steady state value equivalent the current generated by a voltage behind a variable reactance.
- As the generator is still driven by its prime mover, with its field still being energised from the exciter, the steady state fault current will persist.
- There are three values for this variable reactance namely subtransient reactance (Xd''), transient reactance (Xd') and synchronous reactance (Xd).

Sources of Fault Current

- Xd'' determine the fault current during the first cycle (to 0.02s)
- Then the reactance increases to Xd', which determines the current to approximately 2s.
- Finally, the reactant increases to Xd which decide the steady state fault current.

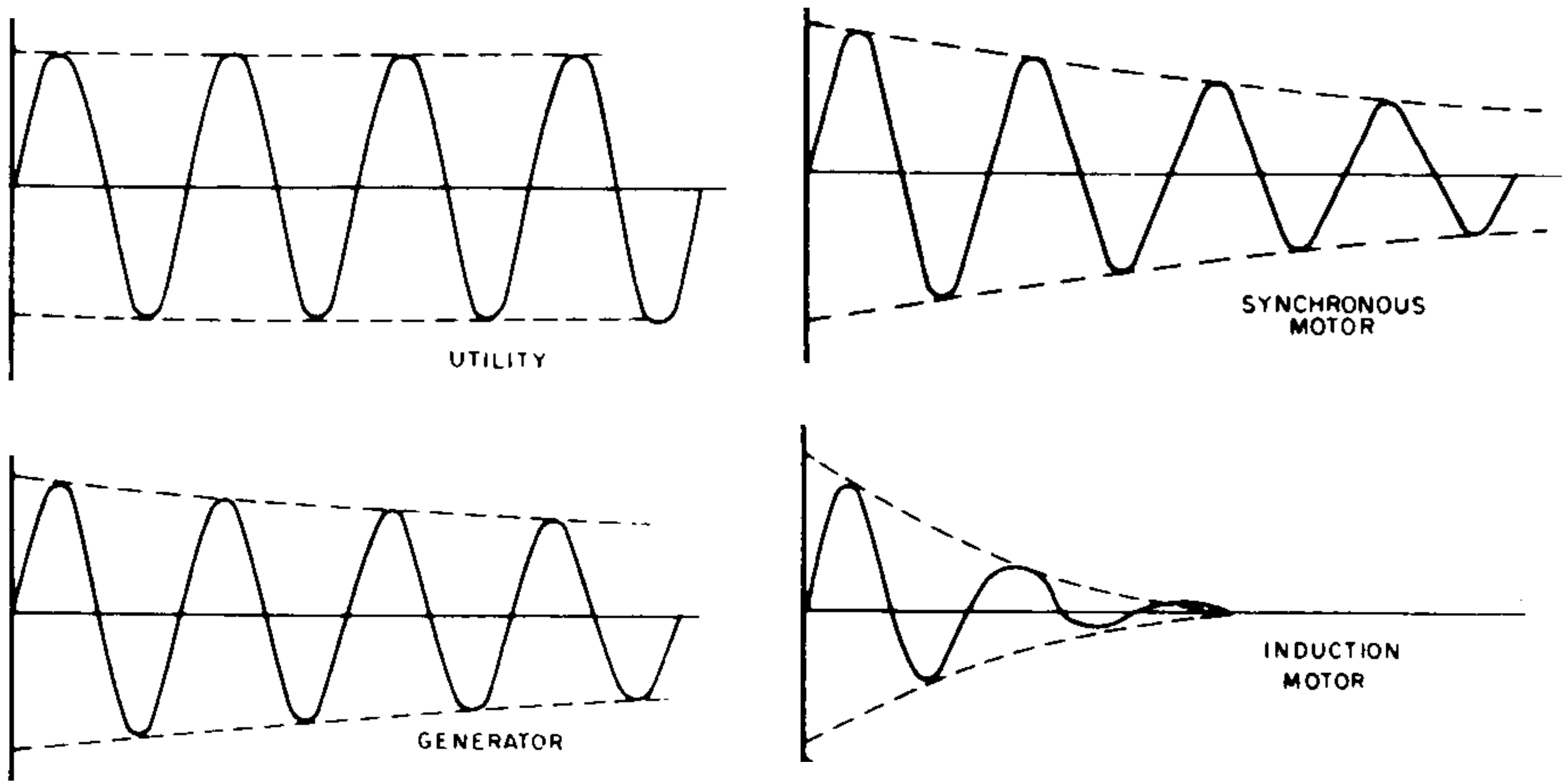


- For low voltage systems, protective devices are mostly activated within the first cycle by the primary current, **so Xd'' is recommended for the calculation of fault current contributed by the local generator**.
- Typical values of Xd'' are in the range of **10% to 15%** of generator kVA rating.

3. Synchronous motors

- Synchronous motors are in principle same as generators: they have field excited by dc, and stator connected to ac. However, **unlike generator, the synchronous motor draws electrical power and perform mechanical work.**
- When a fault occurs, the stator voltage of the synchronous motor reduces and the motor slows down. However, due to the inertia, the motor continue to rotates, and the motor acts as a generator contributing to fault current level.
- Due to the presence of the field exciter, the decay of magnetic field in the synchronous motor is slower than that of the induction motor, resulting in longer decay of the fault current.

Sources of Fault Current



Step by Step approach:

1. Construct a single-line diagram for the system, with all the important equipment and their parameters noted.
2. Select a suitable per unit base, and convert the relevant parameters into per unit form
3. Decide on the location of the fault, for which the fault current will be calculated.
4. Construct the impedance diagram, and obtain the equivalent impedance, Z.
5. Solve for the fault current using equation I = V/Z.

Per Unit System

In power system calculation, it is useful to perform calculation in per unit (p.u.) system rather than in the actual value.

P.u. form is dimensionless and ease the calculation.

Steps:

1. Choose a suitable base power, S_b (total three-phase power). Unless other value of base power is specified, it is convenient to choose values 100 MVA or 10 MVA.
2. Select the voltage level as base voltage, V_b (line-to-line voltage).
3. Calculate the base impedance and base current:

$$Z_b = \frac{V_b^2}{S_b} \qquad I_b = \frac{S_b}{\sqrt{3}V_b}$$

4. Convert all impedance, voltages, current and power into p.u. form.

Utility Source

- The fault level can be given in different forms:

a. Three-phase fault level in MVA.

$$Z_{utility} = \frac{\text{Base MVA}}{\text{Fault MVA}} \text{ p.u.}$$

b. Three-phase short circuit current (I_{sc}) available at given voltage (V_{given}).

$$Z_{utility} = \frac{\text{Base MVA}}{\sqrt{3} \cdot I_{sc} \cdot V_{given}} \text{ p.u.}$$

c. Percent or per unit reactance (Z_{given}) on a specific fault level in MVA.

$$Z_{utility} = Z_{given} \frac{\text{Base MVA}}{\text{Fault MVA}} \text{ p.u.}$$

d. Impedance in Ohm per phase (Z_{ϕ}) at a given voltage (V_{given}).

$$Z_{utility} = Z_{\phi} \frac{\text{Base MVA}}{\left(V_{given}\right)^2} \text{ p.u.}$$

Note: Base power should be in MVA and V_{given} should be in kV.

If Base power is in kVA and V_{given} is in kV, the equation should be divided by 1000.

Per Unit System

From the base impedance, Z_b, the base resistance R_b and base reactance X_b can be calculated based on the X/R ratio.

If X/R ratio is not known, then the resistance is assumed to be negligible, and X = Z.

Transformer

-The transformer impedance is usually expressed as percentage value of the transformer rated MVA.

$$Z_{tranx} = \frac{\text{percentage value}}{100} \times \frac{\text{Base MVA}}{\text{Transformer MVA}} \quad \textbf{p.u.}$$

Cable

-The impedance (resistance and reactance) of the cable can be obtained from the manufacturer's datasheet in Ohm/km. These values will need to be multiplied by the cable length to obtain the actual impedance.

Rotating Machine

-The machine's reactance is usually expressed in terms of percentage or per unit reactance on the rated MVA/kVA of the machine.

-If not specified, the reactance can be assumed to be 25% of the rated MVA/kVA.

$$Z_{machine} = \text{percentage value} \times \frac{\text{Base MVA}}{\text{Machine MVA}} \quad \textbf{p.u.}$$

Impedance Diagram

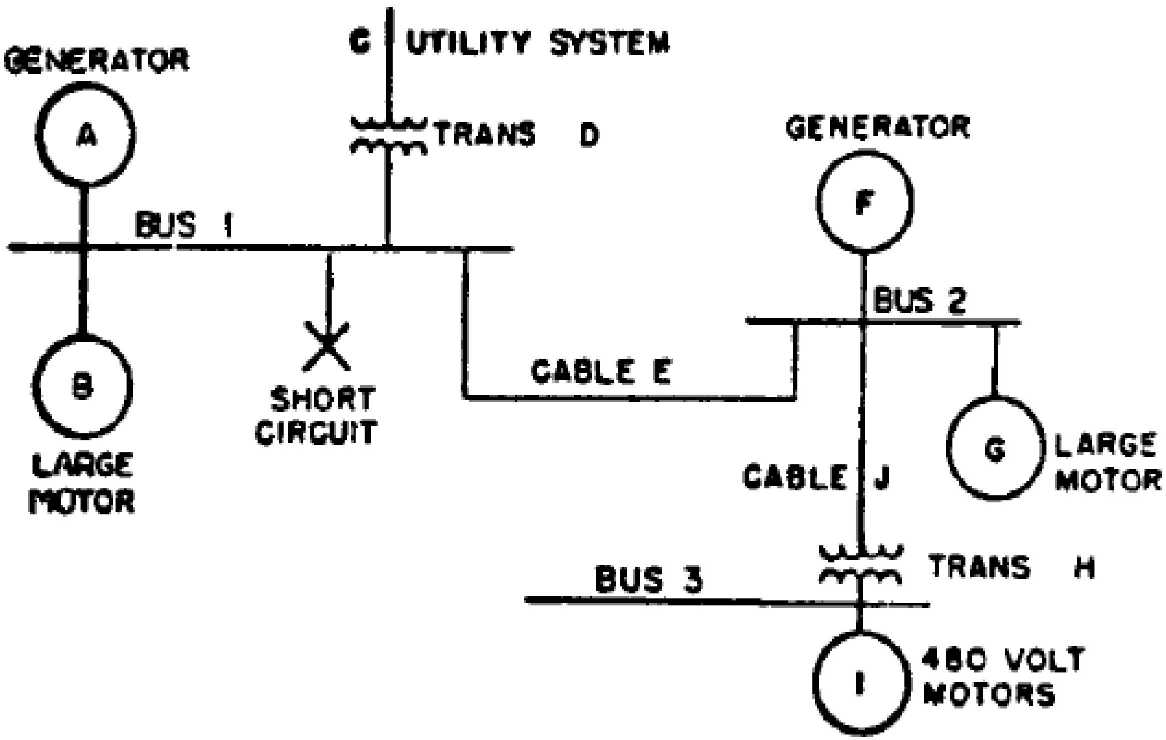
To calculate the fault current, it is necessary to transform the single line diagram into impedance diagram, and determine the equivalent impedance, Z_{eq}.

The steps to be taken:

1. Mark the Z for each relevant component in the system.
2. Construct impedance diagram, with the following considerations:
   a. All sources of fault is considered as the +ve end of the impedance diagram.
   b. The location of fault is considered as the –ve end of the impedance diagram.
3. Solve the impedances to obtain the equivalent Z_{eq} seen across the +ve and –ve ends.

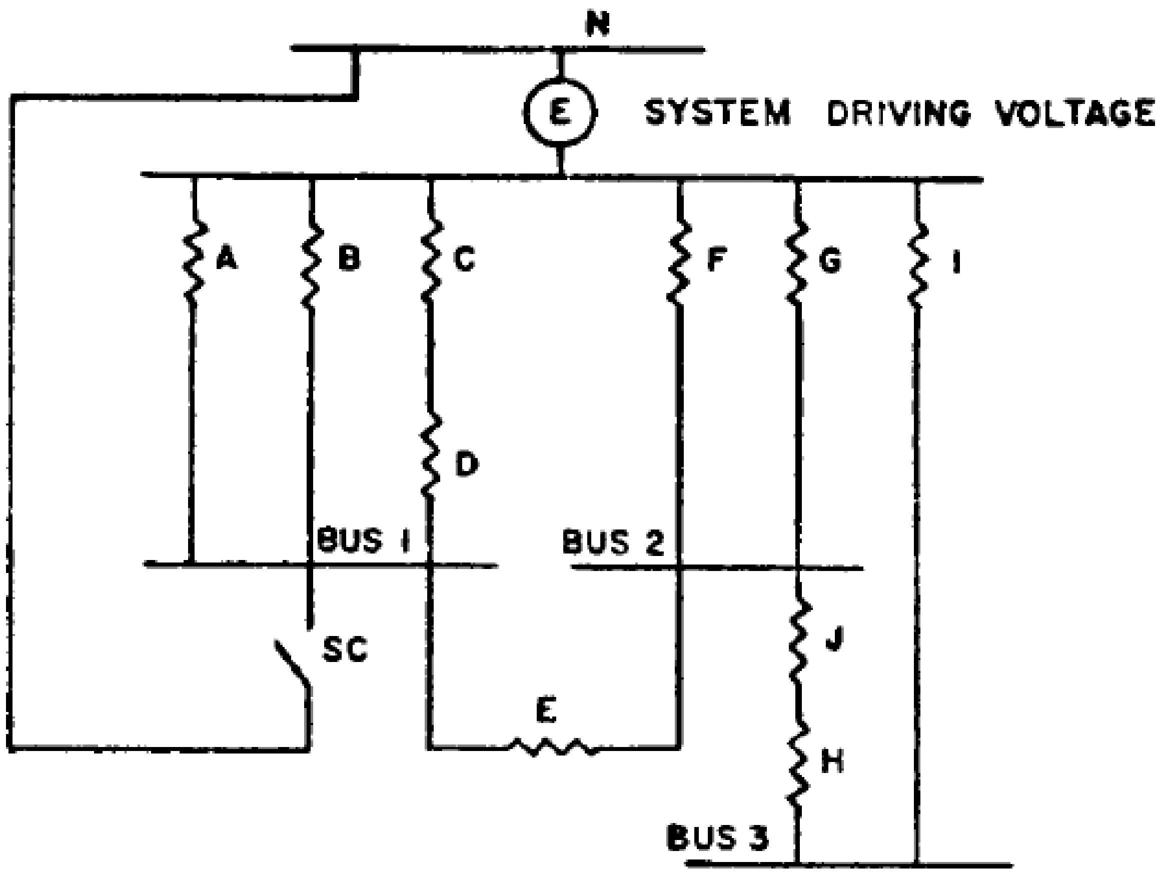
Example - Impedance Diagram

Convert the following single-line diagram into an impedance diagram. Then find the equivalent impedance

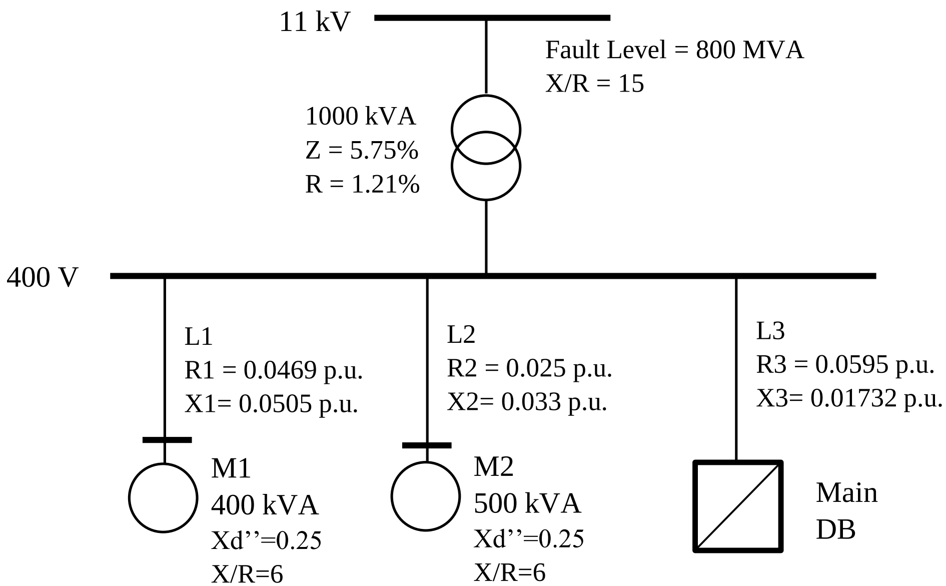


Component	Z (pu)
A	0.650
B	0.500
C	0.00125
D	0.05
E	0.02
F	0.650
G	0.500
H	0.05
I	0.333
J	0.02

Example - Impedance Diagram



Example – Fault Current Calculation



A distribution system has components and parameters as seen below. Find the fault current if fault occurs at

(a) the 400V bas bar;

(b) the terminals of M1.

(Use base MVA of 1MVA)

Impedance Diagram

- Instead of calculating directly based on the impedance Z, it is also possible to separately determine the equivalent resistance (R) and reactance (X) diagram.
- Separating the resistance and reactance will give a higher estimate of the fault current.

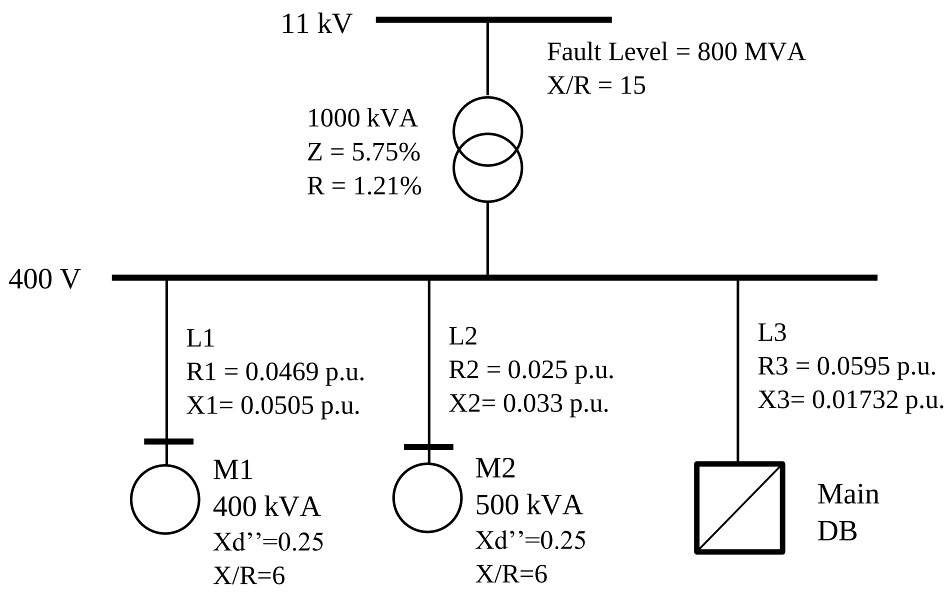
Impedance Diagram – R &X

For the separate R and X diagram approach, here are the steps to be taken:

1. Mark the R and X for each relevant component in the system.
2. Construct two separate diagrams: one for R and one for X, with the following considerations:
   a. All sources of fault is considered as the +ve end of the impedance diagram.
   b. The location of fault is considered as the –ve end of the impedance diagram.
3. Solve the R diagram and X diagram to obtain the equivalent R_{eq} and X_{eq} seen across the +ve and –ve ends of the respective diagram.
4. The equivalent impedance is then

$$Z_{eqn} = \sqrt{R_{eq}^2 + X_{eq}^2}$$

Example – Fault Current Calculation



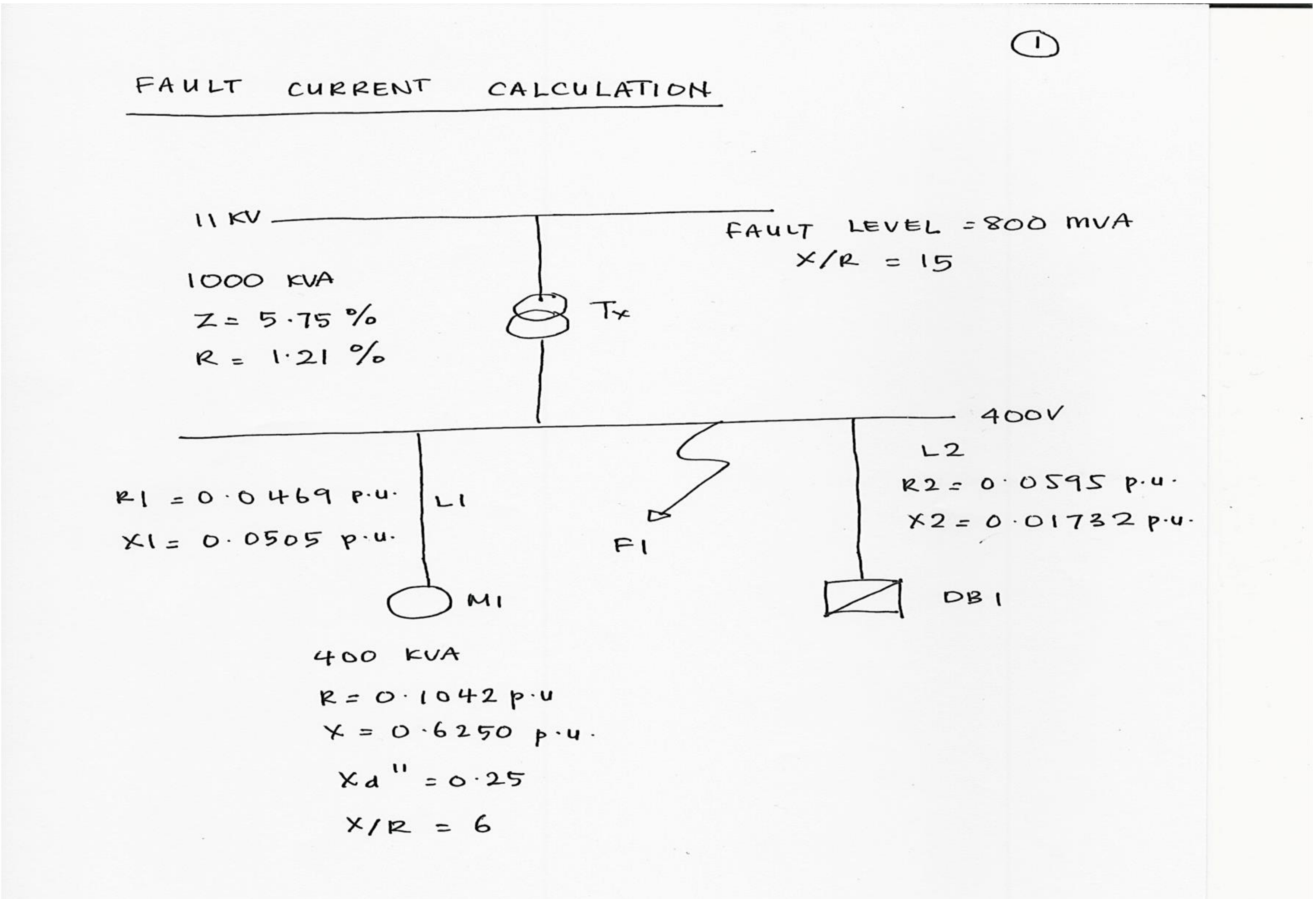
Using the separate R and X diagram, determine the fault current for fault at

(a) the 400V busbar;

(b) the terminals of M2.

Compare the results with those obtained using impedance diagram.

Example – Fault Current Calculation



Example – Fault Current Calculation

Step (2)

(2)

choose $S_{base} = 1$ MVA (based on Tx rating)

$V_{base} = 400$ V (choose fault location)

calculate relevant parameters

$$Z_{utility} = \frac{\text{Base MVA}}{\text{Fault MVA}} = \frac{1 \text{ MVA}}{800 \text{ MVA}}$$

$$= 1.25 \times 10^{-3} \text{ p.u.} \#$$

$$Z_{Tx} = \frac{\% \text{ value}}{100} \times \frac{\text{Base MVA}}{\text{Tx MVA}}$$

$$= \frac{5.75}{100} \times \frac{1 \text{ MVA}}{1 \text{ MVA}} = 0.0575 \text{ p.u.} \#$$

$$Z_{L1} = \sqrt{R_1^2 + X_1^2} = \sqrt{0.0469^2 + 0.0505^2}$$

$$= 0.0689 \text{ p.u.} \#$$

Example – Fault Current Calculation

Motor M1 , 400 KVA (3)

$X_d'' = 0.25$

$X/R = 6$

$$X_{m1} = 0.25 \times \frac{\text{base MVA}}{\text{motor MVA}} = 0.25 \times \frac{1\ \text{MVA}}{0.4\ \text{MVA}}$$

$$= 0.625\ \text{p.u.}$$

$$R_{m1} = \frac{X_{m1}}{6}$$

$$Z_{m1} = \sqrt{\left(\frac{X_{m1}}{6}\right)^2 + X_{m1}^2} = \sqrt{\left(\frac{0.625}{6}\right)^2 + 0.625^2}$$

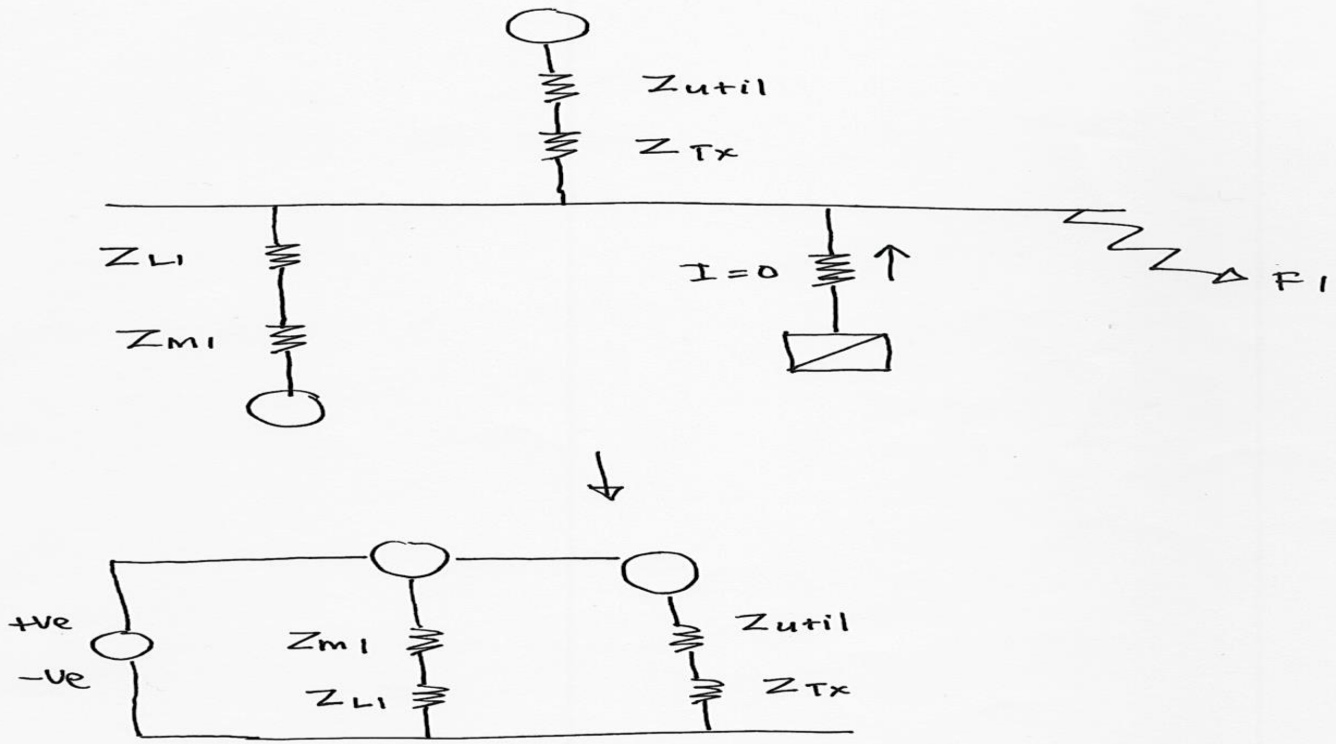
$$= 0.6336\ \text{p.u.}\ \#$$

Step (3) decide location of the fault, where fault current will be calculated

Example – Fault Current Calculation

4

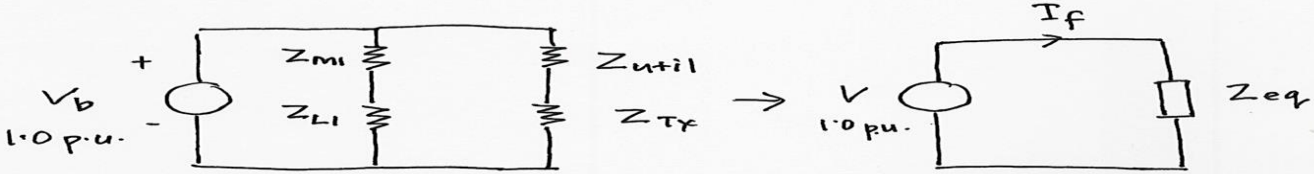
Step (4) construct impedance diagram



* All sources of fault current connected to positive terminal

* s/c becomes negative terminal

5



$$Z_{eq} = (Z_{m1} + Z_{L1}) \,//\, (Z_{util} + Z_{Tx})$$

$$\frac{1}{Z_{eq}} = \frac{1}{Z_{m1} + Z_{L1}} + \frac{1}{Z_{util} + Z_{Tx}}$$

$$= 1.423 + 17.021$$

$$= 18.444$$

$$Z_{eq} = 0.054$$

$$I_f = \frac{V}{Z_{eq}} = \frac{1}{0.054} = 18.518 \text{ p.u.} \;\#$$

$$\text{p.u.} = \frac{\text{Actual}}{\text{Base}} \; ; \quad I_{base} = \frac{S_{base}}{\sqrt{3}\, V_{base}}$$

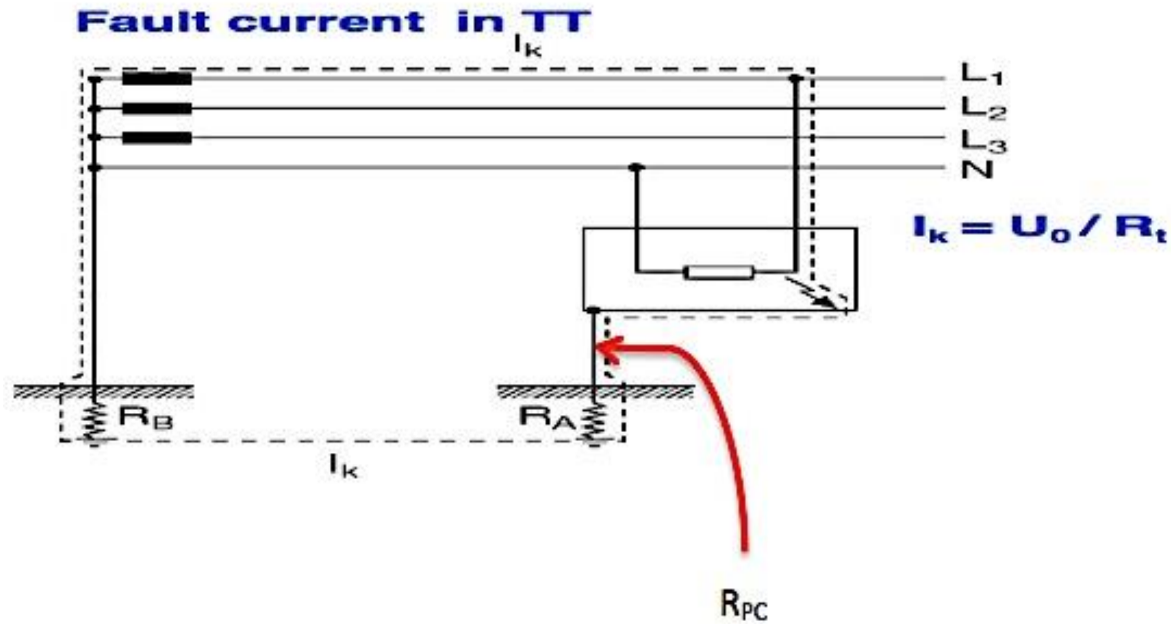
$$= \frac{1 \text{ MVA}}{\sqrt{3} \times 400} = 1443.38 \text{ A}$$

$$\therefore \; I_{fault} = I_{f\,p.u.} \times I_{base} = 18.518 \times 1443.38$$

$$= 26.73 \text{ kA} \;\#$$

Earth Fault Current In TT Earthing System Installation

Earth fault current in TT earthing system (refer to IEC 60364-1, 2005)



$$I_{ef} = I_k = \frac{U_o}{R_t}$$

$$I_{ef} = I_k = \frac{U_o}{R_t}$$

$$R_t = R_A + R_{PC}$$

Where

R_A = Earth electrode resistance

R_t = Total resistance equal to the sum of resistance in earth electrode (R_A) and the protective conductor (R_{PC}) for the exposed conductive part in Ω

Uo = Rated voltage between phase and ground

$I_{ef} = I_k$ = Earth fault current

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