UNIT – 1

Fault Analysis

Unit-01/Lecture-01

INTRODUCTION ABOUT FAULT ANALYSIS –

Type of Faults

There are two types of faults which can occur on any transmission lines; balanced faults and unbalanced faults also known as symmetrical and asymmetrical faults respectively. Most of the faults that occur on power systems are not the balanced three-phase faults, but the unbalances faults. In addition, faults can be categorized as the shunt faults, series faults and simultaneous faults.

Series Faults

Series faults represent open conductor and take place when unbalanced series impedance conditions of the lines are present. Two examples of series fault are when the system holds one or two broken lines . Series faults are characterized by increase of voltage and frequency and fall in current in the faulted phases.

Shunt Faults

The shunt faults are the most common type of fault taking place in the field. They involve power conductors or conductor-to-ground or short circuits between conductors. One of the most important characteristics of shunt faults is the increment the current suffers and fall in voltage and frequency. Shunt faults cab be classified into four categories .

- **Line-to-ground fault**: this type of fault exists when one phase of any transmission lines establishes a connection with the ground either by ice, wind, falling tree or any other incident. 70% of all transmission lines faults are classified under this category.
- **Line-to-line fault**: as a result of high winds, one phase could touch anther phase & line-to-line fault takes place. 15% of all transmission lines faults are considered line-to-line faults
- **Double line-to-ground**: falling tree where two phases become in contact with the ground

could lead to this type of fault. In addition, two phases will be involved instead of one at the line-to-ground faults scenarios. 10% of all transmission lines faults are under this type of faults

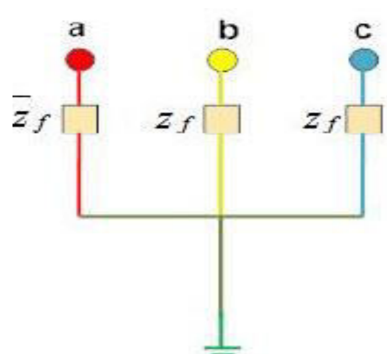
- **Three phase fault**: in this case, falling tower, failure of equipment or even a line breaking and touching the remaining phases can cause three phase faults. In reality, this type of fault not often exists which can be seen from its share of 5% of all transmission lines faults

The first three of these faults are known as asymmetrical faults. Electrical fault is the deviation of voltages and currents from nominal values or states. Under normal operating conditions, power system equipment or lines carry normal voltages and currents which results in a safer operation of the system. But when fault occurs, it causes excessively high currents to flow which causes the damage to equipments and devices. Fault detection and analysis is necessary to select or design suitable switchgear equipments, electromechanical relays, circuit breakers and other protection devices.

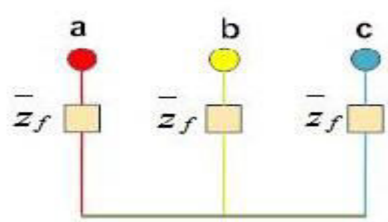
RGPV/ June 2011

1.Symmetrical faults

These are very severe faults and occur infrequently in the power systems. These are also called as balanced faults and are of two types namely line to line to line to ground (L-L-L-G) and line to line to line (L-L-L).



(a) LLLG fault



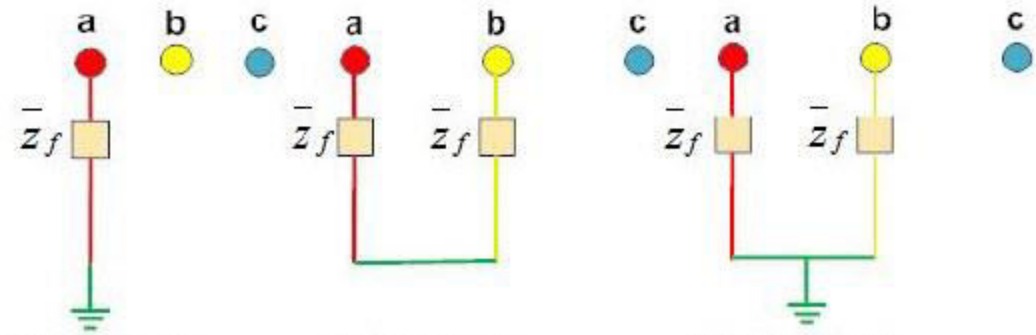
(b) LLL fault

Only 2-5 percent of system faults are symmetrical faults. If these faults occur, system remains balanced but results in severe damage to the electrical power system equipments.

Above figure shows two types of three phase symmetrical faults. Analysis of these fault is easy and usually carried by per phase basis. Three phase fault analysis or information is required for selecting set-phase relays, rupturing capacity of the circuit breakers and rating of the protective switchgear.

2.Unsymmetrical faults

These are very common and less severe than symmetrical faults. There are mainly three types namely line to ground (L-G), line to line (L-L) and double line to ground (LL-G) faults.



(a) LG fault (b) LL fault (c) LLG fault

Line to ground fault (L-G) is most common fault and 65-70 percent of faults are of this type.

It causes the conductor to make contact with earth or ground. 15 to 20 percent of faults are double line to ground and causes the two conductors to make contact with ground. Line to line faults occur when two conductors make contact with each other mainly while swinging of lines due to winds and 5- 10 percent of the faults are of this type.

These are also called unbalanced faults since their occurrence causes unbalance in the system. Unbalance of the system means that that impedance values are different in each phase causing unbalance current to flow in the phases.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Differentiate series and shunt faults.	**RGPV/ June 2013**	7
Q.2	How faults are classified. Explain symmetrical faults.	**RGPV/ June 2011**	7

Unit-01/Lecture-02

Per unit system and advantages

Introduction & Definition

<u>Per Unit System (pu) :</u>

Quantity in Per Unit (pu) = Actual Quantity/Base value of quantity (i)

For example

$S_{pu} = S/ Sb$ $V_{pu} = V/V_b$ $I_{pu} = I/ I_b$ and $Z_{pu} = Z/Z_b$

Generally the 3- phase base volt-ampere Sb or MVA_b and line to line voltage V_b or kV_b are selected for the base value. The numerators (actual values) are phasor quantities or complex values and the denominators (base values) are always real numbers.

$I_b= S_b / \surd 3\ V_b$ (a) and $Z_b = (V_b /\surd 3) / I_b$ (b)

Putting the value of I_b from (a) into (b) ,we get
Or, $Z_b = (V_b)^2 / S_b$

Or, $Z_b = (kV_b)^2 / MVA_b$ (c)

$S_{pu} = V_{pu} * I_{pu}^*$

$V_{pu} = Z_{pu} *I_{pu}$

$S_{L(3\Phi)} = 3V_pI_p^*$

The phase current $I_p= V_p/ Z_p$ Where suffix ‘p’ denote per phase quantity.

$Z_p = 3!V_p!^2 / S_L^*{}_{(3\Phi)}$

$= !V_{L-L!}{}^2 / S^*{}_{L(3\Phi)}$

Now $Z_{pu}= Z_p/ Z_b$

$= !V_{L-L!} / V_b!^2 * S_b / S^*{}_{L(3\Phi)}$

Or, $Z_{pu} = !V_{pu}!^2 /S_L^*{}_{pu}$

<u>Change of Base:</u>

$Z_{pu}^{(old)} = Z/Z_b^{(0ld)} = Z\ S_b^{(old)} / (V_b^{old})^2$ (i)

$Z_{pu}^{(new)} = Z/Z_b^{(new)} = Z\ S_b^{(new)} / (V_b^{new})^2$ (ii)

Dividing (ii) by (i)

$Z_{pu}^{(new)}/ Z_{pu}^{(old)} = [Z\ S_b^{(new)} / (V_b^{new})^2] /[Z\ S_b^{(new)} / (V_b^{new})^2]$

$Z_{pu}^{(new)} = Z_{pu}^{(old)} * (S_b^{(new)} / S_b^{(old)})*(kV_{old}/kV_{new})^2$ (iii)

If the voltage bases are the same then

$Z_{pu}^{(new)} = Z_{pu}^{(old)} S_b^{(new)} / S_b^{(old)}$ (iv)

Advantages of pu system:

1. The per unit system gives a clear idea of relative magnitude of various quantities, such as voltage, current, power and impendence.
2. The pu impedance of equipment of the same general type based on their own ratings fall in a narrow range regardless of the rating of the equipment, where as their impedance in ohms vary greatly in rating.
3. The pu values of impedance, voltage and current of a transformer are the same regardless of whether they are referred to any side of the transformer.
4. The circuit laws are valid in pu systems and the power and voltage equations are simplified since the multiplication factors are eliminated in the pu system.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain advantage and disadvantage of per unit system.	**RGPV/ June 2013,2011**	7
Q.2	Prove that PU impedance of a transformer is same regardless of the side from which it is viewed.	**RGPV/ June 2011**	7

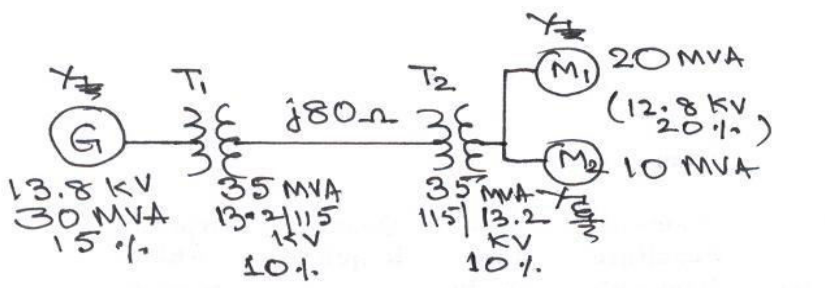
RGPV/JUNE 2013

<u>Problem- 1</u>

A 30 MVA, 13.8 KV, 3-phase generator has a sub transient reactance of 15%. The generator supplies 2 motors through a step-up transformer - transmission line – stepdown transformer arrangement. The motors have rated inputs of 20 MVA and 10 MVA at 12.8 KV with 20% sub transient reactance each. The 3-phase transformers are rated at 35 MVA, 13.2 KV-� /115 KV-Y with 10 % leakage reactance. The line reactance is 80 ohms. Draw the equivalent per unit reactance diagram by selecting the generator ratings as base values in the generator circuit.

Solution:

The one line diagram with the data is obtained as shown in figure



Selection of base quantities:

30 MVA, **13.8** KV in the generator circuit(Given);

The voltage bases in other sections are:

13.8 (115/13.2) = **120.23** KV in the transmission line circuit and

120.23 (13.26/115) = **13.8** KV in the motor circuit.

Calculation of pu values:

XG = j 0.15 pu.

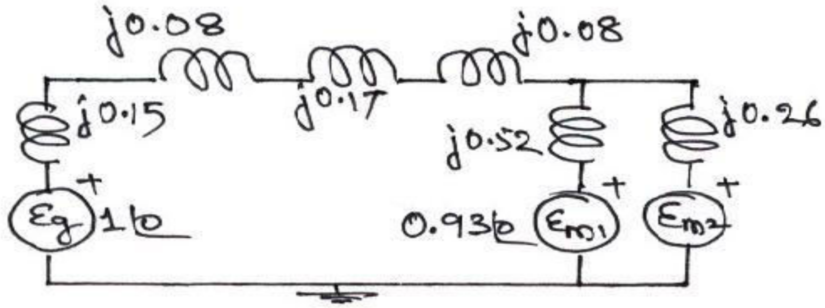
Xm1 = j 0.2 (30/20) (12.8/13.8)2 = j 0.516 pu.

Xm2 = j 0.2 (30/10) (12.8/13.8)2 = j 0.2581 pu.

Xt1 =Xt2 = j 0.1 (30/35) (13.2/13.8)2 = j 0.0784 pu.

Xline = j 80 (30/120.232) = j 0.17 pu.

Eg = 1.0�00 pu; Em1 = Em2 = (6.6/6.31) = 0



Reactance Diagram

<u>Problem-2</u>

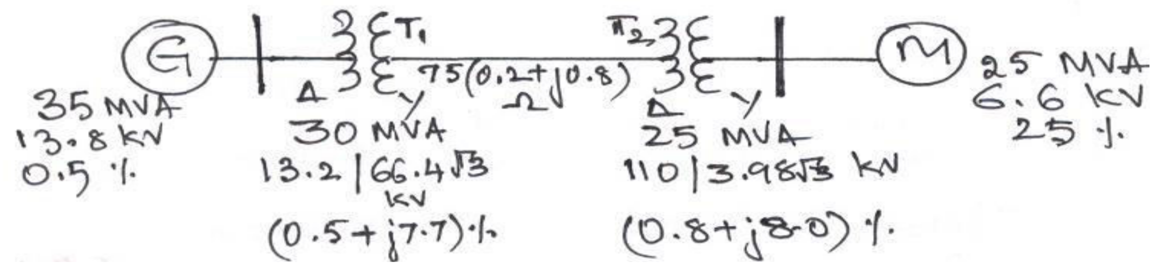
A 33 MVA, 13.8 KV, 3-phase generator has a sub transient reactance of 0.5%. The generator supplies a motor through a step-up transformer - transmission line – step-down transformer arrangement. The motor has rated input of 25 MVA at 6.6 KV with 25% sub transient reactance. Draw the equivalent per unit impedance diagram by selecting 25 MVA (3), 6.6 KV (LL) as base values in the motor circuit, given the transformer and transmission line data as under:

Step up transformer bank: three single phase units, connected ?–Y, each rated 10 MVA,13.2/6.6 KV with 7.7 % leakage reactance and 0.5 % leakage resistance

***Transmission line**:* 75 KM long with a positive sequence reactance of 0.8 ohm/ KM and a resistance of 0.2 ohm/ KM; and

Step down transformer bank: three single phase units, connected ?–Y, each rated 8.33 MVA, 110/3.98 KV with 8% leakage reactance and 0.8 % leakage resistance

Solution:
The one line diagram with the data is obtained as shown in figure



3-phase ratings of transformers:
T1: 3(10) = 30 MVA, 13.2/ 66.43 KV = 13.2/ 115 KV, X = 0.077, R = 0.005 pu.
T2: 3(8.33) = 25 MVA, 110/ 3.983 KV = 110/ 6.8936 KV, X = 0.08, R = 0.008 pu.

Selection of base quantities:
25 MVA, **6.6** KV in the motor circuit (Given); the voltage bases in other sections are: 6.6 (110/6.8936) = **105.316** KV in the transmission line circuit and 105.316 (13.2/115) = **12.09**

KV in the generator circuit.

Calculation of pu values:

Xm = j 0.25 pu; Em = 1.000 pu.

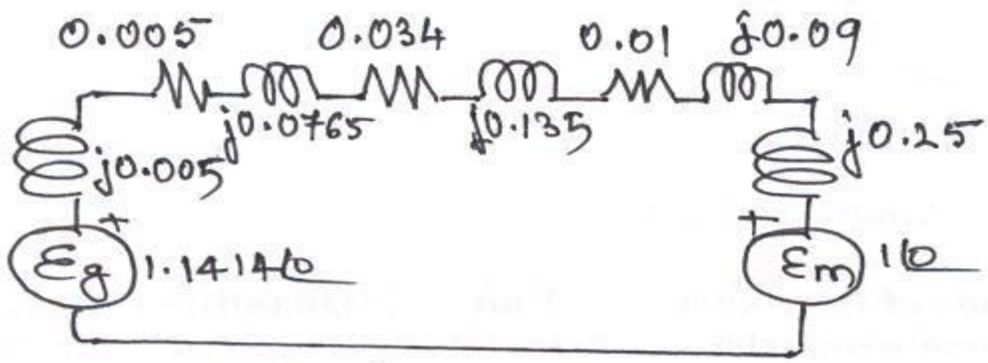
XG = j 0.005 (25/33) (13.8/12.09)2 = j 0.005 pu; Eg = 13.8/12.09 = 1.41400 pu.

Zt1 = 0.005 + j 0.077 (25/30) (13.2/12.09)2 = 0.005 + j 0.0765 pu. (ref. to LV side)

Zt2 = 0.008 + j 0.08 (25/25) (110/105.316)2 = 0.0087 + j 0.0873 pu. (ref. to HV side)

Zline = 75 (0.2+j 0.8) (25/ 105.3162) = 0.0338 + j 0.1351 pu.

Thus the pu reactance diagram can be drawn as shown in figure



Reactance Diagram

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Numerical on Per Unit & Draw the equivalent per unit impedance diagram	**RGPV/ June 2013**	7

Unit-01/Lecture-04

Unsymmetrical or Unbalanced fault analysis:

Faults in a 3 phase system can be single line to ground, double line to ground, line to line or three phase. Power system operation during any of these faults can be analyzed using sequence components. The method of sequence component was discovered by Charles L. Fortes cue in 1918

Fortescue's Theory

Fortescue segregated asymmetrical three-phase voltages and currents into three sets of symmetrical components in 1918 [8]. Fortescue's theorem suggests that any unbalanced fault can be solved into three independent symmetrical components which differ in the phase sequence. These components consist of a positive sequence, negative sequence and a zero sequence.

Positive Sequence Components

The positive sequence components are equal in magnitude and displayed from each other by 120o with the same sequence as the original phases. The positive sequence currents and voltages follow the same cycle order of the original source.

typical counter clockwise rotation electrical system, the positive sequence phasor are shown in FIG The same case applies for the positive current phasors. This sequence is also called the "abc" sequence and usually denoted by the symbol "+" or "1"

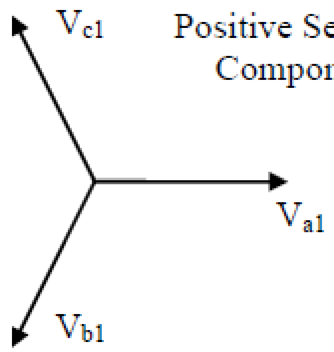
Negative Sequence Components

This sequence has components that are also equal in magnitude and displayed from each other by 120o similar to the positive sequence components. However, it has an opposite phase sequence from the original system. The negative sequence is identified as the "acb" sequence and usually denoted by the symbol "-" or "2" [9].The phasors of this sequence are shown in Fig where the phasors rotate anti- clockwise. This sequence occurs only in case of an unsymmetrical fault in addition to the positive sequence components,

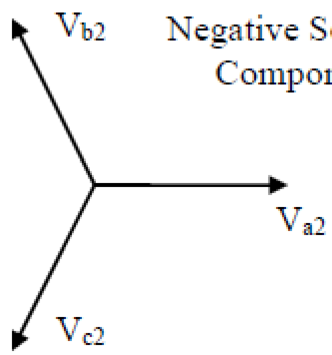
Zero Sequence Components

In this sequence, its components consist of three phasors which are equal in magnitude as before but with a zero displacement. The phasor components are in phase with each other. This is illustrated in Fig 3.3. Under an asymmetrical fault condition, this sequence symbolizes the residual electricity in the system in terms of voltages and currents where a ground or a fourth wire exists. It happens when ground currents return to the power system through any grounding point in the electrical system. In this type of faults, the positive and the negative components are also present. This sequence is known by the symbol "0"

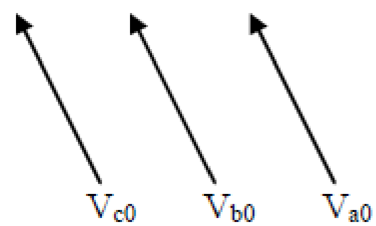
Positive Sequence Components



Negative Sequence Components



Zero Sequence Components



The following are three sets of components to represent three-phase system voltages as positive, negative and zero components:

Positive V_{a1} V_{b1} V_{c1}

Negative V_{a2} V_{b2} V_{c2}

Zero V_{a0} V_{b0} V_{c0}

The addition of all symmetrical components will present the original system phase components V_a, V_b and V_c as seen below:

$$V_a = V_{a0} + V_{a1} + V_{a2}$$
$$V_b = V_{b0} + V_{b1} + V_{b2}$$
$$V_c = V_{c0} + V_{c1} + V_{c2}$$

The “a” operator is defined below:

$$a = 1\angle 0°$$

The following relations can be driven from 3.2:

$$a^2 = 1\angle -120°$$
$$a^3 = 1\angle 0°$$

a) Zero sequence components:

$$V_{a0} = V_{b0} = V_{c0}$$

b) Positive sequence components:

$$V_{b1} = a^2 V_{a1}$$
$$V_{c1} = a V_{a1}$$

c) Negative sequence components:

$$V_{b2} = a V_{a2}$$
$$V_{c2} = a^2 V_{a2}$$

$$V_a = V_{a0} + V_{a1} + V_{a2}$$
$$V_b = V_{a0} + a^2 V_{a1} + a V_{a2}$$
$$V_c = V_{a0} + a V_{a1} + a^2 V_{a2}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$$

$$A = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \qquad \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = A \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} \qquad \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = A^{-1} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$A^{-1} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}$$

These equations can be applied for the phase voltages and currents. In addition, it can express the line currents and the line-to-line voltages of any power system under fault conditions.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Describe the positive sequence, negative sequence and zero sequence networks in power systems. What is its significance?	**RGPV/ June 2010,2012**	7
Q.2	Numerical to determine sequence component of current.	**RGPV/ June 2014**	7

Unit-01/Lecture-05

Sequence Impedance

Positive Sequence Impedance

The impedance offered by the system to the flow of positive sequence current is called **positive sequence impedance** .

Negative Sequence Impedance

The impedance offered by the system to the flow of negative sequence current is called **negative sequence impedance** .

Zero Sequence Impedance

The impedance offered by the system to the flow of zero sequence current is known as **zero sequence impedance** .

In previous fault calculation, Z_1, Z_2 and Z_0 are positive, negative and zero sequence impedance respectively. The **sequence impedance** varies with the type of power system components under consideration:-

1. In static and balanced power system components like transformer and lines, the **sequence impedance** offered by the system are the same for positive and negative sequence currents. In other words, the **positive sequence impedance** and **negative sequence impedance** are same for transformers and power lines.
2. But in case of rotating machines the **positive and negative sequence impedance** are different.
3. The assignment of **zero sequence impedance** values is a more complex one. This is because the three zero sequence current at any point in a electrical power system, being in phase, do not sum to zero but must return through the neutral and /or earth. In three phase transformer and machine fluxes due to zero sequence components do not sum to zero in the yoke or field system. The impedance very widely depending upon the physical arrangement of the magnetic circuits and winding.

- The reactance of transmission lines of zero sequence currents can be about 3 to 5 times the positive sequence current, the lighter value being for lines without earth wires. This is because the spacing between the go and return(i.e. neutral and/or earth) is so much greater than for positive and negative sequence currents which return (balance) within the three phase conductor groups.
- The zero sequence reactance of a machine is compounded of leakage and winding reactance, and a small component due to winding balance).
- The zero sequence reactance of transformers depends both on winding connections and upon construction of core.

Fault Current Calculation in Sequence Domain

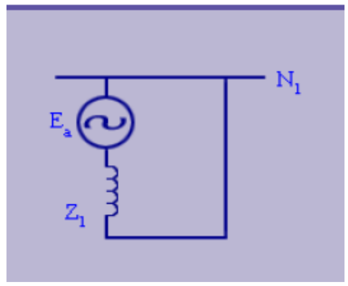
Consider a transposed transmission line connected to an ideal voltage source E. The fault appears at the remote end of transmission line. We now derive sequence network interconnections for different fault types. We begin with a three phase fault.

Three phase fault:

Three phase faults are considered to be symmetrical and hence sequence components are not necessary for their calculation. It can be easily shown that for a three phase
fault, fault currents are balanced with,

$I_2 = I_0 = 0$ and $I_1 = Ia$

Thus, for a Three Phase Fault only PositiveSequence Network is considered. The fault currents are given by the following equations



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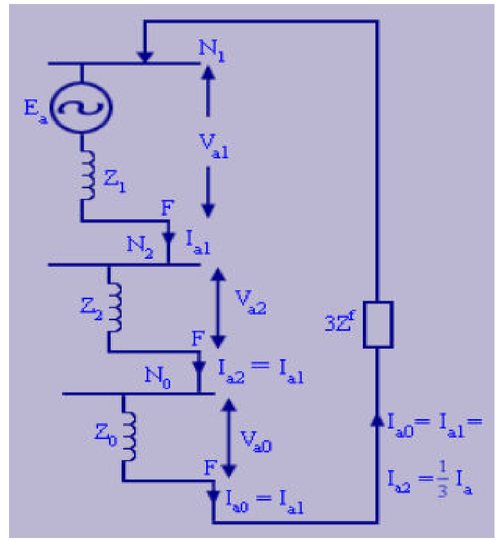
S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Differentiate series and shunt faults.	**RGPV/ June 2013**	7
Q.2	How faults are classified. Explain symmetrical faults.	**RGPV/ June 2011**	7

Unit-01/Lecture-06

LG Fault



Single Line to Ground Fault (SLG):

On an unloaded system (fig 10.7), let there be 'a' phase to ground fault with a fault impedance Z_f. Then, the faulted system is described by,

$I_a = I_f$, $I_b = 0$ and $I_c = 0$. Applying sequence transformation, we get

Thus, $I_0 = I_1 = I_2 = I_a/3$. Let V_f represent the voltage of the transmission line at the receiving end of the line where fault is created.

Further, from equation,

$$\begin{bmatrix} V_f^a \\ V_f^b \\ V_f^c \end{bmatrix} = \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} - \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & & \\ & Z_1 & \\ & & Z_2 \end{bmatrix} \begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix}$$

$$V_0 = -Z_0 I_0$$
$$V_1 = E_a - Z_1 I_1$$
$$V_2 = -Z_2 I_2$$

Eq 11,12,13

Since for SLG fault at phase 'a' $V_{a1} + V_{a2} + V_{a0} = V_a = Z_f I_a$ we can add equations 11, 12 and 13. In addition when we invoke the condition that $I_0 = I_1 = I_2 = I_a/3$ we get, V_f^a

$$Z_f I_a = E_a - Z_1 I_1 - Z_2 I_2 - Z_0 I_0$$

$$Z_f 3I_1 = E_a - (Z_1 + Z_2 + Z_0) I_1$$

$$I_1 = I_2 = I_0 = \frac{E_a}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

The SLG fault can be visualized by a series connection of positive, negative and zero sequence networl with three times the fault impedance.

The positive sequence, negative sequence and Zero sequence fault currents are given by following equations.

$$I_1 = I_2 = I_0 = \frac{E_a}{Z_1 + Z_2 + Z_0}$$ (Solid Fault)

$$I_1 = I_2 = I_0 = \frac{E_a}{Z_1 + Z_2 + Z_0 + 3Z_f}$$ (Fault through impedance Z_f)

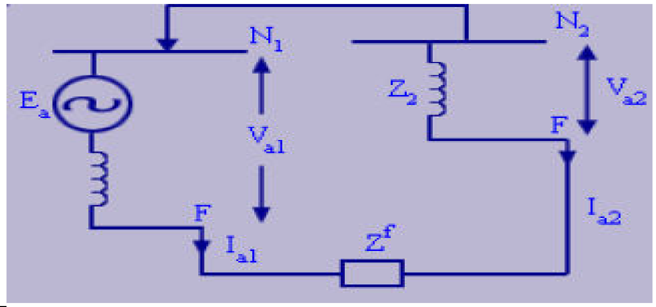
$$I_{aF} = I_1 + I_2 + I_0 = 3I_1 = 3I_2 = 3I_0$$

On similar lines following equations can be derived for LL and LLG faults.

LL Fault

The Zero Sequence Data is not required for this fault.

(solid fault)

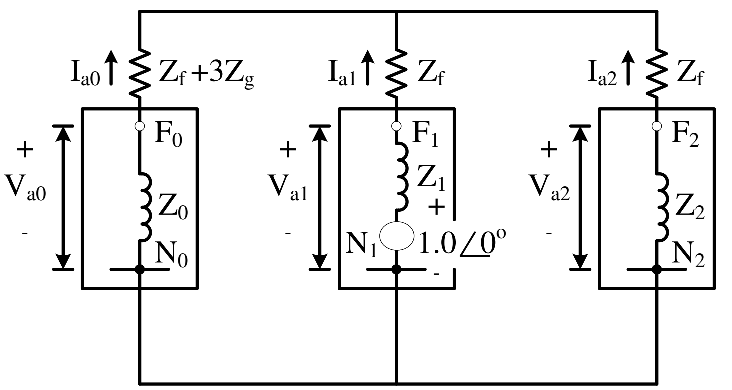


$$I_1 = -I_2 = \frac{E_a}{Z_1 + Z_2}$$

$$I_1 = -I_2 = \frac{E_a}{Z_1 + Z_2 + Z_f}$$ (fault through impedance Z_f)

$$I_F = I_b = -I_c = (a^2 - a)I_1 = -j\sqrt{3}(I_1)$$

LLG Fault



1. Bolted Fault:

- $$I_1 = \frac{E_a}{Z_1 + \dfrac{Z_2 Z_0}{Z_2 + Z_0}}$$
- $$I_2 = -I_1 \frac{Z_0}{Z_2 + Z_0}$$
- $$I_0 = -I_1 \frac{Z_2}{Z_2 + Z_0}$$

2. Fault current through impedance Z_f

- $$I_1 = \frac{E_a}{Z_1 + \dfrac{Z_F}{2} + \dfrac{\left(Z_2 + \dfrac{Z_F}{2}\right)\left(Z_0 + \dfrac{Z_F}{2} + 3Z_{FG}\right)}{Z_2 + Z_0 + Z_F + 3Z_{FG}}}$$
- $$I_2 = -I_1 \frac{\left(Z_0 + \dfrac{Z_F}{2} + 3Z_{FG}\right)}{Z_2 + Z_0 + Z_F + 3Z_{FG}}$$
- $$I_0 = -I_1 \frac{\left(Z_2 + \dfrac{Z_F}{2}\right)}{Z_2 + Z_0 + Z_F + 3Z_{FG}}$$

Fault current in phases b and c:

$I_b = I_0 + a^2 Ia_1 + aIa_2$

$I_c = I_0 + aIa_1 + a^2 Ia_2$

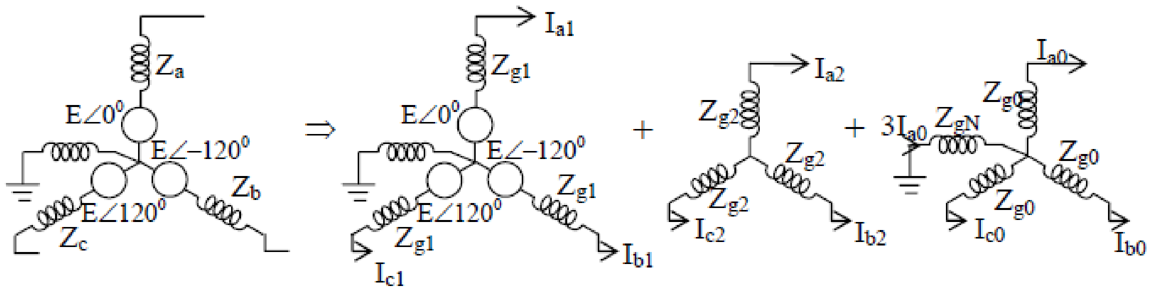
$I_F = I_b + I_c = 3I_0$

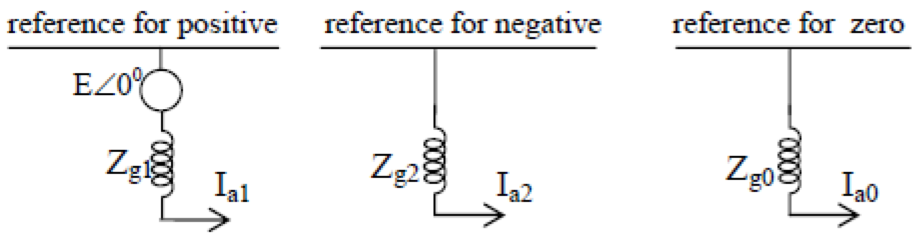
Z_f is fault impedance between the lines, while Z_{FG} is the fault impedance to Ground.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Derive expression for fault current for L-L Fault by sequence component. Draw Sequence networks for LL fault.	**RGPV/ June 2010,2011,2013**	7
Q.2	Prove that for L-G fault, all three sequence network are connected in series.	**RGPV/ June 2013**	7
Q.3	Show the connection of sequence network for (i) L-G Fault (ii) L-L Fault (iii) L-L-G fault on the terminals of unloaded alternator.	**RGPV/ June 2013**	7
Q.4	Numerical on LG fault, L-L fault	**RGPV/ June 2010,2011,2012,2013**	7

Single-line diagrams for network components

Sequence Components Networks of Alternator





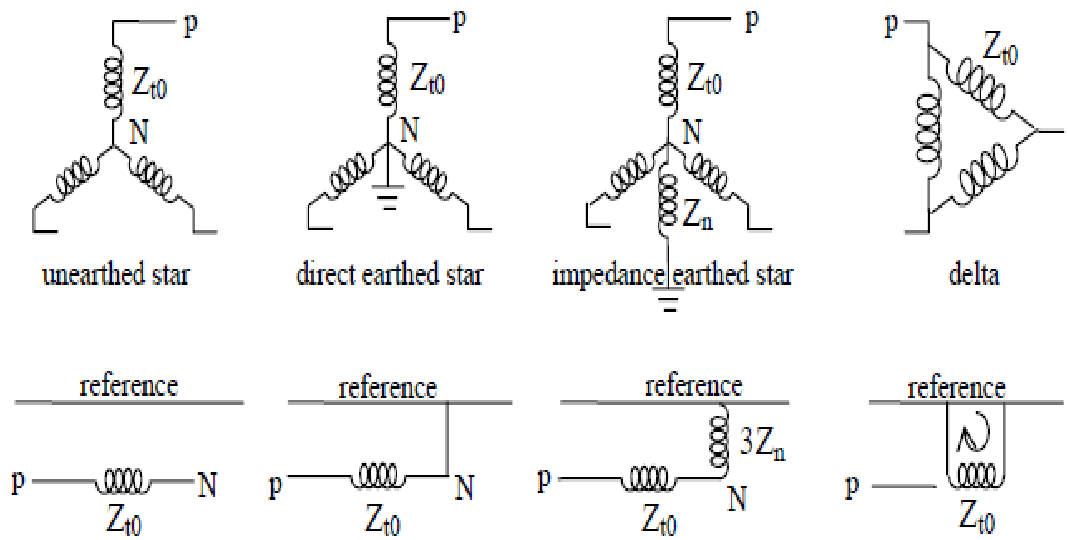
The transmission line (or cable) may be represented by a single reactance in the single-line diagram.

Typically, the ratio of the zero sequence impedance to the positive sequence impedance would be of the order of 2 for a single circuit transmission line with earth wire, about 3.5 for a single circuit with no earth wire or for a double circuit line.

For a single core cable, the ratio of the zero sequence impedance to the positive sequence impedance would be around 1 to 1.25.

Transmission lines are assumed to be symmetrical in all three phases. However, this assumption would not be valid for long un-transposed lines (say beyond 500 km) as the mutual coupling between the phases would be unequal, and symmetrical components then cannot be used.

Zero Sequence Network of Alternator



S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Why a single line to ground fault is more severe than three phase fault. When a short circuit occur at terminal of alternator.	**RGPV/ June 2014,2013**	7
Q.2	How faults are classified. Explain symmetrical faults.	**RGPV/ June 2011**	7

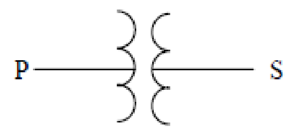
Unit-01/Lecture-08

TRANFORMER

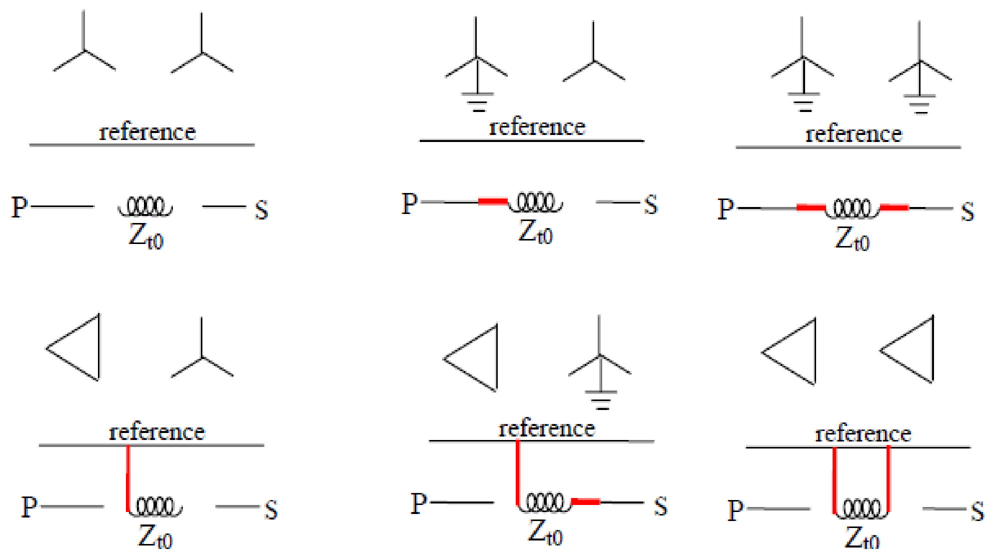
The equivalent circuit of the transformer would be a single reactance in the case of positive sequence and negative sequence for a two-winding transformer, but highly dependant on the winding connection for the zero sequence. The transformer would be a combination of single windings. The magnetising impedance is taken as open circuit for fault studies.

Two-winding transformers

Two winding (primary and secondary), three phase transformers may be categorised into (i) star-star, (ii) earthed star – star, (iii) earthed star – earthed star, (iv) delta – star, (v) delta – earthed star, (vi) delta – delta. There are also zig-zag windings in transformers which has not been dealt with in the following sections.



Zero Sequence Network of Single phase Transformer



Considering the transformer as a whole, it can be seen that the single-line diagrams indicate the correct flow of the zero-sequence current from primary to secondary.

An unearthed star winding does not permit any zero sequence current to flow so that it could be represented in the single line diagram by a 'break' between the line terminal and the winding.

If the star point is solidly earthed, it could be represented by a solid connection across the break and for an earth connection through an impedance, by 3 times the earthing impedance across the break.

In the case of a delta winding, no current would flow from the line, but a current is possible in the winding depending on the secondary winding connections. This could be represented by a break in connection with the line but with the winding impedance being connected to the reference.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Draw the zero sequence networks for various connection of 3- phase transformer.	RGPV/ June 2012,2014	7

Unit-01/Lecture-09

Fault Level Calculations

In a power system, the maximum the fault current (or fault MVA) that can flow into a zero impedance fault is necessary to be known for switch gear solution. This can either be the balanced three phase value or the value at an asymmetrical condition. The Fault Level defines the value for the symmetrical condition. The fault level is usually expressed in MVA (or corresponding per-unit value), with the maximum fault current value being converted using the nominal voltage rating.

MVAbase =√ 3 . Nominal Voltage(kV) . Ibase (kA)

MVAFault =√ 3 . Nominal Voltage(kV) . Isc (kA)

where

MVA_{Fault} – Fault Level at a given point in MVA

I_{base} – Rated or base line current

I_{sc} – Short circuit line current flowing in to a fault

The per unit value of the Fault Level may thus be written as

$$Fault\ Level = \frac{\sqrt{3}\ .\ \text{Nominal Voltage}\ .\ I_{sc}}{\sqrt{3}\ .\ \text{Nominal Voltage}\ .\ I_{base}} = \frac{\sqrt{3}I_{sc}}{\sqrt{3}I_{base}} = I_{sc,pu} = \frac{V_{Nominal,pu}}{Z_{pu}}$$

The per unit voltage for nominal value is unity, so that

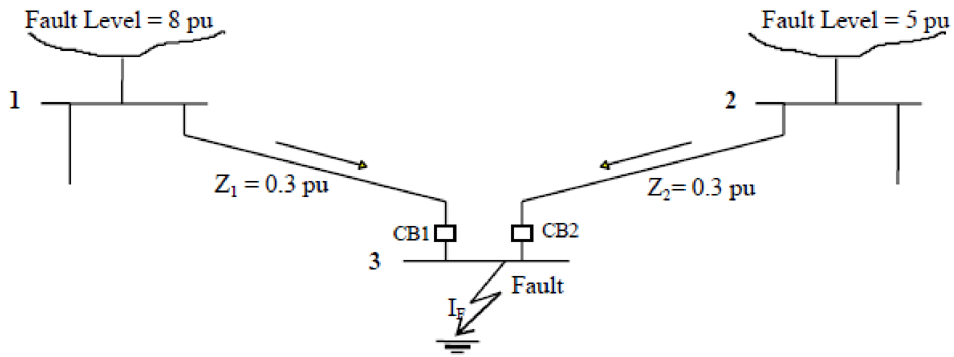
$$Fault\ Level\ (pu) = \frac{1}{Z_{pu}},$$

$$Fault\ MVA = Fault\ Level\ (pu) \times MVA_{base} = \frac{MVA_{base}}{Z_{pu}}$$

The Short circuit capacity (SCC) of a busbar is the fault level of the busbar. The strength of a busbar (or the ability to maintain its voltage) is directly proportional to its SCC. An infinitely strong bus (or Infinite bus bar) has an infinite SCC, with a zero equivalent impedance and will maintain its voltage under all conditions.

Magnitude of short circuit current is time dependant due to synchronous generators. It is initially at its largest value and decreasing to steady value. These higher fault levels tax Circuit Breakers adversely so that current limiting reactors are sometimes used.

The Short circuit MVA is a better indicator of the stress on CBs than the short circuit current as CB has to withstand recovery voltage across breaker following arc interruption. The currents flowing during a fault is determined by the internal emfs of machines in the network, by the impedances of the machines, and by the impedances between the machines and the fault.



Current Limiting Reactors in Power System limiting Short Circuit Currents

The current limiting reactors are used to perform the following functions:

Functions of Reactors:

- Protective reactors are used to reduce the flow of short circuit so as to protect the apparatus from excessive mechanical stresses and from the overheating and thus protect the system as whole
- Protective reactors are used to reduce the magnitude of the voltage disturbances caused by the short circuits
- Reactors also localize the fault by limiting the current that flows into the fault from other healthy feeders or parts of the system, thereby avoiding the fault from spreading. This increases the chances of continuity of the supply
- Reactors reduce the duty imposed on the switching equipment during the short circuits to be within economical ratings. So they are used (1) In the systems where extensions have been made and the circuit breaker rupturing capacities have become inadequate (2) In large systems, so as to limit the short circuit MVA to match with the rupturing capacity of the circuit breakers

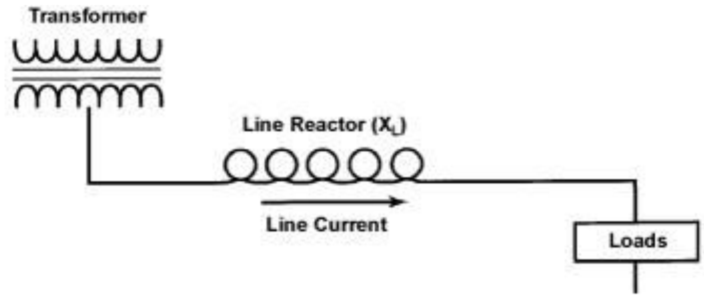
In general reactors should be placed at the points in the network where they can be most effective. Very few occasions arise where it is necessary or desirable to introduce reactance in the generator circuits as modern alternators have sufficient inherent reactance to enable them to withstand the forces of the short circuit. However when older machines operate in parallel with the older machines, a case may arise where the added reactance in the circuits of the older machines will provide protection and give them a roughly the same characteristics as the new machines. Reactors installed in the individual feeder circuits are not an economical proposition as often a considerable number of feeders are involved. Generally reactors are employed so that a group of feeders where the insertion of additional reactance is necessary to protect the group of circuit breakers of rupturing capacity. Similarly interconnection between the new and the old sections of the installation may profitably include a reactor and thus eliminate the need of replacing old circuit breakers.

WHAT IS A LINE REACTOR?

A 3-phase Line Reactor is a set of three (3) coils (also known as windings, chokes or inductors) in one assembly. It is a series device, which means it is connected in the supply line such that all line current flows through the reactor, as shown below.

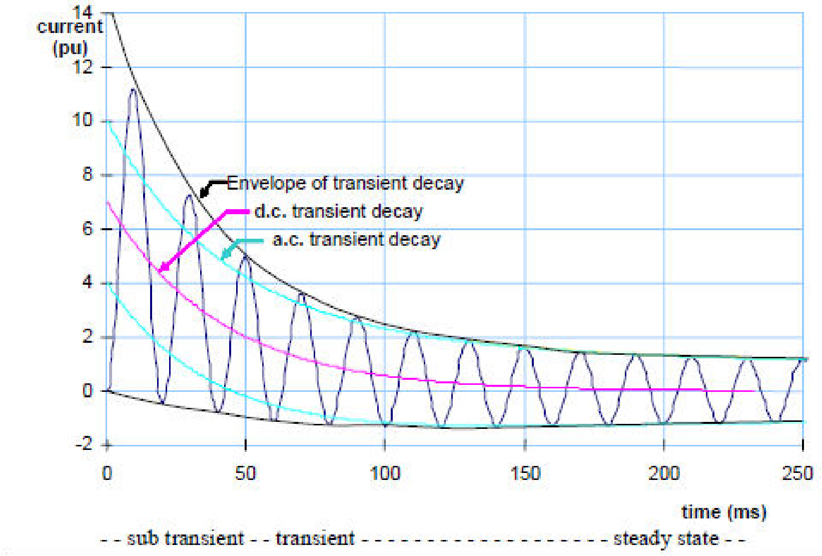
Line Reactors are current-limiting devices and oppose rapid changes in current because of their impedance. They hold down any spikes of current and limit any peak currents. This resistance to change is measured in ohms as the Line Reactor's AC impedance (X_L) and is calculated as follows:

$X_L = 2 \pi f L$ (ohms), where: f = frequency



S.NO	RGPV QUESTIONS	Year	Marks
Q.1	What is the function of current limiting reactor Classify them on the basis of type and location.	**RGPV/ June 2013**	7
Q.2	Numerical on short circuit fault	**RGPV/ June** 2010,**2011**	7

Fault Currents in synchronous machines



As mentioned earlier, the currents flowing in the power system network during a fault is dependant on the machines connected to the system. Due to the effect of armature current on the flux that generates the voltage, the currents flowing in a synchronous machine differs immediately after the occurrence of the fault, a few cycles later, and under sustained or steady-state conditions.

As mentioned earlier, the currents flowing in the power system network during a fault is dependant on the machines connected to the system. Due to the effect of armature current on the flux that generates the voltage, the currents flowing in a synchronous machine differs immediately after the occurrence of the fault, a few cycles later, and under sustained or steady-state conditions.

Further there is an exponentially decaying d.c. component caused by the instantaneous value at the instant of fault occurring. These are shown in figure 2.8.

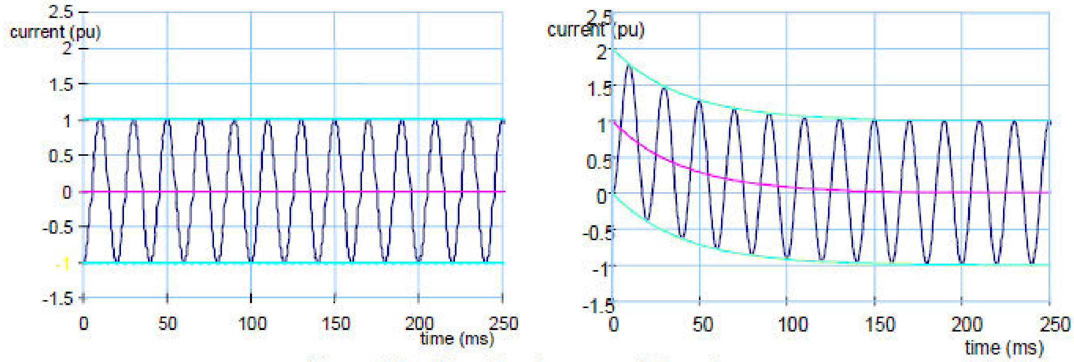


Figure 2.9a & b – Steady state and Transient current

Figure 2.9a and 2.9b show the steady state current waveform, and the transient waveform of a simple R-L circuit, to show the decay in the d.c. component. In addition to this, in the synchronous machine, the magnitude of the a.c. current peak also changes with time as shown in figure 2.9c, with the unidirection component of the transient waveform removed.

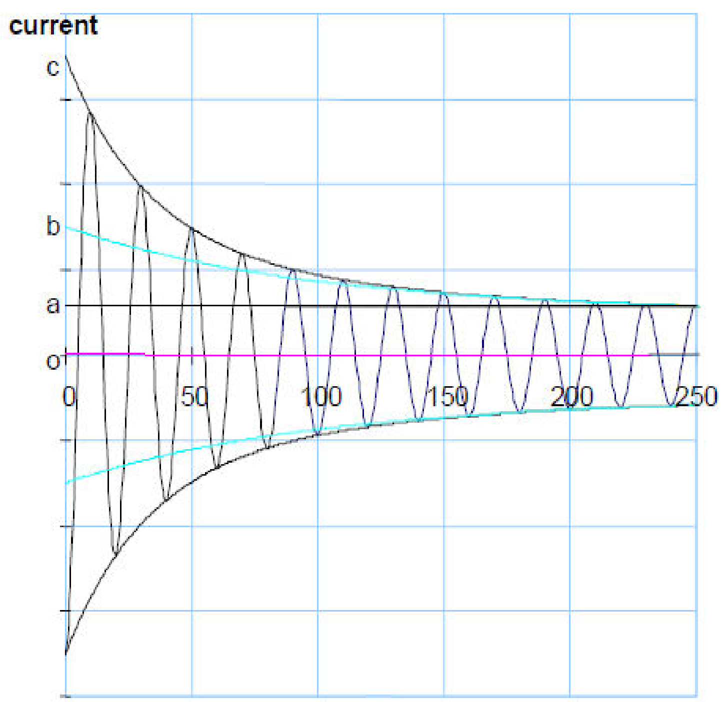


Figure 2.9c–Synchronous machine transient

Due to the initial low back emf at the instant of fault resulting in high current, the effective impedance is very low. Even when the d.c. transient component is not present, the initial current can be several times the steady state value. Thus three regions are identified for determining the reactance. These are the sub-transient reactance x_d'' for the first 10 to 20 ms of fault, the transient reactance x_d' for up to about 500 ms, and the steady state reactance x_d (synchronous reactance).

. The sub-transient must usually be used in fault analysis.

oa - peak value of steady state short-circuit current

ob - peak value of transient short-circuit current

oc - peak value of sub-transient short-circuit current

The r.m.s. values of current are given by

$$|I| = \frac{oa}{\sqrt{2}} = \frac{|E|}{X_d}$$

$$|I'| = \frac{ob}{\sqrt{2}} = \frac{|E|}{X_d'}$$

$$|I''| = \frac{oc}{\sqrt{2}} = \frac{|E|}{X_d''}$$

	subtransient reactance	transient reactance	steady-state reactance
turbo-generator	10-20 %	15-25 %	150-230 %
salient-pole generator	15-25 %	25-35 %	70-120 %

The typical generator reactance values are given above for reference.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Faults Currents in Synchronous generator	**RGPV/ June 2013**	7
Q.2	How faults are classified. Explain symmetrical faults.	**RGPV/ June 2011**	7

Important Model Questions for Unit Test and MID SEM Examinations

Switchgear and protection (EX-603)

(Strictly Based on RGPV EXAMINATION)

Unit-1

1. Draw the zero sequence networks for various connection of 3- phase transformer.
   RGPV/ June 2014, 2012
2. Derive the expression for fault current for L-G fault by symmetrical component method. Also draw the connection for sequence network for L-G fault.
   RGPV/ June 2014. 2013,2011
3. Numerical to determine sequence component of current. **RGPV/ June 2014**
4. Why a single line to ground fault is more severe than three phase fault. When a short circuit occur at terminal of alternator. **RGPV/ June 2014**
5. Distinguish between symmetrical and asymmetrical fault. Prove that for L-G fault, all three sequence network are connected in series. **RGPV/ June 2013**
6. Show the connection of sequence network for (i) L-G Fault (ii) L-L Fault (iii) L-L-G fault on the terminals of unloaded alternator. **RGPV/ June 2013,2012**
7. Numerical on LG fault, L-L fault **RGPV/ June 2013,2012, 2011,2010**
8. Explain advantage and disadvantage of per unit system. **RGPV/ June 2013,2011**
9. Differentiate series and shunt faults. **RGPV/ June 2013**
10. Derive expression for fault current for L-L Fault by sequence component. Draw Sequence networks for LL fault. **RGPV/ June 2013, 2011, 2010**
11. Prove that PU impedance of a transformer is same regardless of the side from which it is viewed.
    RGPV/ June 2011
12. How faults are classified. Explain symmetrical faults. **RGPV/ June 2011**
13. Describe the positive sequence, negative sequence and zero sequence networks in power systems. What is its significance? **RGPV/ June 2012,2010**
14. What is the function of current limiting reactor Classify them on the basis of type and location.
    RGPV/ June 2012
15. Numerical on short circuit faults. **RGPV/ June 2011,2010**