2.1 Introduction

A fault in a power system is any failure which interfere with the normal operation of the system. Short circuit between lines, insulation failure of equipments or flashover of lines initiated by a lightning stroke are the main causes for these faults.

The faults occurring in a power system can be broadly classified into symmetrical faults and unsymmetrical faults.

In the case of symmetrical faults (a symmetrical short circuit involving all the three phases), the fault current is the same in all the three phases and hence the system remains balanced even after fault occurrence. Therefore, the symmetrical fault conditions can be conveniently analyzed on a single phase basis. On the other hand, the fault current is not the same in all three phases in the case of an unsymmetrical fault. Hence, such fault conditions cannot be analyzed on a single phase basis. Special tools line symmetrical components are used in such situations.

This chapter is concerned for the study of symmetrical faults short circuits. A knowledge of expected system short circuit is essential in the economic planning & design of the power system. These studies provides the engineer with information by which he can design to assure the prompt disconnection of faulted equipments with a minimum damage and a minimum of disturbance to the operation of the remaining system. We start with the discussion of the transients that occur in three phase synchronous machine due to a sudden short circuit at its terminals, when the machine is on no-load and on constant excitation.

2.2 Symmetrical short circuit of a synchronous Generator (on No-load)

A synchronous generator consists of an armature winding wound symmetrically for all the three phases on the stator and a field winding wound on the rotor. Also on the field structure are placed the damper windings which are shorted on themselves at both ends. The field winding is excited by direct current. When the rotor rotates, the armature winding(being stationary) is cut by the magnetic flux of the field winding, hence three phase alternating emfs are induced in the armature windings. In turn, alternating three phase currents are set up in these windings. These produces a rotating magnetic field which rotates at synchronous speed in the air gap.

The field structure rotates at synchronous speed along with the rotating magnetic field produced by the armature winding. During normal operating conditions, the field produced by the armature currents will be relatively stationary with respect to the field and damper windings. Hence the rotating magnetic field will not induce any voltages and currents in the field and damper windings during normal operating conditions.

But, when the alternator suddenly undergoes a symmetrical short circuit under constant excitation, the short circuited armature current changes from zero to a very high value in all the three phases. The armature current will have an a.c component as well as an offset d.c component in each of the three phases. A good way to analyse the effect of the three phase fault is to take an oscillogram of the current in one of the phases upon the occurrences of such a fault. The offset d.c component of the short circuit current will be different in each phase and hence is accounted separately on an empirical basis.

In the absence of the offset d.c component, the symmetrical short circuit current in any phase will be as shown in fig 2.1. This current will be similar in all the three phases except for a phase angle difference of 120 degree electrical.

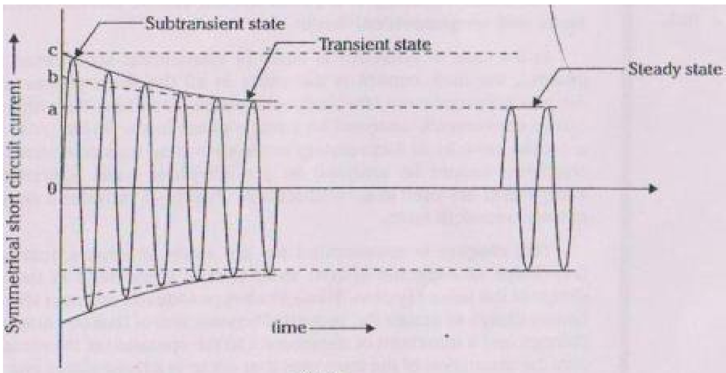

Fig. 2.1

The armature current during symmetrical short circuit can be divided into three regions namely the subtransient, transient, and steady state region. We account for the gradual decrease of current in the following paragraphs.

Under steady state short circuit conditions, the armature reaction of a synchronous generator produces a demagnetizing flux. This effect is represented as a reactance called armature reaction reactance X_a. The sum of leakage reactance X_l and the armature reactance X_a is called the synchronous reactance X_s. In case of salient pole machines the synchronous reactance is called direct axis reactance and denoted by X_d. Neglecting the armature resistance, the steady state short circuit model of an alternator on a per phase basis will be as shown in fig. 2.2

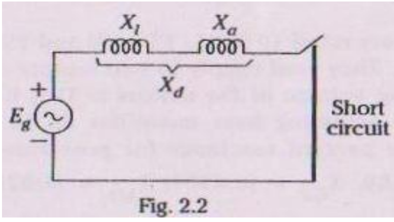

Fig. 2.2

In this case, the direct axis synchronous reactance is given as

$X_d = X_l + X_a$ 2.1

At the instant of short circuit, the offset d.c current appears in all the three phase of the stator. This transient d.c current will induce currents in the rotor field winding and damper winding by transformer action. The induced currents in these two windings will be in such a direction as to oppose the change of magnetic flux produced by the armature. This effect can be represented by two reactances in parallel with X_a as shown in fig 2.3. Here X_f is the reactance of the field winding and X_{dw} the reactance of the damper winding.

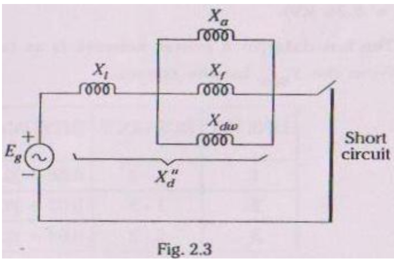

Fig. 2.3

The combined effect of all the three reactances is to reduce the total reactance of the machine and so the short circuit current is very large in this period called as the sub transient state.

The total reactance of the machine under this condition is called as the sub transient reactance X_d'' and is given by

$X_d'' = X_l + (1 / ((1/ X_a) + (1/ X_f) + (1/ X_{dw})))$ 2.2

The induced currents in both the field and damper windings decrease exponentially depending on their time constants (=L/R). The time constant of damper winding is much less than the time constant of field winding. Hence the induced currents in the damper winding dies very fast within the first few cycles effectively X_{dw} becomes open circuited and the resulting reactance is called as transient reactance X_d'. The transient state model of the alternator is shown in fig 2.4

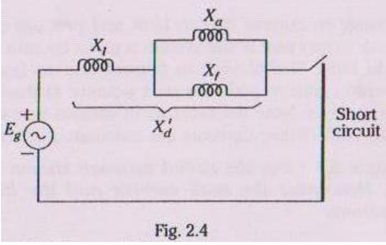

Fig. 2.4

From the figure, it can be observed that

$X_d' = X_l + (1 / ((1/X_a) + (1/X_f)))$ 2.3

The effect of field winding current will also die out in a short time depending on the time constant of the field winding. This effect is equivalent to open circuited X_f and thus the armature regains its normal synchronous reactance Xd. (fig 2.2)

From equations 2.1, 2.2 & 2.3, we can observe that the subtransient reactance of the machine is the smallest and steady state reactance of the machine is highest among the reactances. Therefore, $X_d'' < X_d' < X_d$.

The various reactances of the synchronous machine can be estimated from the oscillogram shown in fig 2.1. The envelope of the current wave during transient period can be extrapolated backwards in time to meet the y-axis at point-b. Similarly the envelope of the current wave during steady state period can be extrapolated backwards in time to meet the y-axis at point a.

Let

$|I|$=RMS value of steady state current

$|I'|$=RMS value of transient current excluding d.c. component

$|I''|$=RMS value of subtransient current excluding d.c. Component

from the oscillogram of fig 2.1, we get

$|I| = oa/\sqrt{2}$; $|I'| = ob/\sqrt{2}$; $|I''| = oc/\sqrt{2}$

therefore,

$X_d'' = E_g/|I''| = E_g/(oc/\sqrt{2})$ 2.4

$X_d' = E_g/|I'| = E_g/(ob/\sqrt{2})$ 2.5

$X_d = E_g/|I| = E_g/(oa/\sqrt{2})$ 2.6

2.3 Short circuit of a loaded synchronous Generator

Our analysis all along had been for a synchronous generator operating on no-load. In practice before short-circuit, the generator would mostly be on load. The determination of short circuit currents when the machine is on load involves the determination of internal voltages behind subtransient, transient and steady state reactances. These are the voltages obtained by adding vectorially the subtransient,

transient and steady state reactance voltage drops respectively due to the load current I_L to the terminal voltage V. Hence

$E_g''=V+I_L(jX_d'')$ 2.7

$E_g'=V+I_L(jX_d')$ 2.8

$E_g=V+I_L(jX_d)$ 2.9

The circuit models of the synchronous generator under the aforesaid conditions is as shown in fig 2.5a, 2.5b and 2.5c.

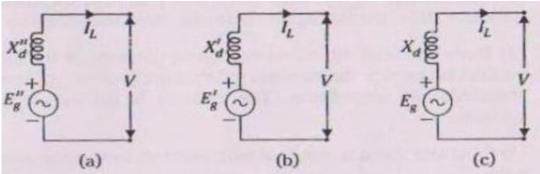

Fig. 2.5

The synchronous motors have internal emfs and reactances similar to that of a generator except that the current direction is reversed. During short circuit conditions these can be replaced by similar circuit models as shown in fig 2.5 except that the voltage behind the subtransient, transient and steady state reactance is given by

$E_m''=V-I_L(jX_d'')$ 2.10

$E_m'=V-I_L(jX_d')$ 2.11

$E_m=V-I_L(jX_d)$ 2.12

2.4 Analysis of three phase symmetrical faults

The symmetrical fault can be analysed on single phase basis using reactance diagram or by using per unit reactance diagram. The symmetrical fault analysis has to be performed separately for subtransient, transient and steady state conditions of the fault, because the reactances and internal emfs of the synchronous machines will be different in each state. Once the per unit reactance diagram of the power system is formed for a particular state (subtransient/transient/steady state) of fault condition, then the currents and voltages in the various parts of the system can be determined by any one of the following method:

i)Using Kirchoff's laws

ii)Using Thevenin's theorem.

iii)By forming the bus impedance matrix.

The first two methods are discussed in this chapter.

Symmetrical fault analysis using Kirchoff's laws.

The following procedure can be followed to directly calculate voltages and currents during symmetrical fault condition in a power system, using Kirchoff's laws,

i) Select appropriate base values and determine the prefault condition reactance diagram of the given power system. (The prefault condition reactance diagram is separately formed for subtransient, transient and steady state condition of the fault).

ii) Calculate the internal emfs of the synchronous machines and the prefault voltages at the fault point using prefault current. (load current).

Note: If the power system is unloaded (i.e if there is no prefault current), then the prefault voltage at the fault point is 1 p.u. Also the internal emfs for subtransient and transient state are the same as steady state induced emf.

iii) Draw the fault condition reactance diagram of the system. This diagram is same as prefault reactance diagram except that the fault is represented by a short circuit or by the specified fault impedance. The currents in this reactance diagram are fault condition currents.

4) Calculate the p.u value of the fault currents in various parts of the system and at the fault point.

5) The actual values of the fault currents are obtained by multiplying the p.u values by the respective base currents.

Symmetrical fault analysis using Thevenin's theorem.

The following procedure can be followed to calculate the voltages and currents during symmetrical fault using Thevenin's theorem.

1) Select appropriate base values and determine the prefault condition reactance diagram of the given power system.

2) Calculate the prefault Thevenin's voltage at the fault point using the prefault current(load current). If the system is unloaded, then the prefault voltage is 1p.u.

3) Determine the Thevenin's impedance of the system at the fault point by shorting all voltage sources.

4) Draw the Thevenin's equivalent at the fault point. Then the p.u value of fault current is given by $I_f=V_{TH}/(Z_{TH}+Z_f)$. Multiplying the p.u value by the base value gives the actual value of the fault current. Here, Z_f is the fault impedance of the system. For a solid three phase short circuit, $Z_f=0$

5) The fault current in other parts of the network are determined from the knowledge of change in current due to fault and prefault current. The fault current (i.e post fault current) in any part of the system is given by sum of prefault current

and change in current due to fault. The change in current due to fault can be estimated by connecting the Thevenin's source with reversed polarity at the fault. Replace all other sources by zero values sources. Now the currents in various part of the system are the change in currents due to fault. These currents are calculated using any conventional technique.

Example 2.1:

For the radial network shown in fig. 2.6, a three phase fault occurs at F. Determine the fault current and the line voltage at 11kV bus under fault conditions.

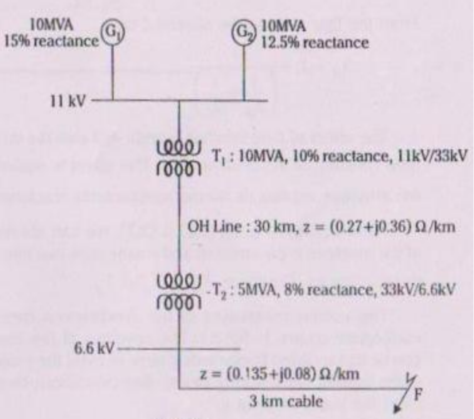

Fig. 2.6

Solution:

Base values:

Let us choose,

base MVA=100

base kV in the overhead line=33

we calculate,

base kV on the generator side=33×11/33= 11

base kV on the cable side=33×6.6/33= 6.6

Reactance of generator G_1:

$X_{G1,\ new} = X_{G1,\ old} \times ((MVA)_{B,\ new} / (MVA)_{B,\ old}) \times ((kV)^2_{B,\ old} / (kV)^2_{B,\ new})$

$= j0.15 \times (100 / 10) \times (11^2 / 11^2)$

$= j\ 1.5$ p.u

Reactance of generator G_2:

$X_{G2,\ new} = X_{G2,\ old} \times ((MVA)_{B,\ new} / (MVA)_{B,\ old}) \times ((kV)^2_{B,\ old} / (kV)^2_{B,\ new})$

$= j0.125 \times (100 / 10) \times (11^2 / 11^2)$

$= j\ 1.25$ p.u

Reactance of transformer T_1: (calculated secondary side it)HV or HT

$X_{T1,\,new} = X_{T1,\,old} \times ((MVA)_{B,\,new} / (MVA)_{B,\,old}) \times ((kV)^2_{B,\,old} / (kV)^2_{B,\,new})$

$= j0.1 \times (100 / 10) \times (33^2 / 33^2)$

$= j\,1.0$ p.u

Reactance of transformer T_2: (calculated primary side of it)HV or HT

$X_{T2,\,new} = X_{T2,\,old} \times ((MVA)_{B,\,new} / (MVA)_{B,\,old}) \times ((kV)^2_{B,\,old} / (kV)^2_{B,\,new})$

$= j0.08 \times (100 / 5) \times (33^2 / 33^2)$

$= j\,1.6$ p.u

Impedance of O.H line:

$Z_{O.H,p.u} = Z_{O.H}(\Omega) \times (MVA)_{B,new} / (kV)^2_B$

$= (30 \times (0.27+j0.36)) \times 100 / 33^2$

$= 0.744+j0.99$ p.u

Impedance of cable:

$Z_c = Z_c(\Omega) \times (MVA)_{B,new} / (kV)^2_B$

$= (3 \times (0.135+j0.08)) \times 100 / 6.6^2$

$= 0.93+j0.55$ p.u

the prefault impedance diagram of the given system is as shown in fig. 2.7

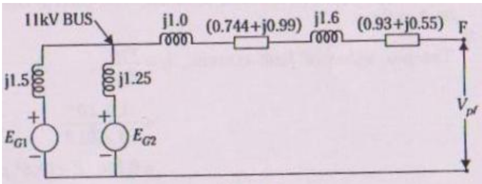

Fig. 2.7

Since the system is unloaded prior to occurrence of fault, V_{pf} is assumed as 1p.u. Thevenin's theorem is employed here to find the fault current.

$V_{TH} = V_{pf} = 1$p.u

To find Z_{TH}:

Shorting the generated voltages, we obtain the equivalent circuit of the system prior to the fault as in fig. 2.8

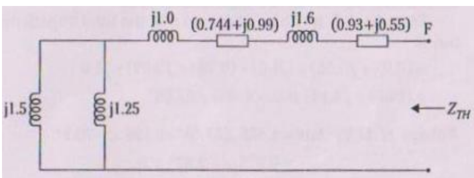

Fig. 2.8

$Z_{TH} = ((j1.5 \times j1.25) / (j1.5+j1.25)) + (j1.0+0.744+j0.99+j1.6+0.93+j0.55) = 1.674+j4.82 = 5.1\angle 70.8°$ p.u

Thus, the Thevenin's equivalent circuit of the system with respect to fault point is as shown if fig 2.9

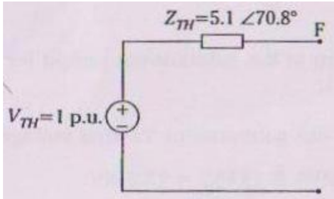

Fig. 2.9

Now short circuiting the terminals of the Thevenin's equivalent circuit as shown in fig. 2.10 is equivalent to the fault condition. The current flowing through the short circuit is the fault current.

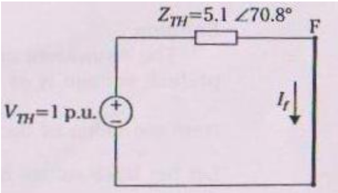

Fig. 2.10

The p.u value of fault current, $I_f=V_{TH}/Z_{TH}=(1.0\angle 0°) / (5.1\angle 70.8°) = 0.196 \angle -70.8°$ p.u

The base current,

I_b= (1000 × base power) / (√3 × base voltage)= (1000×100) / (√3 × 6.6) = 8747 A

therefore,

absolute value of fault current , I_f= 0.196 ∠-70.8° × 8747 = 1714 ∠-70.8° A

To find voltage at 11 kV bus during fault:

From fig 2.7, it can be observed that the total impedance between point F and 11kV bus is,

=(0.93+j0.55)+j1.6+(0.744+j0.99)+j1.0

=(1.674+j4.14)p.u

=4.466∠67.98°

Voltage at 11kV bus=4.466∠67.98°×0.196 ∠-70.8°=0.875∠-2.82° p.u

The absolute value of the voltage at 11kV bus=0.875∠-2.82°×11=0.9625∠-2.82°kV

Example 2.2:

A synchronous generator and motor are rated for 30,000kVA, 13.2kV and both have subtransient reactance of 20%. The line connecting them has a reactance of 10% on the base of machine ratings. The motor is drawing 20,000kW at 0.8p.f leading. The terminal voltage of the motor is 12.8kV. When a symmetrical three phase fault occurs at motor terminals, find the subtransient current in generator, motor and at the fault point.

Solution:

the equivalent circuit of the system in the subtransient period for the calculation of prefault voltage is as shown in fig 2.11.

Here the valued of the voltage sources are subtransient internal voltages.

Let we choose,

base MVA=30

base kV=13.2kV

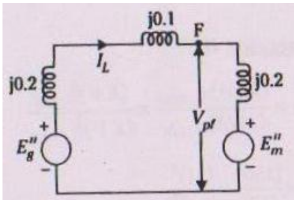

Fig. 2.11

The prefault voltage at the fault point , V_{pf}=12.8kV,

let us use this as the reference phasor per unit value of the prefault voltage,

V_{pf}=actual value/base value=12.8/13.2=0.97∠0°

base current, I_b= (1000 × base power) / (√3 × base voltage)= I_b= (1000 × 30) / (√3 × 13.2)=1312A

The load current, $I_L=(P/\sqrt{3}\ V\ \cos\varphi)\angle\cos^{-1}\varphi=20000/(\sqrt{3}\ \times 12.8\times 0.8)\angle\cos^{-1}0.8=$ 1128∠36.9° A

The load current in p.u IL=1128∠36.9°/1312= 0.8594∠36.9° p.u

Method-1:

Using Kirchoff's laws:

The subtransient voltages E_g'' and E_m'' of the fig 2.11 is calculated by Kirchoff's voltage law as shown below.

E_g'' = j0.2IL+j0.1IL+Vpf

=j0.2 (0.8594∠36.9°)+j0.1(0.8594∠36.9°)+0.97

=0.84∠14.2° p.u

E_m''=Vpf- j0.2IL

=0.97-j0.2(0.8594∠36.9°)

=1.0819∠-7.3° p.u

The equivalent circuit of the system on the occurrences of a three phase fault is as shown in fig 2.12

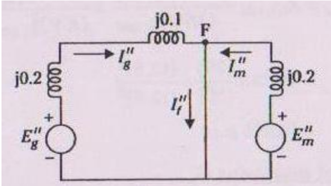

Fig. 2.12

The subtransient fault current I_f'' at the point computed by summing up the subtransient fault current in the generator. I_g'' and the subtransient fault current in the motor I_m'' i.e $I_f''=I_g''+I_m''$.

Applying KVL in the circuit of fig 2.12, we get

$j0.2I_g''+j0.1I_g''=E_g''$

or

$I_g''=E_g''/j0.3=(0.84\angle 14.2°)/ (0.3\angle 90°)=2.8\angle -75.8°$ p.u

also,

from the fig 2.12

$j0.2I_m''=E_m''$

or

$I_m''=E_m''/j0.2=(1.0819\angle -7.3°)/(0.2\angle 90°)=5.4095\angle -97.3°$ p.u

hence,

the current at the fault point $I_f''=I_g''+I_m''$

therefore,

$I_f''=2.8\angle -75.8°+5.4095\angle -97.3°=8.065\angle -90°$

Method-2:

Using Thevenin's theorem:

The prefault voltage at the fault point, $V_{pf}=0.97\angle 0°$ p.u. This is the Thevenin's voltage at the fault point.

Threfore,

$V_{TH}=0.97\angle 0°$ p.u

To compute Z_{TH}:

Short circuiting all the voltage sources in the equivalent circuit of fig.2.11, we get the circuit as shown below.

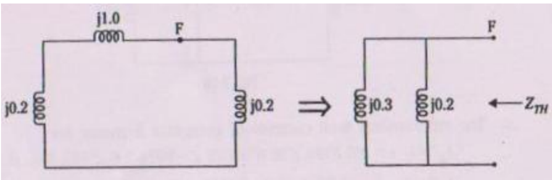

Fig. 2.13

$Z_{TH}= ((j0.3)(j0.2))/(j0.3+j0.2)=j0.12$

Hence the Thevenin's equivalent circuit of the system with respect to the fault point is as shown in fig.2.14

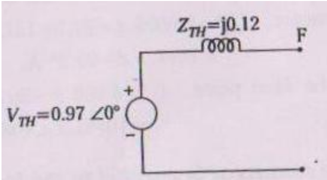

Fig. 2.14

The equivalent circuit during fault condition as shown in fig 2.15

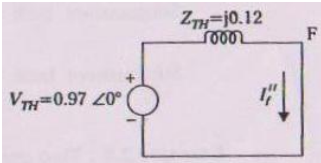

Fig. 2.15

current at the fault point, $I_f''=V_{TH}/Z_{TH}=(0.97\angle 0°)/j0.12=8.06\angle -90°$ p.u

To find subtransient fault current in motor and generator

when the fault occurs, there is a change in the current supplied by the motor and generator. This change is calculated by connecting the Thevenin's voltage with reversed polarity at the fault point as shown in fig 2.16. Here all other voltage sources are replaced by short circuit.

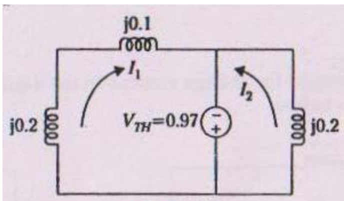

Fig. 2.16

Now,

$I_1=0.97/(j0.2+j0.1)=3.23\angle -90°$

$I_2=0.97/j0.2=4.85\angle -90°$

therefore,

the subtransient fault current of generator and motor are

$I_g''=I_L+I_1=(0.8594\angle 36.9°)+(3.23\angle -90°)=2.8\angle -75.8°$ p.u

$I_m''=I_2-I_L=(4.85\angle -90°)-(0.8594\angle 36.9°)=5.4095\angle -97.3°$ p.u

Thus, we find the currents calculated by both the methods are the same. The absolute values of the currents can be obtained by multiplying the per unit values by the base current.

Therefore,

subtransient fault current in generator, $I_g''=2.8\angle -75.8° \times 1312 = 3673.6\ \angle -75.8°$ A

subtransient fault current in motor, $I_m''=5.4095\angle -97.3° \times 1312=7097.2\angle -97.3°$ A

subtransient fault current at the fault point, $I_f''=8.065\angle 90° \times 1312= 10581.3\angle -90°$ A

Example 2.3:

Two generators are connected in parallel to the low-voltage(L.V) side of a three phase Δ-Y transformer. The ratings of the machines are

Generator G_1: 50 MVA, 13.8kV, Xd"=25%

Generator G_2: 25MVA, 13.8kV, Xd"=25%

Transformer T: 75MVA, 13.8 Δ -69 Y kV, X=10%

Before the fault occurs, the voltage on the high voltage (HV) side of the transformer is 66kV. The transformer is unloaded, and there is no circulating current between the generators. Find the subtransient current in each generator when a three phase fault occurs on the high voltage side of the transformer.

Solution:

base values:

let us choose,

base MVA= 75

base kV on HV side of transformer=69

we calculate,

base kV on the generator =69×13.8/69=13.8

Reactance of generator G_1:

$X_{G1,\ new} = X_{G1,\ old} \times ((MVA)_{B,\ new} / (MVA)_{B,\ old}) \times ((kV)^2_{B,\ old} / (kV)^2_{B,\ new})$

$= j0.25 \times (75 / 50) \times (13.8^2 / 13.8^2)$

$= j\,0.375$ p.u

Reactance of generator G_2:

$X_{G2,\ new} = X_{G2,\ old} \times ((MVA)_{B,\ new} / (MVA)_{B,\ old}) \times ((kV)^2_{B,\ old} / (kV)^2_{B,\ new})$

$= j0.25 \times (75 / 25) \times (13.8^2 / 13.8^2)$

$= j\,0.75$ p.u

Reactance of transformer:

X_T=j0.1

as the base values choose are of the same transformer, so its p.u reactance remains the same.

The reactance diagram of the system for the calculation of prefault values is as shown in fig 2.17

The prefault voltage on the high voltage side is 66kV. This is equal to 66/69=0.957 p.u

The equivalent subtransient reactance as visualised from the fault point is,

$((j0.375 \times j0.75)/(j0.375+j0.75))+j0.1=j0.35$ p.u

therefore,

the subtransient current in the short circuit is,

$I_f'' = 0.957/j0.35 = 2.735\angle{-90°}$ p.u

To find the subtransient currents in the generators:

The subtransient fault current divides between the generators inversely as the impedances of the generators.

In generator G_1:

$I_{g1}''=2.735\angle-90° \times (j0.75/j1.125)=1.823\angle-90°$ p.u

In generator G_2:

$I_{g2}''=2.735\angle-90° \times (j0.375/j1.125)=0.912\angle-90°$ p.u

The absolute values of the above currents can be obtained by multiplying the p.u values by the base current.

Base current,

$I_B=(1000 \times \text{base power}) / (\sqrt{3} \times \text{base voltage})=(1000 \times 75) / (\sqrt{3} \times 13.8)=3137.7$ A

hence the actual currents are,

$I_f''=2.735\angle-90° \times 3137.7 =8581.6\angle-90°$A

$I_{g1}''= 1.823\angle-90° \times 3137.7= 5720\angle-90°$A

$I_{g2}''= 0.912\angle-90° \times 3137.7= 2861.6\angle-90°$ A

2.5 Selection of circuit breakers

When fault occur in a part of power system, heavy current flows in that part of circuit which may cause permanent damage to the equipments connected therin. Hence the faulty part should be isolated from the healthy part immediately on the occurrence of a fault. This is can be achieved by providing protective relays and circuit breakers. The protective relays sense the faulty conditions and sends signals to circuit breakers to open the circuit under faulty condition, the circuit breakers can be used as a switch.

The selection of a circuit breaker for a power system depends not only upon the current that the breaker is to carry under normal operating conditions but also upon the maximum current it may have to carry momentarily and the current is may have to interrupt at the voltage of the line in which it is placed. Hence, the choice of a circuit breaker for particular application depends on the following ratings of the circuit breaker.

1)Normal working power level specified as rated interrupting current or rated interrupting MVA.

2)The fault specified as either the rated short circuit interrupting current or rated short circuit interrupting MVA.

3)Momentary current rating.

4)Normal working voltage.

5)Speed of circuit breaker.

The speed of circuit breaker is the time between the occurrence of the fault to the extinction of the arc(when the contact opens). It is normally specified in cycle of power frequency. One cycle for 50Hz power frequency is 1/50=0.02 m sec. The standard speed of circuit breakers are 8,5,3,2 or 1 1//2 cycles.

The momentary current rating is the maximum current that may flow through a circuit breaker for a short duration. It is the current that flow during subtransient period of fault condition. In fault analysis, the subtransient fault current calculated using subtransient circuit model is the a.c component of the short circuit current. It is multiplied by a factor of 1.6 to account for the d.c offset current. This gives the maximum momentary current during fault.

The circuit breaker will open its contacts usually in the transient period and so the short circuit interrupting current rating depends on the transient currents. In fault analysis, the a.c component of the transient current obtained is multiplied by a factor 1.0 to 1.5 to get the maximum interrupting current. The factor 1.0 to 1.5 accounts for the d.c. Offset current during transient period. The circuit breaker is chosen such that its short circuit interrupting current rating is less than the calculated value. The multiplying factor to find the interrupting current depends on the speed of the circuit breaker. These are indicated in table 2.1

Speed of circuit breaker	Multiplying factor
8 cycles or more	1.0
5 cycles	1.1
5 cycles	1.2
5 cycles	1.4
1 1/2 cycles	1.5

Table 2.1

Example 2.4:

A 25MVA, 13.8kV generator with X_d''=15% is connected through a transformer to a bus that supplies four identical motors as shown in fig. 2.18. Each motor has X_d''=20% & X_d'=30% on a base of 5MVA, 6.9kV. The three phase rating of the transformer is 25MVA, 13.8-6.9 kV. With a leakage reactance of 10%. The bus voltage at the motors is 6.9kV when a three-phase fault occurs at the point P. For the fault specified determine:

a)The subtransient current in the fault.

b) The subtransient current in the breaker A.

c) The momentary current in breaker A.

d)The current to be interrupted by breaker A in 5 cycles.

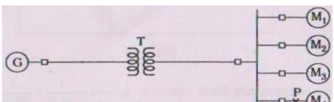

Fig. 2.18

Solution:

base values:

let we choose,

base MVA=25

base kV in the generator circuit=13.8

we calculate,

base voltage on the motor side=13.8×6.9/13.8=6.9

Reactance of generator G:

X_{dG}'' =j0.15(same as old p.u value in given because base values have been chosen on the same machine ratings)

X_{dG}' =j0.15(same as subtransient reactance as it is not specified in data).

Reactance of transformer T:

X_T=j0.1(same as old p.u value in given because base values have been chosen on the same machine ratings)

Reactances of motors:

$X_{dM,p.u,new}'' = X_{dM,p.u,old}'' \times ((MVA)_{B,\ new} / (MVA)_{B,\ old}) \times ((kV)^2_{B,\ old} / (kV)^2_{B,\ new})$

$= j0.2 \times (25 / 5) \times (6.9^2 / 6.9^2)$

$= j\ 1.0$ p.u

$X_{dM,p.u,new}' = X_{dM,p.u,old}' \times ((MVA)_{B,\ new} / (MVA)_{B,\ old}) \times ((kV)^2_{B,\ old} / (kV)^2_{B,\ new})$

$= j0.3 \times (25 / 5) \times (6.9^2 / 6.9^2)$

$= j\ 1.5$ p.u

The prefault voltage at the point P is 6.9kV=6.9/6.9=1p.u and the base current in the 6.9kV circuit is,

I_b= (1000 × base power) / (√3 × base voltage)= (1000 × 25) / (√3 × 6.9)=2091.8A

The reactance diagram with subtransient values of the reactance marked is shown in fig 2.19.

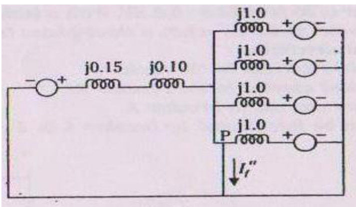

Fig. 2.19

a) therefore subtransient fault current, I_f''=4×(1/j1.0)+(1/j0.25)= -j8p.u

The absolute value of the current is I_f''= -j8 × 2091.8 = - j16734.4 A

b) therefore subtransient current in breaker A, I″= 3×(1/j1.0)+(1/j0.25)= -j7p.u

The absolute value of the current is I″= -j7 × 2091.8 = - j14642.6 A

c)To find the momentary current in the breaker A, we must account for the d.c. Offset current. This is done empirically as follows:

Momentary current through breaker A= 1.6×14642.6=23428.16 A

d)To compute the current to be interrupted by the breaker A, it is required to obtain the transient reactance model of the system. This is shown in fig 2.20

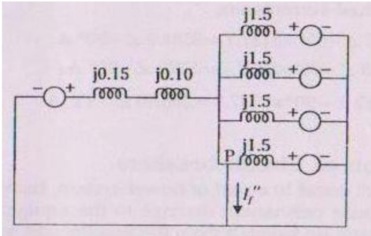

Fig. 2.20

The current to be interrupted by the breaker A now is =3×(1/j1.5)+(1/j0.25)= -j6p.u

Allowance is made for the d.c. Offset current by multiplying with a factor 1.1(see table 2.1). therefore the current to be interrupted is,

1.1×6×2091=13805.88A

Additional Examples:

Example 2.7:

A three phase, 5MVA, 6.6kV alternator with reactance of 8% is connected to a feeder of series impedance of (0.12+j0.48) ohms/phase per km. The transformer is rated at 3MVA, 6.6kV/33kV and has a series reactance of 5%. Determine the fault current supplied by the generator operating under no-load with a voltage of 6.9kV, when a three phase symmetrical fault occurs at a point 15km along the feeder.

Solution:

The single line diagram of the power system is as shown in fig 2.29. let F be the point of occurrence of the fault.

Base vaules:

Let us chose the generator rating as base values.

Therefore,

base MVA= 5

base kV on the generator=6.6

base kV on the transmission line=6.6×33/6.6=33

Reactance of generator:

X_G=8%=j0.08 p.u

Reactance of transformer T: (calculated secondary side of it)HV or HT

$X_{T,\ new} = X_{T,\ old} \times ((MVA)_{B,\ new} / (MVA)_{B,\ old}) \times ((kV)^2_{B,\ old} / (kV)^2_{B,\ new})$

$= j0.05 \times (5 / 3) \times (33^2 / 33^2)$

= j 0.833 p.u

Impedance of the feeder:

$Z_{TL,p.u} = Z_{TL}(\Omega) \times (MVA)_{B,new} / (kV)^2_B$

$= (15 \times (0.12+j0.48)) \times 5 / 33^2$

$= 0.0083+j0.033$ p.u

using these values, the prefault impedance diagram is as shown in fig 2.30

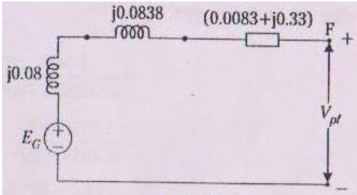

Fig. 2.30

To find E_G and V_{pf}:

Actual value of induced emf, E_G= 6.9kV

p.u value of induced emf, E_G= actual value/base value=6.9/6.9=1.0455 p.u

The prefault voltage V_{pf} at fault point F is the voltage under no-load=34.5kV therefore,

prefault voltage V_{pf}=34.5kV

The p.u value of prefault voltage, V_{pf}=actual value/base value=34.5/33=1.0455p.u

To find fault current:

The Thevenin's equivalent circuit of the system in fig 2.30 as seen from the fault point F is shown in fig 2.31. Here

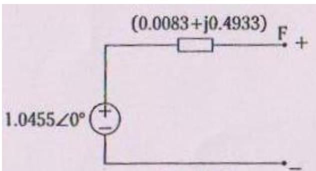

Fig. 2.31

$V_{TH}=1.045\angle 0°$

$Z_{TH}=j0.08+j0.0833+(0.0083+j0.33)=0.0083+j0.04933$

The fault in the feeder can be represented by a short circuit as shown in fig. 2.32. Now the current If through the short circuit is the fault current.

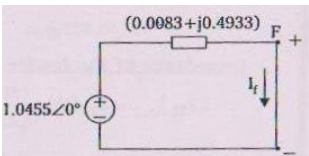

Fig. 2.32

Therefore,

p.u value of fault current, $If=V_{TH}/Z_{TH}=(1.045\angle 0°)/(0.0083+j0.04933)=2.12\angle -89°$ p.u therefore,

actual value of fault current, If= p.u value × base current

base current=(1000 × base power) / (√3 × base voltage)= (1000 × 5) / (√3 × 33)=87.47A

If=(2.12∠-89°)×87.47=185.45∠-89° A

Example 2.8:

Two synchronous motors are connected to the bus of a large system through a short transmission line as shown in fig 2.33. The ratings of the various components are:

Motors (each): 1MVA, 440V, 0.1p.u, transient reactance

line: 0.05 ohm reactance

large system: short circuit MVA at its bus at 440V is 8. when the motors are operating at 440V, calculate the short circuit current fed into a three phase fault at the motor bus.

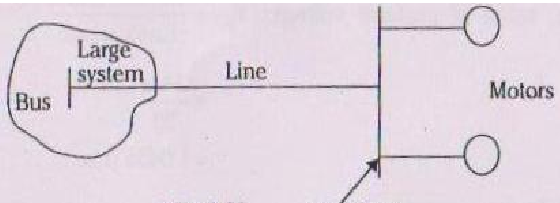

Fig. 2.33

Solution:

base values:

let us choose the motor ratings as base values

therefore,

base MVA=1

base kV on the motor side=0.44

The large system can be considered as a source of constant voltage feeding the line through an "infinite bus". The voltage rating of the bus is 440V(as given)

Reactance of Motors:

X_M=j0.1 p.u

Reactance of line:

$X_{TL,p.u}= X_{TL}(\Omega) \times (MVA)_{B,new} / (kV)^2_B$

$= j0.05 \times 1 / 0.44^2$

=j0.258 p.u

Hence the p.u reactance diagram is as shown in fig 2.34.

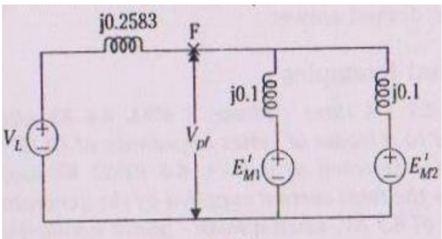

Fig. 2.34

The prefault voltage at the motor bus, V_{pf}=400V

p.u value of prefault voltage, V_{pf}=400/440=0.909p.u

p.u value of voltage at infinite bus, V_L=440/440=1p.u

The fault condition of the system is shown in fig 2.35. The total fault current I_f' is sum of the fault current I_{f1}' and I_{f2}'

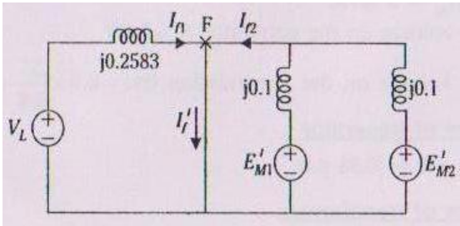

Fig. 2.35

From the fig 2.35, it can be observed that,

$I_{f1}'=V_L/j0.2583=1\angle 0°/j0.2583= -j3.87$ p.u

$I_{f2}'=V_{pf}/(j0.1/2)=0.909\angle 0°/j0.5= -j18.18$ p.u

$I_f'= I_{f1}'+I_{f2}'= -j3.87 -j\ 18.18 = -j22.05$ p.u $= 22.05\angle -90°$ p.u

Actual value of fault current = p.u value of fault current × base current

$=22.05\angle -90° \times (1000 \times 1) / (\sqrt{3} \times 0.44)$

$=28933.12 \angle -90°$ A.

Unsolved example:

2.3) A 25 MVA, 11kV, synchronous generator having a subtransient reactance of 1.5 p.u is supplying 20MW power at 0.8p.f.lagging to a synchronous motor through a transmission line. The voltage at the terminals of the generator is 10.5kV. The transmission line has a reactance of 0.5 ohm and the motor a subtransient reactance of 1.2 ohm. If a three phase fault occurs at the terminals of the motor, determine the fault current from each machine.

Ans:($I_g''=3794\angle -77°$ A. $I_m''=4301\angle -110.8°$ A).

------------END-----------