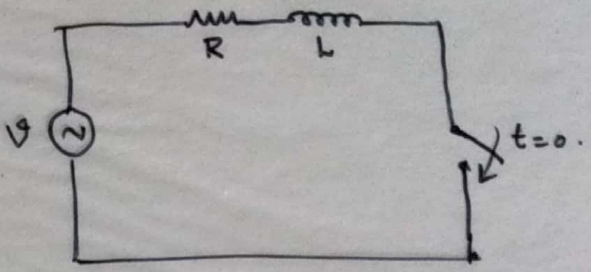
Transients in Series R-L circuit :-

Consider an R-L series circuit, which is connected at the instant $t=0$, to a source of alternating voltage $v = V_{max}\sin(\omega t+\alpha)$ where α is the phase displacement between the voltage v and the reference wave which passes through zero at the time $t=0$.



$$v = V_R + V_L$$

$$v = iR + L\frac{di}{dt}$$

$$V_m \sin(\omega t+\alpha) = iR + L\frac{di}{dt}. \quad \text{—— (1)}$$

The complete solution of the above equation consists of two parts which are called the particular integral and complementary function. The particular integral is the solution corresponding to the steady-state conditions, namely

$$i_p = \frac{V_{max}}{\sqrt{R^2+\omega^2L^2}}\sin(\omega t+\alpha-\phi) = \frac{V_{max}}{Z}\sin(\omega t+\alpha-\phi)$$

where $Z = \sqrt{R^2+(\omega L)^2}$, the circuit impedance.

$\phi = \tan^{-1}\left(\frac{X_L}{R}\right)$, the phase angle between current and voltage

→ Complete solution of Equation (1) is given as

$$i = \overset{\text{D.C}}{i_c} + \overset{\text{a.c}}{i_p}$$

$$i = Ae^{-\frac{R}{L}t} + \frac{V_{max}}{Z}\sin(\omega t+\alpha-\phi) \quad \text{—— (2)}$$

Now when $t=0$; $i=0$ hence substituting these values in above eqn (2), we have

$$0 = \frac{V_{max}}{Z}\sin(\alpha-\phi) + A$$

(or) $$A = -\frac{V_{max}}{Z}\sin(\alpha-\phi).$$

hence equation (2) can be rewritten as

$$i = \frac{V_{max}}{Z}\sin(\omega t+\alpha-\phi) - \frac{V_{max}}{Z}\sin(\alpha-\phi)e^{-\frac{R}{L}.t}.$$

$$\boxed{i = I_{max}\sin(\omega t+\alpha-\phi) - I_{max}\sin(\alpha-\phi)e^{-\frac{R}{L}.t}} \quad \text{(3)}$$

* The first term in eqn (3) for i is current corresponding to steady state condition and the second term is transient which vanishes theoretically after infinite time. But practically, it vanishes very quickly after two or three cycles.

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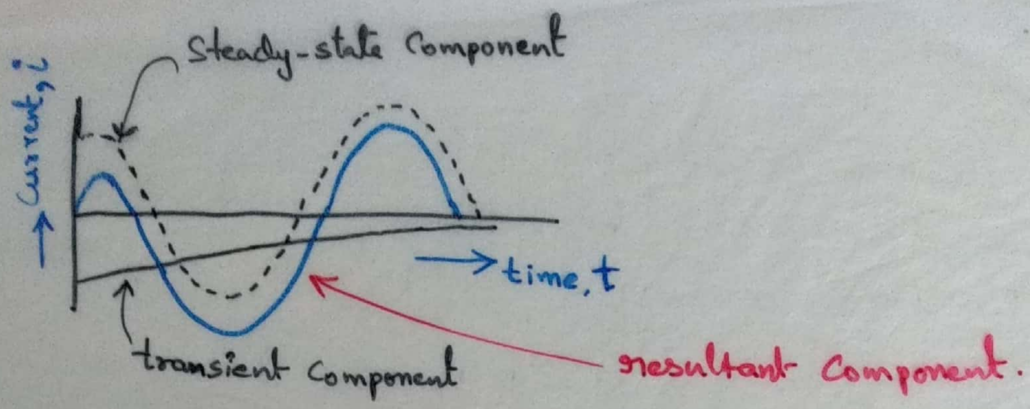
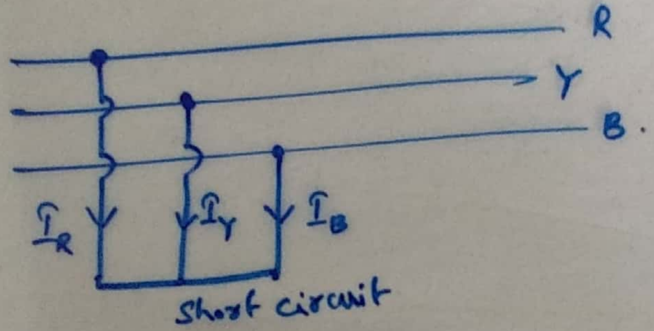

Steady-state Component
Current, i
time, t
transient Component
resultant Component.

Symmetrical fault :- The fault on a power system which gives rise to symmetrical currents (i.e., equal fault currents in the lines with 120° displacement) is called a Symmetrical fault.

→ In a 3-phase System the Symmetrical fault occurs when all the three Conductors of the 3-phase line are brought together simultaneously into a short circuit Conditions, as shown in fig. While making Calculations, because of balanced nature of fault Only one phase need to be Considered since the Conditions will also be Similar in the other two phases.



→ The Symmetrical fault rarely occurs in practice, however, it is the most Severe and imposes more heavy duty on the circuit breaker.

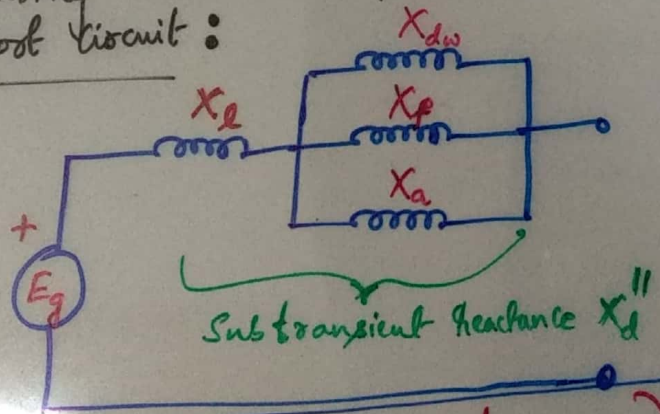
* → The value of fault current which Can flow in any System under short circuit is limited only by the Impedances in that System. Therefore, it is necessary in any Calculation to have knowledge of these Impedances.

→ In several Situations, the Impedances limiting the fault Current are largely reactive, Such as transformers, reactors and generators. Cables and lines are mostly resistive, but where the total reactance in Calculations exceeds three times the resistance, the latter is usually neglected. The error Introduced by this assumption will not Exceed five percent.

Reactance of Synchronous Machine :-

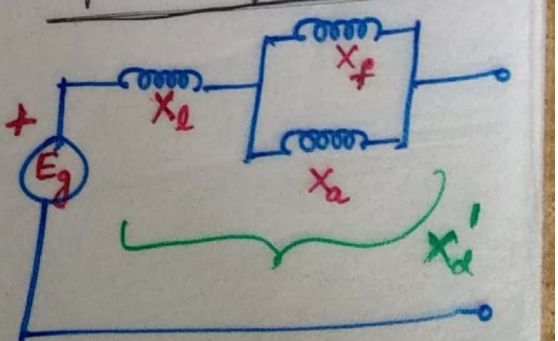
The current flowing in the armature of a Synchronous generator when its terminals are short circuited is Similar to that flowing when a Sinusoidal voltage is Suddenly applied to an R-L Series circuit. However, there is one important difference, that is, in case of an R-L Series circuit, reactance X_L (ωL) is a Constant quantity whereas in case of the Synchronous generator the reactance is not a constant one but is a function of time. In practice three discrete values are assigned and thus we have three reactances — direct-axis Subtransient reactance Symbolized as X_d'', direct-axis transient reactance Symbolized as X_d' and direct-axis Synchronous reactance Symbolized as X_d.

Approximate equivalent circuit model during Subtransient period of Short circuit :



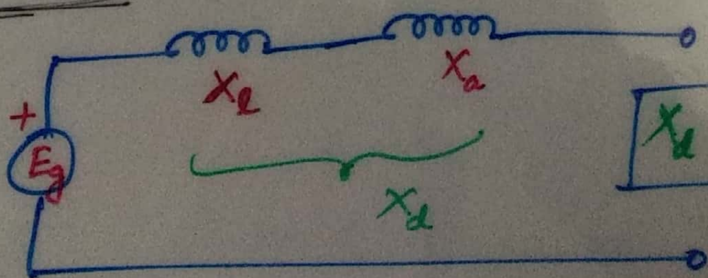
$$\boxed{X_d'' = X_l + \left(\frac{1}{\frac{1}{X_{dw}} + \frac{1}{X_f} + \frac{1}{X_a}}\right)}$$

Approximate equivalent circuit during transient period of short circuit :



$$\boxed{X_d' = X_l + \left(\frac{1}{\frac{1}{X_f} + \frac{1}{X_a}}\right)}$$

Steady state short circuit model :



$$\boxed{X_d = X_l + X_a}$$

Procedure for calculation of symmetrical fault currents :

① Draw the single line reactance diagram representing all the components in p.u system upto the fault point to a common base MVA.

② Identify the fault terminals and calculate Z_{Th} upto fault point from the reactance diagram.

③ Assume $V_b = V_{Th} = 1$ p.u , Calculate I_f in p.u using.

$$I_{f\,p.u} = \frac{V_{Th}}{Z_{Th\,p.u}} = \frac{1}{Z_{Th\,p.u.}}$$

④ Calculate base current depending on the fault current

$$I_b = \frac{S_b}{\sqrt{3} \cdot V_b}$$

⑤ Calculate I_f in amps

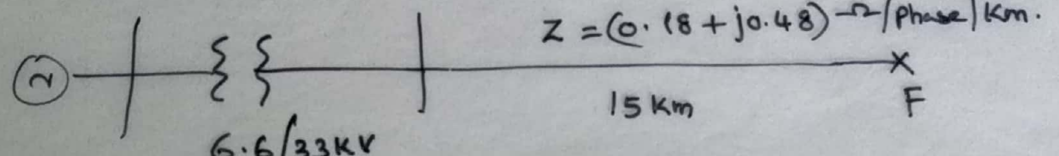
i.e., $I_f\ (\text{amps}) = I_{f\,pu} \times I_b$

⑥ Calculate short circuit MVA

$$(MVA)_{sc} = \frac{(MVA)_b}{Z_{Th\,p.u.}}$$

Q: A 3-Φ, 5MVA, 6.6 KV Alternator has reactance of 8% is (15) Connected to a feeder having an Impedance of 0.18+j0.48 Ω/p/km. Transformer is rated 3MVA, 6.6/33KV is placed between generator and the transmission line and transformer has reactance 5%. A 3-Φ symmetrical fault occur at a distance of 15 km of line. find the fault current at the fault point

Sol:



6.6KV
5MVA
8%

3MVA
5%

Let $S_{base} = 5MVA$

$V_b = 6.6KV = V_{Th} = 1 p.u$

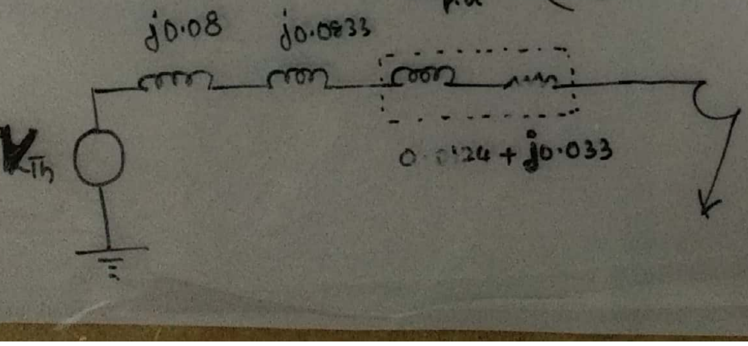
G : $X_{p.unG} = 0.08 \times \frac{5}{5} \times \left(\frac{6.6}{6.6}\right)^2 = 0.08 p.u.$

T_1 : $X_{p.unT_1} = 0.05 \times \frac{5}{3} \times \left(\frac{6.6}{6.6}\right)^2 = 8.33\% = 0.0833 p.u.$

Tr. Line : $Z_{p.un} = Z_{\Omega} \cdot \frac{(MVA)_b}{(KV_b)^2}$

$= (0.18 + j0.48) \times 15 \times \frac{5}{(33)^2}$

$Z_{p.u} = (0.0124 + j0.033) p.u.$



$Z_{Th} = 0.0124 + j0.033$

$$I_{f\,p.u} = \frac{V_{Th\,p.u}}{Z_{Th\,p.u}} = \frac{1}{Z_{Th\,p.u}} = \frac{1}{(0.0124 + j0.196)} = 5.09\,\underline{\angle -86.37^\circ}\ p.u$$

$$I_b = \frac{S_b}{\sqrt{3}\cdot V_b} = \frac{5\times10^6}{\sqrt{3}\times(33\times10^3)} = 87.47A$$

fault pt voltage

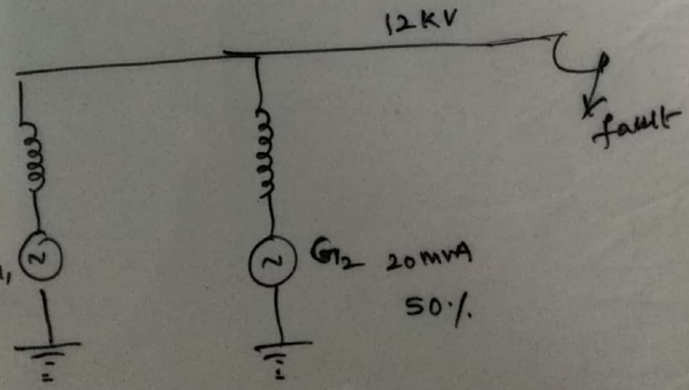
$$I_{f\,Amp} = I_{f\,p.u} \times I_b = 5.09 \times 87.47 = \underline{445.22A}.$$

Q: A generating station has 2 generators. G_1 = 15MVA, 30% and G_2 = 20 MVA, 50% reactance are connected in parallel to a common bus bar ~~of~~ operating at a volt of 12KV. If a 3-φ fault occur at the bus bar find

(i) Total fault current

(ii) I_f feed by each generator

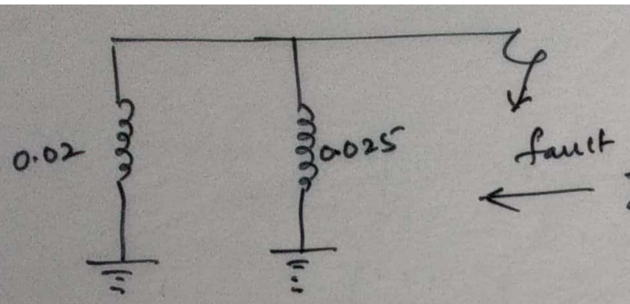
Sol :



Let S_b = 1 MVA , V_b = 12KV

G_1 : $X_{p.u\,nG_1} = 0.3 \times \frac{1}{15} \times \left(\frac{12}{12}\right)^2 = 0.02$

G_2 : $X_{p.u\,nG_2} = 0.5 \times \frac{1}{20} \times \left(\frac{12}{12}\right)^2 = 0.025$



$\leftarrow Z_{Th} = 0.02 // 0.025 = 0.011.$

$$I_{f\,p.u} = \frac{V_{Th\,p.u}}{Z_{Th\,p.u}} = \frac{1}{0.011} = 90.9$$

$$I_b = \frac{S_b}{\sqrt{3}.\, V_b} = \frac{1\times10^6}{\sqrt{3}\,.\,(12\times10^3)} = 48.11A$$

$$I_{f\,(Amps)} = I_{f\,p.u} \cdot I_b = 90.9 \times 48.11$$

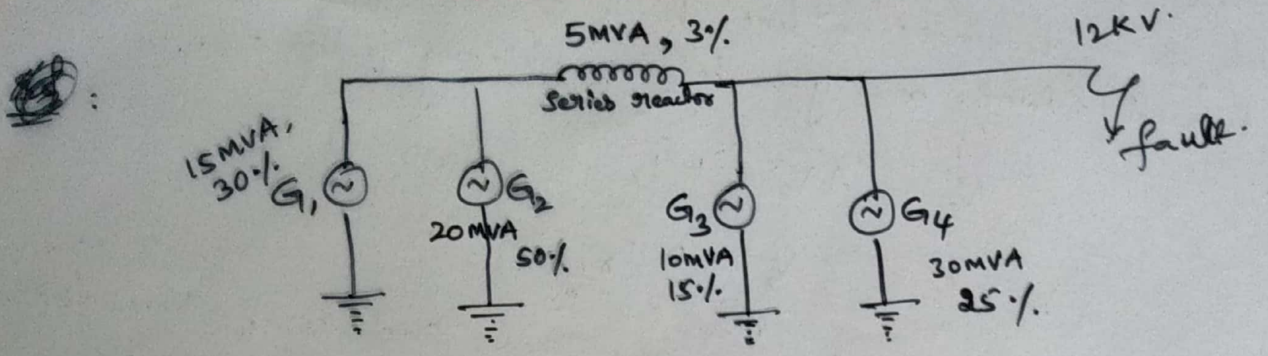
$$= 4.33kA$$

$$I_{f_1} = \frac{4.33 \times 2.5}{2.5+2} = 2.4kA$$

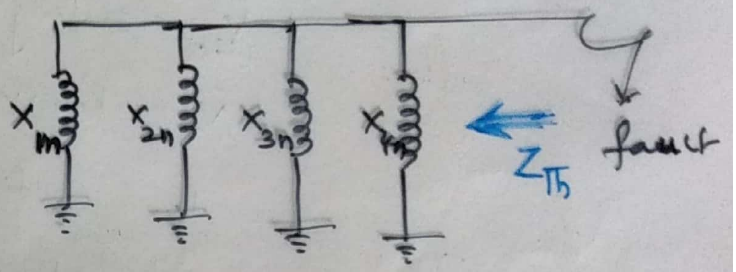
$$I_{f_2} = 4.33 - 2.4 = 1.9kA$$

Q: 4 generators are connected in parallel as shown in fig. If a fault is occured at the bus bar of generators, find I_f and fault MVA (i) without series reactor (ii) with series reactor. (18)

Sol:



Sol: Without series reactor



Let base MVA = 10MVA
base KV = 12KV.

$X_{1n} = 0.3 \times \frac{10}{15} \times \left(\frac{12}{12}\right)^2$

$\boxed{X_{1n} = 0.2}$ p.u.

$X_{2n} = 0.5 \times \frac{10}{20} \times \left(\frac{12}{12}\right)^2$

$\boxed{X_{2n} = 0.25}$ p.u

$X_{3n} = 0.15 \times \frac{10}{10} \times \left(\frac{12}{12}\right)^2$

$\boxed{X_{3n} = 0.15}$ p.u

$X_{4n} = 0.25 \times \frac{10}{30} \times \left(\frac{12}{12}\right)^2$

$\boxed{X_{4n} = 0.0833}$ p.u

$Z_{Th} = X_{1n} \parallel X_{2n} \parallel X_{3n} \parallel X_{4n}$

$\frac{1}{Z_{Th}} = \frac{1}{X_{1n}} + \frac{1}{X_{2n}} + \frac{1}{X_{3n}} + \frac{1}{X_{4n}}$

$\frac{1}{Z_{Th}} = \frac{1}{0.2} + \frac{1}{0.25} + \frac{1}{0.15} + \frac{1}{0.083}$

$\boxed{Z_{Th} = 0.0361 \text{ p.u}}$

Let $V_{Th} = 1$ p.u.

then $I_f \text{ p.u} = \frac{V_{Th} \text{ p.u}}{Z_{Th} \text{ p.u}} = \frac{1}{Z_{Th} \text{ p.u}} = \frac{1}{0.0361} = 27.7$ p.u

$I_b = \frac{S_b}{\sqrt{3} \cdot V} = \frac{10 \times 10^6}{\sqrt{3} \times (12 \times 10^3)} = 0.48 \text{KA}$

$$I_{f(Amp)} = I_{f\,p.u} \times I_b$$

$$I_{f(Amp)} = 27.7 \times (0.48 \times 10^3)$$

$$\boxed{I_{f(Amp)} = 13.3\,KA}$$

$$(MVA)_{sc} = \sqrt{3}\, I_{f(Amp)} \cdot V_b$$

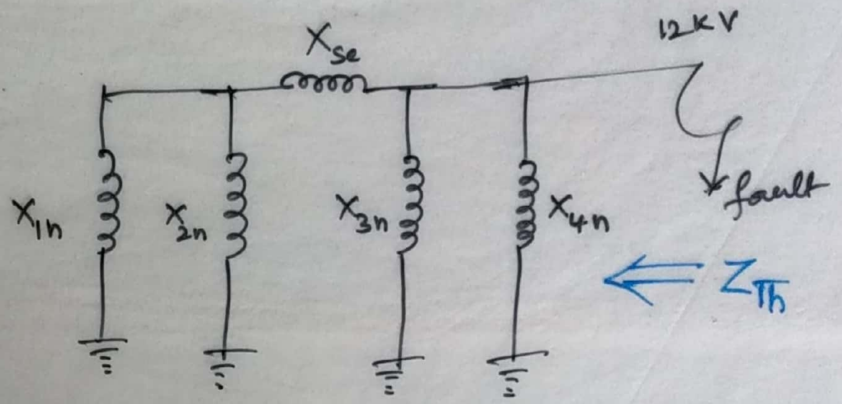
$$= \sqrt{3} \times (13.3 \times 10^3) \cdot (12 \times 10^3)$$

$$\boxed{(MVA)_{sc} = 276.85\,MVA}$$

ii) With Series reactor :

$$X_{se} = 0.03 \times \frac{10}{5} \times \left(\frac{12}{12}\right)^2$$

$$\boxed{X_{se} = 0.06\,p.u}$$



$$\left(\left(X_{1n} \parallel X_{2n}\right) + X_{se}\right) \parallel \left(X_{3n} \parallel X_{4n}\right)$$

$$\left((0.2 \parallel 0.25) + 0.06\right) \parallel (0.15 \parallel 0.0833)$$

$$I_{f\,p.u} = \frac{V_{Th\,p.u}}{Z_{Th\,p.u}} = \frac{1}{Z_{Th\,p.u}}$$

$$Z_{Th} = 0.0407\,p.u.$$

$$I_{f\,p.u} = \frac{1}{0.0407} = 21.27\,p.u.$$

$$I_b = \frac{S_b}{\sqrt{3} \cdot V} = \frac{10 \times 10^6}{\sqrt{3} \times (12 \times 10^3)} = 0.48\,KA$$

$$I_{f(Amp)} = I_{f\,p.u} \times I_b \Rightarrow I_{f(Amp)} = 21.27 \times (0.48 \times 10^3) = 11.8\,KA$$

$$\Rightarrow \boxed{I_{f(Amp)} = 11.8\,KA}$$

$$(MVA)_{sc} = \sqrt{3} \times (11.8 \times 10^3)(12 \times 10^3)$$

$$\boxed{(MVA)_{sc} = 245\,MVA}$$

Note: With series reactor the magnitude of fault current or fault current ripples are reduced.