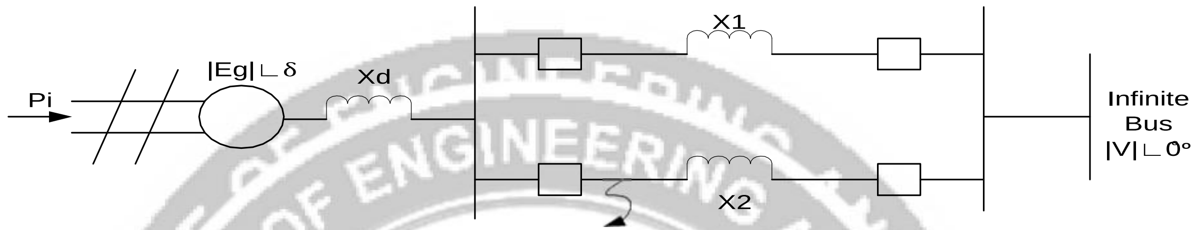
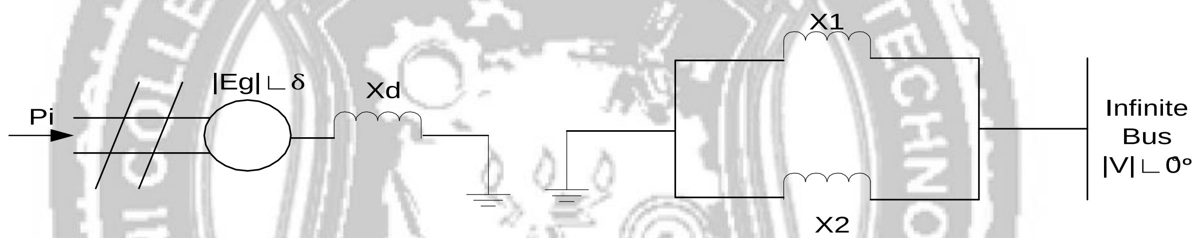
Sudden Short Circuit on One of Parallel Lines:-

(1) Short circuit at one end of line:-

Let us a temporary three phase bolted fault occurs at the sending end of one of the line.



(a)



(b)

(Fig.13 Short circuit at one of the line)

Before the occurrence of a fault, the power angle curve is given by

$$P_{eI} = \frac{|E_g||V|}{X_d + X_1||X_2} \sin\delta = P_{maxI} \sin\delta$$

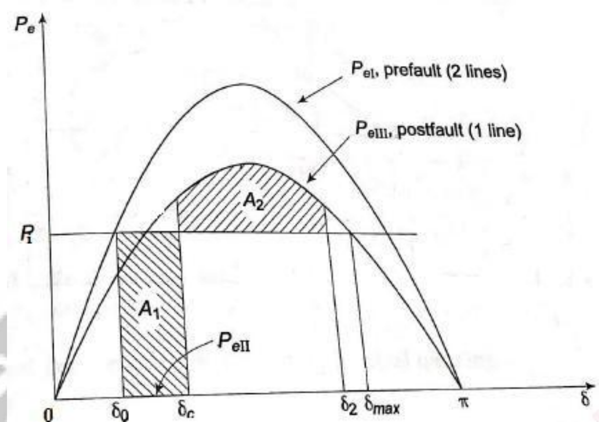
This is plotted in Fig. 12.

Upon occurrence of a three-phase fault at the generator end of line 2 , generator gets isolated from the power system for purpose of power flow as shown Fig. 13 (b). Thus during the period the fault lasts.

$$P_{eII} = 0$$

The rotor therefore accelerates and angles δ increases. Synchronism will be lost unless the fault is cleared in time. The circuit breakers at the two ends of the faulted line open at time t_c (corresponding to angle δ_c), the clearing time, disconnecting the faulted line. The power flow is now restored via the healthy line (through higher line reactance X_2 in place of $(X_1||X_2)$, with power angle curve

$$P_{eII} = \frac{|E_g||V|}{X_d + X_1} \sin\delta = P_{maxIII} \sin\delta$$



(Fig. 14 Equal area criterion applied to the system)

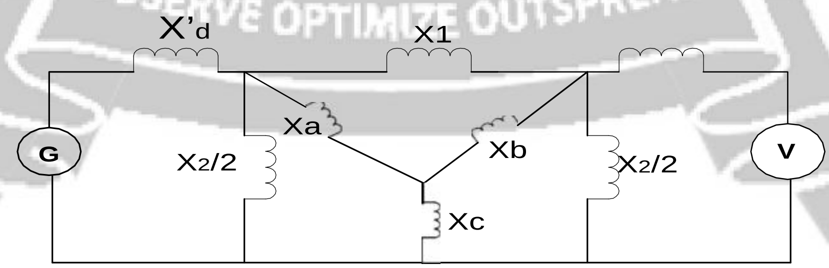
Obviously, $P_{maxIII} < P_{maxI}$. The rotor now starts decelerate as shown in Fig 14. The system will be stable if a decelerating area A2 can be found equal to accelerating area A1before δ reaches the maximum allowable value δ_{max}. As area A1 depends upon clearing time t_c (corresponding to clearing angle δ_c), clearing time must be less than a certain value (critical clearing time) for the system to be stable.

(2) Short circuit at the middle of a line:-

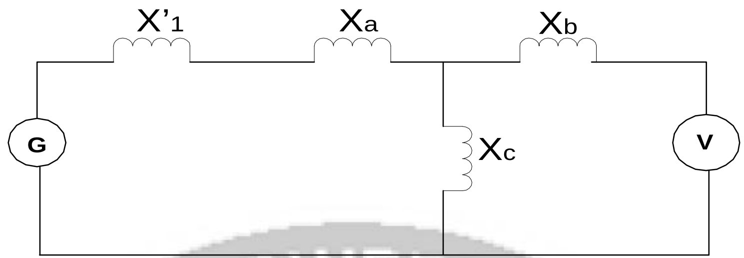
When fault occur at the middle of a line or away from line ends, there is some power flow during the fault through considerably reduced. Circuit model of the system during the fault is shown in fig. 15 (a). This circuit reduces to fig. 15 (c) through one delta-star and star-delta conversion.

The power angle curve during fault is given by

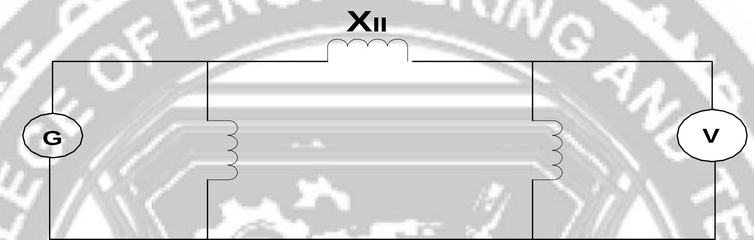
$$P_{eII} = \frac{|E_g||V|}{X_{II}} \sin\delta = P_{maxII} \sin\delta$$



(a)



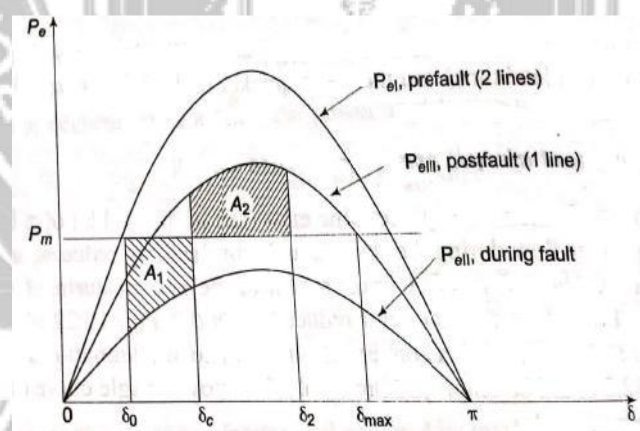
(b)



(c)

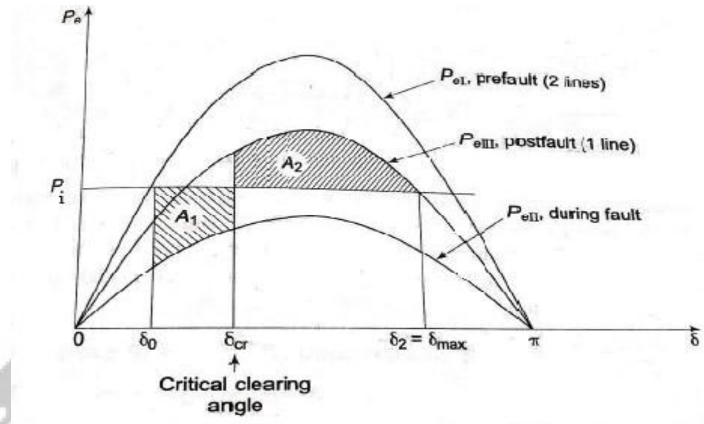
(Fig.15 Circuit Model)

P_{eI} and P_{eIII} as in Fig. 12 and P_{eII}as obtained above are all plotted in Fig. 16.



(Fig. 16 Fault on middle of one line of the system with $\delta_c < \delta_{cr}$)

Accelerating area A_1 corresponding to a given clearing angle δ_c is less in this case. Stable system operation is shown in Fig. 16, wherein it is possible to find an area A_2 equal to A_1 for$\delta_2 < \delta_{max}$. As the clearing angle δ_c is increased, area A_1 increases and to find $A_2 = A_1$, δ_2 increases till it has a valueδ_{max}, the maximum allowable for stability. This case of critical clearing angle is shown in Fig. 17.



(Fig. 17 Fault on middle on one line of the system)

Applying equal area criterion to the case of critical clearing angle of Fig. 17, we can write

$$\int_{\delta_0}^{\delta_{cr}} (P_i - P_{maxII}\sin\delta)d\delta = \int_{\delta_{cr}}^{\delta_{max}} (P_{maxIII}\sin\delta - P_i)d\delta$$

Where

$$\delta_{max} = \pi - \sin^{-1}\frac{P_i}{P_{maxIII}} \quad \cdots\cdots\cdots (68)$$

Integrating we get

$$(P_i\delta + P_{maxII}\cos\delta)\Big|_{\delta_0}^{\delta_{cr}} + (P_{maxIII}\cos\delta + P_i\delta)\Big|_{\delta_{cr}}^{\delta_{max}} = 0$$

or $P_i(\delta_{cr} - \delta_0) + P_{maxII}(\cos\delta_{cr} + \cos\delta_0) + P_i(\delta_{max} - \delta_{cr})$

$$+P_{maxIII}(\cos\delta_{max} - \cos\delta_{cr}) = 0$$

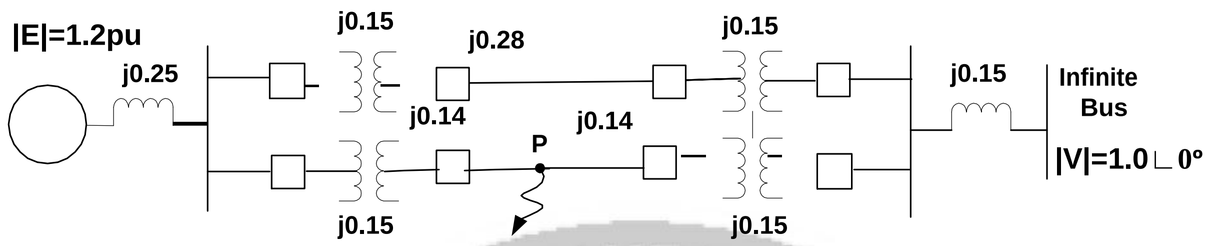
$$\cos\delta_{cr} = \frac{P_i(\delta_{max} - \delta_0) - P_{maxII}\cos\delta_0 + P_{maxIII}\cos\delta_{max}}{P_{maxIII} - P_{maxII}}$$

This critical clearing angle is in radian. The equation modifies as below if the angles are in degree

$$\cos\delta_{cr} = \frac{\frac{\pi}{180}P_i(\delta_{max} - \delta_0) - P_{maxII}\cos\delta_0 + P_{maxIII}\cos\delta_{max}}{P_{maxIII} - P_{maxII}}$$

<u>Example 4</u>:-

Find the critical clearing angle for the system shown in Fig. 18 for a three phase fault at point P. The generator is delivering 1.0 pu. Power under prefault conditions.



(Fig. 18)

Solution:-

1. **Prefault Operation:-** Transfer reactance between generator and infinite bus is

$$X_I = 0.25+0.17 + \frac{0.15+0.28+0.15}{2} = 0.71$$

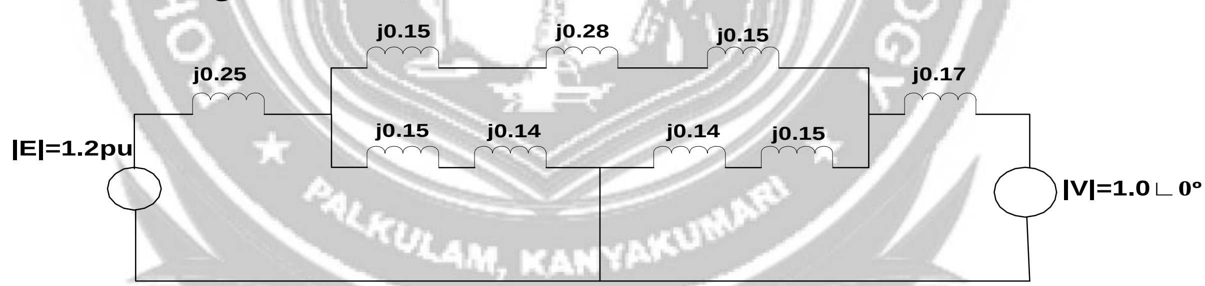
$$P_{eI} = \frac{1.2X1}{0.71}\sin\delta = 1.69\sin\delta$$

The operating power angle is given by

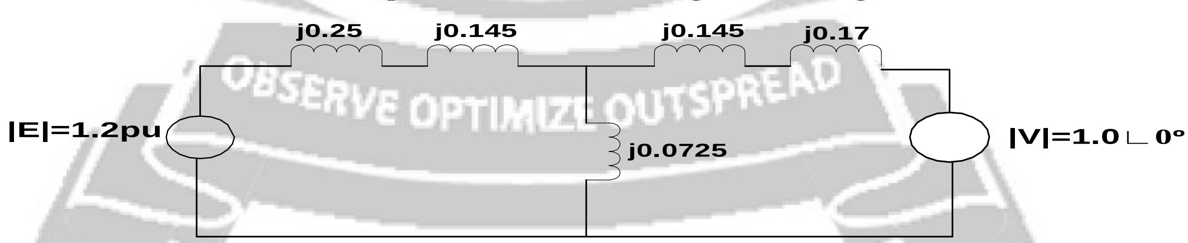
$$1.0 = 1.69\sin\delta$$

$$\text{or } \delta_0 = 0.633\text{rad}$$

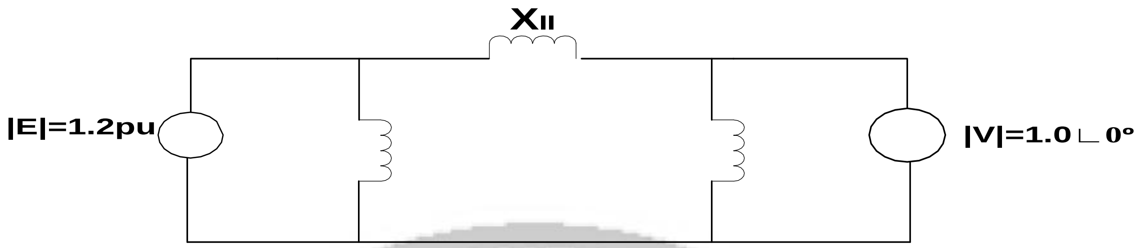
2. **During Fault:-** The positive sequence reactance diagram during fault is presented in Fig. 17.



(a) Positive sequence reactance diagram during fault



(b) Network after delta-star conversion



(c) Network after star- delta conversion

(Fig.19)

Converting delta to star, the reactance network is changed to that Fig. 19 (b). Further upon converting star to delta, we obtain the reactance network of Fig. 19(c). The transfer reactance is given by

$$X_{II} = \frac{(0.25+0.145)0.0725 + (0.145+0.17)0.0725 + (0.25+0.145)(0.145+0.17)}{0.075}$$

$$=2.424$$

$$P_{eII} = \frac{1.2x1}{2.424}\sin\delta = 0.495\sin\delta$$

3. **Post fault operation(faulty line switched off):-**

$$X_{III} = 0.25 + 0.15 + 0.28 + 0.15 + 0.17 = 1.0$$

$$P_{eIII} = \frac{1.2x1}{1}\sin\delta = 1.2\sin\delta$$

With reference to Fig. 16 and equation (68), we have

$$\delta_{max} = \pi - \sin^{-1}\frac{1}{1.2} = 2.155\text{rad}$$

To find critical clearing angle, areas A1 and A2 are to be equated.

$$A_1 = 1.0(\delta_{cr} - 0.633) - \int_{\delta_0}^{\delta_{cr}} 0.495\sin\delta\, d\delta$$

And $$A_2 = \int_{\delta_{cr}}^{\delta_{max}} 1.2\sin\delta\, d\delta - 1.0(2.155 - \delta_c)$$

Now $A_1 = A_2$

or $$\delta_{cr} = 0.633 - \int_{0.633}^{\delta_{cr}} 0.495\sin\delta\, d\delta$$

$$= \int_{\delta_{cr}}^{2.155} 1.2\sin\delta\, d\delta - 2.155 + \delta_{cr}$$

or $$-0.633 + 0.495\cos\delta\,|_{0.633}^{\delta_{cr}} = -1.2\cos\delta\,|_{\delta_{cr}}^{2.155} - 2.155$$

or $$-0.633 + 0.495 \quad \delta_{cr} - 0.399 = 0.661 - 1.2\cos\delta_{cr} - 2.155$$

or $$\cos\delta_{cr} = 0.655$$

or $$\delta_{cr} = 49.1°$$