EXPERIMENT NO. 2

OBJECTIVE
To plot Swing Curve for one Machine System

SOFTWARE USED
MATLAB

THEORY
Basic Model of a Synchronous Generator

Assumptions for representing the generator by classical model

Some assumptions are made to represent a synchronous generator mathematically by a classical model. The assumptions are:
1. The saliency of the generator is neglected, that is the generator is assumed to be of cylindrical type rotor
2. The effect of damper windings, present on the rotor of the synchronous generators, is neglected.
3. The input mechanical power to the generator is assumed to be constant during the period of study.
4. The exciter dynamics are not considered and the field current is assumed to be constant so that the generator stator induced voltage is always constant.

For the sake of understanding the classical model better the case of a generator connected to an infinite bus through a transformer and transmission lines is considered. This type of system is called as Single Machine Infinite Bus (SMIB) system. The single line diagram of SMIB system is shown in Fig. 1.1. Since resistance of synchronous generator stator, transformer and the transmission line are relatively negligible as compared to the corresponding reactance, only reactance of synchronous generator, transformer and transmission line are considered. Here, infinite bus represents rest of the system or grid, where the voltage magnitude and frequency are held constant. The infinite bus can act like infinite source or sink. It can also be considered as a generator with infinite inertia and fixed voltage. In Fig. 2.1, $E \angle \delta$ represents the complex internal voltage of the synchronous generator behind the transient reactance X_g'. it can be assumed to be a reactance of the generator during transients. V_{TT} is the terminal voltage of the synchronous generator. X_T, X_L represent the transformer and line reactance. The complex infinite bus voltage is represented as $V \angle 0$. The infinite bus voltage is a taken as the reference because of which the angle is taken as zero. The generator internal voltage angle is defined with respect to the infinite bus voltage angle.

The input mechanical power is represented as P_m
And the output electrical power is represented as P_e
The inertia constant of the generator is represented as H

From Fig. 1.1, the real power output of generator, P_e can be computed as

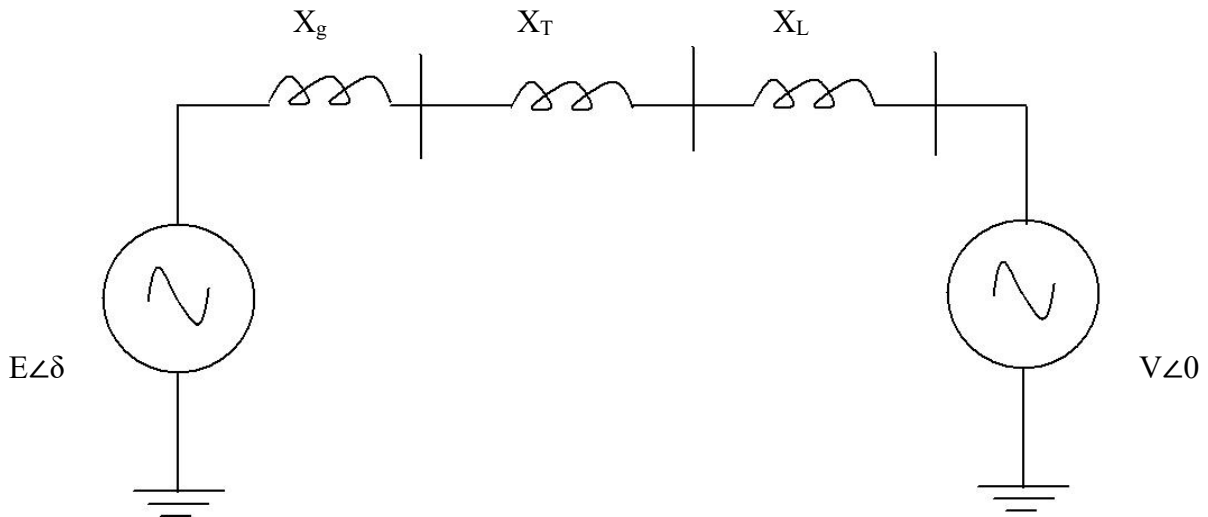$$P_e = P_{\max} \sin \delta$$

Fig. 1.1: Single line diagram of the SMIB system

Where P_{max} is given as

$$P_{\max} = \frac{E * V}{X}$$

$$X = X_g + X_T + X_L$$

Swing Equation for the synchronous machine is written as differential equation as given below

$$J\frac{d^2\theta_m}{dt^2} = (T_m - T_e) = T_a$$

Where

θ_m = angle in rad (mech)
T_m = turbine torque in Nm
T_e = electromagnetic torque developed in Nm

This Equation is converted in to the power form by assuming rotor speed is remaining constant at the synchronous speed (w_{sm}). Multiplying both sides by wsm in above equation, we can write as

$$J\omega\frac{d^2\theta_m}{dt^2} = P_m - P_e = P_a$$

……………………….. (1)

θ_m constant in steady state we can measure this angle with respect to a synchronously rotating reference instead of a stationary reference. Hence, we can write

$\theta_m = \delta_m + w_m$

But, the rate of change of the rotor mechanical angle θ_m with respect to time.

$$W_m = d\theta_m / dt \quad rps \; .$$

$$d\delta / dt = W_m - W_{ms}$$

δ is known as rotor angle and equation (1) is written as

$$M \frac{d^2\delta}{dt^2} = P_m - P_e = P_a$$

……………………………..(2)

In other form of equation (2) Is

$$\frac{H}{\Pi f} \frac{d^2\delta}{dt^2} = P_m - P_e = P_a$$

…………………………………(3)

Equation (3) is known as **Swing Equation** and it is describes rotor dynamics of Synchronous Machine.

$$\frac{H}{\Pi f} \frac{d^2\delta}{dt^2} = P_m - P_{max} \sin\delta = P_a$$

Since, the mechanical power input P_m and the maximum power output of the generator P_{max} are known for a given system topology and load, we can find the rotor angle as

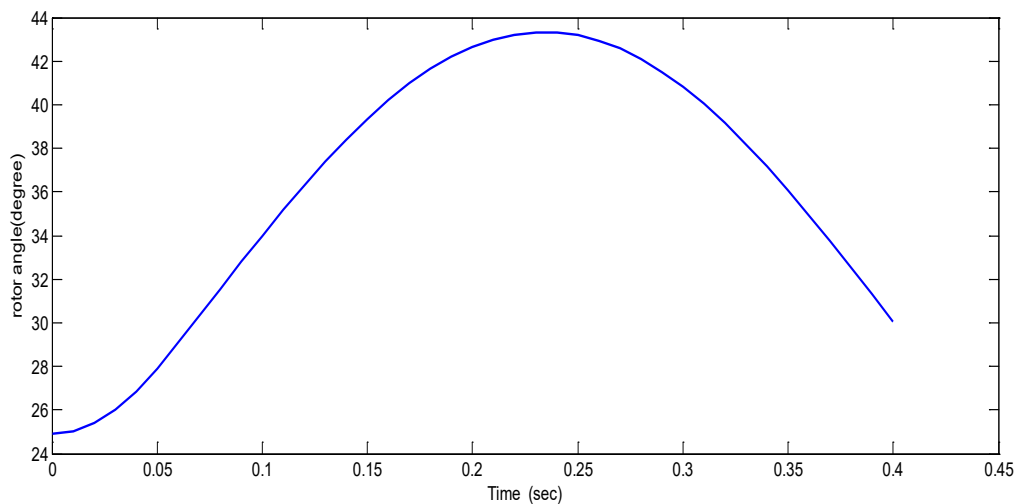$$\delta = \sin^{-1}(P_m / P_{max}) \quad and \quad \pi - \sin^{-1}(P_m / P_{max})$$
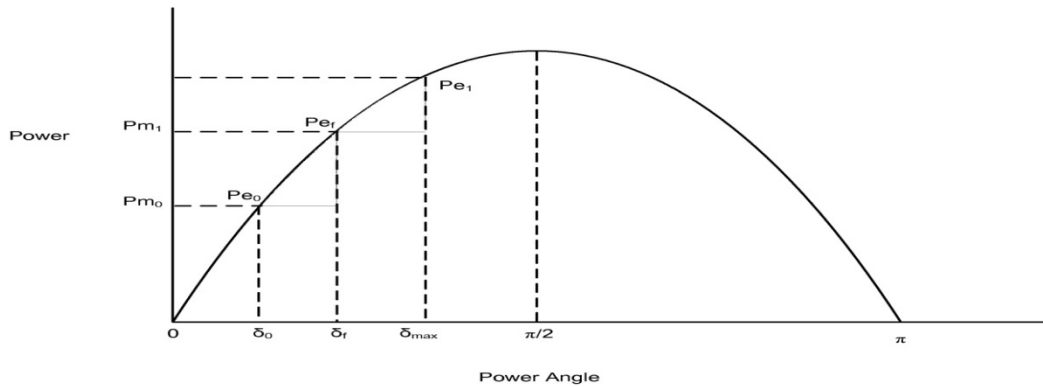

Figure 1.2: - for Swing Curve

Figure1.3 : - Power Angle Curve

PROBLEM STATEMENT

A 20 MVA , 50 Hz generator delivers 18MW over a double circuit line to an infinite bus. The generator has kinetic energy of 2.52 MJ/MVA at rated speed . The generator transient reactance is $X_d' = 0.35$pu. Each transmission circuit has R=0 and a reactance of 0.2 pu on a 20 MVA base . $|E'| = 1.1$ pu and infinite bus voltage V= $1.0\angle0$. A three – phase short circuit occurs at the mid point of one the transmission lines. Plot swing curves with fault cleared by simultaneous opening of breaker at both ends of the line at 2.5 cycles and 6.25 cycles after the occurrence of fault . Also plot the swing curve over the period of 0.5 s if the fault is sustained.

SOLVING PROCESS

By using **Point To Point** method or **Runge – Kutta** method . In these method we solve numerical method for solving quadratic equation
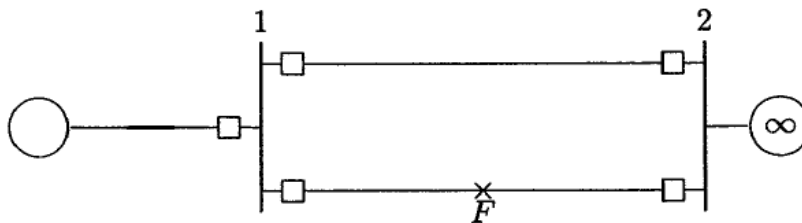

Figure1.4: Double Circuit Line of SMIB system, with one line faulted

The swing equation is given by:-

$$\frac{d^2\delta}{dt^2} = \frac{\pi f_0}{H}\left(P_m - P_{2\max}\sin\delta\right) = \frac{\pi f_0}{H}P_a$$

The above swing equation is transformed into the state variable form as:-

$$\frac{d\delta}{dt} = \Delta\omega$$

$$\frac{d\Delta\omega}{dt} = \frac{\pi f_0}{H} P_a$$

We now apply modified Euler's method to the above equations. By using the derivatives at the beginning of the step, the value at the end of the step ($t_1 = t_0 + \Delta t$) is predicted from:-

$$\delta_{i+1}^p = \delta_i + \frac{d\delta}{dt}\bigg|_{\Delta\omega_i} \Delta t$$

$$\Delta\omega_{i+1}^p = \Delta\omega_i + \frac{d\Delta\omega}{dt}\bigg|_{\delta_i} \Delta t$$

Using the predicted value of δ_{i+1}^p and $\Delta\omega_{i+1}^p$, the derivatives at the end of the interval is determined by:-

$$\frac{d\delta}{dt}\bigg|_{\Delta\omega_{i+1}^p} = \Delta\omega_{i+1}^p$$

$$\frac{d\Delta\omega}{dt}\bigg|_{\delta_{i+1}^p} = \frac{\pi f_0}{H} P_a\bigg|_{\delta_{i+1}^p}$$

Then, the average value of the two derivatives is used to find the corrected value.

$$\delta_{i+1}^c = \delta_i + \left(\frac{\frac{d\delta}{dt}\big|_{\Delta\omega_i} + \frac{d\delta}{dt}\big|_{\Delta\omega_{i+1}^p}}{2}\right)\Delta t$$

$$\Delta\omega_{i+1}^c = \Delta\omega_i + \left(\frac{\frac{d\Delta\omega}{dt}\big|_{\delta_i} + \frac{d\Delta\omega}{dt}\big|_{\delta_{i+1}^p}}{2}\right)\Delta t$$

The above equations are used to obtain the values of δ and are plotted with respect to time

CONCLUSION

Here we plot the Swing curve for time with respect to rotor angle delta. Delta varies with time if any fault occurs, after a some time it regain its steady state .

APPENDIX

```
Matlab coding
clear
t = 0
tf=0
tfinal =0.5
tc=0.125
tstep=9.95
M=2.52/(180*50)
j=2
de1ta=21.64*pi/180
ddelta=0
time(1)=0
ang(1)=21.64
Pm=0.9
Pnaxbf=2.44
Pmaxdf=0.88
Pmaxaf=2.00
while t<tfinal,
 if ( t==tf ),
Paminus=0.9-Pmaxbf*sin(delta)
Paplus=O.9-Pmaxdf*sine(delta)
Paav=(Paminus+Paplus)/2
 Pa=Paav
end
if ( t==tc ) ,
Paminus=0.9-Pmaxdf*sin(delta)
Paplus=0.9-Pmaxaf*sin(delta)
Paav=(Paminus+Paplus)/2
Pa=Paav
end
if (t>tf & t<tc ),
Pa=Pm-Pmaxdf*sin(delta)
end
if (t>tc) ,
Pa=Pm-Pmaxaf*sin(delta)
end
t,Pa
ddelta=ddelta+(tstep*tstep*pa/M)
delta=(delta*180/pi+ddelta)*pi/180
deltadeg=det1a*180/Pi
t=t+tstep
pause
time(i)=t
ang(i)= deltadeg
ang(i)=deltadeg
i=i+1
end
axis([0 0.6 0 160])
plot(time,ang,'ko')
```