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NSCET E-LEARNING PRESENTATION

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ELECTRICAL AND ELCTRONICS ENGINEERING

III rd YEAR / V th SEMESTER

EE8501 – Power System Analysis

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UNIT 05 – Stability Analysis

The Pessimist sees the difficulty in every opportunity. The optimist sees the opportunity In every difficulty.

-Winston Churchill

UNIT-5

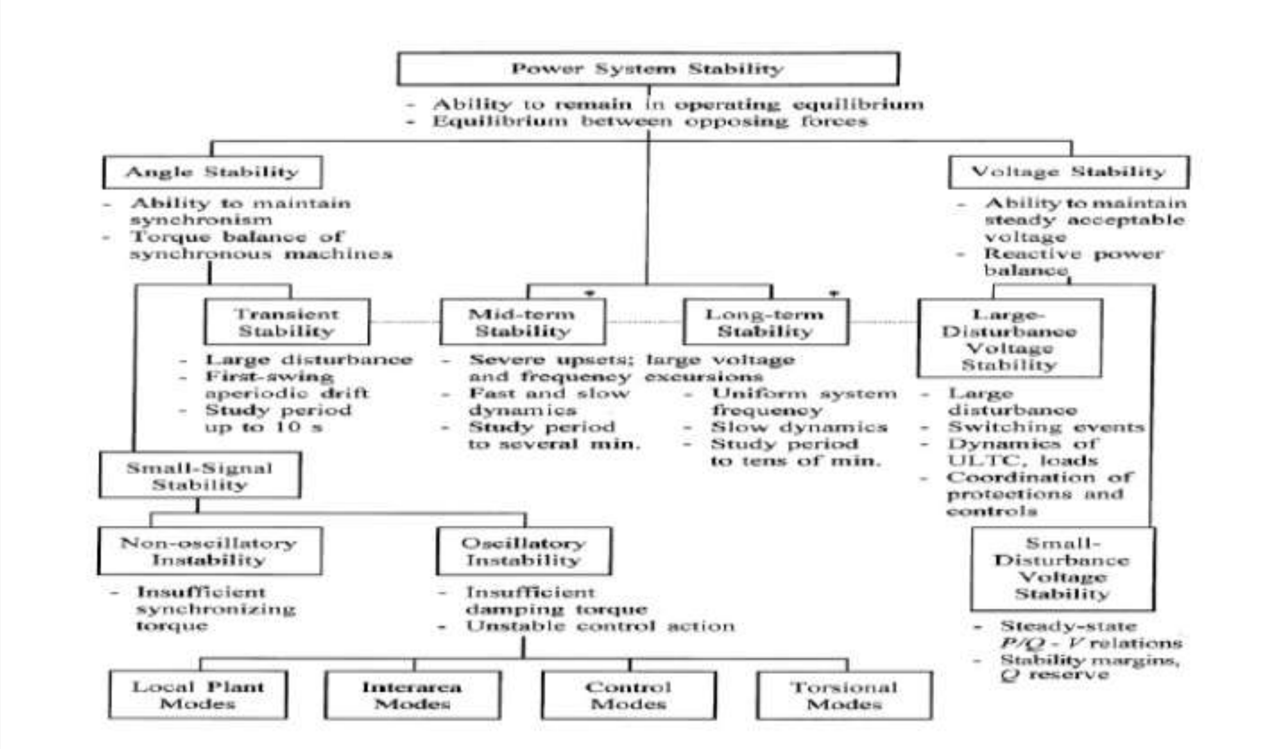
- Classification of power system stability
- Swing equation
- Power angle equation
- Equal area criterion
- Critical clearing angle and time
- Classical step-by-step solution of the swing equation

Classification of Power system stability-Angle and voltage stability

Power system stability

The stability of an interconnected power system means is the ability of the power system is to return or regain to normal or stable operating condition after having been subjected to some form of disturbance.

Classification:



ANGLE AND VOLTAGE STABILITY

Rotor angle stability

Rotor angle stability is the ability of interconnected synchronous machines of a power system to remain in synchronism.

Steady state stability

Steady state stability is defined as the ability of the power system to bring it to a stable condition or remain in synchronism after a small disturbance.

Steady state stability limit

The steady sate stability limit is the maximum power that can be transferred by a machine to receiving system without loss of synchronism

Transient stability

Transient stability is defined as the ability of the power system to bring it to a stable condition or remain in synchronism after a large disturbance.

Transient stability limit

The transient stability limit is the maximum power that can be transferred by a machine to a fault or a receiving system during a transient state without loss of synchronism. Transient stability limit is always less than steady state stability limit

Dynamic stability

It is the ability of a power system to remain in synchronism after the initial swing (transient stability period) until the system has settled down to the new steady state equilibrium condition

Voltage stability

It is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance.

Causes of voltage instability

A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable drop in voltage. The main factor causing instability is the inability of the power system to meet the demand for reactive power.

Power Angle Equation

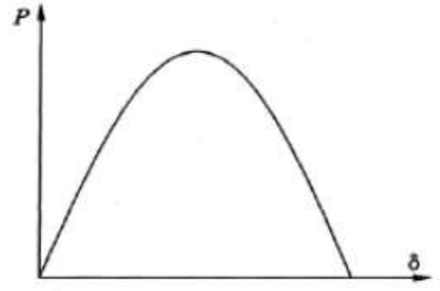
Power angle equation and draw the power angle curve

$$P = \frac{V_s V_r}{X_T} \sin \delta$$

Where, P – Real Power in watts

V_s – Sending end voltage
V_r- Receiving end voltage
X_T - Total reactance between sending end receiving end
δ - Rotor angle.

Power angle curve:



Maximum power transfer.

$$P_{max} = \frac{V_s V_r}{X_T}$$

Swing Equation

Swing equation for a SMIB (Single machine connected to an infinite bus bar) system:

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

Since M in p.u = $H/\pi f$

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

Where,

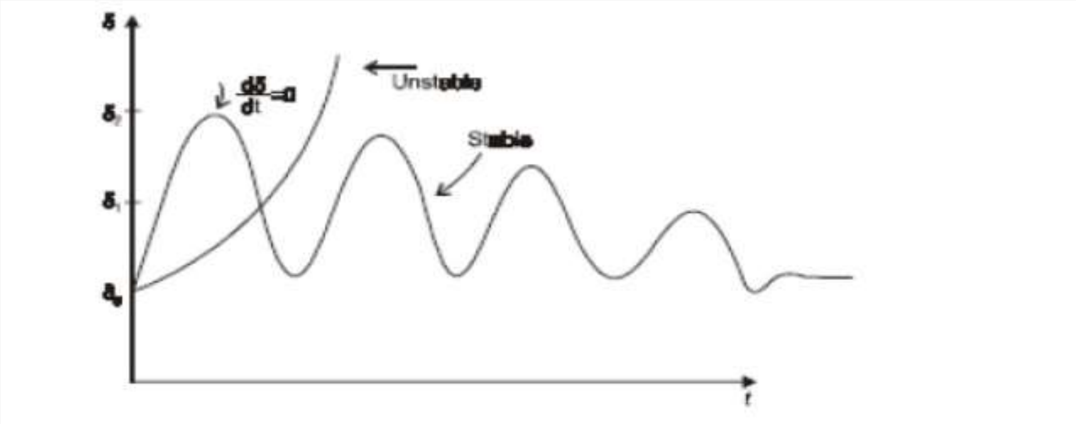
H = inertia constant in MW/MVA

f = frequency in Hz

M = inertia constant in p.u

Swing curve

The swing curve is the plot or graph between the power angle δ and time t. From the nature of variations of δ the stability of a system for any disturbance can be determined.



3 machine system having ratings G1, G2 and G3 and inertia constants M1, M2 and M3.What is the inertia constants M and H of the equivalent system.

$$M_{eq} = \frac{M_1 G_1}{G_b} + \frac{M_2 G_2}{G_b} + \frac{M_3 G_3}{G_b}$$

$$H_{eq} = \frac{\pi f M_{eq}}{G_b}$$

Where ,

G1, G2, G3 – MVA rating of machines 1, 2, and 3

Gb = Base MVA or system MVA

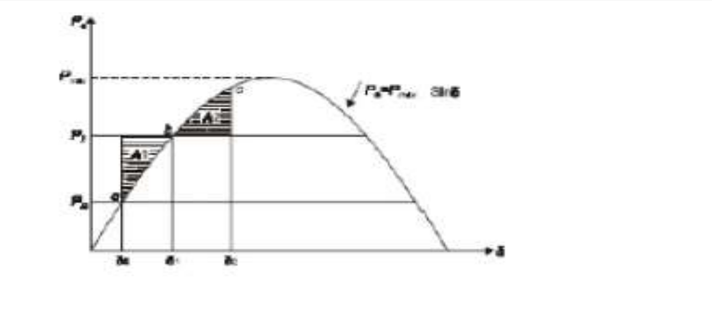
<u>Assumptions made in stability studies</u>:

- Machines represents by classical model
- The losses in the system are neglected (all resistance are neglected)
- The voltage behind transient reactance is assumed to remain constant.
- Controllers are not considered (Shunt and series capacitor)
- Effect of damper winding is neglected.

Equal Area Criterion:

The equal area criterion for stability states that the system is stable if the area under P – δ curve reduces to zero at some value of δ.

This is possible if the positive (accelerating) area under P – δ curve is equal to the negative (decelerating) area under P – δ curve for a finite change in δ. hence stability criterion is called equal area criterion.



Critical Clearing angle & Time

Critical clearing angle.

- The critical clearing angle , is the maximum allowable change in the power angle δ before clearing the fault, without loss of synchronism.
- The time corresponding to this angle is called critical clearing time, .It can be defined as the maximum time delay that can be allowed to clear a fault without loss of synchronism.

Methods of improving the transient stability limit of a power system.

- Reduction in system transfer reactance
- Increase of system voltage and use AVR
- Use of high speed excitation systems
- Use of high speed reclosing breakers

Numerical integration methods of power system stability

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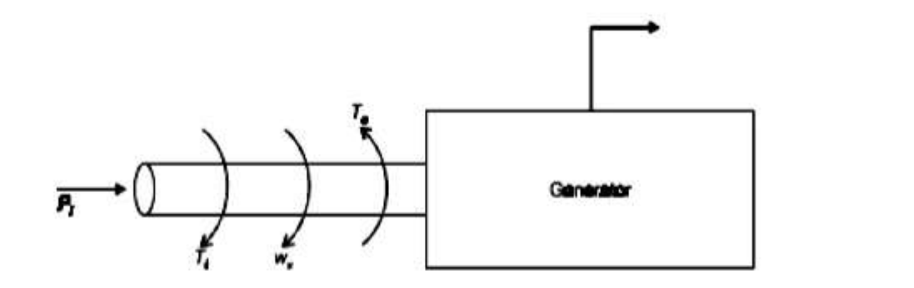
- Point by point method or step by step method
- Euler method
- Modified Euler method
- Runge-Kutta method(R-K method)

SINGLE MACHINE INFINITE BUS (SMIB) SYSTEM: DEVELOPMENT OF SWING EQUATION.



- Consider a synchronous generator developing an electromagnetic torque Te (and a corresponding electromagnetic power Pe) while operating at the synchronous speed ωm.
- I the input torque provided by the prime mover at the generator shaft is Ti, then under steady state conditions (with no disturbance).Te = Ti

Here we have neglected any retarding torque due to rotational losses. Therefore we have

$$T_e w_s = T_i w_s$$

and $$T_i w_s - T_e w_s = P_i - P_e = 0$$

If there is a departure from steady state occurs, or example, a change in load or a fault, then input power Pi is not equal to Pe if the armature resistance is neglected.

$$P_i - P_e = M.\frac{d^2\theta_e}{dt^2} + D.\frac{d\theta_e}{dt} = P_a$$

D is a damping coefficient and qe is the electrical angular position o the rotor. It is more convenient to measure the angular position o the rotor with respect to a synchronously rotating frame of reference. Let

$$\delta = \theta_e - w_s.t$$

$$\frac{d^2\theta_e}{dt^2} = \frac{d^2\delta}{dt^2}$$

Where δ is the power angle of the synchronous machine. Neglecting damping (i.e., D=0) and substituting

$$M.\frac{d^2\delta}{dt^2} = P_i - P_e \;\; MW$$

$$\frac{GH}{\pi f}\frac{d^2\delta}{dt^2} = P_i - P_e \, MW$$

Dividing throughout by G, the MVA rating of the machine,

$$M\,(\text{pu})\frac{d^2\delta}{dt^2} = (P_i - P_e)\ \text{pu}$$

where $$M(\text{pu}) = \frac{H}{\pi f}$$

or $$\frac{H}{\pi f}\frac{d^2\delta}{dt^2} = (P_i - P_e)\ \text{pu}$$

This equation is called <u>swing equation</u>. It describes the rotor dynamics for a synchronous machine. Although damping is ignored but it helps to stabilizer the system. Damping must be considered in dynamic stability study.

Problem#1:

A 400 MVA synchronous machine has H1=4.6 MJ/MVA and a 1200 MVA machines H2=3.0 MJ/MVA. Two machines operate in parallel in a power plant. Find out Heq relative to a 100MVA base.

Solutions:

Total kinetic energy of the two machines is

$$KE = 4.6 \times 400 + 3 \times 1200 = 5440 \text{ MJ}.$$

Using the formula given in eqn. (11.28),

$$H_{eq} = \left(\frac{400}{100}\right) \times 4.6 + \left(\frac{1200}{100}\right) \times 3$$

$$\therefore \quad H_{eq} = 54.4 \text{ MJ/MVA}$$

or, equivalent inertia relative to a 100 MVA base is

$$H_{eq} = \frac{\text{KE}}{\text{System base}} = \frac{5440}{100} = 54.4 \text{ MJ/MVA} \quad \textbf{Ans.}$$

Problem#2:

A 100 MVA, two pole, 50Hz generator has moment of inertia 40 x 103 kg-m2.what is the energy stored in the rotor at the rated speed? What is the corresponding angular momentum? Determine the inertia constant h.

Solution:

$$\eta_s = \frac{120f}{P} = \frac{120 \times 50}{2} = 3000 \text{ rpm.}$$

The stored energy is

$$\text{KE (stored)} = \frac{1}{2} J w_m^2 = \frac{1}{2}(40 \times 10^3)\left(\frac{2\pi \times 3000}{50}\right)^2 \text{ MJ}$$

$$= 2842.4 \text{ MJ}$$

Then

$$H = \frac{\text{KE (stored)}}{\text{MVA}} = \frac{2842.4}{100} = 28.424 \text{ MJ/MVA.}$$

$$M = \text{J}w_m = (40 \times 10^3)\left(\frac{2\pi \times 3000}{50}\right)$$

$\therefore$ $M = 15.07$ MJ-Sec/mech-radian **Ans.**

Equal area criterion in transient stability

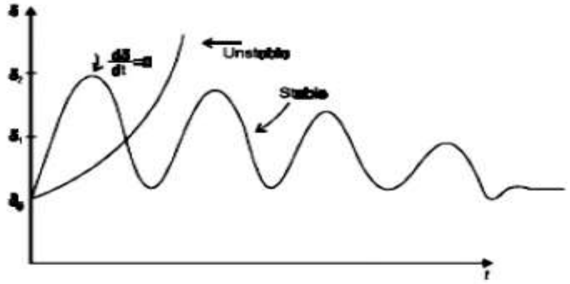
Solution o swing equation is not always necessary to investigate the system stability. Rather, in some cases, a direct approach may be taken. Such an approach is based on the equal-area criterion.

$$\frac{Md^2\delta}{dt^2} = P_i - P_e$$

$$\frac{Md^2\delta}{dt^2} = P_a$$

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

unstable system, δ increases indefinitely with time and machine some synchronism. In a stable system, δ undergoes oscillations, which eventually die out to damping.



$$\frac{2d\delta}{dt}\cdot\frac{d^2\delta}{dt^2} = \frac{2P_a}{M}\frac{d\delta}{dt}$$

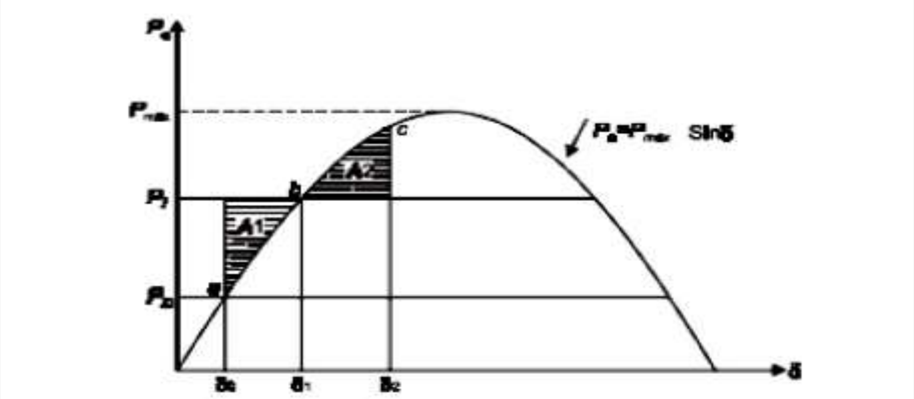
which, upon integration with respect to time, gives

$$\left(\frac{d\delta}{dt}\right)^2 = \frac{2}{M}\int_{\delta_0}^{\delta} P_a d\delta$$

Note that $P_a = P_i - P_e$ = accelerating power and δ_0 is the initial power angle before the rotor begins to swing because of a disturbance. The stability criterion $\frac{d\delta}{dt} = 0$ (at some moment) implies that

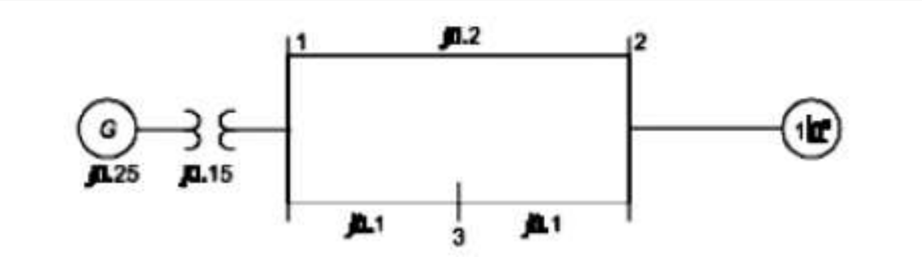
$$\int_{\delta_0}^{\delta} P_a d\delta = 0$$

- This condition requires that, for stability, the area under the graph of accelerating power Pa versus δ must be zero for some value of δ; that is, the positive(or accelerating) area under the graph must be equal to the negative (or decelerating) area. This criterion is therefore known as the equal-area criterion for stability and it is shown in fig.

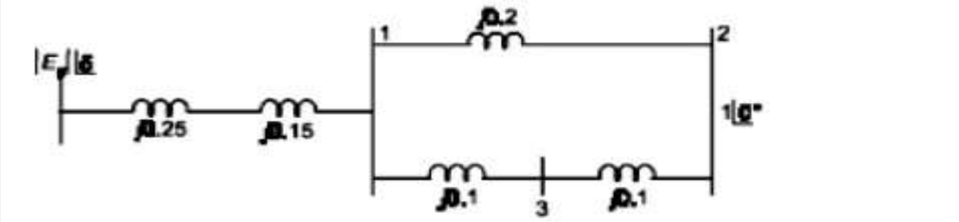


Problem#3:

A single line diagram of a system is shown in fig. All the values are in per unit on a common base. The power delivered into bus 2 is 1.0 p.u at 0.80 power factor lagging. Obtain the power angle equation and the swing equation for the system. Neglect all losses.



Solution:



$$x_{eq} = 0.25 + 0.15 + \frac{0.2 \times 0.2}{0.4} = 0.50 \text{ pu}$$

$$\cos\Phi = 0.8,\ \Phi = 36.87^\circ \text{ (lagging)}$$

current into bus 2 is

$$I = \frac{1.0}{1 \times 0.8} \angle{-36.87^\circ} = 1.25 \angle{-36.87^\circ} \text{ pu}$$

The voltage E_g is then given by

$$|E_g| \angle\delta = |V_2| \angle 0^\circ + jx_{eq} I$$

$$|E_g| \angle\delta = 1\angle 0^\circ + 0.5\angle 90^\circ \times 1.25 \angle{-36.87^\circ}$$

$$|E_g| \angle \delta = 1 + 0.625 \angle 53.13^\circ$$

$$|E_g| \angle \delta = 1.375 + j\,0.5$$

$$|E_g| \angle \delta = 1.463 \angle 20^\circ$$

$$|E_g| = 1.463, \quad \delta = 20^\circ$$

$$P_e = \frac{E_g . V_2}{x_{eq}} \sin\delta = \frac{1.463 \times 1}{0.5} \sin(\delta)$$

$$P_e = 2.926 \sin\delta .$$

$$\frac{H}{\pi f} \frac{d^2\delta}{dt^2} = P_i - P_e$$

$$\frac{H}{180f}\frac{d^2\delta}{dt^2} = P_i - P_e$$

Here P_i = 1.0 pu mechanical power input to the generator.

$$\therefore \quad \frac{H}{180f}\frac{d^2\delta}{dt^2} = 1 - 2.926 \sin\delta \qquad \textbf{Ans.}$$

As a verification of the result, at steady-state

$P_i = P_e = 1 \quad \therefore \; 2.926 \sin\delta = 1 \quad \therefore \; \delta = 20°.$

Thank you