Topic ______ Date ______

Loss of Synchronism & Swing curves

Any unbalance between the generation and load initiates a transients that causes the rotors of the synchronous machines to swing because net accelerating (or decelerating) torques are exerted on these rotors. Let us consider a severe impact initiated by a sizeable generation unbalance say excess generation. The major portion of the excess energy will be converted into kinetic energy. Thus most of the machine rotor angular velocities will increase. However an appreciable increase in machine speeds may not necessarily mean that synchronism will be lost. The important factor here is the angular differences between all the machines. This is illustrated in following figure, ~~where~~ in which the rotor angles of a hypothetical four ~~two~~ machine system are plotted against time during a transient.

In case (a) all the angle differences are small and the system will be stable if it eventually settles ~~on~~ to a new equilibrium.

In case (b) it is evident that the machines are separated into two groups where the rotor angles continue to drift apart. This system is unstable.

Topic Date

Although we may choose to plot the ~~machine's~~ angle between machine's rotor and a synchronously rotating reference axis it is the relative angles between machines which are important. We may not be able to make any judgement regarding the stability from the plot of absolute rotor angles. As a result we plot the relative rotor angles with respect to one of the generators (say generator 1 having largest inertia). From the relative rotor angle plots we can judge whether the generators remain in synchronism.

Problem : A generator having $H = 6\ MJ/_{MVA}$ is connected to a synchronous motor having $H = 4\ MJ/_{MVA}$ through a network of reactances. The generator is delivering power of 1.0 per unit to the motor when a fault occurs which reduces the delivered power. At the time when the reduced power delivered is 0.6 per unit determine the angular acceleration of the generator with respect to the motor.

Ans.

$$\frac{6 \times 4}{6+4} \times \frac{1}{180f} \frac{d^2\delta_{12}}{dt^2} = 1.0 - 6$$

$$\frac{d^2\delta_{12}}{dt^2} = 1800 \text{ elec. degrees}/s^2$$

Problem :

Classical Stability model

The equation of motion of the rotor of a Synchronous m/c is given by its swing equation. To obtain a time solution for the rotor angle (swing curve), we need the expression for mechanical and electrical powers. In classical model, following assumptions are usually made, in the determination of mechanical and electrical powers:

1. The mechanical power remains constant during the entire period of swing curve computation.

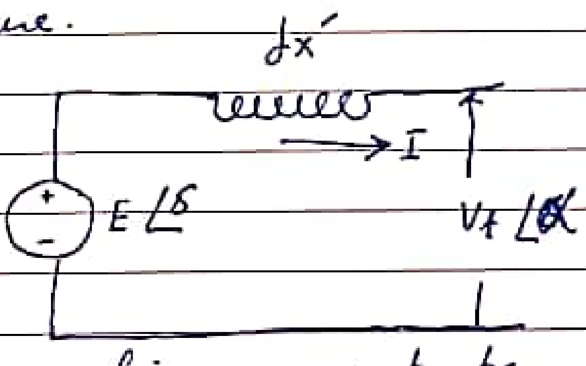
Discussion: The input is initially equal to output. When a disturbance occurs, the output usually undergoes an abrupt change, but the input is unchanged. The input to a generating unit is controlled by the governor of its prime mover. The governor will not act untill the speed change exceeds a certain amount (usually 1% of normal speed) depending on the adjustment of the governor, and even then there is a time lag before the governor changes the input. During swings of the synchronous machines the percentage change in speed is very small until after synchronism is actually lost. Therefore governor action is usually not a factor in determining whether synchronism will be lost and accordingly it is neglected — governor systems are not modeled.

Topic Date

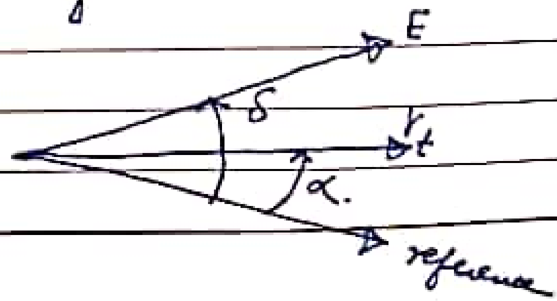
2. Damping or asynchronous power is negligible.

Discussion: The output (electric power) of synchronous m/cs consists of a synchronous part, depending on the relative angular positions of all the m/cs of the system, and an asynchronous part, depending on the relative angular speeds of all the m/cs. The asynchronous part may be taken into account, if desired but as it is usually unimportant in comparison to the synchronous part, it is commonly neglected in the interest of simplicity.

3. The synchronous machines are represented by electrically by constant-voltage-behind-transient reactance models, as shown in following figure.



Since each machine must be considered relative to the system of which it is part, the phasor angles of the machine quantities are measured with respect to the common system reference.



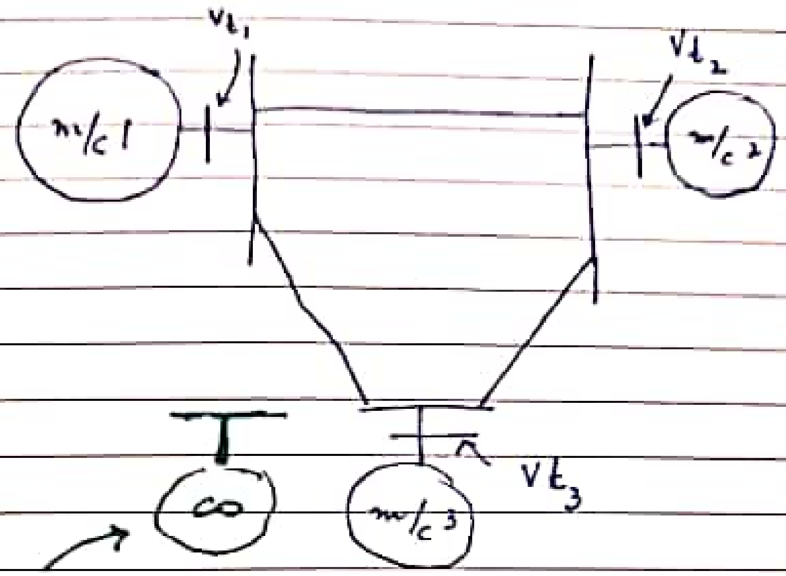
Topic ______ Date ______

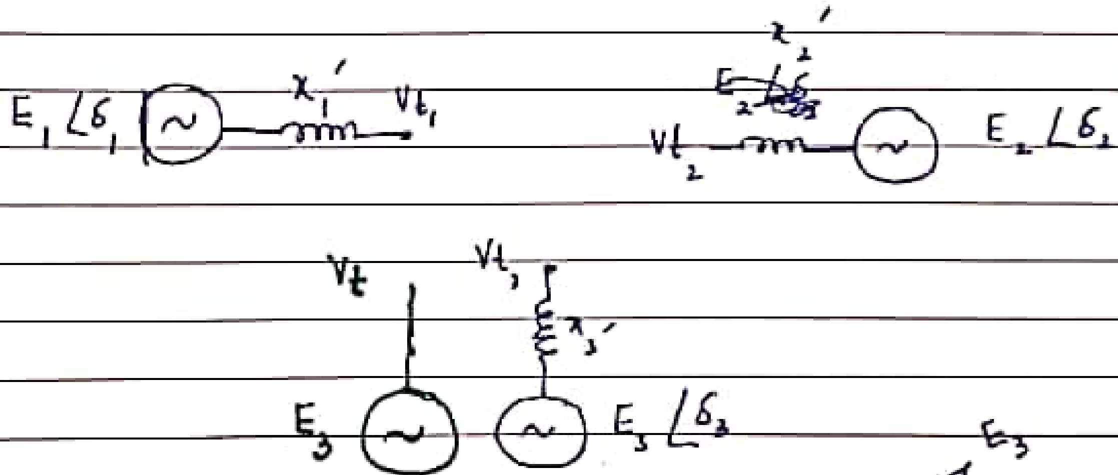
4. The motion of each Generator rotor (relative to synchronously rotating reference frame) coincides with the angle of the voltage behind the transient reactance.
The constant voltage source $E\angle\delta$ is determined from the initial conditions (i.e. predisturbance power flow conditions). During the transient E is held constant while the variation of δ is Governed by Swing equation

5. Loads are Represented by constant impedances

The assumption that each can be Represented by a constant reactance in Series with a constant voltage and the assumption that the mechanical position of the rotor coincides with the phase angle of the constant voltage are not entirely correct. As a rule however they do not lead to serious error in the determination of whether a given system is stable. The examination and justification of these assumption requires a considerable knowledge of Synchronous machine theory

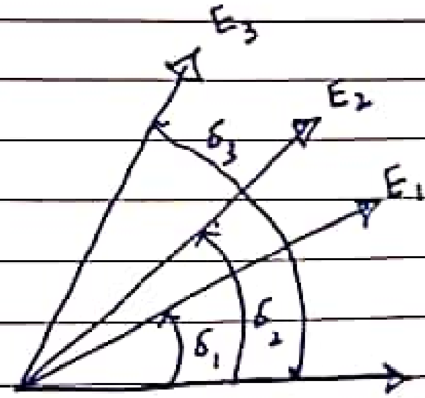
Topic Date 22-A





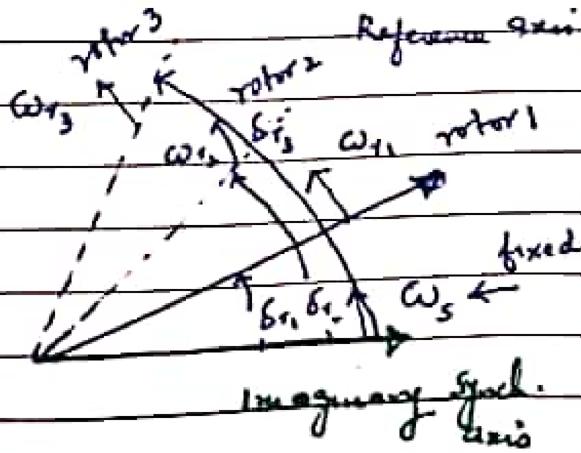
$$P_{e_1} = f(\delta_1, \delta_2, \delta_3, \dot{\delta}_1, \dot{\delta}_2, \dot{\delta}_3)$$

$\uparrow \omega_1 \quad \uparrow \omega_2 \quad \uparrow \omega_3$



→ motion governed by swing equations

$$\left.\begin{aligned} \delta_1 &= \delta_{r_1} \\ \delta_2 &= \delta_{r_2} \\ \delta_3 &= \delta_{r_3} \end{aligned}\right\}$$

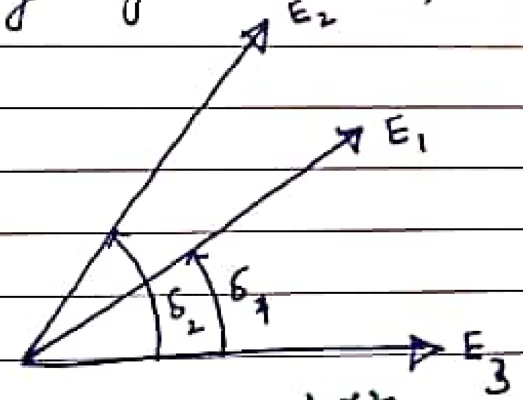


Citizen

Topic   Date 22-B

As a special case system may include an infinite bus — in this case the direction of its internal voltage may be considered as reference axis and its rotor position may be considered as imaginary synch. axis, as shown below

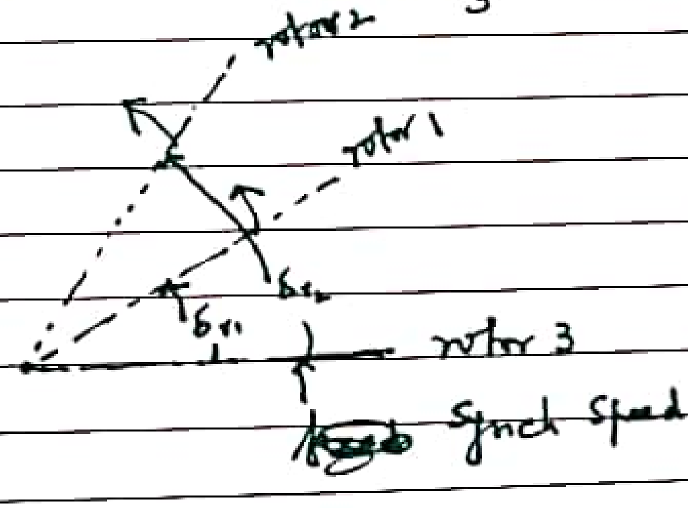
$\delta_3 = 0$



$\delta_1 = \delta_{r_1}$

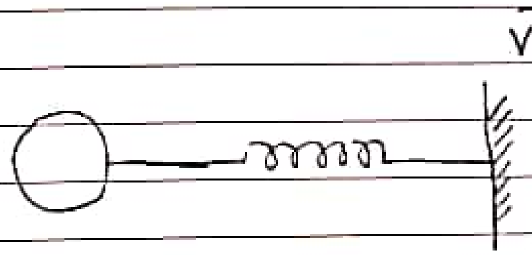
$\delta_2 = \delta_{r_2}$

$\delta_3 = 0$

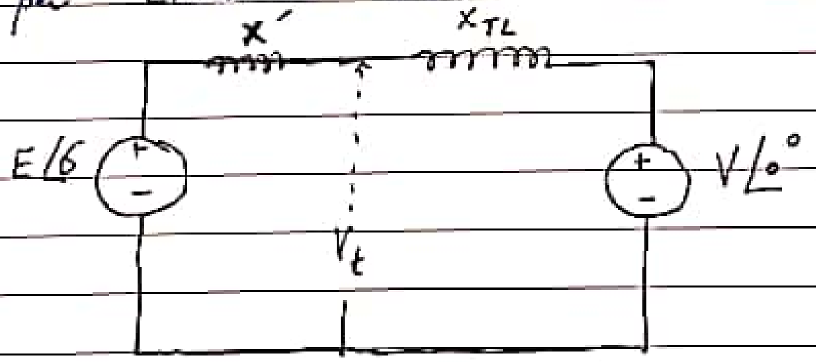


System of one machine and infinite bus:

Consider a power system consisting of one machine connected to an infinite bus through a transmission network. A schematic representation of this system as shown in figure.



The equivalent circuit of above system as per classical model is as shown below



where X' - is transient reactance of m/c
E = voltage behind transient reactance
V_t = terminal voltage of
$\bar{V}$ = voltage of the infinite bus which is used as reference
δ = rotor angle and it represents the angle by which $\bar{E}$ leads V
X_{TL} = Series reactance of transmission network

When the system is perturbed, the magnitude of $\bar{E}$ remains constant at its predisturbance value and δ changes as the rotor speed deviates from synchronous speed.

Topic Date (23)

The generator's electrical power output is

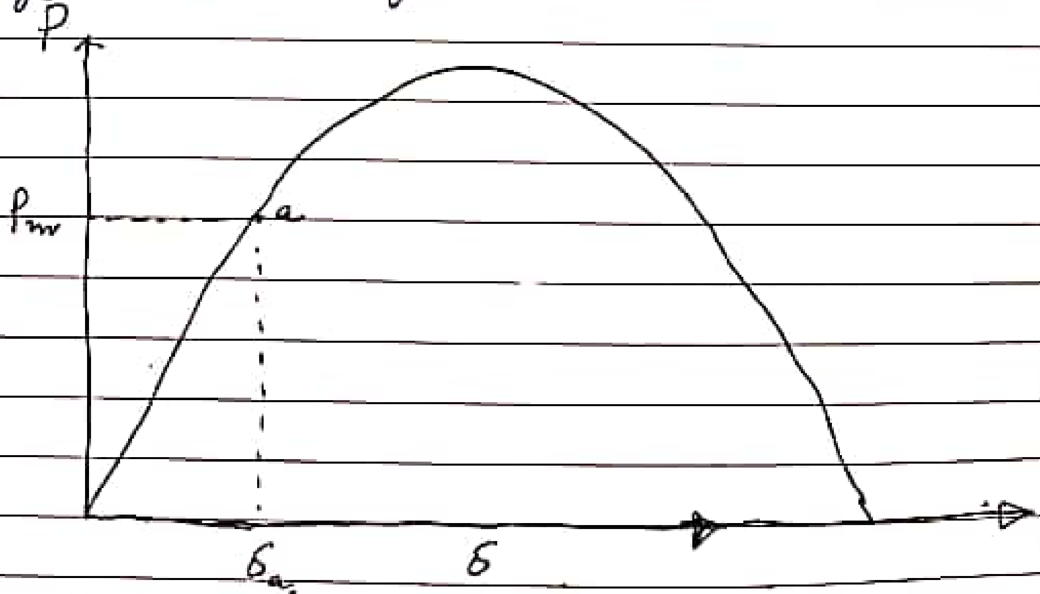
$$P_e = \frac{EV}{X_T} \cdot \sin\delta = P_{max} \sin\delta \quad \text{——}$$

where $P_{max} = \frac{EV}{(X'_d + X_{TL})}$

Since we have neglected the stator resistance P_e represents the air-gap power as well as terminal power.

eq ( ) is called power angle equation. Its plot as a function of δ is called power angle curve.

The power-angle relationship with transmission network in service is graphically shown in following figure as curve 1. With a mechanical power input of P_m, the steady state electrical power P_e is equal to P_m and the operating point is represented by point a on the curve. The corresponding rotor angle is δ_a

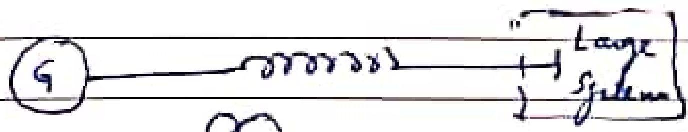


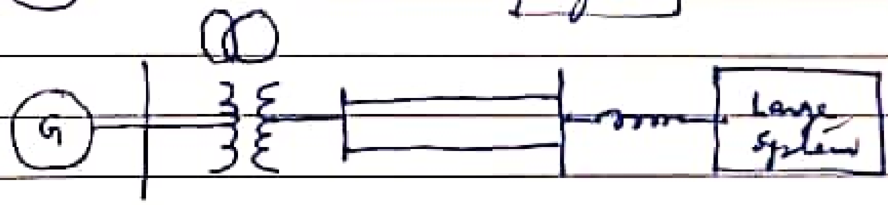
Power angle curve of SMIB system.

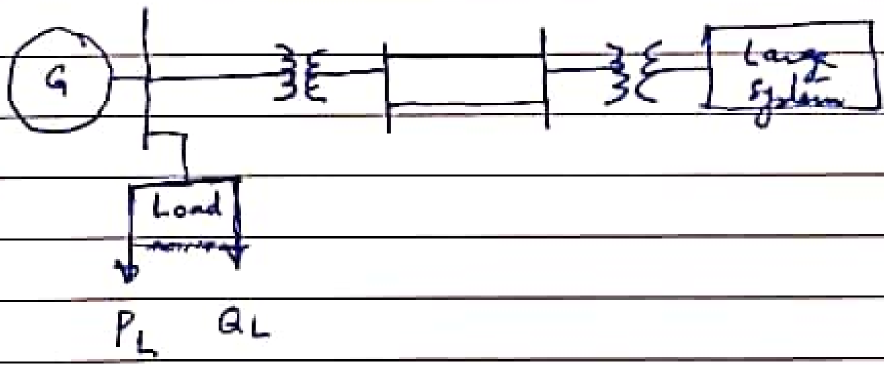
Topic ______ Date ______

Single - Machine Infinite Bus System

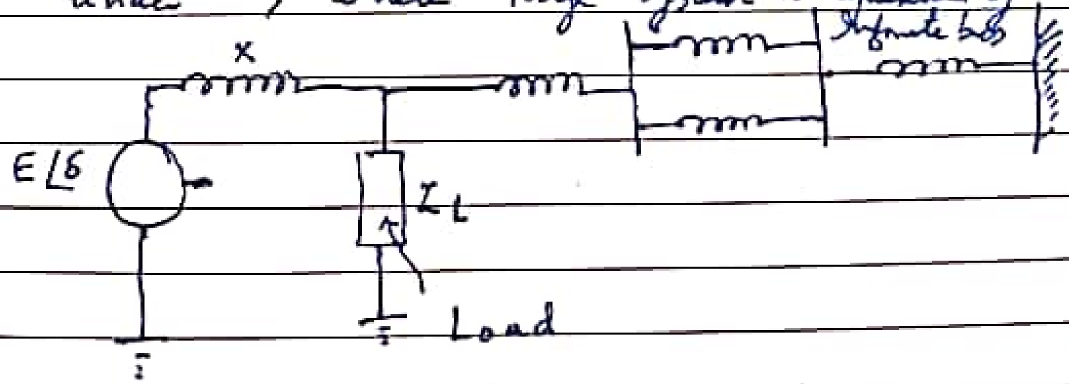
Let us consider a single machine connected to a large system.
Many configuration are possible







The equivalent circuit for system (c) can be as under, where large system is represented by infinite bus $V\angle 0$



Topic Date

Transient Stability

Large-disturbance rotor angle stability or transient stability, as it is commonly referred to is concerned with the ability of power system to maintain synchronism when subjected to a severe disturbance such as a short circuit on a transmission line. The resulting system response involves large excursions of the generator rotor angles and is influenced by the non linear power angle relationship.

Transient instability normally manifests as first swing instability.

The basic problem is described as follows: The generator is running at synchronous speed stable, and loaded to some known amount. This state we shall call the prefault condition. At $t=0$, an arbitrary switching action, called fault occurs in the external system. The system in this state is identified as faulted system. After some time has elapsed at $t = T_c$ the fault is cleared that is a second switching action occurs, intended to remove or isolate the fault. The resulting configuration is ~~called~~ referred to as the postfault system.

Since there are three configurations there are three P_e functions, denoted by P_e^0, P_e^f, P_e^{pf} the prefault, faulted and postfault functions. The prefault function is used in determining initial conditions (like δ^0) The faulted and postfault functions are used in the faulted $(0 < t < T_c)$