Power System Analysis

→ The goal of the course is to provide an overview of interconnected power system operation.

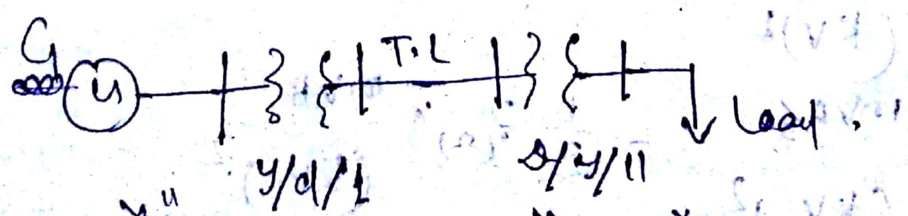
→ Modern methods of power system Analysis and design.

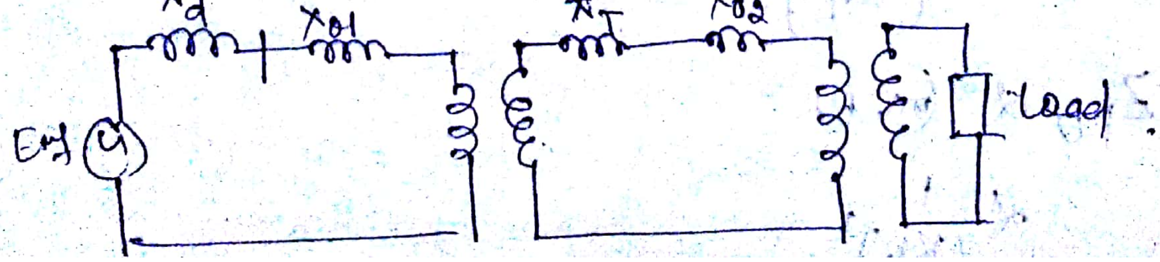
→ The course will equip the students with the basic tools for analyzing the operation of a power system in normal as well as emergency condition.

— o —

PS - I	PS - II
① Transmission line parameter.	→ fault.
② Performance of transmission line.	→ Stability.
③ Static power equation.	→ load flow.
④ Voltage control.	
⑤ power factor correction.	
⑥ distribution system.	

Single line diagram





To represent the total system in per unit system.

$$\text{Per unit} = \frac{\text{Actual value}}{\text{Base value}}$$

$$Z_{pu} = \frac{Z_{a}(\Omega)}{Z_b} \qquad Z_b = \frac{V_b}{I_b} = \frac{V_{rated} \times V_{rated}}{I_{rated} \times V_{rated}} = \frac{V_{rated}^2}{VA}$$

$$\boxed{Z_{pu} = \frac{Z(\Omega)}{V_{rated}^2} \times (VA)} \Rightarrow \boxed{\frac{Z(\Omega) \times MVA}{(KV)^2}}$$

No unit.

* Per unit value is defined in per-phase only.

Y-connection

$$Z_{pu} = Z(\Omega) \times \frac{MVA}{(KV)^2}$$

$$Z_{pu} = Z(\Omega) \times \frac{3\phi\ MVA/3}{\left(\frac{KV_L}{\sqrt{3}}\right)^2} = Z(\Omega) \times \frac{3\phi\ MVA}{(KV_L)^2}$$

Δ-connection

$$Z_{pu} = Z(\Omega) \times \frac{MVA}{(KV)^2}$$

$$= Z(\Omega) \times \frac{MVA/3}{(KV_L)^2} = \frac{1}{3} Z(\Omega) \times \frac{MVA}{(KV_L)^2}$$

$$Z_{pu} \propto (MVA)$$

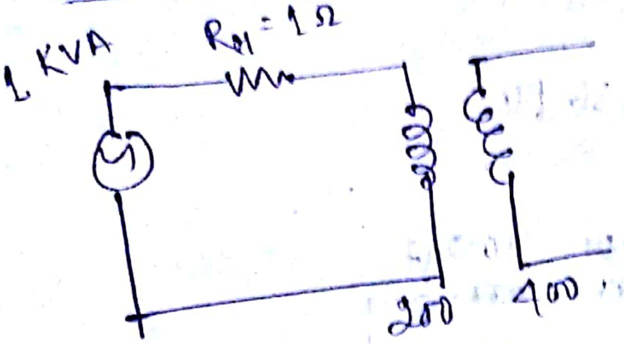
$$\propto \frac{1}{(KV)^2}$$

Scanned by CamScanner

$$\frac{Z_{pu}(new)}{Z_{pu}(old)} = \frac{(MVA)_{new}}{(MVA)_{old}} \times \frac{(KV_b)_{old}}{(KV_b)_{new}}$$

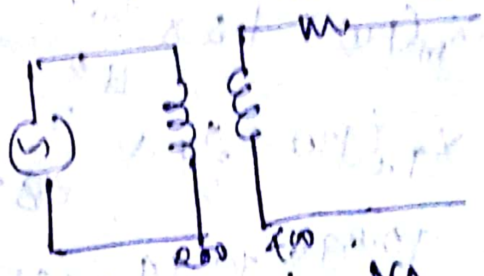
$$\boxed{Z_{pu}(new) = Z_{pu}(old) \times \frac{VA_{new}}{VA_{old}} \times \left(\frac{V_b\ old}{V_b\ new}\right)^2}$$

Y-connection



$R_{01}' = R_{01} \times \left(\frac{N_2}{N_1}\right)^2$

$R_{01}' = 1 \times \left(\frac{4}{2}\right)^2 = 4\,\Omega$

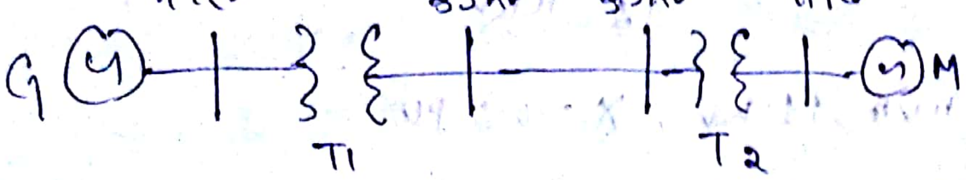


$$R_{01}(pu) = R(\Omega) \times \frac{VA}{V_b^2}$$
$$= 1 \times \frac{1000}{(200)^2}$$
$$= \frac{1}{40}\ PU$$

$$R_{01}'\,_{PU} = R_{01}' \times \frac{VA}{V_b^2}$$
$$= 4 \times \frac{1000}{(400)^2}$$
$$= \frac{1}{40}\ PU.$$

Reactance diagram

Case-I when reactance are given in Ω



G = 30 MVA, 11 KV, X = 1.6 Ω

T_1 = 15 MVA, 11 KV/33 KV, X = 16 Ω/Ph on HV side.

T_2 = 15 MVA, 33 KV/11 KV, X = 17 Ω/Ph LV side.

M = 25 MVA, 11 KV, X = 1.2 Ω

TL = 20.5 Ω/Ph

Draw reactance diagram by taking any base value.

30 MVA & 11 KV as base value at generating station

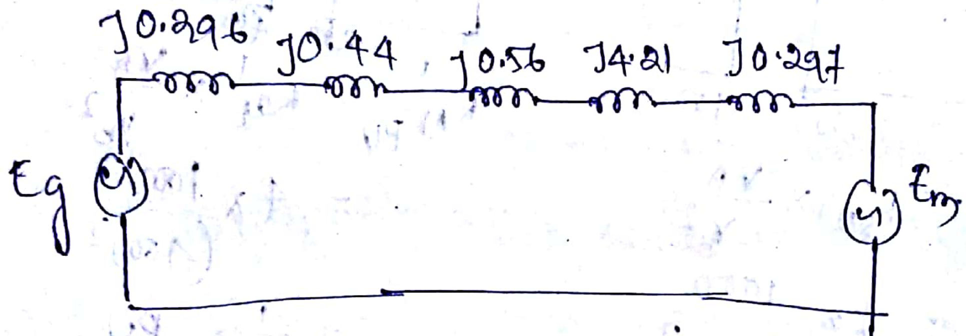
$X_{G(PU)} = 1.6 \times \frac{30}{11^2} = 0.396$ PU

$X_{T_1}(PU) = 16 \times \frac{30}{33^2} = 0.44$ PU

$X_{T_2}(PU) = 17 \times \frac{30}{11^2} = 4.21$ PU

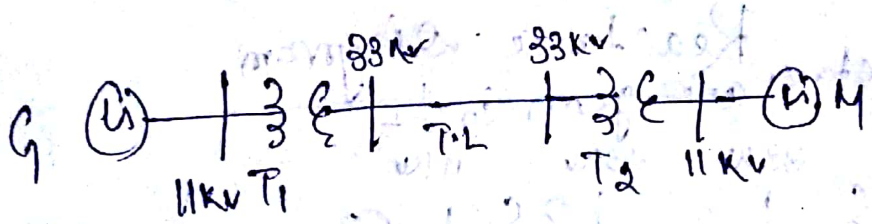
$X_m(PU) = 1.2 \times \frac{30}{11^2} = 0.297$ PU

$X_{T.L}(PU) = 20.5 \frac{30}{33^2} = 0.56$ PU



Case-II

When reactance are given in PU.



$G = 30$ MVA, 11 KV, $X = 0.2$ PU

$T_1 = 15$ MVA, 11 KV/33KV, $X = 0.1$ PU

$T_2 = 15$ MVA, 33 KV/11KV, $X = 0.1$ PU

$M = 25$ MVA, 11 KV, $X = 0.2$ PU

$T.L = 20.5\ \Omega/Ph$

Draw the reactance diagram by taking 100 ~~MVA~~ MVA, 11 KV base voltage at G.

$$Z_{pu(new)} = Z_{pu}(old) \times \frac{(MVA)_{new}}{(MVA)_{old}} \times \left(\frac{V_{b\,old}}{V_{b\,new}}\right)^2$$

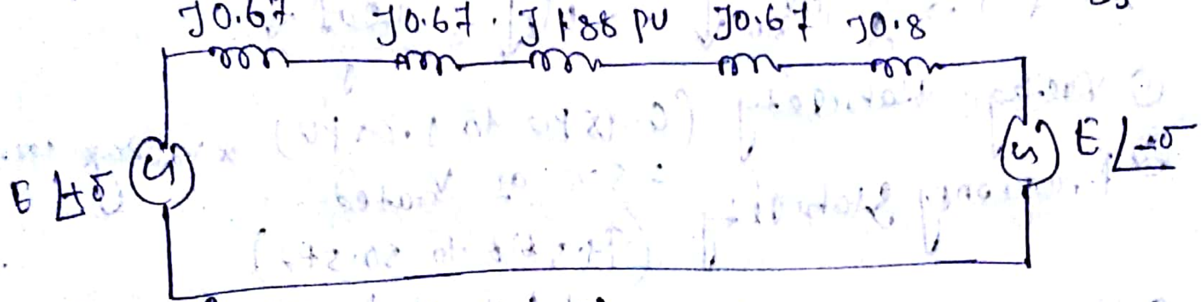
$$X_{G}(new) = 0.2 \times \frac{100}{30} \times \left(\frac{11}{11}\right)^2$$

$$= 0.67 \text{ PU}.$$

$$X_{T_1}(PU) = 0.1 \times \frac{100}{15} \times \left(\frac{11}{11}\right)^2 = 0.67 \text{ PU} = X_{T_2}(PU)\ new$$

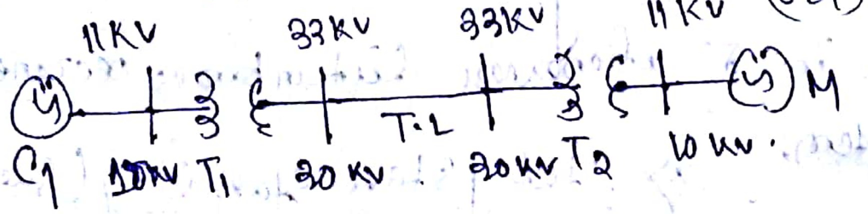
$$X_m = 0.2 \times \frac{100}{25} \times \left(\frac{11\,kV}{11\,kV}\right)^2 = 0.8 \text{ PU}.$$

$$X_{TL} = 20.5 \times \frac{100}{33^2} = J1.88 \text{ PU}$$



Case-III when $V_b(new) \neq V_b(old)$.

(old).



G = 30 MVA, 11 KV, $X = 0.2$ PU.

T_1 = 15 MVA, 11 KV/33 KV $X_{T_1} = 0.1$ PU

T_2 = 15 MVA; 33 KV/11 KV, $X_{T_2} = 0.1$ PU.

M = 25 MVA, 11 KV, $X = 0.2$ PU

T.L = 20.5 Ω/ph

Draw reactance diagram by taking 100 MVA 10 KV base voltage at G.

$$X_G(new) = 0.2 \times \frac{100}{30} \times \left(\frac{11\,KV}{10}\right)^2 =$$

$$X_{T_1}(new) = 0.1 \times \frac{100}{15} \times \left(\frac{11}{10}\right)^2 =$$

$$X_{T_2}(new) = 0.1 \times \frac{100}{15} \times \left(\frac{11}{10}\right)^2 =$$

$$X_m(new) = 0.2 \times \frac{100}{25} \times \left(\frac{11}{10}\right)^2 =$$

$$X_{PU} = 20.5 \times \frac{100}{30^2}$$

Scanned by CamScanner

Ch-3: POWER System Stability

→ The Phenomenon of regaining the original operating point of a System Subjected to marginal or considerable disturbance within a time slot of 'Δt' is considered as Stability.

→ Stability can also be defined as ability of the System to transfer power continuously.

depending upon the intensity of the disturbance the Stability phenomenon is classified in three types.

Steady State Stability

The Phenomenon of Stability under Slow & Small changes is considered as Steady State Stability.

Ex Small load change, Slight variation in excitation.

The parameter deviation in this Phenomenon will not exceed by 5%.

→ The remedys are use of AVR and ALFC.

$$P = \frac{EV}{X} \sin\delta$$

$$P \propto \frac{E \sin\delta}{\Delta\alpha} \rightarrow \text{AFC}$$

Transient Stability

The phenomenon of stability under large changes within a small time is consider as transient stability.

Ex – sudden load change and faults.

→ The parametric deviation under this phenomenon is more than 5%.

→ The remedys are
i) use of Automatic excitation controller. (more than 5% less than 5% → AVR).
ii) use of parallel lines $P = \frac{EV}{X/2}\sin\delta = \frac{2EV}{X}\sin\delta$.
iii) use of circuit breaker of fast acting with auto recloser.

<u>Dynamic Stability</u>

The phenomenon of stability under parametric deviation within ~~transient~~ developed band of (2–3%) is considered as dynamic stability.

This phenomenon will never cause the system to become unstable but it to excite oscillation.

→ These oscillation will deteriorate mechanical strength and system collapses physically.

These are called as low power frequency oscillation and are in the range of 0.2 Hz to 2.0 HZ.

This oscillation can be damped out by designing power system stabilizer (PSS).
These are pure resistive component.
Resistor is the equivalent in electrical system for the mechanical damper.

Assumption on Stability Studies :-

To carry stability studies on all the power system the following assumption must be considered :

1. All the resistances including armature winding are assume to be negligible to determine optimistic stability limit.

2> Speed should always be synchronous so that frequency doesn't changes. i.e contraction or expansion of operating parameter is not allowed.

3> The synchronous Machine should be modeled in single machine connected to infinite bus bar. (SMIB)
This modeling is also called as classical modeling.

4> All the loads are modeled as constant Admittance model.

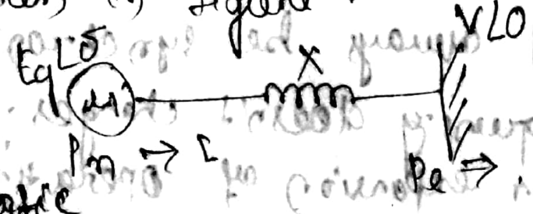
$$sT = mT$$

Mathematical Modeling.

For the power system stability analysis the system should be properly modelled.

The power system is originating from generator there by system stability is very much depend upon M/c stability. That's why more emphasis is given to synchronous machine in power system stability analysis.

The power system with synchronous machine is made as classical modeling as shown in figure.



The ~~Steady~~ Static mathematical modelling can be considered as power angle characteristic as can be written as

$$P_e = \frac{E_q V}{X} \sin\delta$$

Now dynamic modeling should be obtained. The synchronous machine is supplied with mechanical torque of T_m.

It generates equivalent electrical torque T_e under the cond^n of equilibrium

$$T_m = T_e$$

If $T_m \neq T_e$

Scanned by CamScanner

The machine subjected to acceleration or deceleration.

If $T_m > T_e$ Acceleration

If $T_m < T_e$ deceleration.

There by the acceleration torque can be developed written as

$T_a = T_m - T_e$

So from the fundamental machine dynamics the acceleration torque

$$T_a = J\frac{d^2\theta_m}{dt^2} + B\frac{d\theta_m}{dt} + K\theta_m$$

As per the assumption taken

$B = 0, \; K = 0$

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

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

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

$\omega_m = (2/P)\omega_e$

$$\theta_m = (2/P)\theta_e$$

Thus $(2/P)^2 \frac{d^2\theta_e}{dt^2} = P_a = P_m - P_e$

Here $J\omega_m (2/P)^2$ As M

$\theta_e = \delta$

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

This eqn is considered as dynamic model of the system, as the basis of this mathematical model necessary analysis is carried.

This eqn is termed as swing equation. In the terminology it can be defined as

"The equation which describe the relative position of rotor w.r.t stator magnetic field as a function of time."

It is the mathematical model that estimate dynamics. Swing is produced due to continuous oscillatory force. This eqn is also called as Machine differential eqn, machine characteristic eqn, machine dynamic eqn.

Dynamics of M/c

Kinetic energy absorbed by any rotating machine fundamentally can be estimated as

$$K.E = \frac{1}{2} J \omega_m^2.$$

Regarding the synchronous machines, it is rotating with angular velocity ω_s rad/sec.

The kinetic energy is defined as

$$K.E = GH$$

$$GH = \frac{1}{2} J \omega_m^2$$

$$= \frac{1}{2} J \left(\frac{2}{p}\omega_s \frac{2}{p}\omega_s\right.$$

$GH = \frac{1}{2} m v^2$

$= \frac{1}{2} \times m \times 2\pi f$

$\Rightarrow \boxed{m = \frac{GH}{\pi f}}$ mj-sec/degree or rad

m can also be called as inertia of constant with different units.

MultiMachine Modelling.

The power system is consisting of more than one machine for the purpose of analysis it should be modeled. For the ease of mathematical explanation let us consider two machine.

The consideration of two M/c the modelling is carried with the consideration of

i) The M/c swinging together

ii) The M/c don't swing together.

Machines Swing together:

In this case the rotor pos^n of both the machine is same.

$\delta_1 = \delta_2 = \delta$.

The total Accelerating power is the summation of individual Accelerating powers.

$P_a = P_{a_1} + P_{a_2}$

$$m\frac{d^2\delta}{dt^2} = m_1\frac{d^2\delta_1}{dt^2} + m_2\frac{d^2\delta_2}{dt^2}$$

As $\delta_1 = \delta_2 = \delta$

$$\boxed{M\frac{d^2\delta}{dt^2} = (m_1+m_2)\frac{d^2\delta}{dt^2}}$$

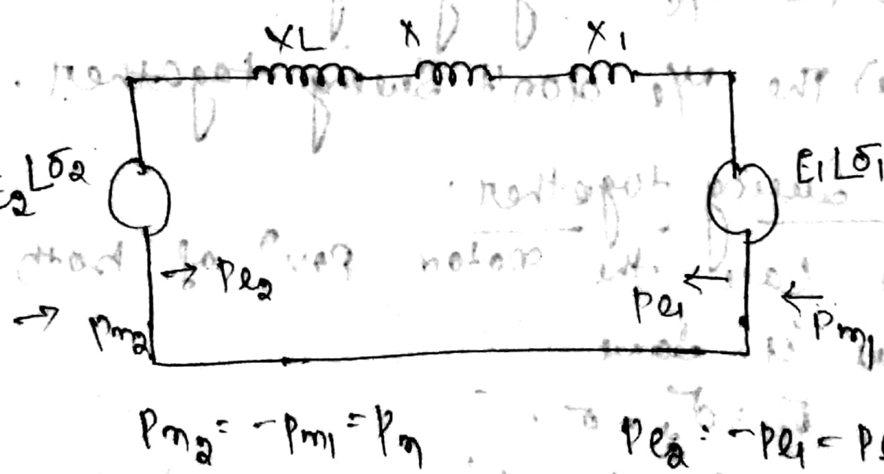
$$\boxed{M_{eq} = m_1+m_2}$$

The machine don't swing together.

In this case the angular posn of both the rotor are different.

One rotor may be advanced than other. There by the machine which is having more δ can be considered for generating action.

The machine which is having lesser load angle 'δ' is considered for motoring angle.



$P_{m2} = -P_{m1} = P_m$ $\quad P_{e2} = -P_{e1} = P_e$.

The net load angle can be consider as

$$\delta = \delta_2 - \delta_1$$

$$\frac{d^2\delta}{dt^2} = \frac{d^2\delta_2}{dt^2} - \frac{d^2\delta_1}{dt^2}$$

$$\frac{d^2\delta}{dt^2} = \frac{P_{m_2} - P_{e_2}}{m_2} - \frac{P_{m_1} - P_{e_1}}{m_1}$$

$$\frac{d^2\delta}{dt^2} = \frac{P_m - P_e}{m}, \quad \frac{d^2\delta}{dt^2} = \frac{P_m - P_e}{m_2}$$

$$= \frac{m_1 P_{m_2} - m_1 P_{e_2} - m_2 P_{m_1} + m_2 P_{e_1}}{m_1 m_2}$$

$$\frac{d^2\delta}{dt^2} = \frac{m_1 P_m - m_1 P_e + m_2 P_m - m_2 P_e}{m_1 m_2}$$

$$\Rightarrow \frac{d^2\delta}{dt^2} = \left(\frac{m_1 + m_2}{m_1 m_2}\right)(P_m - P_e)$$

$$\Rightarrow \left(\frac{m_1 m_2}{m_1 + m_2}\right) \times \frac{d^2\delta}{dt^2} = P_m - P_e$$

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

ans. $$\boxed{M_{eq} = \frac{m_1 m_2}{m_1 + m_2}}$$

Problem

A 3φ star connected 120 MVA alternator takes the mechanical torque of 480 MJ. Find the values of H & M

Sol:

$$\text{energy} = KE = GH = 480$$

$$\Rightarrow H = \frac{480}{120} = 4 \text{ MJ/MVA}$$

$$M = \frac{GH}{\pi f} = \frac{480}{3.1416 \times 50} = 3.06 \text{ MJ-sec/rad.}$$

(3) A pool of power system ... the inertia of 200 MVA alternator each has inertia constant of 6 MJ/MVA and five 200 MVA alternator each of inertia constant 4 MJ/MVA. Find the equivalent inertia constant referred to 1000 MVA.

Sol:
In this case the total energy can be obtained as

$$\sum GH = 4 \times 200 \times 6 + 5 \times 200 \times 4$$

$$= 7200 + 4000$$

$$= 11200 \text{ MJ}$$

This total energy should be equated to

$$G_{sy} H_{eq} = 11200$$

$$H_{eq} = \frac{11200}{1000} = 11.2 \text{ MJ/MVA}$$

(4) 2 synchronous machine are combine to operate with inertia constant of $m_1 = 10$, $m_2 = 15$. Find the equivalent inertia constant when both the machine swing together

ii) Not swing together.

Sol
i) Both machine swing together

$$= m_1 + m_2 = 10 + 15 = 25$$

ii) Both the M/C don't swing together

$$\frac{m_1 m_2}{m_1 + m_2} = \frac{10 \times 15}{10 + 15} = 6$$

Scanned by CamScanner

Steady State Stability - Analysis

The phenomenon of stability under slow & small changes is considered as steady state stability.

→ Under this steady changes the system stability can be determine by making proper analysis.

→ Let us consider a system is maintaining equilibrium in such a way that

$P_m = P_{e0}$ at δ_0.

If the load is increased by 'Δp' the electrical power becomes as

$$P_e = P_{e0} + \Delta P$$

The load angle also changes correspondingly to δ_1 such that

$$\delta_1 = \delta_0 + \Delta\delta.$$

The system stability corresponding to this new load angle should be determined.

$$P = \frac{EV}{X} \sin\delta$$

$$\Delta p = \frac{EV}{X} \cos\delta \, \Delta\delta$$

$$= \frac{\partial P_e}{\partial \delta} \Delta \delta.$$

$$M\frac{d^2\delta_1}{dt^2} = P_m - P_e.$$

$$M \frac{d^2}{dt^2}(\delta_0 + \Delta\delta) = P_m - (P_{e0} + \Delta P)$$

$$M \frac{d^2 \Delta\delta}{dt^2} = -\Delta P.$$

$$M \frac{d^2 \Delta\delta}{dt^2} + \frac{\partial P_e}{\partial \delta} \Delta\delta = 0.$$

$$\left(M p^2 + \frac{\partial P_e}{\partial \delta}\right) \Delta\delta = 0.$$

$$\text{Eq'n } p_{1,2} = \pm j\left[\frac{1}{M} \frac{\partial P_e}{\partial \delta}\right]^{1/2}.$$

The orientation of the two roots are specifies the stability of the system. This in turn depends upon absoluteness of m and $\frac{\partial P_e}{\partial \delta}$, but of

m can have always +ve value

$\frac{\partial P_e}{\partial \delta}$ can have both the +ve or -ve value.

1) If $\frac{\partial P_e}{\partial \delta} < 0$, roots are real and different. They orient as

then the system becomes unstable.

2) If $\frac{\partial P_e}{\partial \delta} > 0$, the roots are imaginary and conjugate. They will orient as

originally this can be stated as marginal stable condition but in this case we stable condition can be considered. (as because this system could be able to manage up to marginal stable condn. even though the natural damping is seized?.

For every practical system will definitely have natural damping. This amount of natural damping is sufficient to give the system stability there by the consideration of

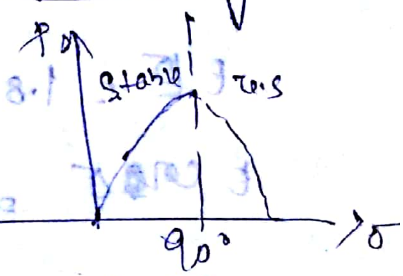
$\frac{\partial P_e}{\partial \delta} > 0$ is taken as condn for Stability.

$\frac{EV}{X} \cos\delta > 0$.

$\cos\delta > 0$.

$\boxed{\delta < 90^\circ}$.

From this it can be stated that under steady state condition load can be increased until the load angle increases to 90 to retain steady state stability. until the reach of 90°. load angle 90°, what ever the load increases that is on the steady margin on this phenomenon the stability concern is determined by angle therefore this stability phenomenon is also called as angle stability.



Steady State Stability limit.

It is the max^m power that can be delivered or transferred by Machine or system without loosing synchronism.

→ It can be estimated as

$$P = \frac{EV}{X} \sin\delta$$

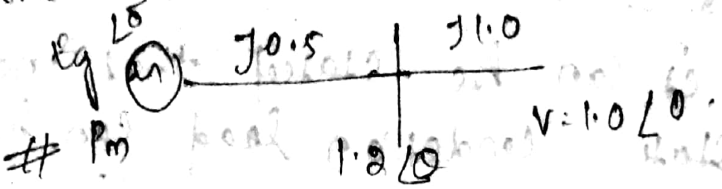
at steady state condtn $\delta = 90^\circ$

$$P_{ss} = \frac{EV}{X} \sin 90^\circ = \frac{EV}{X}$$

$$\boxed{P_{ss} = \frac{EV}{X} = P_{e\,max}}$$

Problem

1) Find the steady state stability limit of the configuration given below. All the value are specified in p.u.



Soln

$$P_{es} = \frac{EV}{X_{eq}}$$

$$E \angle \delta = 1.2 \angle \theta + (I)\, j0.5$$

$$I = \frac{1.2 \angle \theta - 1.0 \angle 0}{j1.0}$$

$$E \angle \delta = 1.2 \angle \theta + \frac{1.2 \angle \theta - 1.0 \angle 0}{j1.0} \times j0.5$$

$$E \angle \delta = 1.8 \angle \theta - 0.5 .$$

$$E \cos \delta = 1.8 \cos \theta - 0.5 .$$

$$E \sin \delta = 1.8 \sin \theta .$$

for SS condition $\delta = 90^\circ$

$$E \cos 90^\circ = 0 = 1.8 \cos \theta - 0.5$$

$$\theta = \cos^{-1}\left(\frac{0.5}{1.8}\right) = 73.8^\circ .$$

$$E \sin 90^\circ = E = 1.8 \sin 73.8$$

$$= 1.73 .$$

$$P_{es} = \frac{1.73 \times 1.0}{1.5} = 1.15 \text{ p.u.}$$

Scanned by CamScanner

Transient Stability.

The Phenomenon of stability under large changes with small time is considered as transient stability.

System stability under transient condition can be determine by two techniques

> **Energy balancing methode.**

> This is invented by Liapnov & Papov.

> every system under disturbing condition will loose some part of kinetic energy

> under this condition it can be said as stable one if it could be able to develop the P.E of more or equal to the kinetic energy loss.

> **By Solving Machine differential Equation**

under the disturbed condition as per the data type and system configuration the machine differential eqn is formed as

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

This Machine differential eqn is solved in δ in terms of t

Commonly used methode are

→ Step by step methode.

→ Modified Euler's methode.

→ R-K 4th order methode.

In any methods the aggregation should be followed to get the soln

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

$$\Rightarrow \frac{d\delta}{dt} = \frac{P_a}{m} t + k.$$

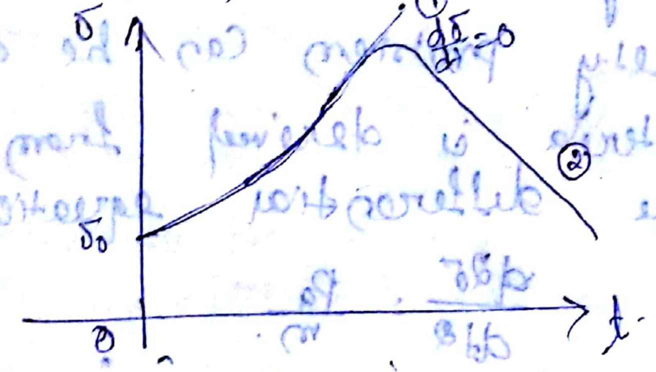
$t=0,\ \delta = \delta_0.$

$$\Rightarrow \delta = \frac{P_a}{2m} t^2 + k'$$

$k' = \delta_0.$

$$\boxed{\delta = \delta_0 + \frac{P_a}{2m} t^2.}$$

with this soln a graph is plotted 'δ' vs 't' which can have two probabilities



with increase in time 'δ' can also increases continuously as shown in curve '1'. under this case system is consider to be unstable.

This is possible when 'P_a' assume to be constant. but it is not constant again it is function of 'δ', and also at +ve side.

There by incrementation of δ up to certain instant may be possible from then onwards 'δ' decreases as shown curve '2' under this case we can say system is coming towards region of convergence of stability. It has indicated from the point

$$\frac{d\delta}{dt} = 0$$

This condition known as conditional stability in this studies.

Equal Area criterion.

It is a mathematical criteria developed for the determination of stability under transient condition.

By making use of this criteria, transient stability problem can be analysed. The criteria is derived from fundamental machine differential equation.

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

Multiply both the side with $2\frac{d\delta}{dt}$.

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

Integrate both the side then we get

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

For stability, $\frac{d\delta}{dt} = 0$.

$$\frac{2}{M}\int P_a \, d\delta = 0$$

$$\Rightarrow \int P_a \, d\delta = 0$$

This eqn mathematically is not correct because the objective integral will not give definite value. There by eq should be corrected as

$$\int_{\delta_0}^{\delta_2} P \, d\delta = 0$$

→ This integral specifies area bounded by a curve tracing defined b/w two limits δ_1 & δ_2 is equal to zero. i.e This curve tracing binding two equal & opposite area.

→ The +ve area binded by P-δ curve is called as acceleration A_1.

→ The -ve area binded by P-δ curve is called as acceleration A_2.

For the system to be stable

$$A_1 = A_2$$

This eq is called as equal Area criterion.

NOTE

On the operation of power system acceleration is always considered as unstable phenomenon.

Deceleration is considered as stable phenomenon.

Conditional stability consider as $A_1 = A_2$ under critical condition only. where as the eq absolute

condition for stability is
$\delta_1 < \delta_2$.
This means decelerating area is more than accelerating area. under this condition system couldn't be able to attain getting one more acceleration

→ 1st swing stability is guaranty achived.

Analysis:
The system should be analysed against transient condition set up in the machine by two consideration.

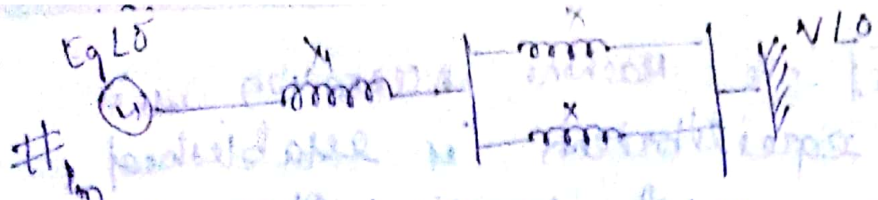
1) Keeping the electrical power output constant, sudden rise in mechanical input.

2) Keeping the mechanical input constant decrement in electrical power.

→ under this two conditions the accelerating power is +ve, and the machine is subjected for acceleration.

→ under this condition there might be determination condition of stability through analysis

→ For this the following system can be taken as test system.



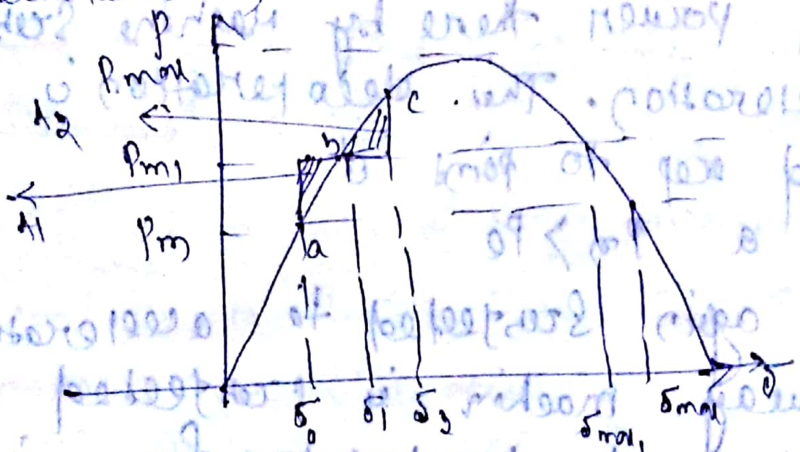
P_m

$$P_e = \frac{E_q V}{x_1 + x/2}\sin\delta = P_{max}\sin\delta$$

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

1) When the mechanical input is suddenly raised.

Under this case machine definetly subjected acceleration.



→ Initially system is assume to be under equilibrium condition thereby machine operates at operating point 'a'. The respective load angle is δ_0.

→ If mechanical input suddenly rises to because of excess kinetic energy rotor starts advancing and load angle increases. Machine subjected to acceleration → with this increase in load angle electrical power also increases continuously and the new operating point will be 'B'.

→ At 'b' if the Machine Acceleration were stopped equilibrium is established we can come out of transient Phenomenon.

→ But due to lack of damping the swing may not be consider as control swing and can be continued to other equilibrium points many.

→ We are considering a point 'c' at which electrical power is more than mechanical power there by machine subjected to deceleration. This deceleration is continued up to point 'a'.

→ At point a $P_m > P_e$
machine again subjected to acceleration.

→ In this way machine is subjected to acceleration and deceleration from a to c and c to a.

→ under this condition Machine can be set as stable one if it releases the energy what is at deceleration what it grasped at acceleration.

→ The two energy calculated in terms of two areas

$$A_1 = \int_{\delta_0}^{\delta_1} (P_m - P_{emax} \sin\delta)\, d\delta$$

and

$$A_2 = \int_{\delta_1}^{\delta_2} (P_{emax}\sin\delta - P_m)\, d\delta$$

System is stable if $A_1 = A_2$

→ so graph from the figure it can be said that at the point 'C' $A_1 = A_2$. Therefore the system can be said as stable one from the point C onwards.

→ The point C can be extended upto the angular point of δ_{max}, which is greater than 90°.

→ From this it can be said that for the operating load angle beyond 90° there is transient stability only.

→ For this step rise of P_m, system is found to be stable one. If we further increase the step rise the δ_2 observe to be oriented towards right and δ_{max} orienting towards left. Under this condition we can cause max^m step rise in such a way that δ_2 coincide with δ_{max}.

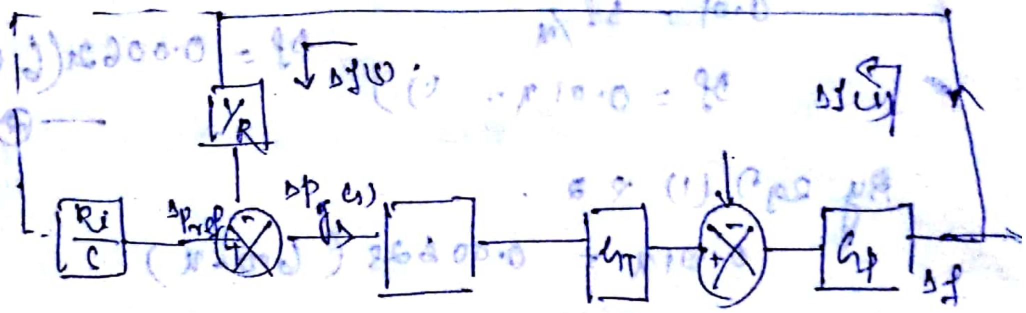
Secondary ALFC.

A Load frequency controller consider as Primary ALFC cond's make static deviation is equal to zero to its control.

The controller adopted here is proportional controller which always reduces the error.

To make error and static deviation to be zero integral controller should be adopted.

The Primary ALFC with integral controller can be consider as 2ndary ALFC.



$$\Delta f(s) = \frac{-\frac{\Delta P_D}{s} K_p}{(1+sT_P) + \left(\frac{K_i}{s} + \frac{1}{R}\right)\frac{K_P}{(1+sT_P)(1+sT_H)}}$$

$$\Delta f_{ss} = \lim_{s \to 0} s\,\Delta f(s)$$

$$\Delta f_{ss} = \lim_{s \to 0}$$

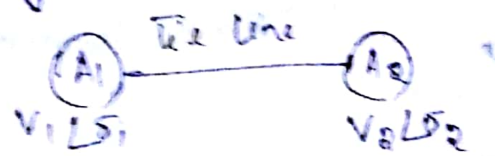
From this it can be proved that the static deviation with integral controller equal to zero. The system will called as single area system.

In the power system some time it is necessary to two area for the

Loss of reliability of the power transfer.
The two areas are interconnected with a connection is called tie-line.

Tie-line modelling.

Tie-line is the interconnection of the two power system held at different operating frequency it is ought to transfer the power from A_1 to A_2. In this case we have to assume the two areas are strong and tie-line is weak.



$$P_{12} = \frac{|V_1||V_2|}{X} \sin(\delta_1 - \delta_2)$$

$$\Delta P_{12} = \frac{|V_1||V_2|}{X} \cos(\delta_1 - \delta_2)(\Delta\delta_1 - \Delta\delta_2)$$

$$\frac{|V_1||V_2|}{X} \cos(\delta_1 - \delta_2) = P_{cy} = T.$$

$$\Delta P_{12} = T(\Delta\delta_1 - \Delta\delta_2)$$

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

$$2\pi f = \frac{d\delta}{dt}$$

$$2\pi \Delta f = \frac{d}{dt}(\Delta\delta)$$

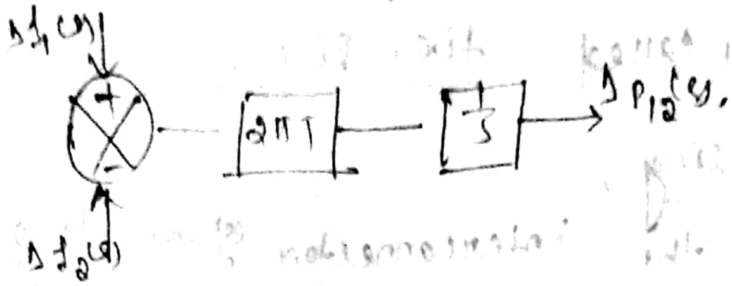
$$\frac{d\Delta\delta}{dt} = 2\pi \Delta f$$

$$\Delta\delta = 2\pi \int \Delta f \, dt$$

$$\Delta\delta(s) = \frac{2\pi}{s} \Delta f(s)$$

$$\Delta P_{12}(s) = T\left(\frac{2\pi}{s}(\Delta f_1(s) - \Delta f_2(s))\right)$$

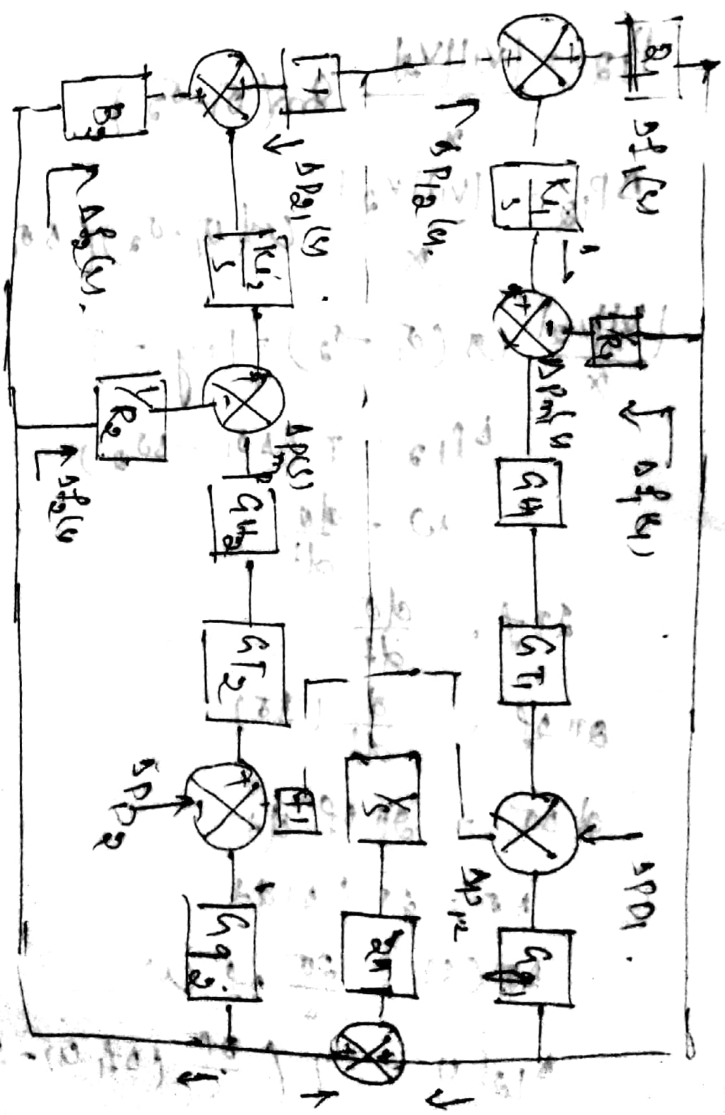
$\Delta P_{12}(s) = \frac{2\pi T}{s}(\Delta f_1(s) - \Delta f_2(s))$



Two Area System.

The tie-line is used for the controlling of two area as interconnected and its modeling is as shown in figure.

Two are are inter



Imp -

$ACE_1 = \Delta P_{12} + B_1 \Delta f_1$
$ACE_2 = \Delta P_{21} + B_2 \Delta f_2$

The best selectivity of B parameter.

$B_{21} \to B_1$

$B_{22} \to B_2$

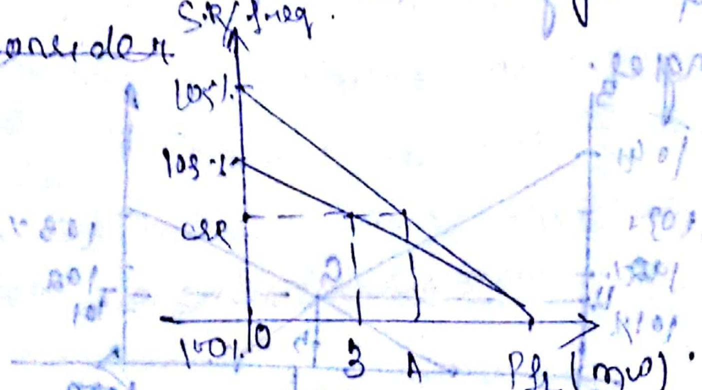
$B_1 = \theta_1 + X_{R1}$.

$B_2 = \theta_2 + X_{R2}$.

Load Sharing

- The load sharing between two generator always depends upon drooping characteristics.
- The synchronous machine connected in parallel needed to operate constant voltage the drooping were defined on frequency (speed)
- Let us consider two synchronous generator with two different speed regulation.

Let us consider



If this two generator are connected in parallel a set will operate at a common speed regulation relation (CSR) which is less than 103%.

The intersection of CSR with speed regulation relation characteristics is as shown in fig.

From this it can be stated that 'OA' is the load shared by 1st machine OB is the load shared by 2nd machine.

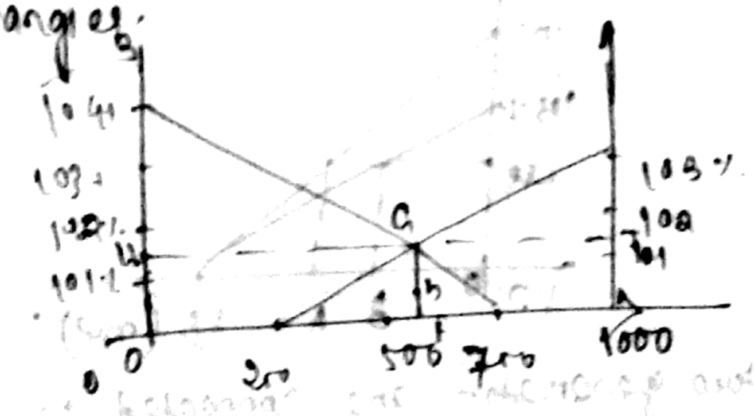
Relatively OA > OB.
From this it can be conclude that the machine which is having more speed regulation (+ve) will share more load.

Problem

Two 110 Ampere Alternator are connected in parallel to share a common load of 1000 MW. The speed relation characteristics are

104% → 100% from no load to
and 103% → 100% from no load to
full load. Find the load sharing and operating frequency.

Sol
This data should be formulated and can be solved by the technique methods of triangles.



Δ OAG & ΔBHG are similar

$\frac{HG}{OA} = \frac{GA}{BG}$

$\Rightarrow HG = 750\left(\frac{4-h}{4}\right)$

$= 750 - 187.5h$

(c) ΔCDE & ΔGDR are similar

$$\frac{GR}{CE} = \frac{DR}{DE}$$

$$\Rightarrow GR = 750\left(\frac{8-h}{8}\right)$$

$$= 750 - 200h \quad \text{---(2)}$$

Total load $= 1000 = HG + GR$.

$$1000 = 750 - 187.5h + 750 - 200h$$

$$h = \frac{500}{437.5} = 1.142$$

Load shared by M/c 1 $= 750 - 187.5 \times 1.42$
$= 535.8$

M/c 2 $= 750 - 200 \times 1.42 = 464$ MW

$$f_2 = f_1\left(1 + \frac{h}{100}\right)$$

$$= 50\left(1 + \frac{1.42}{100}\right) = 50.57 \text{ Hz}.$$

This set can handle nearly load in between 1465 to 1485. because the speed relation of both the generator is not same so there might be a small deficiency by which capacity is less than the rated capacity.

This set can min. operate at a load of 187.5 MW where generation proceed to one generator is only possible.