# Scheme of Evaluation

IV/IV B.Tech (Reg/supplementary) Degree Examinations
(VII Semester) NOV - 2019

Electrical & Electronics Engineering

Subject code: 14EE702

Subject: Power system operation control & stability

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1 Answer all questions Each question one mark

(a) What is equality and inequality?

Ans Equality means that the total system generation equals total system load.

Inequality refers to currents and voltages being kept within rated limits.

(b) Define incremental efficiency.

Ans it is defined as the reciprocal of Incremental Production cost (or) Incremental fuel rate

Incremental efficiency = $\frac{\text{output}}{\text{Input}}$

(c) Define economic dispatch problem?

Ans the objective of economic dispatch problem is to minimize the operating cost of active power generation.

(d) what are the advantages of pool operation with respect to LFC?

Ans (i) 50% of the added load in area 2 will be supplied by area 1 through the tie line.

(ii) Frequency droop will be only half compared with that of single area.

(e) Define speed governing system.

Ans This includes the speed - governor, speed - control mechanism, governor - controlled valves and speed changer.

(f) Give some reasons for limits on frequency.

Ans the reasons for limits on frequency are

(a) The electric clocks are driven by synchronous motors and the accuracy at these clocks is not only a function of frequency error but is actually of the integral of this error.

(b) The system operation at subnormal frequency and voltage leads to ~~loss~~ loss of revenue to the suppliers due to accompanying reduction in load demand.

(g) what are the disadvantages of voltage regulation?

Ans (i) voltage variation is more than a prespecified value, the performance of equipments is poor.

(h) How the ALFC loop is affected by AVR loop?

Ans AVR affect the magnitude of generated emf Eg.

the generated emf affects the generated real power.

therefore changes in AVR loop affect ALFC loop.

(i) List the various compensating devices.

Ans the various compensating devices

(a) Capacitors

(b) Capacitors and Inductors

(c) Active voltage source (synchronous generator).

(d) SVC

(e) STATCOM.

(j) what is a small disturbance? Give example.

Ans stability is the ability of the power system to maintain synchronism under small disturbances. such as small variations in loads and generations

(k) what is transient state of the power system?

Ans Transient state is any sudden change in the system caused by generator shifting, faults, outages,

(K) addition (or) removal of a heavy load (or) any switching operation in the system.

(l) what are the assumptions made in solving swing equation?

Ans

① mechanical power input to the machine ($P_m$) remains constant during the period of electro mechanical transient of interest.

② Rotor speed changes are insignificant - these have already been ignored in formulating the swing equation.

③ Effect of voltage regulating loop during the transient is ignored, as a consequence the generated machine emf remains constant.

# Unit-I

(2) (a) The fuel cost of two units are given by $F_1 = F_1(P_{G_1}) = 1.5 + 20P_{G_1} + 0.1P_{G_1}^2$ Rs/hr $F_2 = F_2(P_{G_2}) = 1.9 + 30P_{G_2} + 0.1P_{G_2}^2$ Rs/hr if the ~~load~~ total demand on the generator is 200MW. Calculate the economic load scheduling of the two units. [6M]

Ans

$$F_1 = 1.5 + 20P_{G_1} + 0.1P_{G_1}^2$$

Solution - 4m

Answer - 2m

$$F_2 = 1.9 + 30P_{G_2} + 0.1P_{G_2}^2$$

$P_D = 200MW$

$P_1 + P_2 = 200MW$

$$\frac{dF_1}{dP_{G_1}} = 20 + 0.2P_{G_1}$$

$$\frac{dF_2}{dP_{G_2}} = 30 + 0.2P_{G_2}$$

optimal condition for economic load dispatch

$$\frac{dF_1}{dP_{G_1}} = \frac{dF_2}{dP_{G_2}}$$

$$20 + 0.2P_{G_1} = 30 + 0.2P_{G_2}$$

$$0.2P_{G_1} - 0.2P_{G_2} = 10 \quad \text{--- (1)}$$

$$P_{G_1} + P_{G_2} = 200 \quad \text{--- (2)}$$

after solving equation (1) & (2)

$$0.2P_{G_1} - 0.2P_{G_2} = 10$$

$$0.2P_{G_1} + 0.2P_{G_2} = 40$$

$$0.4P_{G_1} + 0 = 50$$

$0.4 P_{G_1} = 50$

$P_{G_1} = \frac{50}{0.4}$

$P_{G_1} = 125\,MW$ $\qquad P_{G_1} + P_{G_2} = 200\,MW$

$P_{G_2} = 75\,MW$

② (b) what are B- coefficients and derive them. [6M]

Explanation - 3M

Ans - Derivation - 3M

Two generating plants connected to an arbitrary number of loads through a transmission network. one line within the network is designated as branch p. Fig ③

Imagine that the total load current $I_D$ is supplied by plant 1 only as in fig ①.

let the current in line p be $I_{p1}$. Define

$$M_{p1} = \frac{I_{p1}}{I_D} \quad — ①$$

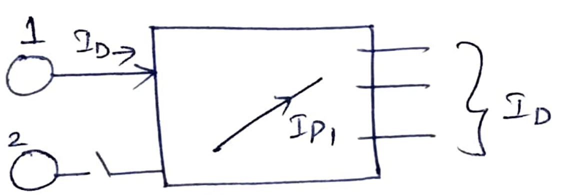


Fig ①

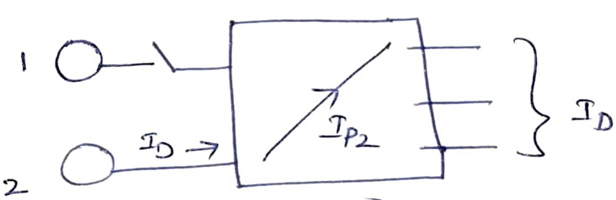


Fig ②

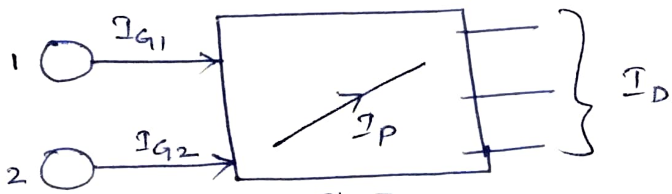


Fig ③

Similarly, with plant 2 alone supplying the total load current (fig ②) we can define

$$M_{P_2} = \frac{I_{P_2}}{I_D} \quad - ②$$

$M_{P_1}$ and $M_{P_2}$ are called current distribution factors. The values of current distribution factors depend upon impedance of the lines and their interconnection and are independent of the current $I_D$.

When both generators 1 and 2 are supplying current into the network as in fig ③, applying the principle of superposition the current in the line 'p' can be expressed as

$$I_P = M_{P_1} I_{G_1} + M_{P_2} I_{G_2} \quad - ③$$

where $I_{G_1}$ and $I_{G_2}$ are the currents supplied by plants 1 & 2, respectively

Simplifying assumptions

① All load currents have the same phase angle with respect to a common reference.

② Ratio X/R is the same for all network branches.

These two assumptions lead us to the conclusion that $I_{P_1}$ and $I_D$ fig ① have same phase angle and so have

$I_{P2}$ and $I_D$ (fig ②) such that the current distribution factors $M_{P1}$ and $M_{P2}$ are real rather than complex.

Let

$$I_{G1} = |I_{G1}| \angle \sigma_1 \quad \&, \quad I_{G2} = |I_{G2}| \angle \sigma_2$$

where $\sigma_1$ & $\sigma_2$ are phase angles of $I_{G1}$ and $I_{G2}$ respectively with respect to the common reference.

From eq ③ we can write

$$|I_P|^2 = (m_{P1}|I_{G1}| \cos\sigma_1 + m_{P2}|I_{G2}| \cos\sigma_2)^2 + (m_{P1}|I_{G1}| \sin\sigma_1 + m_{P2}|I_{G2}| \sin\sigma_2)^2 \quad \text{— ④}$$

Expanding & simplifying the above equation we get

$$|I_P|^2 = m_{P1}^2 |I_{G1}|^2 + m_{P2}^2 |I_{G2}|^2 + 2 m_{P1} m_{P2} |I_{G1}| |I_{G2}| \cos(\sigma_1 - \sigma_2) \quad \text{— ⑤}$$

Now $|I_{G1}| = \dfrac{P_{G1}}{\sqrt{3}\, V_1 \cos\phi_1}$ ; $|I_{G2}| = \dfrac{P_{G2}}{\sqrt{3}\, V_2 \cos\phi_2}$ — ⑥

where $P_{G1}$ and $P_{G2}$ are the three-phase real power outputs of plants 1 and 2 at power factors of $\cos\phi_1$ and $\cos\phi_2$ and $V_1$ & $V_2$ are the bus voltages at the plants.

If $R_p$ is the resistance of branch $p$, the total transmission loss is given by

$$P_L = \sum_p 3 |I_p|^2 R_p$$

Substituting for $|I_p|^2$ from eq (5) and $|I_{G_1}|$ and $|I_{G_2}|$ from eq (6) we obtain

$$P_L = \frac{P_{G_1}^2}{|V_1|^2 (\cos\phi_1)^2} \sum_p M_{p_1}^2 R_p + \frac{2 P_{G_1} P_{G_2} \cos(\sigma_1 - \sigma_2)}{|V_1||V_2| \cos\phi_1 \cos\phi_2}$$

$$+ \frac{P_{G_2}^2}{|V_2|^2 (\cos\phi_2)^2} \sum_p M_{p_2}^2 R_p \quad \text{--- (7)}$$

eq (7) can be recongnized as

$$P_L = P_{G_1}^2 B_{11} + 2 P_{G_1} P_{G_2} B_{12} + P_{G_2}^2 B_{22}$$

$$\left.\begin{aligned} B_{11} &= \frac{1}{|V_1|^2 (\cos\phi_1)^2} \sum_p M_{p_1}^2 R_p \\ B_{12} &= \frac{\cos(\sigma_1 - \sigma_2)}{|V_1||V_2| \cos\phi_1 \cos\phi_2} \sum_p M_{p_1} M_{p_2} R_p \\ B_{22} &= \frac{1}{|V_2|^2 (\cos\phi_2)^2} \sum_p M_{p_2}^2 R_p \end{aligned}\right\} \quad \text{--- (8)}$$

the terms $B_{11}$, $B_{12}$ & $B_{22}$ are called loss coefficients (or) B - coefficients. if voltages are line to line KV with resistances in ohms, the units of B-coefficients are in $MW^{-1}$. $P_{G1}$, $P_{G2}$ & $P_L$ will also be in MW.

$$P_L = \sum_{m=1}^{K} \sum_{n=1}^{K} P_{Gm} B_{mn} P_{Gn}$$

$$B_{mn} = \frac{\cos(\theta_m - \theta_n)}{|V_m||V_n| \cos\phi_m \cos\phi_n} \sum_{P} M_{pm} M_{pn} R_p$$

OR

(3) (a) Explain the important characteristics of steam unit [6M]

Ans

Each curve - 2m

Input-output curve:-

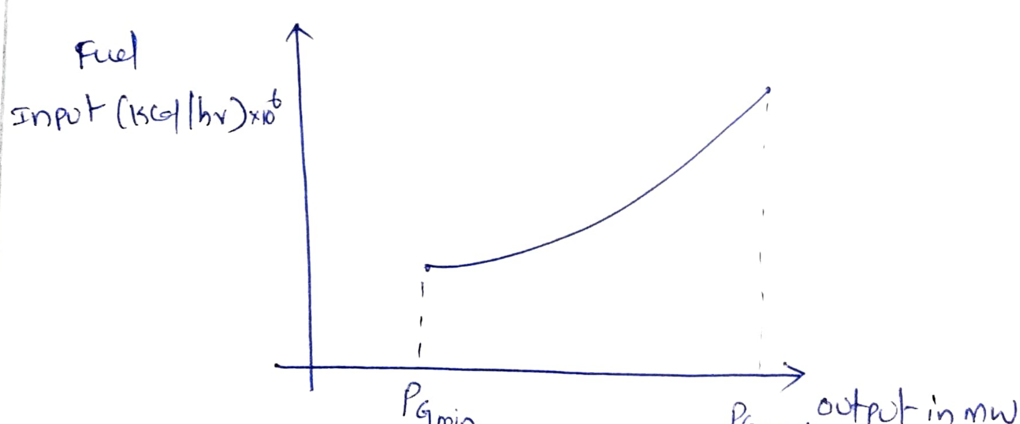


Fig ① Input-output characteristics of steam unit

The relation ship between the energy input to the turbine and energy output from electrical generator, shown in above fig ①

The input to the turbine shown on the ordinate may be either interms of heat energy requirement which is generally measured in BTU/hr (or) Kcal/hr (or) Rs/hr. The output is normally the net electrical power output of that steam unit in MW.

## Heat-rate curve:-

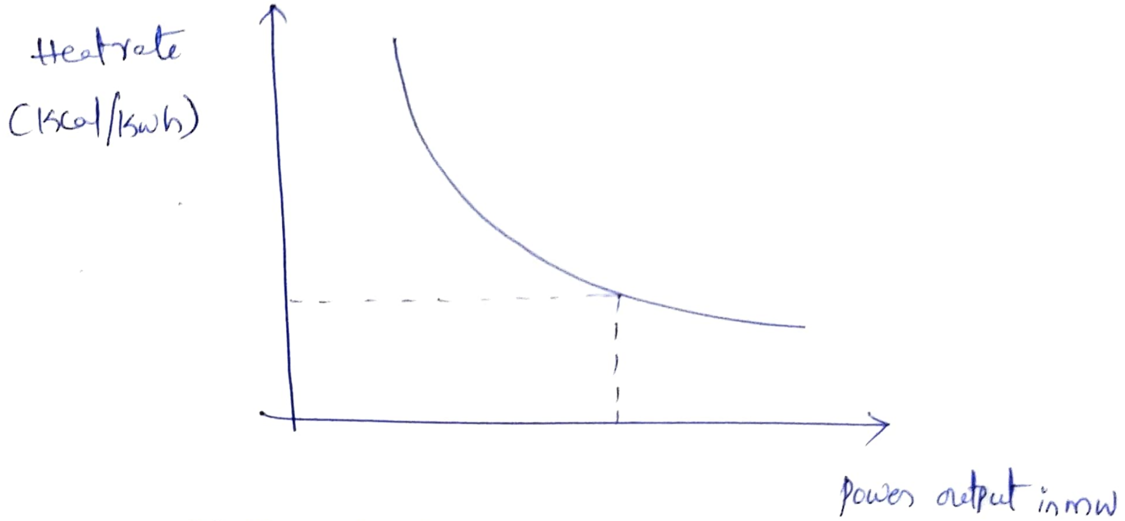


Fig ② Heat rate curve

The steam unit is most efficient at minimum heat rate which corresponds to a particular generation $P_G$. the curve indicates an increase in heat rate at low and high power limits.

## Incremental fuel cost curve:-

The IFC is defined as the ratio of a small change in the input to the corresponding small change in the output.

$$\text{Incremental fuel cost} = \frac{\Delta \text{Input}}{\Delta \text{output}} = \frac{\Delta F}{\Delta P_G}$$

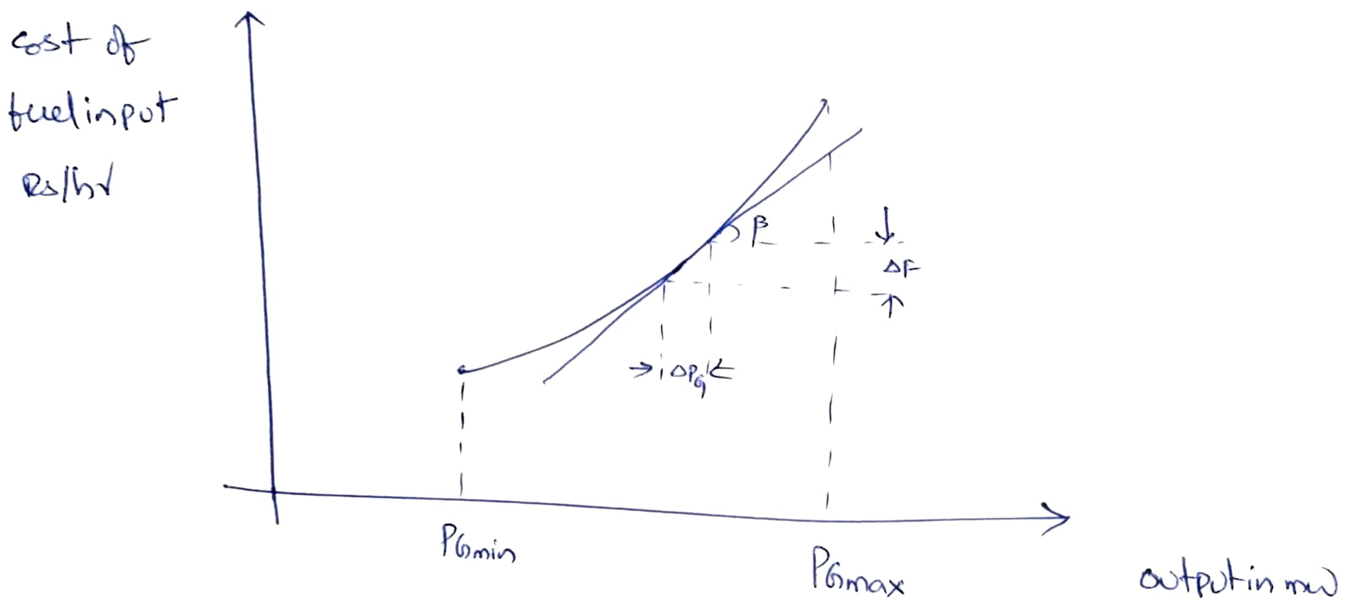


Fig (3) Incremental fuel cost curve

$(IC)_i$ = slope of the fuel cost curve

i.e $\tan\beta = \frac{\Delta F}{\Delta P_G}$ in Rs/mwh.

(3) (b) The cost characteristics of three plants of a system are (BTL-1)

$C_1 = 0.05P_1^2 + 17.0P_1 + 160$ Rs/hr, $C_2 = 0.06P_2^2 + 14.4P_2 + 200$ Rs/hr

$C_3 = 0.08P_3^2 + 9P_3 + 240$ Rs/hr. where $P_1, P_2, P_3$ are in MW. The Incremental transmission losses for the network with respect to plants 1, 2 and 3 are 0.05, 0.10 and 0.15 MW per MW of generation. Examine the optimal dispatch for a total load of 100 MW and

(12) also its incremental cost of received power. [6M]

3 (b)

Solution – 4M

Answer – 2M

Ans

$$\frac{dc_1}{dP_1} = 0.1P_1 + 17 \qquad \frac{\partial P_L}{\partial P_1} = 0.05$$

$$\frac{dc_2}{dP_2} = 0.12P_2 + 14.4 \qquad \frac{\partial P_L}{\partial P_2} = 0.1$$

$$\frac{dc_3}{dP_3} = 0.16P_3 + 9 \qquad \frac{\partial P_L}{\partial P_3} = 0.15$$

$$P_1 + P_2 + P_3 = 100\,\text{MW} \quad \text{— (1)}$$

$$\frac{\frac{dc_1}{dP_1}}{\left(1 - \frac{\partial P_L}{\partial P_1}\right)} = \frac{\frac{dc_2}{dP_2}}{\left(1 - \frac{\partial P_L}{\partial P_2}\right)} = \frac{\frac{dc_3}{dP_3}}{\left(1 - \frac{\partial P_L}{\partial P_3}\right)}$$

$$\frac{0.1P_1 + 17}{(1 - 0.05)} = \frac{0.12P_2 + 14.4}{(1 - 0.1)} = \frac{0.16P_3 + 9}{(1 - 0.15)}$$

$$(0.1P_1 + 17) \times (1.052) = (0.12P_2 + 14.4)(1.111) = (0.16P_3 + 9)(1.176)$$

$$0.1052P_1 + 17.884 = 0.1332P_2 + 15.99 = 0.18816P_3 + 10.584$$

$$P_2 + P_3 = 100 - P_1 \quad \text{— (2)}$$

$$\boxed{\frac{dc_2}{dP_2} = \frac{dc_3}{dP_3}}$$

$$0.1332P_2 + 15.99 = 0.18816P_3 + 10.584$$

and eq (2) multiply with 0.18816

$$0.133P_2 - 0.18816P_3 = -5.406 \quad \text{— (3)}$$

$$0.188P_2 + 0.18816P_3 = 18.816 - P_1 \times 0.18816$$

$$0.32136\,P_2 = 13.41 - P_1 \times 0.18816$$

$+0.18816P_1 + 0.32136P_2 = 13.41$ — (5)

$$\boxed{\frac{dc_1}{dP_1} = \frac{dc_2}{dP_2}}$$

$0.1052P_1 + 17.884 = 0.1332P_2 + 15.99$

$0.1052P_1 - 0.1332P_2 = -1.894$ — (4)

(4) $\times 0.32136$

$0.0339P_1 - 0.0430P_2 = -0.6120$

(5) $\times 0.1332$

$0.0250P_1 + 0.04280P_2 = 1.7862$

$0.0589P_1 = 1.1742$

$$P_1 = \frac{1.1742}{0.0589}$$

$P_1 = 19.93\,MW$

$P_2 + P_3 = 100 - 19.93$

$P_2 + P_3 = 80.06\,MW$

$$P_2 = \frac{1.7862 - 0.0250 \times 19.93}{0.04280}$$

$P_2 = 30.09\,MW$

$P_3 = 80.06 - 30.09$

$P_3 = 49.96\,MW$

$C_1 = 0.05P_1^2 + 17P_1 + 160$ Rs/hr

$= 0.05(19.93)^2 + 17(19.93) + 160$

$C_1 = \underline{518.67}$ Rs/hr

$C_2 = 0.06(30.09)^2 + 14.4(30.09) + 200$

$C_2 = \underline{687.62}$ Rs/hr

$C_3 = 0.08(49.96)^2 + 9(49.96) + 240$

$C_3 = \underline{889.320}$ Rs/hr

## Unit - II

(4) (a) Explain the necessity of maintaining a constant frequency in power system operation. [6M]

each point - 1M

Ans

① Frequency in a power system is intimately related to the electrical speed of synchronous generators

② The acceleration of a ~~generator~~ generator is solely governed by the difference between mechanical and electrical torques, therefore to maintain a constant speed, mechanical input and electrical output power need to be continually matched.

③ Electrical load can vary randomly, but ~~hours~~ the total load versus time roughly follows a trend. frequency of grid is depends upon many factor like load variation, Prime move control of generator etc.

④ Loads and other electrical equipment are usually designed to operate at a particular frequency.

⑤ Off-nominal frequency operation causes electrical loads to deviate from the desired output.

⑥ Steam turbine blades are designed to operate in a narrow band of frequencies. Deviation of frequency beyond this band may cause gradual (or) immediate turbine damage.

⑦ A 50 HZ steam turbine may not be able to with stand frequency deviation of + 2.5HZ to - 2.5HZ for more than an hour in its entire life.

(4)(b) Two generators rated 200MW and 400MW are operating in parallel. The droop characteristics of their governors are 4% and 5% respectively from no load to full load. Assuming that the ~~gov~~ generators are operating at 50HZ at no load, how would a load of 600MW be shared between them? What will be the system frequency at this load? Assume free governor operation. Repeat the problem if both the governors have a droop of 4%.

Solution - 4M [6M]
Answer - 2M

Ans

The generators are in parallel they will operate at the same frequency at steady load.

Let load on generator 1 (200MW) = $x$ MW

and load on generator 2 (400MW) = $(600 - x)$ MW

Reduction in frequency = $\Delta f$

Now

$$\frac{\Delta f}{x} = \frac{0.04 \times 50}{200} \quad \text{--- (1)}$$

$$\frac{\Delta f}{600 - x} = \frac{0.05 \times 50}{400} \quad \text{--- (2)}$$

equating $\Delta f$ in (1) and (2) we get

$x = 231$ MW (load on generator 1)

$600 - x = 369$ MW (load on generator 2)

System frequency $= 50 - \frac{0.04 \times 50}{200} \times 231$

$= 47.69$ Hz

it is observed here that due to difference in droop characteristics of governors, generator 1 gets overloaded while generator 2 is underloaded.

→ if both governors have a droop of 4% they will share the load as 200MW and 400MW respectively, i.e they are loaded corresponding to their ratings.

OR

(5) (a) Explain how voltage control can be affected by injection of Reactive power.

Explanation - 4m
Equation - 2m (6M)

Ans I norder to keep the receiving-end voltage at a specified value $|V_R^s|$, a fixed amount of VARS $|Q_R^s|$ must be drawn from the line.

To accomplish this under conditions of a varying VAR demand $Q_D$, a local VAR generator (controlled reactive power source/compensating equipment) must be used as shown

(18)

(5) (e) in fig (1). The VAR balance equation at the receiving end is now.

$$Q_R^S + Q_C = Q_D$$

Fluctuations in $Q_D$ are absorbed by the local VAR generator $Q_C$ such that the VARs drawn from the line remain fixed at $Q_R^S$. The receiving-end voltage would thus remain fixed at $|V_R^S|$ (this assumes a fixed sending-end voltage $|V_S|$).

Local VAR compensation can in fact be made automatic by using the signal from the VAR meter installed at the receiving end of the line.

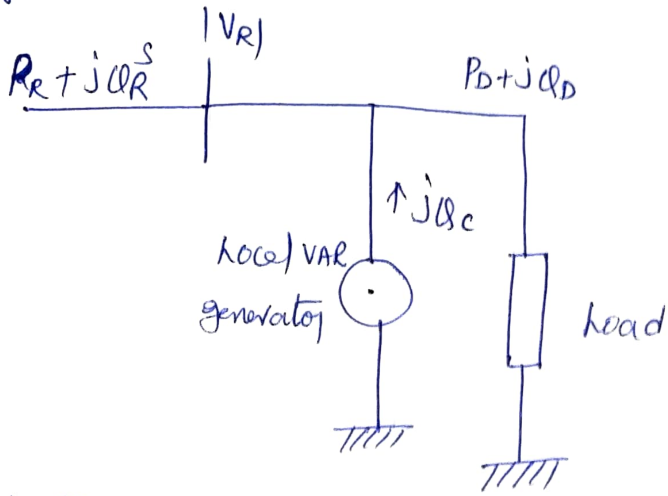


Fig (1) use of local VAR generator at the load bus

⑤ ⓐ under heavy load conditions when positive VARs are needed, capacitors banks are employed,

under light load conditions when negative VAR's are needed, inductor banks are switched on.

if capacitor employed

$$Q_{C(3-\phi)} = \frac{|V_R|^2}{X_C} \text{ MVAR}$$

if inductor employed instead VAR's fed into the line are

$$Q_{L(3-\phi)} = \frac{-|V_R|^2}{X_L} \text{ MVAR.}$$

⑤ ⓑ Explain the turbine speed governing system with a neat sketch.

diagram - 3m
Explanation - 3m [6M]

Ans. Fig ① shows schematically the speed governing system of a steam turbine.

The system consists of the following components

① Fly ball speed governor

② Hydraulic amplifier

③ Linkage mechanism

④ Speed changer.

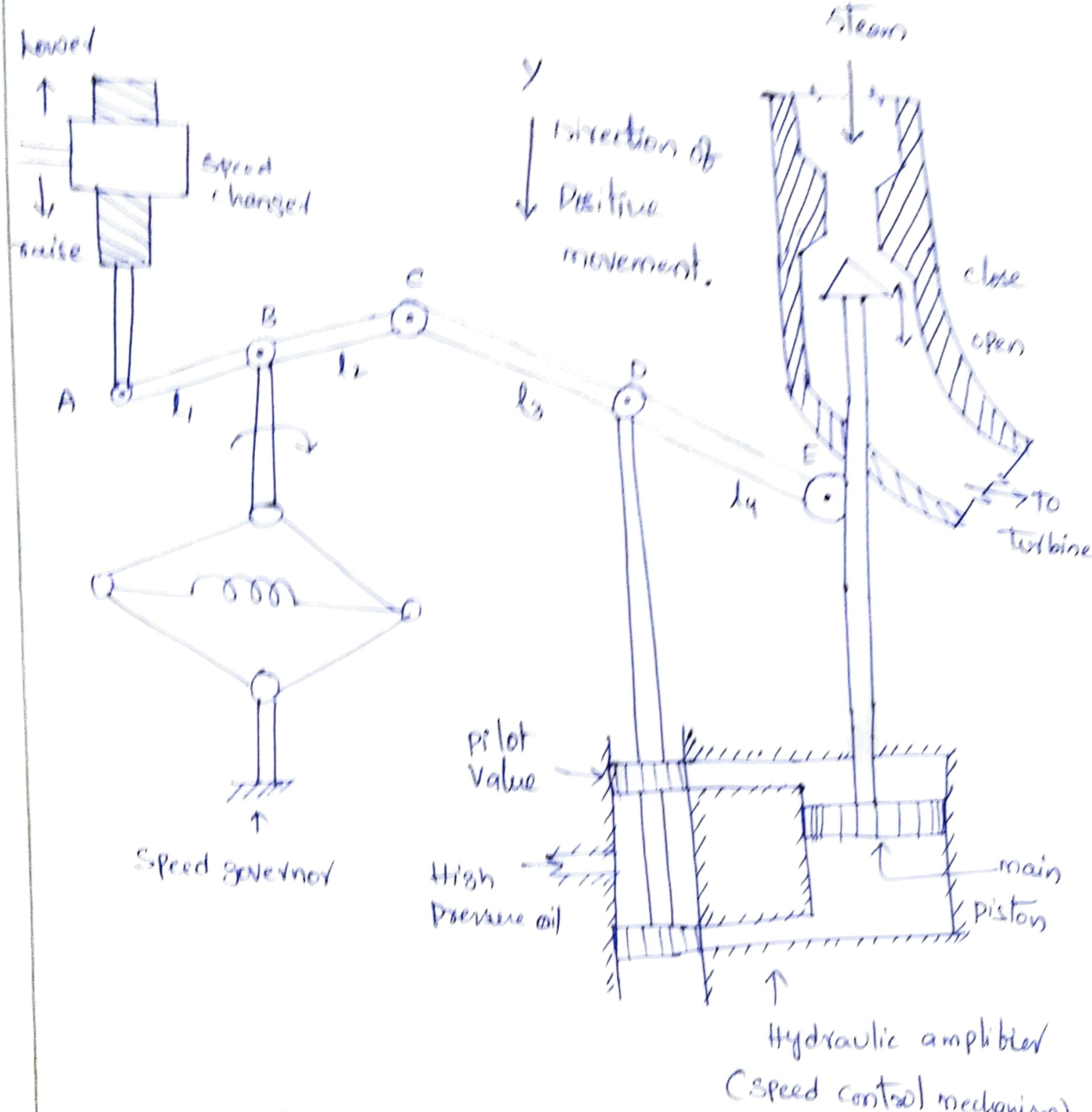


Fig ① turbine speed governing system

① Fly ball speed governor:-

this is the heart of the system which senses the change in speed (-frequency). As the speed increases the fly balls move outwards and the point B on linkage mechanism move downwards. the reverse happens when speed decreases

⑤ ⓑ ② Hydraulic amplifier:- it comprises a pilot valve and main piston arrangement. Low power level pilot valve movement is converted into high power level piston valve movement. This is necessary in order to open (or) close the steam valve against high pressure steam.

③ Linkage mechanism: ABC is a rigid link pivoted at B and CDE is another rigid link pivoted at D. This link mechanism provides a movement to the control valve in proportion to change in speed. It also provides a feed back from the steam valve movement (link 4).

④ Speed changer:- it provides a steady state power output setting for the turbine. Its downward movement opens the upper pilot valve so that more steam is admitted to the turbine under steady conditions (hence more steady power output). The reverse happens for upward movement of speed changer.

unit-III

(6) (a) Explain clearly what do mean by compensation of a line and discuss briefly different methods of compensation (6m)

Ans

Each method - 3m

Ideal voltage profile for a transmission line is flat, which can only be achieved by loading the line with its surge impedance loading while this may not be achievable, the characteristics of the line can be modified by line compensators.

"the power transfer capability of the line is enhanced by modifying the characteristics of a line is known as line compensation.

Two types of line compensation

(1) Series compensation. of line

(2) Shunt compensation. of line

Series compensation :-

A capacitor in series with a line gives control over the effective reactance between line ends.

this effective reactance is given by

$$X_L' = X - X_C$$

where

$X_l$ = line reactance

$X_C$ = Capacitor reactance

① voltage drop in the line reduces (gets compensated) i.e minimization of end-voltage variations.

② prevents voltage collapse

③ steady-state power transfer increases it is inversely proportional to $x_l'$

④ Transient stability limit also Increases.

<u>Shunt compensator</u> :-

Shunt compensators are connected in shunt at various system nodes (major substations) and some times at mid-point of lines.

These serve the purposes of voltage control and load stabilization. As a result of installation of shunt compensators in the system, the nearby generators

- operate at near unity p.f and voltage emergencies mostly do not arise.

it needs to be pointed out here that Shunt capacitors/ shunt inductors can not be distributed uniformally along the line. normally at the end of line and mid point of the line.

6 (b) what is load compensation? Discuss its objectives in power system. [6M]

~~define~~
definition-2m
Explanation- 4m

ans it is the management of reactive power to improve power quality i.e voltage profile and p.f. Here the reactive power flow is controlled by installing shunt compensating devices (capacitors / reactors) at the load end bringing about proper balance between generated and consumed reactive power.

Objectives in powersystem:-

1. Increase the power factor of system
2. To balance the real power drawn from the system
3. compensate voltage regulation.

- operate at near unity p.f and voltage emergencies mostly do not arise.

it needs to be pointed out here that shunt capacitors/ shunt inductors can not be distributed uniformally along the line. normally at the end of line and mid point of the line.

⑥ ⓑ what is load compensation? Discuss its objectives in power system. [6M]

definition-2M
Explanation- 4M

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Objectives in powersystem:-

① Increase the power factor of system

② To balance the real power drawn from the system

③ compensate voltage regulation.

(i) To eliminate current harmonics.

Power factor:- it is desirable both economically and technically to operate system at near unity p.f. Usually p.f correction means to generate reactive power as close as possible to the load which requires it rather than generate it at a distance and transmit it to the load as this result not only in large conductor size but also in increased losses.

Power balancing:- it is desirable to operate the three phase system under balanced condition as unbalanced operation results in flow of negative sequence current in the system and is highly dangerous especially for the rotating machines.

Current harmonics:- the non linear loads such as arc furnaces generate harmonics in the system and hence arc furnace compensators usually have harmonic filters to filter out these harmonics so that the voltage remains mostly of fundamental frequency.

OR

7 (a) Discuss operation of SVC with its schematic diagram [6M]

Basic - 2M

Ans

Basic SVC operation:-

Each type - 2M, 2M
(or)
any two - 2M, 2M

Thyristors in antiparallel can be used to switch on a capacitor /reactor unit in stepwise control.

When the circuitary is designed to adjust the firing angle, capacitor / reactor unit acts as continuously variable in the power circuit.

SVC configurations:-

① Thyristor - controlled reactor (TCR)

② Thyristor - switched capacitor (TSC)

③ Combined TCR & TSC compensators

TCR:-

The reactive power is changed by adjusting the thyristor firing angle. TCRs are characterised by continuous control, no transients and generation of harmonics. The control system consists of voltage and current measuring devices, a controller for error-signal conditioning, a linearising circuit and one (or) more synchronising circuit

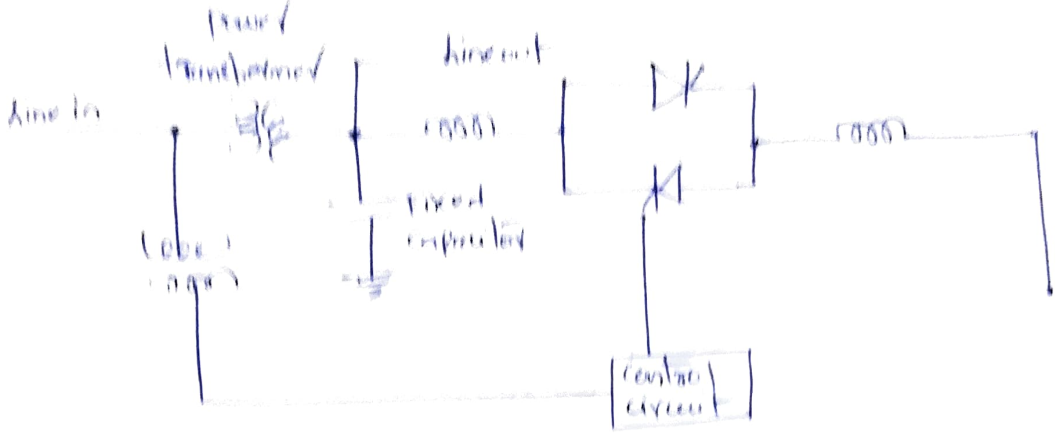



Fig (1) TCR with fixed capacitor

TSC:

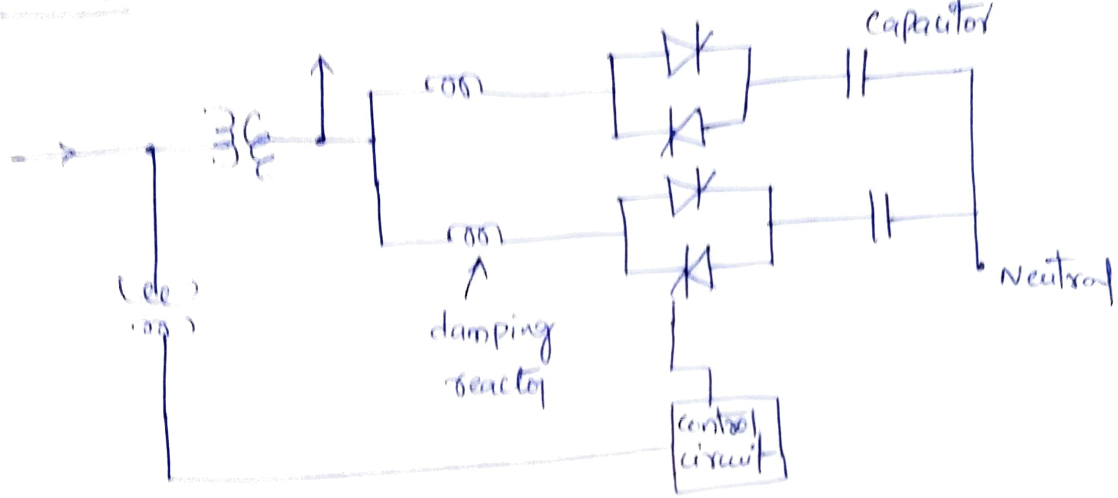



Fig (2) TSC

it consists of only a thyristor switched capacitor banks which is split into a numbers of units of equal rating to achieve a stepwise control.

As such they are applied as ~~direel~~ discretly variable reactive power source, where this type of voltage support is deemed adequate. All switching takes place when the voltage across the thyristor valve is zero.

7 (a) thus providing almost transient free switching. Disconnection is effected by suppressing the firing plus to the thyristors, which will block when the current reaches zero. TSC's are characterised by step wise control, no transients, very low harmonics, low losses, redundancy and flexibility.

7 (b) Explain how the generators acts as VAR sources in a power network.

circuit - 3m [6m]
Explanation - 3m

Ans

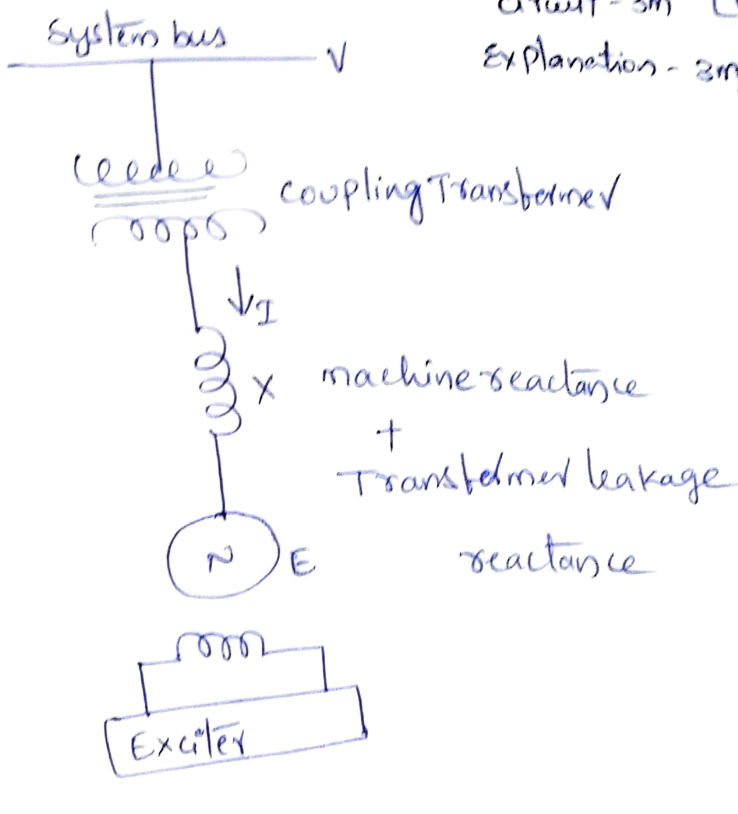



Fig (1) Reactive power generation by a rotating synchronous machine

7 (b)

For purely reactive power flow, the three-phase induced electromotive forces (EMFs), $e_a, e_b, e_c$ of the synchronous rotating machine are in phase with system voltages $V_a$, $V_b$ & $V_c$.

The current drawn by synchronous machine is determined by the magnitude of the system voltage V, that of the internal voltage E, and the total circuit reactance 'X'

$$I = \frac{V-E}{X} \quad -① \qquad V > E,$$

$$Q = \frac{1 - \frac{E}{V}}{X} \cdot V^2 \quad -②$$

$$I = \frac{E-V}{X} \quad - ③ \qquad E > V$$

By controlling the excitation of the machine, and hence the amplitude E of its internal voltage relative to the amplitude V of the system voltage, the reactive power flow can be controlled.

Increasing E above V (i.e operating over excited) results in a leading current, that is the machine is

- "Seen" as a capacitor by the ac system.

Decreasing E below V (i.e operating under-excited) produces a lagging current, that is the machine is 'seen' as a reactor (inductor) by the ac system.

## Unit IV

8 (a) Discuss the various factors affecting the transient stability of the system.

List out - 3M (6M)
Explanation - 3M

1. Reduction in system transfer reactance
2. Increase of system voltages, use of AVR
3. use of high speed excitation systems.
4. use of high speed reclosing breakers.
5. Short circuit current limiters, which can be used to increase transfer impedance during fault, there by reducing short circuit currents.
6. A recent method is fast valving of the turbine where in the mechanical power is lowered quickly during the fault and restored once fault is cleared.

(8) (a)

Reducing transfer reactance is another important practical method of increasing stability limit. Incidentally this also raises system voltage profile.

The reactance of a transmission line can be decreased

(i) by reducing the conductor spacing

(ii) by increasing conductor diameter

The use of bundled conductors is of course, an effective means of reducing series reactance.

→ when a fault takes place on a system, the voltages at all buses are reduced. At generator terminals, these are sensed by the automatic voltage regulators which help restore generator terminal voltages by acting within the excitation system.

→ modern exciter systems having solid state controls quickly respond to bus voltage reduction and can achieve from one-half to one and one-half cycles $(\frac{1}{2} - 1\frac{1}{2})$ gain in critical clearing times for three-phase faults on the HT bus of the generator transformer.

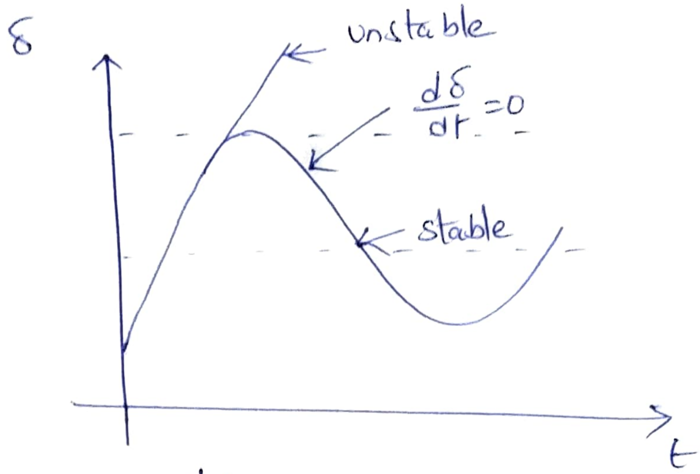
(8)(b) State and explain equal area criterion. How do you apply equal area criterion to find the maximum additional load. [6M]

Statement - 3M

Explanation - 3M

Ans

It is a graphical technique used to examine the transient stability of the machine systems (one (or) more than one) with an infinite bus.




Plot of δ Vs t

Swing equation

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

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

$$\frac{d^2\delta}{dt^2} = \frac{1}{M}(P_m - P_e) = \frac{P_a}{M}$$ , $P_a$ = accelerating power

$M = \frac{H}{\pi f}$ in PU system

multiplying both sides of the swing equation by $\left(2\frac{d\delta}{dt}\right)$

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

Integrating, we have

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

(8)(b)

$$\frac{d\delta}{dt} = \left[\frac{2}{M}\int_{\delta_0}^{\delta} P_a \, d\delta\right]^{1/2}$$

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

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

the condition for stability can be written as

$$\left[\frac{2}{M}\int_{\delta_0}^{\delta} P_a \, d\delta\right]^{1/2} = 0$$

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

→ the system is stable if the area under Pa (accelerating power) − δ curve reduces to zero at some value of δ.

→ In other words the positive (accelerating) area under Pa − δ curve must equal the negative (decelerating) area and hence the name 'equal area' criterion of stability.

(8)(b) maximum additional load :-

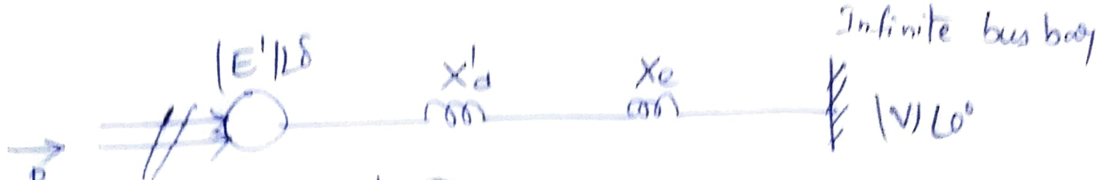



fig (1)

fig (1) shows the transient model of a single machine tied to infinite bus bar.

$$P_e = \frac{|E'||V|}{X_d' + X_e} \sin\delta = P_{max} \sin\delta$$

under steady operation condition

$$P_{mo} = P_{eo} = P_{max} \sin\delta_0$$

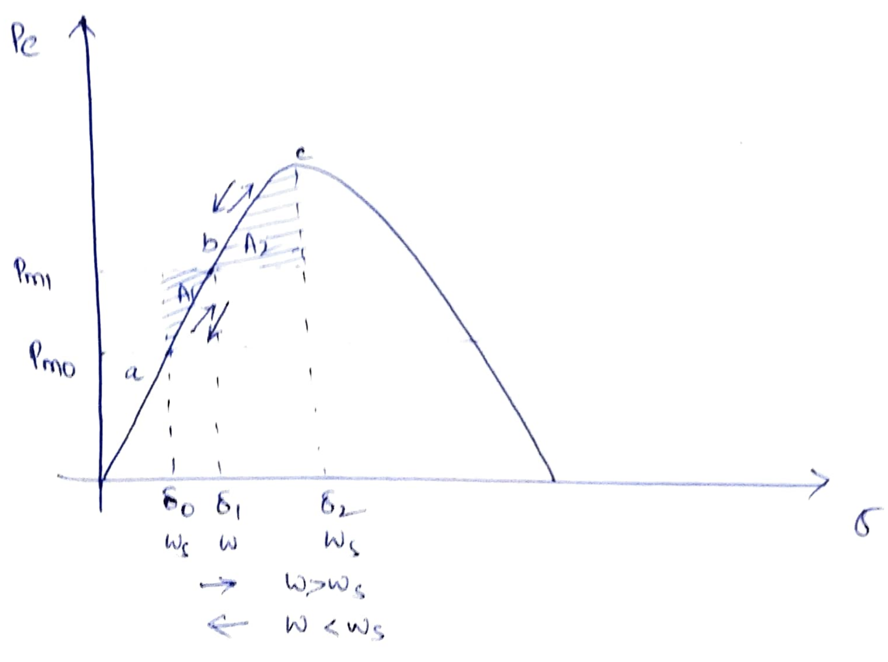



Fig (2) sudden increase in mechanical input to generator

the decelerating area $A_2$ equals the accelerating area $A_1$

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

fig ② Area $A_1$ & $A_2$ are given by

$$A_1 = \int_{\delta_0}^{\delta_1} (P_{m_1} - P_e)\, d\delta \qquad A_2 = \int_{\delta_1}^{\delta_2} (P_e - P_{m_1})\, d\delta$$

for the system stable it should be possible to find angle $\delta_2$ such that $A_1 = A_2$

$P_{m_1}$ is increased a limiting condition is finally reached when $A_1$ equals to the area above the $P_{m_1}$ line shown in fig ③

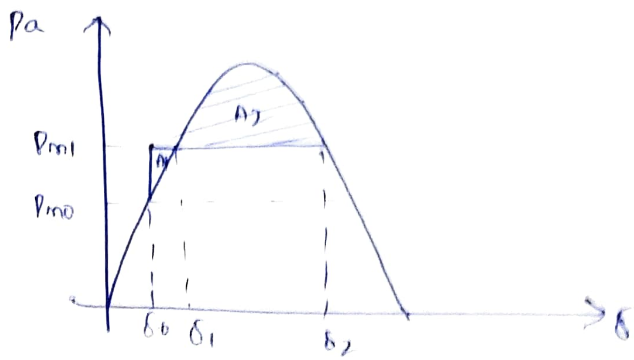



Fig ③

if the steady load is increased (line $P_m$ is shifted upwards in fig ③), a limit is finally reached beyond which decelerating area equal to $A_1$ cannot be found and therefore, the system behaves as an unstable one.

For the limiting case of stability, $\delta_1$ has a maximum value given by

$$\delta_1 = \delta_{max} = \pi - \delta_c .$$

OR

(9)(a) Developing necessary equations, describe the step by step solution of swing bus.

Graphs – 2m [6M]
Equations – 2 m
Explanation – 2m

Ans

the step by step method for one machine tied to infinite bus bar.

→ the procedure is however, general and can be applied to every machine of a multimachine system.

Consider the swing equation

$$\frac{d^2\delta}{dt^2} = \frac{1}{M}\left(P_m - P_{max}\sin\delta\right) = \frac{P_a}{M}$$

The solution $\delta(t)$ is obtained at discrete intervals of time with interval spread of $\Delta t$ uniform throughout.

9 (a) ① The accelerating power 'Pa' computed at the beginning of an interval is assumed to remain constant from the middle of the preceding interval to the middle ~~in~~ of the interval being considered as shown in fig ①

② The angular rotor velocity $\omega = \frac{d\delta}{dt}$ (over and above synchronous velocity $\omega_s$) is assumed constant throughout any interval, at the value computed for the middle of the interval as shown in fig ①.

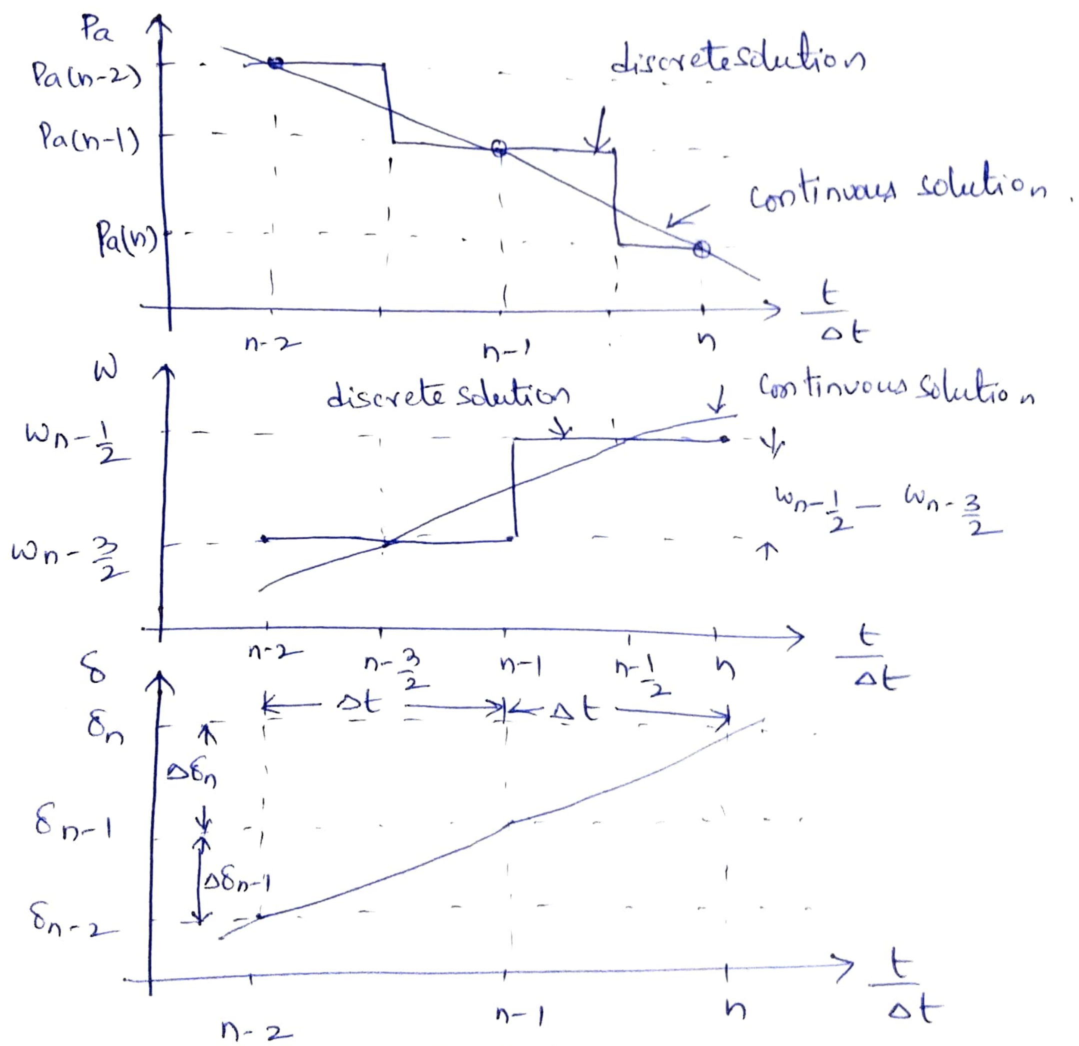



Fig ① Point-by-point solution of swing equation the process of computation is now repeated to obtain

$P_{a(n)}$, $\Delta\delta_{n+1}$ and $\delta_{n+1}$.

(9)(b) Explain critical clearing time and critical clearing angle, deriving the expressions.

critical clearing time - 2m [6m]
critical clearing angle - 3m
for any fault.

ans

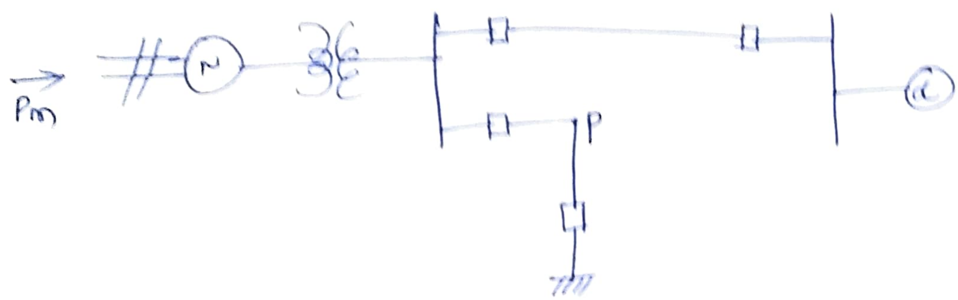
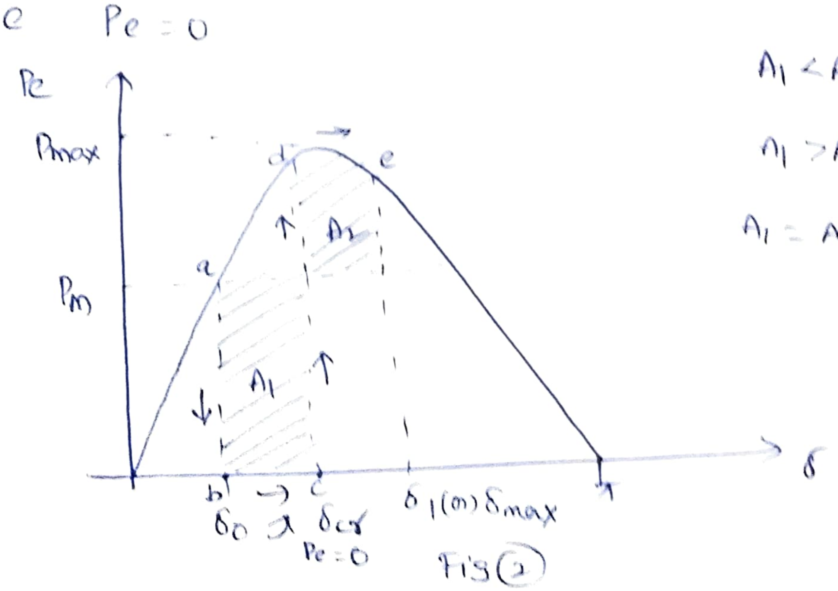



Fig ①

if the 3-$\phi$ fault occurs at the point P of the outgoing radial line the output of the generator instantly reduces to zero i.e $P_e = 0$




$A_1 < A_2$ stable

$A_1 > A_2$ unstable

$A_1 = A_2$ = critically stable

Fig ②

9 (a)

in fig (1) the numbering on $\frac{t}{\Delta t}$ Axis Pertains to end of intervals

at the end of the $(n-1)$th interval the acceleration power is

$$P_{a(n-1)} = P_m - P_{max} \sin \delta_{n-1} \quad -(1)$$

the change in velocity $\left(\omega = \frac{d\delta}{dt}\right)$ caused by the $P_{a(n-1)}$,

assumed constant over $\Delta t$ from $\left(n-\frac{3}{2}\right)$ to $\left(n-\frac{1}{2}\right)$ is

$$\omega_{n-\frac{1}{2}} - \omega_{n-\frac{3}{2}} = \frac{\Delta t}{M} P_{a(n-1)} \quad -(2)$$

the change in $\delta$ during the $(n-1)$ th interval is

$$\Delta\delta_{n-1} = \delta_{n-1} - \delta_{n-2} = \Delta t . \omega_{n-\frac{3}{2}} \quad -(3)$$

and during the nth interval

$$\Delta\delta_n = \delta_n - \delta_{n-1} = \Delta t . \omega_{n-\frac{1}{2}} \quad -(4)$$

subtracting eq (3) from eq (4) and using equation (2)

we get $\Delta\delta_n = \Delta\delta_{n-1} + \frac{(\Delta t)^2}{M} P_{a(n-1)} \quad -(5)$

using the eq (5) we can write

$$\delta_n = \delta_{n-1} + \Delta\delta_n \quad -(6)$$

(7)(b) the accelerating area $A_1$ begins to increase and so does the rotor angle while the state point moves along bc.

At time $t_c$ corresponding to angle $\delta_c$ the fault line is cleared by the ~~operating~~ opening of the line circuit breaker the value of $t_c$ and $\delta_c$ are respectively known as clearing time and clearing angle

→ For this simple case $P_e = 0$ during 3-$\phi$ fault

from fig (1)

$$\delta_{max} = \pi - \delta_0 \quad -(1)$$

$$P_m - P_e = P_{max} \sin \delta_0 \qquad P_e = 0$$

$$P_m = P_{max} \sin \delta_0 \quad -(2)$$

$$A_1 = \int_{\delta_0}^{\delta_{cr}} (P_m - 0)\, d\delta = P_m [\delta_{cr} - \delta_0]$$

$$A_2 = \int_{\delta_{cr}}^{\delta_{max}} (P_{max} \sin \delta - P_m)\, d\delta$$

$$= P_{max}(\cos \delta_{cr} - \cos \delta_{max}) - P_m (\delta_{max} - \delta_{cr})$$

$A_1 = A_2$

$$\cos \delta_{cr} = \frac{P_m}{P_{max}} (\delta_{max} - \delta_0) + \cos \delta_{max} \quad -(3)$$

sub eq ① & ② in eq ③ we get

$$\delta_{cr} = \cos^{-1}\left[(\pi - 2\delta_0)\sin\delta_0 - \cos\delta_0\right] \quad - (4)$$

During the period the fault is persisting the swing equation is

$$\frac{d^2\delta}{dt^2} = \frac{\pi f}{H} P_m \quad , \quad P_e = 0 \quad - (5)$$

Integrating twice

where

$t_{cr}$ = critical clearing time

$\delta_{cr}$ = critical clearing angle

$$\delta = \frac{\pi f}{2H} P_m t^2 + \delta_0$$

(or)

$$\delta_{cr} = \frac{\pi f}{2H} P_m t_{cr}^2 + \delta_0 \quad - (6)$$

from eq (6)

$$t_{cr} = \sqrt{\frac{2H(\delta_{cr} - \delta_0)}{\pi f P_m}} \quad - (7)$$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