Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner should assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given importance (Not applicable for subject English and Communication Skills).
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner should give credit for any equivalent figure/figures drawn.
5) Credits to be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer (as long as the assumptions are not incorrect).
6) In case of some questions credit may be given by judgment on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept

1 a) Attempt any THREE of the following **12**

1 a) i) State the concept of real power flow in power system.

Ans:

Real power in power system

Electrical power cannot be stored and hence has to be used when it is generated. Therefore power generated must be equal to power consumption i.e. power demand by consumers. Power has two components: real power and reactive power. 2 marks

Real power is generated at generating station by generators to meet the real power demand. During transmission of power from generating station to load centers some of the power in lost in the apparatus such as transmission line, transformers & generators which is also accounted as real power loss.

Considering entire power system, when real power flows from generating end to load end, it can be represented in equation form as…

Real power generated = Real power demanded by load + Real power lost in the system 1 mark

$P_g = P_d + P_L$ ………….. Real power balance equation

Effect of Real power on Frequency:

Now the real power flow in a system includes generated power, load connected to the system and power demanded by the system. The system also requires some power to overcome losses in it. Losses in the system include:

1) Losses in the transmission lines (I^2R) 1 mark
2) Losses due to corona
3) Losses in transformers, generators etc.

We know that electrical energy cannot be stored .Whatever amount of energy is generated has to be utilized at the same moment. That means rate of energy generation must be met by rate of energy consumption.

We also know that energy is transmitted almost at the velocity of light. Hence real power flow through the system can be written in equation form as

$P_g = P_d + P_L$ i.e. power balance equation.

If this equation is not satisfied then difference between generated power and used power will enter into or exit from kinetic energy storage in prime mover. This kinetic energy decides the speed of the generator. Hence imbalance in power is reflected in variation in speed i.e. variation of frequency of generated voltage.

Under normal operating condition the system generators run synchronously and generate together the power that at each moment is being drawn by all loads plus the real transmission losses.

If there is sudden drop or rise in load demand or fault occurred or failure of generator, then unbalance is caused, then $P_g > P_D$ or $P_g < P_D$ So this difference enters or exits in kinetic energy of prime mover, hence speed of generator i.e. frequency of generated emf varies.

It is understood that variation in the power, due to variation in the load causes variation in frequency.

Say suddenly all the loads connected to the system are put off then,

$P_g \neq P_d + P_L$ i.e $P_g > P_d + P_L$ i.e power balance is disturbed.

Now $P_g >>> P_L$, Hence speed of the generator i.e frequency of the supply increases.

But the over speed protective system operates and generators are tripped off.

Similarly when load on the system suddenly increases then, $P_g < P_d + P_L$

In this condition load tries to draw more power from the generators than its capacity and as P_g is less, supply frequency reduces due to decrease in the speed of the generator and therefore due to action of protective system, generators will be tripped off.

If the generators are tripped off, we cannot restore the supply immediately or instantly. Generator units in hydro power station require half an hour to restart the generation. Thermal power station requires more time & once the generators are started, they have to be connected in parallel. Load on the system has to be increased in discrete steps.

1 a) ii) List the data required for load flow analysis.

Ans:

a) Single line diagram of a power system.

b) Transmission line data -

1. Line parameters – Series impedance (z) in per unit, shunt admittance (y), thermal limits of the line.
2. Length of the line.
3. Identification of each line and its π equivalent circuit

c) Transformer ratings, impedance and tap setting are required. Quite often it may be necessary to adjust voltages on one or both sides of the transformers to maintain the potential levels at the neighboring buses within specified limits. For achieving this, auto and double winding transformers with provision for tap changing on h. v. side are used so as to facilitate smoother control.

Each point 1 Mark = Max.4 marks

d) At certain buses, static capacitors are used for voltage level improvement; their admittance values should be clearly specified.

e) Some of lines may be tuned, for the purpose of voltage stabilization, by using shunt reactors or series capacitors. Their values should be made available.

f) Depending upon buses in the system bus data should be made available : -

Type of bus	No of buses	Bus data
Generator bus		P, |V|
Load bus		P, Q

If the load flows study is to be carried out for a specified load demand then the most effective manner in which generation can be scheduled at the various buses so as to ensure the desired voltage profile.

A no. of load flow solutions is possible for different sets of control parameters. It is therefore necessary to define the objective functions so as to ensure the desired voltage profile.

1 a) iii)Describe power flow equations in the form of line flow equations.

Ans:

SLFE Equations:

$S_1^* = V_1^2 Y_{11} + Y_{12} V_2 V_1 \angle(\delta_2 - \delta_1)$ $= P_1 - j Q_1$ $P_1 = V_1^2 Y_{11} + Y_{12} V_2 V_1 \cos(\delta_2 - \delta_1)$ $Q_1 = V_1^2 Y_{11} + Y_{12} V_2 V_1 \sin(\delta_2 - \delta_1)$	$S_2^* = V_2^2 Y_{22} + Y_{21} V_2 V_1 \angle(\delta_1 - \delta_2)$ $= P_2 - j Q_2$ $P_2 = V_2^2 Y_{21} + Y_{21} V_2 V_1 \cos(\delta_1 - \delta_2)$ $Q_2 = V_2^2 Y_{22} + Y_{12} V_2 V_1 \sin(\delta_1 - \delta_2)$	2 marks each.

For a simple two bus system Load flow equations can be written as….

$P_1 = V_1^2 Y_{11} \cos \alpha_{11} + Y_{12} V_2 V_1 \cos(\delta_2 - \delta_1) = (P_{G1} - P_{D1})$

$Q_1 = -[(V_1^2 Y_{11} \sin \alpha_{11} + Y_{12} V_2 V_1 \sin(\delta_2 - \delta_1)] = -(Q_{G1} - Q_{D1})$

where $V_1 \angle\delta_1$, $V_2 \angle\delta_2$ are the voltages at bus-1, bus-2 respectively.

P_1, Q_1 are the real power and reactive power at bus 1

Y_{11}, Y_{22} are the self-admittances at bus 1 & bus 2 respectively.

Y_{12} is the mutual admittance between bus 1 and bus 2

P_2, Q_2 are the real power and reactive power at bus 2

1 a) iv)Define power system stability. Classify power system stability.

Ans:

Power System Stability: 1 mark

It is the ability of power system to return to normal or stable operation after having been subjected to some form of disturbance.

Classification of stability :

- **Steady State Stability:** It is the ability of the power system to regain its normal operating condition even after experiencing small disturbance in the system.
- **Transient state stability:** It is the ability of the power system to regain its original or new operating condition even after experiencing a large disturbance in the system.
- **Dynamic state stability:** It is the condition of the power system which lies between the steady state stability and transient state stability.

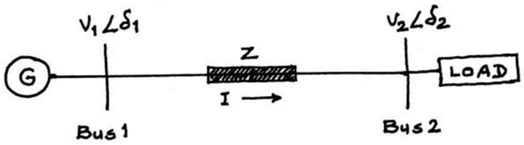
Each point 1 mark = 4 marks

1 b) Attempt any ONE of the following: **6 marks**

1 b) i) Derive the relation between real power and frequency for a simple two bus system.

Ans:

Effect of Real power on Frequency:



1 mark for diagram

Consider a simple two bus system in which power is transmitted from bus 1 to bus 2 through a short transmission line.

Let $V_1 \angle\delta_1$ be the voltage at bus 1,

$V_2 \angle\delta_2$ be the voltage at bus 2

Z be the total series impedance of the transmission line per phase $= R + jX$

Since R<<<X, $z = jX$

I be the current through the line per phase

$$\therefore I = \frac{V_1\angle\delta_1 - V_2\angle\delta_2}{z} = \frac{V_1\angle\delta_1 - V_2\angle\delta_2}{jX}$$

S_{12} be the complex power transferred from bus-1 to bus-2$= V_1 I_1^*$

$$\therefore S_{12} = V_1\angle\delta_1\left(\frac{V_1\angle-\delta_1 - V_2\angle-\delta_2}{-jX}\right) = \frac{V_1^2 - V_1V_2\angle(\delta_1-\delta_2)}{-jX}$$

Multiplying numerator and denominator by jX,

$$\therefore S_{12} = \frac{jXV_1^2 - jXV_1V_2\angle(\delta_1-\delta_2)}{X^2} = \frac{jV_1^2 - jV_1V_2\angle(\delta_1-\delta_2)}{X}$$

$$= \frac{jV_1^2 - jV_1V_2(\cos\delta + j\sin\delta)}{X}$$ where $\delta_1 - \delta_2 = \delta$

$$= \frac{jV_1^2 - jV_1V_2\cos\delta + V_1V_2\sin\delta}{X}$$

2 marks

$$= \frac{V_1V_2\sin\delta}{X} + j\left[\frac{V_1^2 - V_1V_2\cos\delta}{X}\right] = P_1 + jQ_1$$

So now $P_1 = \frac{V_1V_2}{\delta}\sin\delta$ and $Q_1 = \left[\frac{V_1^2 - V_1V_2\cos\delta}{X}\right]$

Similarly, we can also calculate complex power S_{21} that flows from bus 2 to bus 1. $\therefore S_{21} = V_2 I_2^* = V_2\angle\delta_2\left(\frac{V_2\angle-\delta_2 - V_1\angle-\delta_1}{-jX}\right) = \frac{V_2^2 - V_1V_2\angle(\delta_2-\delta_1)}{-jX}$

$$= \frac{jV_2^2 - jV_1V_2\angle(\delta_2-\delta_1)}{X}$$

$$= \frac{jV_2^2 - jV_1V_2(\cos\delta - j\sin\delta)}{X}$$ where $\delta_2 - \delta_1 = -\delta$

1 mark

$$= \frac{jV_2^2 - jV_1V_2\cos\delta - V_1V_2\sin\delta}{X}$$

$$= \frac{-V_1V_2\sin\delta}{X} + j\left[\frac{V_2^2 - V_1V_2\cos\delta}{X}\right] = P_2 + jQ_2$$

1 mark

1 mark

So now $P_2 = \frac{-V_1V_2}{X}\sin\delta$ and $Q_2 = \left[\frac{V_2^2 - V_1V_2\cos\delta}{X}\right]$

Thus it is seen that $P_1 = -P_2 = \frac{V_1V_2}{\delta}\sin\delta$ i.e there is no loss in the line

Therefore, the net power flow through the line is $P = \frac{V_1 V_2}{\delta} sin\delta$

For given system X is constant.

If voltages at both ends of the line are maintained constant i.e. V_1 and V_2 remains same, then $P \propto sin\delta$

The angle $\delta = (\delta_1 - \delta_2)$ is referred as load angle and expressed as $\delta = \omega t = 2\pi f t$

Thus angular frequency ω is proportional to the load angle. i.e $\omega \propto \delta$ or $f \propto \delta$

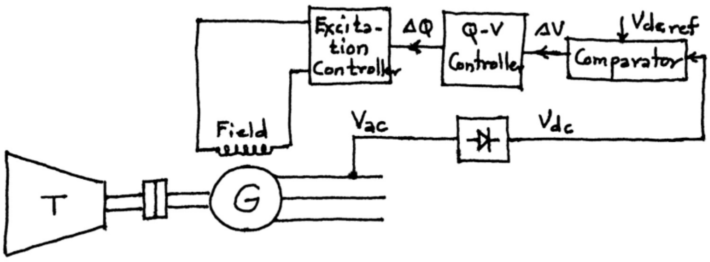
The change in power P is reflected as change in δ and the change in δ is reflected in change in frequency. This shows that the variation in real power flow results in variation in supply frequency.

1 b) ii) Describe automatic voltage control with the help of neat diagram.

Ans:

Automatic Voltage Control:

The objective of voltage controller is to exert control of excitation of generator. A voltage sensor senses the terminal voltage and converts into an equivalent D.C. Voltage. This D.C. voltage is compared with reference voltage by comparator. The output of comparator ΔV is given as input to Q-V controller, which transfers into reactive power signal ΔQ and feeds it to excitation controller. This in turn modifies the generator terminal voltage. 3 marks for explanation



3 marks for diagram

OR OR

Potential transformer: It gives sample terminal volt V_T

Differencing device: It gives the actuating error $E=V_{REF} - V_T$

The error initiates the corrective action of adjusting the alternator excitation.

Error amplifier: It demodulates and amplifies the error signal. Its gain is K_a.

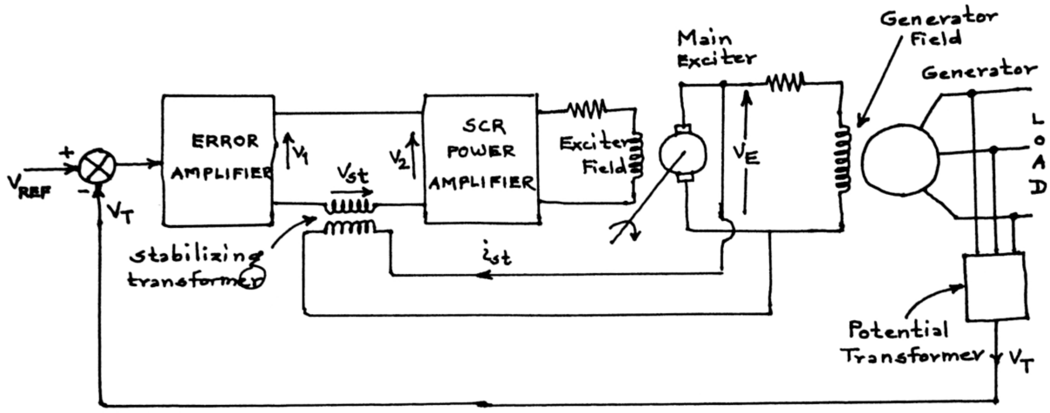
SCR power amplifier and exciter field: It provides the necessary power amplification to the signal for controlling the exciter field.

Alternator: Its field is excited by the main exciter voltage V_E. Under no load it produces a voltage proportional to field current.

Stabilizing transformer: T_{ef} and T_{gf} are large enough time constants to impair the systems dynamic response. It is well known that the dynamic response of a central system can be improved by the internal derivative feedback leap. Its output is fed at the input terminals of SCR power amplifier.

3 marks for explanation

3 marks for diagram



2 **Attempt any FOUR of the following:** **16**

2 a) Describe the necessity of reactive power compensation.

Ans:

Necessity of Reactive Power Compensation:-

1 mark for each (max. 4 marks)

- Most of the loads are inductive which absorb lagging vars.
- During peak loads vars demanded greatly exceed than the transmitted. Hence there is necessity of generating additional lagging vars.
- During off peak load vars produced by lines are larger than required by loads. Thus additional vars must be absorbed.
- If the vars are not compensated then voltages at buses vary from the nominal value. Hence there is necessity for reactive power compensation.

2 b) List the characteristics of SLFE.

Ans:

Characteristics of SLFE:

- The load flow equations are algebraic and are Non-linear.
- It is difficult to obtain analytical solution, however numerical solutions are possible.
- The static load flow equation has 12 variables.

$(P_{g_1}, Q_{g_1}, P_{l_1}, Q_{l_1}, V_1, \delta_1, P_{g_2}, Q_{g_2}, P_{l_2}, Q_{l_2}, V_2 \; \& \; \delta_2)$

In addition to this the network has fixed parameters α, X_L & X_C. As static load flow equations are four, we can't determine the 12 variables, so the

1 mark for each of any four

unknowns must be reduced to four.

- In network analysis usually the equation relate to voltages and currents, but these equations relate with voltages and power.
- The real power balance is given by equation -13 where the third term on R.H.S. represents real power loss. When R=0 then α=0 resulting into zero line loss.
  The real power loss

$$L_p = \frac{\sin\alpha}{X_L}[|V_1|^2 + |V_2|^2 - 2|V_1||V_2|\cos(\delta_1 - \delta_2)]$$

OR

$$L_p = L_p(|V_1|, |V_2|, \delta_1, \delta_2)$$

i.e. it is a function of $V_1, V_2, \delta_1 \& \delta_2$

- The reactive power balance is represented by equation

$$Q_{q1} + Q_{q2} = Q_{L1} + Q_{L2} + \frac{|V_1|^2 + |V_2|^2}{X_c} - \frac{\cos\alpha}{X_L}[|V_1|^2 + |V_2|^2 - 2|V_1||V_2|(\cos\delta_1 - \delta_2)]$$

The third and fourth terms on R.H.S represents reactive power loss L_Q and reactive line generation.

Similarly, $L_Q = L_Q(|V_1|, |V_2|, \delta_1, \delta_2)$

2 c) State the concept of steady state and transient stability.

Ans:

Steady state stability:

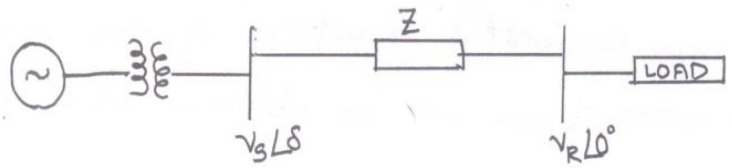
Steady state stability is the ability of the power system to regain and maintain equilibrium condition (synchronous speed) after experiencing a small/ slow disturbance such as small load variation or changes in load condition occurs, then the phenomenon is known as steady state stability. 2 mark

Transient stability:

Transient stability is the ability of the power system to regain or maintain equilibrium conditions after experiencing a large & sudden disturbance. 2 marks

2 d) Derive the expression for maximum power flow under steady state condition.

Ans:



Complex power at receiving end is given by,

$$P_R = \frac{V_S.V_R}{B}\cos(\beta-\delta) - \frac{AV_R^2}{B}\cos(\beta-\alpha)$$ 1 mark

Consider a transmission line whose shunt admittance are neglected, i.e. Y=0.
Now equivalent circuit of medium & long transmission line is similar to that short transmission line having GCC as, A=1∠0°& B=Z∠β.
Substituting in above equation we get,

$$P_R = \frac{V_S.V_R}{Z}\cos(\beta-\delta) - \frac{V_R^2}{Z}\cos\beta$$ 1 mark

$$= \frac{V_R}{Z}[V_S.\cos(\beta-\delta) - V_R\cos\beta]\times\frac{Z}{Z}$$

$$= \frac{V_R}{Z^2}[V_S.Z\cos(\beta-\delta) - V_R.R] \ldots..(as Z\cos\beta = R) \ldots\ldots.(1)$$

'P_R' will be maximum if $\frac{dP_R}{d\delta} = 0$

$$\therefore \frac{dP_R}{d\delta} = \frac{V_R}{Z}[V_S.Z\sin(\beta-\delta)] = 0$$ 1 mark

$$\therefore \sin(\beta-\delta) = 0$$

$\therefore$β-δ=0; $\therefore$β=δ

$\therefore$Substituting in Eq^n in (1), we get

$$P_{R_{max}} = \frac{V_R}{Z^2}[V_S Z. - V_R.R]$$

$$= \frac{V_R}{(R^2+X^2)}\left[V_S.\sqrt{R^2+X^2} - V_R.R\right]$$

$$P_{R_{max}} = \frac{V_S.V_R}{\sqrt{R^2+X^2}} - \frac{V_R^2.R}{(R^2+X^2)}$$ 1 mark

This is maximum steady-state power.

2 e) List the methods of voltage control.

Ans:

Following are the methods of voltage control in power system.

- By tap changing transformers.
  - Off load tap changing
  - On load tap changing
- By shunt reactors
- By shunt capacitors
- By static shunt compensation
- By synchronous condenser
- By series capacitors
- By flexible AC transmission (FACT) devices

1 mark for each of any four

2 f) List the functions of state load dispatch centre.
Ans:

For Transmission of power within a State, the State Government has established State Load Dispatch Stations. SLDS shall facilitate wheeling and inter-connection arrangements of local grid systems within its territorial jurisdiction, for the transmission and supply of electricity by economical and efficient ways.

The State Load Dispatch Centre shall be operated by a Government company or any authority or corporation established or constituted Government Company or any authority or corporation established or constituted by or under any State Act, as may be notified by the State Government. No State Load Dispatch Centre shall engage in the business of trading in electricity.

In India each state has its own SLDS and in Maharashtra SLDS is located in Kalwa and Nagpur.

In accordance with section 32 of Electricity Act, 2003 roles and functions of SLDCs are as under:

1. The State Load Dispatch Centre shall be the apex body to ensure integrated operation of the power system in a State.
2. The State Load Dispatch Centre shall – be responsible for optimum scheduling and dispatch of electricity within a State, in accordance with the contracts entered into with the licensees or the generating companies operating in that State;
3. It should monitor grid operations within the state.
4. It has to keep the accounts of the quantity of electricity transmitted through the State grid.
5. It has to exercise supervision and control over the intra-state transmission system.
6. SLDC are responsible for carrying out real time operations for grid control and dispatch of electricity within the State through secure and economic operation of the State grid in accordance with the Grid Standards and the State Grid Code.
7. The State Load Dispatch Centre may collect such fee and charges from the generating companies and licensees engaged in intra-State transmission of electricity as may be specified by the State Commission.
8. Overall supervision, monitoring and control of the integrated power system in the State on real time basis for ensuring stability, security and economy operation of the power system in the State.
9. Optimum scheduling and dispatch of electricity within the State. For this SLDCs estimate the demand of the State / DISCOMS, as may be the case, availability of power in the State/DISCOMS from State generators and other sources like Central Generating stations, bilateral contracts etc, conveys the final requisition to RLDCs on the State's entitlement from the Central Generating Stations and bilateral transactions under open access, if any, and issues final dispatch schedule to the State Generators and drawl schedule to the DISCOMS.

1 mark for each of any four functions

3 Attempt any FOUR of the following: 16

3 a) "Reactive power compensation can be achieved by controlling bus voltage level". Justify.

Ans:

- VAR compensation is defined as the management of reactive power to improve the performance of ac power systems. The concept of VAR compensation holds a wide and diverse field of both system and customer problems, especially related with power quality issues, since most of power quality problems can be solved with an adequate control of reactive power.
- The voltage, relative to nominal voltage, at the different buses of the power system is known as Voltage Profile. Most of the equipment are operated close to the preset limits of design. In view of this, the modern power system is operated with a voltage profile of ±5%.
- Flow of reactive power through line is responsible for voltage drop in the line . Bus voltage levels has to be maintained within permissible limit for better operation & control of power system.
- Reactive power compensation in transmission systems also improves the stability of the ac system by increasing the maximum active power that can be transmitted. It also helps to maintain a substantially flat voltage profile at all levels of power transmission,
- Reactive power compensation is viewed from two aspects: load compensation and voltage support.
- Hence apparatus used to control voltage at buses and reactive power compenasating apparatus are one and the same.

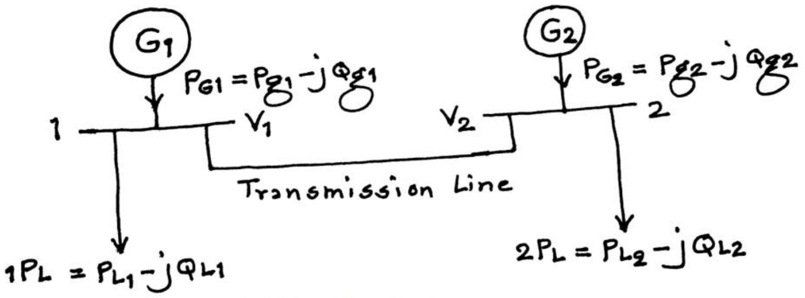
  Hence Reactive power compensation can be achieved by controlling bus voltage level.

1 mark for each point / (at the discretion of examiner)

3 b) Derive static load flow equations for simple two bus system.

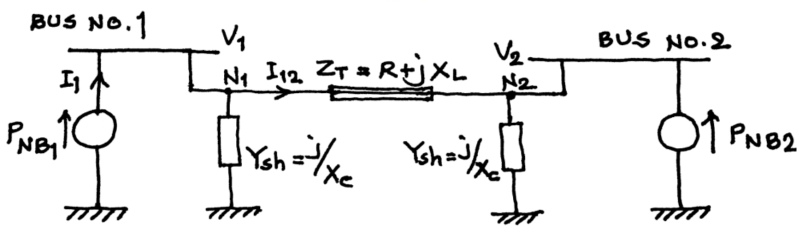
Ans:

Static Load Flow Equations For Simple Two-Bus System:



(a) Two-Bus System

1 mark for figures



(b) Equivalent Network

Fig.(a) shows the two generating stations G_1 and G_2 are interconnected through a transmission line. P_{G1} and P_{G2} are power generated at each station respectively, ${}_1P_L$ and ${}_2P_L$ are the load at those buses. Fig.(b) shows equivalent network of fig.(a) wherein P_{NB} are the net powers.

$P_{NB1} = P_{G1} - {}_1P_L = (P_{g1} - P_{L1}) - j(Q_{g1} - Q_{L1})$

$= P_1 - jQ_1 \dots\dots\dots\dots\dots\dots(1)$

$P_{NB2} = P_{G2} - {}_2P_L = (P_{g2} - P_{L2}) - j(Q_{g2} - Q_{L2})$

$= P_2 - jQ_2 \dots\dots\dots\dots\dots\dots(2)$

From fig.(b), at bus 1,

$I_1 = \frac{P_{NB1}^*}{V_1^*}$, also $I_1 = V_1 Y_{sh} + \frac{V_1 - V_2}{Z_T} \dots\dots\dots\dots\dots(3)$

At bus 2,

$I_2 = \frac{P_{NB2}^*}{V_2^*}$, also $I_2 = V_2 Y_{sh} + \frac{V_2 - V_1}{Z_T} \dots\dots\dots\dots\dots(4)$

But $Y_{sh} = {}^{j}/_{X_C} \dots\dots\dots\dots\dots(5)$

And $Z_T = R + jX_L$

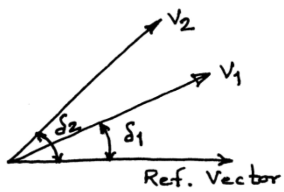
$\alpha = \frac{R}{X_L}$ (Loss factor)

$Z_T = X_L\left(\frac{R}{X_L} + j1\right)$

$= X_L(\alpha + j1) \cong X_L e^{j\left(\frac{\pi}{2} - \alpha\right)} \dots\dots\dots\dots\dots(6)$

Also from fig. $V_1 = |V_1|e^{j\delta_1} \dots\dots\dots\dots\dots(7)$

$V_2 = |V_2|e^{j\delta_2} \dots\dots\dots\dots\dots(8)$



3 marks for step-wise derivation

Now substituting eq. (1), (2), (5) & (6) in eq. (3) & (4),
from eq. (3),

$$I_1 = \frac{P_{NB1}^*}{V_1^*} = V_1 Y_{sh} + \frac{V_1 - V_2}{Z_T}$$

$$\frac{(P_{g1} - P_{L1}) + j(Q_{g1} - Q_{L1})}{|V_1|e^{-j\delta_1}} = |V_1|e^{j\delta_1}\frac{j}{X_C} + \frac{|V_1|e^{j\delta_1} - |V_2|e^{j\delta_2}}{X_L e^{j\left(\frac{\pi}{2} - \alpha\right)}}$$

$$(P_{g1} - P_{L1}) - j(Q_{g1} - Q_{L1}) = \frac{j|V_1|^2}{X_C} + \frac{|V_1|^2}{X_L}e^{-j\left(\frac{\pi}{2} - \alpha\right)} - \frac{|V_1||V_2|}{X_L}e^{j\left(\delta_2 - \delta_1 + \alpha - \frac{\pi}{2}\right)}$$

$$= \frac{j|V_1|^2}{X_C} + \frac{|V_1|^2}{X_L}\left[\cos\left(\frac{\pi}{2} - \alpha\right) - j\sin\left(\frac{\pi}{2} - \alpha\right)\right]$$

$$- \frac{|V_1||V_2|}{X_L}\left[\cos\left(\alpha - \delta_1 + \delta_2 - \frac{\pi}{2}\right) + j\sin\left(\alpha - \delta_1 + \delta_2 - \frac{\pi}{2}\right)\right]$$

$$= \frac{j|V_1|^2}{X_C} + \frac{|V_1|^2}{X_L}\left[\cos\left(\frac{\pi}{2}\right)\cos\alpha + \sin\left(\frac{\pi}{2}\right)\sin\alpha - j\sin\left(\frac{\pi}{2}\right)\cos\alpha + j\cos\left(\frac{\pi}{2}\right)\sin\alpha\right]$$

$$- \frac{|V_1||V_2|}{X_L}\left[\cos(\alpha - (\delta_1 - \delta_2))\cos\left(\frac{\pi}{2}\right) + \sin(\alpha - (\delta_1 - \delta_2))\sin\left(\frac{\pi}{2}\right)\right]$$

$$\frac{-j|V_1||V_2|}{X_L}\left[\sin\left(\alpha - (\delta_1 - \delta_2)\right)\cos\left(\frac{\pi}{2}\right) - \cos\left(\alpha - (\delta_1 - \delta_2)\right)\sin\left(\frac{\pi}{2}\right)\right]$$

$$(P_{g1} - P_{L1}) - j(Q_{g1} - Q_{L1}) = j\left[\frac{|V_1|^2}{X_C} - \frac{|V_1|^2}{X_L}cos\alpha + \frac{|V_1||V_2|}{X_L}cos(\alpha - (\delta_1 - \delta_2))\right] + \left(\frac{|V_1|^2}{X_L}sin\alpha - \frac{|V_1||V_2|}{X_L}cos(\alpha - (\delta_1 - \delta_2))\right)$$

Equal real and imaginary terms,

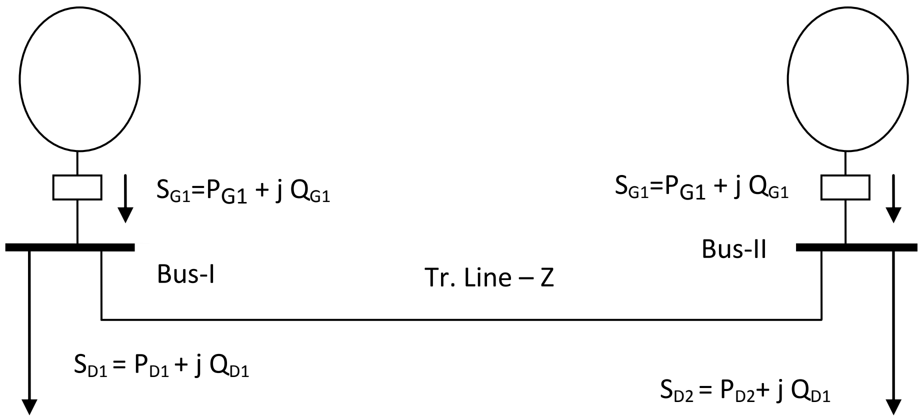
$$P_{g1} - P_{L1} - \frac{|V_1|^2}{X_L}sin\alpha + \frac{|V_1||V_2|}{X_L}cos(\alpha - (\delta_1 - \delta_2)) = 0$$

$$Q_{g1} - Q_{L1} + \frac{|V_1|^2}{X_C} - \frac{|V_1|^2}{X_L}cos\alpha + \frac{|V_1||V_2|}{X_L}cos(\alpha - (\delta_1 - \delta_2)) = 0$$

(Note: Marks can be given if some of the steps are neglected)

3 b)

OR



Let S_{G1} & S_{G2} be the power injected by the generators in bus I and bus II respectively which was measured on the h. v. side of the transformers. Let S_{D1} & S_{D2} be the load demands on bus I & bus II respectively. Two buses are inter-connected by a transmission line having π equivalent circuit. Let V_1 and V_2 be the voltage at two buses I & II respectively.

Let S_1 & S_2 be the bus power which is defined as difference between generated power and load demand.

Hence,

$S_1 = S_{G1} - S_{D1}$

$= (P_{G1} - P_{D1}) + j (Q_{G1} - Q_{D1})$

$= P_1 + j Q_1$

And

$S_2 = S_{G2} - S_{D2}$

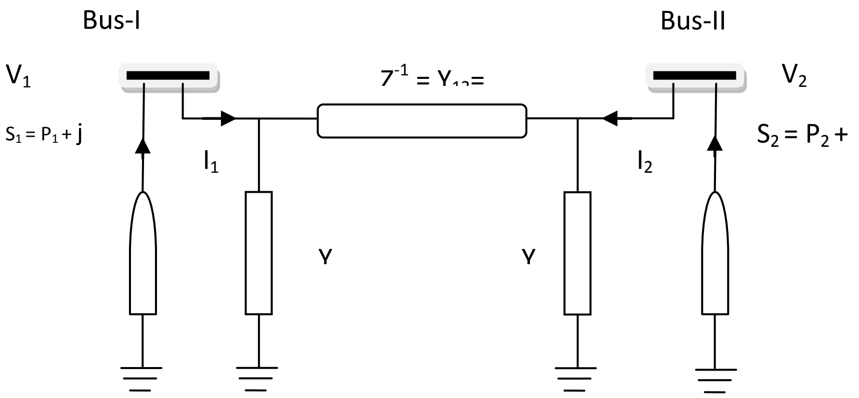
$= (P_{G2} - P_{D2}) + j (Q_{G2} - Q_{D2})$

$= P_2 + j Q_2$

1 mark

This bus power can be considered as the power injected into the bus by a bus power source. Hence an equivalent circuit for the given system can be drawn as follow:

Let I_1 – net current entering bus I, i. e. bus current of bus - I
I_2 – net current entering bus II, i.e. bus current of bus - II



Bus power S_1 can also be written as, 1 mark

$S_1 = V_1 / I_1^*$ $\quad I_1^* = S_1/V_1$ $\quad I_1 = S_1^*/V_1^*$

where I_1 enters transmission line from bus I .

By applying KCL at bus I , we get

$I_1 = V_1 Y + (V_1 - V_2) Y'$

We get

$I_1 = S_1^*/V_1^* = V_1 Y + (V_1 - V_2) Y'$ ----------------- (1)

$I_2 = S_2^*/V_2^* = V_2 Y + (V_2 - V_1) Y'$ ----------------- (2)

The above two equations can be simplified as

$I_1 = V_1 (Y + Y') - Y' V_2$ ------------------ (3)

$I_2 = -Y_1 Y' + (Y+Y') V_2$ ------------------- (4)

Let $Y+Y' = Y_{11} = Y_{22}$

$-Y = Y_{12} = Y_{21}$

Substituting in above equations we get 1 mark

$I_1 = Y_{11} V_1 + Y_{12} V_2$ ------------------ (5)

$I_2 = Y_2 V_1 + Y_{22} V_2$ ------------------ (6)

Above equations. can be written in matrix form as,

I bus = Y bus V bus ---------------- (8)

I bus = bus current vector

V bus = bus voltage vector

Y bus – bus admittance matrix $\begin{vmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{vmatrix}$

This equation is called as "Nodal current equation". Above equation can also be written as

I bus Z bus = V bus ------------------- (9)

1mark

Where Z bus – bus admittance matrix $\begin{vmatrix} Z_{11} \\ Z_{12} \\ Z_{21} \\ Z_{22} \end{vmatrix}$ = Y bus^{-1}

By knowing Z bus or Y bus, if V bus is given then we can calculate I_{bus} easily or vice versa.

3 c) Describe the necessity of load flow analysis.

Ans:

Necessity of Load Flow Analysis:

The load flow studies give magnitude and phase angle of the voltage at each bus, real and reactive power flow through transmission lines.

i) For designing the power station
ii) For operation of the system
iii) For future expansion of the system to meet increase in the demand.
iv) For interconnecting two systems to meet the load demand.
v) For analysing both normal and abnormal operating conditions.

Any four 1 mark each

It also gives initial conditions of the system when the transient behaviuor of the system is to be studied.

3 d) State the methods of improving transient stability.

Ans:

Methods of Improving Transient Stability:

There are main two methods:

1) Traditional Technique
2) New Approaches

Traditional Technique:

i) Effect of generator design.
ii) Increase of voltage
iii) Reduction in transfer reactance
iv) Rapid fault clearing

½ mark each (any four)

v) Automatic reclosing

New Approaches:

i) Quick valve opening action.
ii) Application of braking resistors
iii) Single pole switching
iv) Fast acting automatic voltage regulator

½ mark each

3 e) Derive Y-bus for following system.

Bus	Line impedance (pu)	Charging admittance (pu)
1 – 2	0.2 + j 0.8	j 0.002
2 – 3	0.3 + j 0.9	j 0.003
1 - 3	0.25 + j 1.0	j 0.04

Ans:

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}$$

$$z_{12} = 0.2 + j0.8 \qquad y_{12} = \frac{1}{z_{12}} = \frac{1}{0.2 + j0.8} = 0.3045 - j1.174$$

$$z_{23} = 0.3 + j0.9 \qquad y_{23} = \frac{1}{z_{23}} = \frac{1}{0.3 + j0.9} = 0.4108 - j1.095$$

$$z_{13} = 0.25 + j1.0 \qquad y_{13} = \frac{1}{z_{13}} = \frac{1}{0.25 + j1.0} = 0.2355 - j0.941$$

1 mark

$$y_{10} = j0.02 + j0.04 = j0.06\,S$$
$$y_{20} = j0.02 + j0.03 = j0.05\,S$$
$$y_{30} = j0.03 + j0.04 = j0.07$$

1 mark

$$y_{12} = y_{21} = 0.3045 - j1.1745\,S$$
$$y_{23} = y_{32} = 0.4108 - j1.095\,S$$
$$y_{13} = y_{31} = 0.2355 - j0.941\,S$$

$$Y_{11} = y_{10} + y_{12} + y_{13} = j0.06 + 0.3045 - j1.174 + 0.2355 - j0.941$$
$$= 0.54 - j2.055\,S$$
$$Y_{22} = y_{20} + y_{12} + y_{23} = j0.05 + 0.3045 - j1.174 + 0.4108 - j1.095$$
$$= 0.7153 - j2.219\,S$$
$$Y_{33} = y_{30} + y_{31} + y_{32} = j0.07 + 0.2355 - j0.941 + 0.4108 - j1.095$$
$$= 0.6463 - j1.966\,S$$
$$Y_{12} = Y_{21} = -y_{12} = -0.3045 + j1.174\,S$$
$$Y_{23} = Y_{32} = -y_{23} = -0.4108 + j1.095\,S$$
$$Y_{31} = Y_{13} = -y_{13} = -0.2355 + j0.941\,S$$

1 mark

$$Y_{bus} = \begin{bmatrix} 0.54 - j2.055 & -0.3045 + j1.174 & -0.2355 + j0.941 \\ -0.3045 + j1.174 & 0.7153 - j2.219 & -0.4108 + j1.095 \\ -0.2355 + j0.941 & -0.4108 + j1.095 & 0.6463 - j1.966 \end{bmatrix}$$

1mark

4 a) Attempt any THREE of the following: **12**

4 a) i) Distinguish between shunt compensation and synchronous compensation.

Ans:

Sr. No.	Shunt Compensation	Synchronous Compensation
1	Static system/No moving parts	Rotary system /It is a revolving machine
2	Control is slow and stepwise compared to synchronous compensation	Control is fast and continuous
3	It cannot be overloaded	It can be overloaded for short periods
4	Located near load	Located away from load
5	Less maintenance	More maintenance
6	Failure of one unit of static capacitor bank affects that unit only, remaining unit continue to operate	Failure of synchronous compensator means loss of complete unit
7	Applicable for small reactive power requirement.	Applicable for large i.e above 10 MVAr it is required.
8	Maintenance is easy	Maintenance is difficult
9	e.g Reactor, Capacitor	e.g Synchronous motor

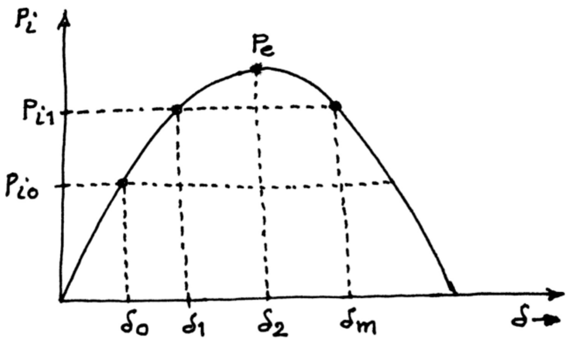
1 mark for each of any four points = maximum 4 marks

4 a) ii) Describe transient stability with the help of power angle curve.

Ans:

Transient Stability:

Many sudden disturbances like fault, change in transfer reactance due to switching, sudden change in load may cause a system to loose stability, even when the system is being operated below its steady state stability limit. The maximum power transfer is limited by the requirement of maintaining transient stability.



Power Angle Curve

1 mark for diagram

3 marks for explanation

The figure shows the power angle curve of a generator. Suppose the system is operating in steady state at $P_i = P_{io}$ and $\delta = \delta_0$.When the mechanical power is suddenly increased to P_{i1} at t = 0, δ cannot adjust instantly due to rotor inertia. Thus at t = 0, $\delta = \delta_0$ and input exceeds output. The rotor starts accelerating and δ starts increasing.

When $\delta = \delta_1$, the input and output becomes equal but the rotor cannot stop here due to inertia and δ continues to increase. For $\delta>\delta_1$, input becomes less than output and rotor retardation takes place. Eventually rotor may stop at δ_2 and swings back towards δ_1. There will be oscillations around δ_1. However, these oscillations will damp out and rotor will stabilize at the new equilibrium value.

The maximum swing of the rotor beyond δ_1 depends on the amount of sudden increase in input. If during the swing δ becomes greater than δ_m , input again becomes greater than output, the rotor will again accelerate causing δ to increase. Therefore, stability will be lost is δ swings past δ_m.

4 a) iii) "Static load flow equations are important for analyzing power system network". Justify.

Ans:

Justifications…..

i) Accuracy of the result increases.
ii) Flexibility in operation of the system.
iii) Analysis consumes less time.
iv) Quicker operation of the system.
v) Can obtain economical operational condition.
vi) Assuming values for certain number of variables, values for remaining can be determined.

1 mark for each point any four

4 a) iv) Describe the necessity of load forecasting.

Ans:

Necessity of Load Forecasting:

i) Electricity is the most preferred form of energy and electrification is an ongoing process.
ii) Demand for electricity tends to grow more rapidly for economic development.
iii) Increasing demand of electricity is due to several factors such as population growth, growth of per capita income, migration to urban areas and increase in energy using products.
iv) Understanding electricity demand, planning and control is critical for all countries.
v) Power system planning involves forecast of future load of both demand and energy.
vi) Forecasting is useful to determine capacity of generation, transmission and distribution and decide generation facilities required.
vii) Load forecasting is useful for establishing policy for procurement of capital equipment and fuel.
viii) Forecasting is gaining importance due to increasing scarcity of electrical energy along with more powerful computing equipment and software.

1 mark for each of any four points = 4 marks

4 b) Attempt any ONE of the following: **6**

4 b) (i) Describe the effect of change in supply frequency on:

i. Consumers and
ii. Utilities

Ans:

Effect of change in supply frequency on consumers:

i. Variation in f varies the speed of motor and will affect the quality of product/ performance.
ii. Causes variation in hysteresis losses and eddy current losses that leads to variation in heating of parts i.e. subjected to variable thermal stress. Results

1mark each any 3

into reduction of life of apparatus.

iii. Sensitive equipment fail/damaged e.g TV picture starts rolling

iv. In some industries such as the textiles rubber, plastic & paper require frequency constant or to a tolerance of ± 0.25 per min.

v. Electric gear systems used in industries requires the frequency 49.5 Hz to 50.5 Hz range.

Effect of change in supply frequency on utilities:

i. Malfunctioning of Relays

ii. Imbalance in power flow in system.

iii. Difficult in operation of power system at stability condition.

iv. Turbine's blades will vibrate at natural frequency /damaged.

v. Detection of fault not easy.

vi. Steady state stability condition of system may be pulled into transient state. 1mark each any 3

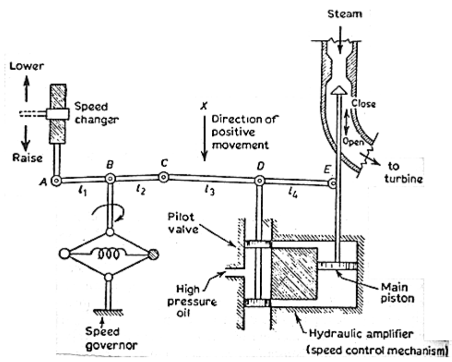
vii. Power systems are interconnected through H.V. line to meet increase in demand. Hence to regulate the power flow through these lines, need accurate constant frequency.

viii. With reduced frequency the blast by ID fans and FD fans decrease, and so the generation decreases and thus it becomes a multiplying effect and may result in shut down of the plant.

4 b) (ii)Draw the turbine governing system. Describe function of each part.

Ans:

Turbine Governing System: Labeled diagram – 3marks



Turbine-Speed Governing System

The system consists of the following components:

Function of any 3 major part – 1 mark each

i) Fly ball speed governor:
This is the heart of the system which senses the change in speed. As the speed increases the fly balls move outwards and the point B on linkage mechanism moves downwards. The reverse happens when the speed decreases.

ii) 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.

iii) 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 control valve in proportion to change in speed. It also provides a feedback from the steam valve movement (link 4)

iv) Speed Changer:
It provides a steady state power output setting for the turbine. Their downward movements open the upper pilot valve so that more steam is admitted to the

turbine under steady conditions. The reverse happens for upward movement of speed changer.

5 Attempt any FOUR of the following: 16

5 a) List the information obtained from load flow equations.

Ans:

Information obtained from Load Flow Equations:

i) We get MW and MVAR flow in the various parts of the system network.
ii) We get information about voltages at various buses in the system.
iii) We get information about optional load distribution.
iv) Impact of any change in generation on the system.
v) Influence of any modification or extension of the existing circuits on the system loading.
vi) It also gives information for choice of appropriate rating and tap setting of the power transformer in the system.
vii) Influence of any change in conductor size and system voltage level on power flow.

1mark for each of any four points = 4 marks

5 b) Write the expression for swing equation and state the meaning of each term in it.

Ans:

Swing Equation:

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

2 marks

where, M : Inertia constant
P_a : Accelerating Power
P_m : Mechanical power input to synchronous generator
P_e : Electrical Power output of synchronous generator
δ : Load angle in radian.

½ mark for each of any four variables

5 c) List the methods of voltage control.

Ans:

Methods of Voltage Control:

i) Excitation control at generating station (Tirril Regulator, Brown Boveri Regulators)
ii) Reactive power injection
iii) Induction regulators
iv) Use of Static VAR generator or static capacitor or shunt reactor.
v) Use of rotating VAR generator or synchronous motor.
vi) Control by Auto- transformer / tap-changing transformer.
vii) Use of Series capacitor.
viii) Booster transformers.

1 mark for each of any four

5 d) Describe load frequency control.

Ans:

Load Frequency Control:

This is also referred to as Megawatt frequency control or pf control. The aim of this control is to maintain real power balance in the system through control of system frequency. Whenever the real power demand changes, a frequency change occurs. 1 mark

This frequency error is amplified, mixed and changed into a command signal which is sent to the turbine governor. The governor operates to restore the balance between the input and output by changing the turbine input.

Method of frequency control:

i) Manual Control: Very small isolated generating stations can have manual control of frequency. The generator adjusts the input to bring the frequency within the permissible limit.

ii) Flat frequency control: To control the frequency of any generator in a tie line, the frequency of other generator is controlled.

iii) Flat tie line: The station A is used for frequency control and also the regulation is improved by adjusting the input of other.

1 mark for each point (3 marks)

5 e) State the factors governing load shedding.

Ans:

Factors Governing Load Shedding:

i) The imbalance between power demand and power generation due insufficient resources. To reduce effect of imbalance intentionally supply to some load are cut off.

ii) The sudden rise or fall in power demand leads to wide gap between demand and supply, and that results into instability in the system. To reduce effect of instability load shedding is carried out.

iii) Due to major faults like three phase short circuit fault, line to ground fault, failure of switch gears or major equipments instability condition occurs in the system. To reduce effect of instability load shedding is carried out.

iv) To reduce wastage of energy and to adopt energy conservation techniques supply to selective loads (mostly lighting loads) are shut off.

v) To reduce the maximum demand of any industry or commercial complex local load shedding is carried out to reduce the peak demand and also to reduce energy bills.

vi) Refer to individual load; lighting control strategy is adopted for selectively reducing the output of light fixtures on a temporary basis so that it will reduce peak demand charges.

vii) Load shedding is carried out to selectively shut off a set of output receptacles so that the capacity of the UPS battery can be extended.

viii) To share power, the UPS switches off selected devices to increase run time of critical loads.

ix) The onset of summer every year brings with it the woes of load shedding. It has hit the manufacturing sector and many times forcing them to shut down operations resulting in losses worth several crore.

1 mark for each of any four.

6 Attempt any FOUR of the following: 16

6 a) Describe concept of economic load dispatch.

Ans:

Economic Load Dispatch:

- *The economic load dispatch*, deals with determining the power output of each plant to meet the specified load, such that the overall fuel cost is minimized. The factors influencing the cost of generation are the generator efficiency, fuel cost and transmission losses. The most efficient generator may not give minimum cost, since it may be located in a place where fuel cost is high. Further, if the plant is located far from the load centres, transmission losses may be high and running the plant may become uneconomical. The economic dispatch problem basically determines the generation of different plants to minimize total operating cost.

- The economic load dispatch involves the solution of unit commitment or pre-dispatch problem wherein it is required to select optimally act of the available generating sources to operate and to meet the expected load and provide a specified margin of operating reserve over a specified period of time. 4 marks
- *For economic generation scheduling to meet a particular load demand, when transmission losses are neglected and generation limits are not imposed, all plants must operate at equal incremental production costs, subject to the constraint that the total generation be equal to the demand*
- *The minimum operation cost is obtained when the product of the incremental fuel cost and the penalty factor of all units is the same, when losses are considered.*
- The second one is on-line economic dispatch wherein it is required to distribute the load among the generating units actually parallel with the system to minimize the total cost of supplying the minute for minute requirement of the system.

6 b) State factors affecting transient stability.

Ans:

Factors affecting Transient Stability:

i) Generators play a vital role in any power system. Their characteristics have a significant impact on the stability characteristics of the system.

ii) Under transient conditions, the transient reactance, rotor inertia (inertia constant), excitation response and the electrical damping provided by the generator rotor and the mechanical damping by the prime mover determine the generator performance. 1 mark for each of any four

iii) From swing equation the acceleration of the rotor $d^2\delta/_{dt^2}$ is inversely proportional to the moment of inertia of the machine, when accelerating power is constant, which means higher the moment of inertia, the slower will be the change in rotor angle, hence longer time for breaker operation.

iv) By reducing the switching time and also the transient reactance, power limit can be substantially improved.

v) Voltage regulators improve stability limits subsequent to the first swing oscillation, after the clearing of the faulty section.

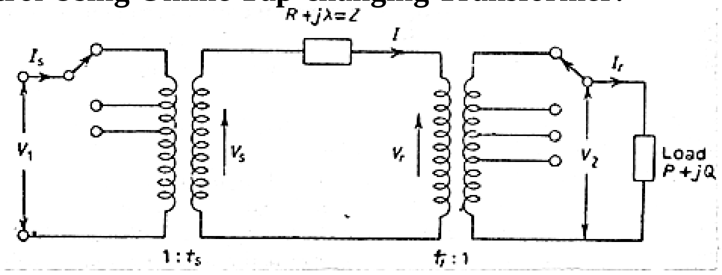
vi) Excitation response

6 c) Describe the method of voltage control using:

i) Online tap changing transformer and
ii) Regulating transformer

Ans:

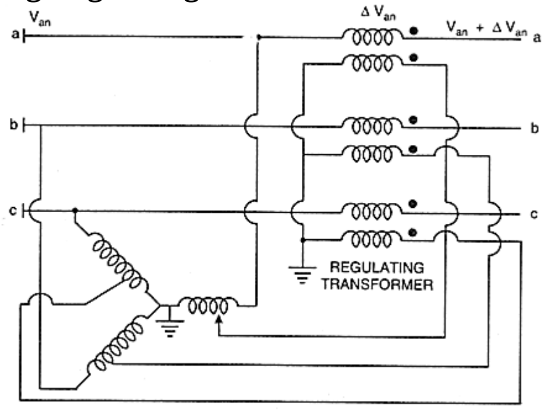
Voltage Control Using Online Tap-changing Transformer:



1 mark

All transformers are provided with taps on the winding for adjusting the ratio of transformation. Taps are usually provided on the high voltage winding to enable a fine control of voltage. Generally the tap changing can be done only when the transformer is in de-energized state. However in some cases tap changing is also possible when the transformer is energized. These transformers make it possible to maintain a constant voltage level on important buses in the system. 1 mark

Voltage Control Using Regulating Transformer:



1 mark

A special type of transformer designed for small adjustments of voltage is known as regulating transformer. The figure shows a typical arrangement to use a regulating transformer for voltage magnitude control in a three-phase circuit. A 3-ph transformer provides an adjustable voltage to the primary winding of the regulating transformer. The secondary winding of the regulating transformer is connected in series with the lines. Thus a voltage magnitude $|\Delta V|$ is added to the voltage of each phase. 1 mark

6 d) "Environmental factors are important in load forecasting" Justify with reason.

Ans:

Load Forecasting plays important role in power system planning & operation of system. Environmental factors also affect the load forecasting but their influence varies from area to area and country to country. Hence Environmental factors are important in load forecasting. 1 mark each any 4 points

Reason.-

1. Time dependent factor –
   Shows regular (during time of day, day of week, week of year), irregular (holidays, weekends, special days) and random nature(unexpected change in weather condition /transient faults).

2. weather dependent factor –(dirty & wet weather, dew point, humidity, sky cover)
3. temperature & wind speed –affects air conditioner,
4. Cloud ,fog – affects illumination
5. Random weather change –affect infrastructure of power system

6 e) The cost curve of two generating units of a power plant are given by

$$\frac{dC_1}{dP_1} = 0.4P_1 + 30 \ ₹/\text{MWh}$$
$$\frac{dC_2}{dP_2} = 0.3P_1 + 15 \ ₹/\text{MWh}$$

Determine incremental fuel cost of unit for total load on station to be 300 MW considering economic load dispatch.

Ans:

$$\frac{dC_1}{dP_1} = 0.4P_1 + 30 \ ₹/\text{MWh}$$

$$\frac{dC_2}{dP_2} = 0.3P_1 + 15 \ ₹/\text{MWh}$$

Total load = 300 MW

$\therefore P_1 + P_2 = 300MW$

$P_1 = 300 - P_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$ 1 mark

For economic load dispatch,

$$\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2}$$

$0.4P_1 + 30 = 0.3P_2 + 15$

$0.4P_1 - 0.3P_2 = 15 - 30 = -15$

$0.4P_1 - 0.3P_2 = -15 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$ 1 mark

Put P_1 from eq. 1 in eq. 2,

$0.4(300 - P_2) - 0.3P_2 = -15$

$120 - 0.4P_2 - 0.3P_2 = -15$

$-0.7P_2 = -15 - 120$

$$P_2 = \frac{135}{0.7} = 192.85\ MW \approx 193\ MW$$

$P_1 = 300 - P_2 = 300 - 193$

$P_1 = 107\ MW$ 1 mark

$\therefore$ Incremental fuel cost $\frac{dC_1}{dP_1} = 0.4(107) + 30 = 72.8$ ₹/MWh

$\frac{dC_2}{dP_2} = 0.3(193) + 15 = 72.8$ ₹/MWh 1 mark