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 may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more 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 may give credit for any equivalent figure drawn.
5) Credits may 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.
6) In case of some questions credit may be given by judgement 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.

Q.1.a) Effect of change in frequency on consumers **(any 4 points--- 1 mark for each point)**

Consumers need constant frequency supply because

1) In most of the industries, Induction motor is used as common drive, which runs at speed that is directly related with frequency. (N= 120f/p) variation in frequency affects the quality of the product and rate of production.
2) Induction motor used as common A.C. drives, though has rigid construction but due to variation in supply frequency, life of induction motor reduces by 500 Hrs. They are not sensitive for small variation in the supply frequency. i.e. of the order of 50 $\pm$ 2 Hz.
3) In railway stations, the electric chokes are driven by single-phase synchronous motor, The speed of the synchronous motor depends on supply frequency directly. Hence it needs constant frequency supply for all 24 Hrs. of the day. If frequency falls by 1 hr , then clock falls back by 15 min. & it takes no. of hours to reduce the error to zero.
4) In some industries such as the textiles rubber, plastic & paper require frequency constant or to a tolerance of $\pm$ 0.25 per min.
5) Electric gear systems used in industries requires the frequency 49.5 Hz to 50.5 Hz range.

Q.1.b) Need of Load flow analysis **(Any 4 points, 1 mark for each point)**

Load flow studies gives magnitude & phase angle of the voltage at each bus, real and reactive power flow through tr. Lines, current flow through tr. Lines. Hence load flow studies are essential for- - - -

- For designing the power system.

- For operation of the system.
- For future expansion of the system to meet increase in the demand.
- For inter connecting the two systems to meet the load demand.
- For analyzing both normal and abnormal (means outage of tr. Lines or transformer or gen. units) operating conditions.
- For analyzing the initial conditions of the system when the transient behavior of the system is to be studied.
- Transmission lines can carry only certain amount of current and we must make sure that we do not operate these links too close to their stability or thermal limits so LFA helps to know the amount current flowing through various lines in the network.
- LFA also helps in maintaining the stability of the system by giving the information about real, reactive power flow in the system.

Q.1.c) Data required for LFA: **(Any 4 Points, 1 Mark for each)**

- Single line diagram of a power system.
- Transmission line data -

  (a) Line parameters – Series impedance (z) in per unit shunt admittance (y) thermal limits of the line.

  (b) Length of the line.

  (c) Identification of each line and its II equ. Ckt.

- 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 or used so as to facilitate smoother control.
- At certain buses, static capacitors are used for voltage level improvement their admittance value should be clearly specified.
- 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.
- Depending upon no. 07 buses in the system bus data should be made available : -

Type of bus	No of buses	Bus date
Generator bus		P, (V)
Load bus		P, Q

- If the load flow 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 and objective functions so as to ensure the desired voltage profile.

Q.1.d) Steady state stability & Transient state stability **(2 marks for each point)**

Steady state stability:-

A power system has steady state stability if after a small slow disturbance it can regain and maintain synchronism and returns to essentially the same steady state operating condition. The small slow disturbance means normal load variations or changes, settings of excitation system, voltage regulators etc. Steady state stability limit is the maximum possible flow of power without loss of stability, when the power is changed gradually.

Transient state stability:-

Transient state stability is the ability of the system to return to its normal operating condition of same equilibrium or new equilibrium position after experiencing sudden and large disturbance in the network. Large disturbance means occurrence of faults, sudden increase in large amount of load etc. Transient state stability limit refers to maximum possible flow of power through a point without loss of stability when a large sudden disturbance occurs.

Q.1.e) Expression for maximum steady state power:

(Initial data and expression for P_R – 1 Mark, Substituting condition R = 0 and neglecting Y- 1 Mark, Deriving Condition – dP/dR- 1 Mark, Expression for Maximum Steady State Power- 1 Mark)

NOTE: ***Similar derivation with two bus system may be considered***

Complex Power at the receiving End is given by,

$$P_R = \frac{V_S \cdot V_R}{B} \cos(\beta - \delta) - \frac{A \cdot V_R^2}{B} \cos(\beta - \alpha)$$

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 of short transmission line having GCC as $A = 1\angle 0°$ & $B = Z\angle\beta$.

Substituting in above Equation, we get

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

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

$$= \frac{V_R}{Z^2}\left[V_S \cdot Z \cos(\beta - \delta) - V_R \cdot R\right] \text{ ..... (1)} \quad \text{as } (Z\cos\beta = R)$$

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

$$\therefore \frac{dP_R}{d\delta} = \frac{V_R}{Z^2}\left[V_S \cdot Z \sin(\beta - \delta) - 0\right] = 0$$

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

$$\therefore \beta - \delta = 0$$

i.e. $\boxed{\beta = \delta}$

$\therefore$ Substituting in Equation (1), we get,

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

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

$$= \frac{V_S \cdot V_R}{\sqrt{R^2 + X^2}} - \frac{V_R^2 \cdot R}{(R^2 + X^2)}$$

This is max. steady state Power.

Q.1.f) Different types of LDC with locations: **(1 Mark For Each Type with Location)**

Type of LDC		**Locations**
NLDC- National Load Dispatch Centre		Delhi
RLDC –Regional Load Dispatch Centre	ERLDC- Eastern Region	Kolkata
	SRLDC-Southern Region	Banglore
	WRLDC-Western Region	Mumbai(Kalwa)
	NERLDC- North East Region	Shillong
	NRLDC- Northern Region	Delhi
SLDC- State Load Dispatch Centre	**Eg.**Maharashtra State LDC	Nagpur (Ambazari)
SSLDC-Sub State Load Dispatch	**eg** Maharashtra State LDC	Mumbai(Andheri)
LLDC- Local Load Dispatch centre	**Eg.** Tata Power Company Ltd.	Mumbai(Trombe)

Q.1.g) Definitions:- **(1 mark for each def)**

- Fuel rate in Kcal/MWH:- it is defined as the ratio of fuel input to power output

$$\text{Fuel rate} = \frac{Fuel\ input}{power\ output} = \frac{F1}{P1}$$

$$= \frac{Kcal\ per\ hr}{MW}$$

$$= \text{Kcal / MWH}$$

- Incremental fuel rate in Kcal/MWH: - it is defined as the ratio of small change in fuel input to the corresponding change in power output.

$$\text{Incremental fuel rate} = \frac{dF}{dP} \ldots\ldots\text{Kcal/MWH}$$

- Incremental fuel cost:- it is defined as the product of incremental fuel rate and fuel cost.

$$\text{Incremental fuel cost} = \text{Incremental fuel rate} * \text{Fuel cost}$$

$$= \frac{Kcal}{MWH} * \frac{Rs}{Kcal} \ldots\ldots\ldots \text{ Rs. / MWH}$$

- Fuel efficiency:- it is defined as the ratio of power output in MW to fuel input in Kcal /hr

$$\text{Fuel efficiency} = \frac{MW\ hrs}{Kcal}$$

Q.2.a) SLFE equations with characteristics: - **(2 marks for equ. and any 6 chara-1 mark for each)**

- **SLFE equations:-**

$S_1^* = V_1^2 Y_{11} L œ_{11} + Y_{12} V_2 V_1 L(\delta_2 - \delta_1) = P_1 - j Q_1$	$S_2^* = V_2^2 Y_{22} L œ_{22} + Y_{21} V_2 V_1 (\delta_1 - \delta_2) = P_2 - j Q_2$
$P_1 = V_1^2 Y_{11} \text{Cos } œ_{11} + Y_{12} V_2 V_1 \text{Cos } (\delta_2 - \delta_1)$	$P_2 = V_2^2 Y_{21} \text{Cos } œ_{22} + Y_{21} V_2 V_1 \text{Cos } (\delta_1 - \delta_2)$
$Q_1 = (V_1^2 Y_{11} \text{Sin } œ_{11} + Y_{12} V_2 V_1 \text{Sin } (\delta_2 - \delta_1)$	$Q_2 = (V_2^2 Y_{22} \text{Sin } œ_{11} + Y_{12} V_2 V_1 \text{Sin } (\delta_1 - \delta_2)$

-

Characteristics of SLFE

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

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

$Q_1 = \text{-- } [(V_1^2 Y_{11} \text{Sin } œ_{11} + Y_{12} V_2 V_1 \text{Sin } (\delta_2 - \delta_1) = -(Q_{G1} - Q_{D1})$

(1) The equations are algebraic equations, because they represent a system operating in steady state or a model of a static system (under transient condition these equation cannot be used for calculations.

(2) The equations are non-linear, so generator it is practically impossible to get analytical solutions, Hence digital computers can be used to get the solutions.

(3) The real power balance in the system can be studied by adding. Equation (1) & (2)

$P_1 + P_2 = (P_{G1} - P_{D1}) + (P_{G2} - P_{D2}) = f_1(P) + f_2(P)$

$(P_{G1} + P_{G2}) = (P_{D1} + P_{D2}) + (f_1(P) + f_2(P))$

i.e. $P_G = P_D + P_L$

i.e. Sum of power generated in the system equals the power demand and real power loss P_L where

$P_L = f_1(P) + f_2(P)$

(4) Similarly reactive power balance can be demonstrated by adding =q.ns (3) × (4).

$Q_1 + Q_2 = (Q_{G1} - Q_{D1}) + (Q_{G2} - Q_{D2}) = f_1(Q) + f_2(Q)$

$(Q_{G2} + Q_{G2}) = (Q_{D1} + Q_{D2}) + f_1(Q) + f_2(Q)$

$Q_G = Q_D + Q_L$

Hence Q_2 indicates actual reactive power loss in the line (series inductance) minus the reactive power generated in the line (shunt capacitance)

(5) The four functions $f_1(P)$, $f_2(P)$, $f_1(Q)$, $f_2(Q)$ defined in above are functions of the voltage variables and load angles.

$P = f(V_1, V_2, \delta_1, \delta_2)$

$Q = f(V_1, V2, \delta_1, \delta_2)$

The losses in the system that occurs are also functions of voltages and load angles.

(6) Note that in all four SLEF the load angle 'δ' appears in difference form i.e. $(\delta_1 - \delta_2)$ or $(\delta_2 - \delta_1)$

(7) In addition to the fixed network parameters the equations contain 12 variables.

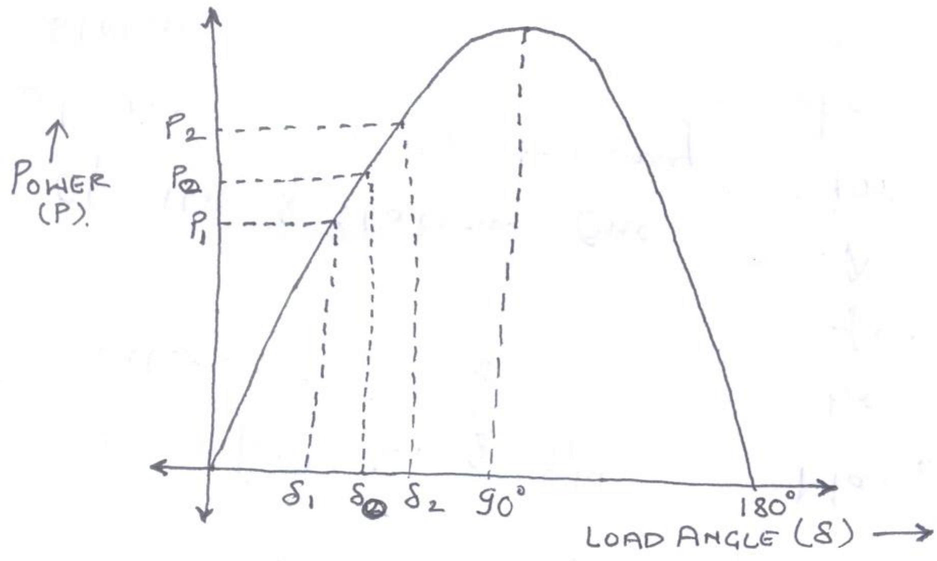
$V_1, V_2, \delta_1, \delta_2, P_{G1}, P_{G2}, P_{D1}, P_{D2}, Q_{G1}, Q_{G2}, \&\ Q_{D1}, Q_{D2}$.

It is not possible to obtain a solution for any of the variables unless we of remaining reduce the no. 07 unknowns by fixing the values for some of the variables. In above SLEF for a two bus system there are 12 unknowns which we have to reduce it to 21 to match the no. of equations by fixing the values for 8 unknowns thus if values of 8 unknown are g. We can determine the values of remaining 4 unknowns by salving the SLEF.

Q.2.b) Steady state stability condition with PA diagram.: (Diag. with labeling- 4 Marks, Exp. 4 Marks)

Steady State stability: A power system has a steady state stability if after a small slope disturbance it can regain and maintain synchronism. The small slow disturbance means normal load variations or changes, settings of excitation systems or voltage regulators. Steady State Stability is the maximum possible flow of power, without loss of stability when the power is changed gradually.

Consider a power angle curve of a synchronous generator connected to a infinite bus bar as shown below:



Suppose that generator is operating at steady state with load angle δ_0 and power flow P_0. Now Pg = Pd where Pg = power generator. And Pd= power demanded. Assume loss less system.

Suppose an arbitrary change in load takes place that reduce the load angle to δ_1 and power P_1. Now the generator output is greater than load power that is at generating station generator input is greater than its output power so speed of generator accelerate and load angle also increases. Hence the system will oscillate around the load angle δ_0 and the oscillations would be damped and load angle would return to its original value $\delta_{0.}$

A similar situation takes place if load angle increases to $\delta_{2.}$

Now the generator output power is greater than input power. So generator retards, the load angle decreases and finally returns to its original value $\delta_{0.}$ Thus, if the system is operating at the load angle δ_0 is subjected to small arbitrary disturbing forces, then regardless the direction of the force, the system returns to its original position.

Q. 2 C.Functioning of SCADA at Load Dispatch Station (Diag. 4 Marks , 01 mark for each component with function)

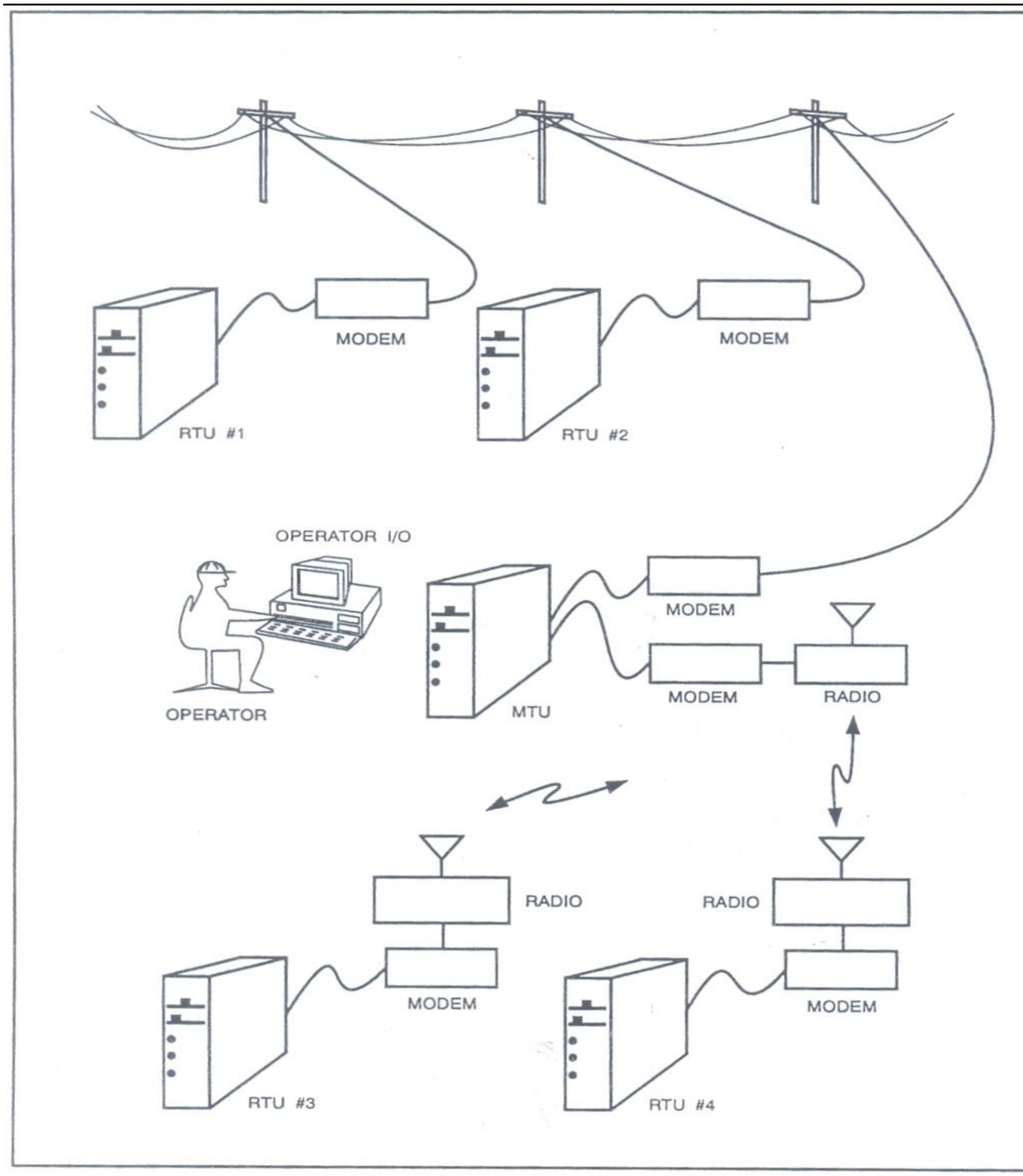
SCADA: SCADA is the technology that enables the user to collect data from one or more distinct facilities and / or send control instruction to those facilities. SCADA makes it unnecessary for an operator to be assigned to stay at or to visit remote locations in the normal operations of that remote facility.

Main components of SCADA are

1. Operator interface device
2. MTU (Master Terminal Unit

3. RTU (Remote Terminal Unit
4. Communication system

1. Operator interface device: At the centre the operator accesses the system through an interface device which is also called as an operator I/O (For Input /Output). Interface device may a CRT display or VDU. It provides the information about the input quantity to operator whenever he wants. This is placed in th central control room. These devices displays the values of parameter, measured values and computer characteristics in tabular form.
2. MTU: It is the main controller of this whole system. It is generally a computer. It can monitor and control the field even in the absence of operator. MTU also has auxiliary devices attached to such as printer, backup memory, etc. MTU also sends accounting information to other computers or management information to other systems through LAN connections.
3. RTU: A system can contain number of RTUs. Each RTU must have the capability to understand the message, to decoded and to act on the message, to respond if necessary and then to shut down till next new message is receive. Acting on the message is the complex procedure. It may require checking the present position of field equipments, comparing existing position to the required position, sending an electrical signal to a field device ordering it to change states, checking a set of switches ensure that the order was obeyed and sending message back to the MTU to confirm that the new condition has been reached.
4. Communication System: This is used to interlock MTUs and RTUs that are located away from the central control room. Commonly two ways of communication system are used – Optical Fiber, Or Electrical Cable (either owned by the company or leased from a telephone utility) and the other is Radio. A modem is used to modulate and demodulate a signal that is received.


MODEM
MODEM
RTU #1
RTU #2
OPERATOR I/O
MODEM
OPERATOR
MODEM
RADIO
MTU
RADIO
RADIO
MODEM
MODEM
RTU #3
RTU #4

Q3.a) Imbalance in real power flow: **(½ marks for each point)**

- Majority of consumers demand more real power than reactive power. Only few consumers demand reactive power such as induction furnaces, welding transformers etc. Some electrical apparatus require reactive power to set up magnetic field for its operation.
- Practically the load on the power system is measured and expressed in-terms of real power i.e. MW.
- 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…

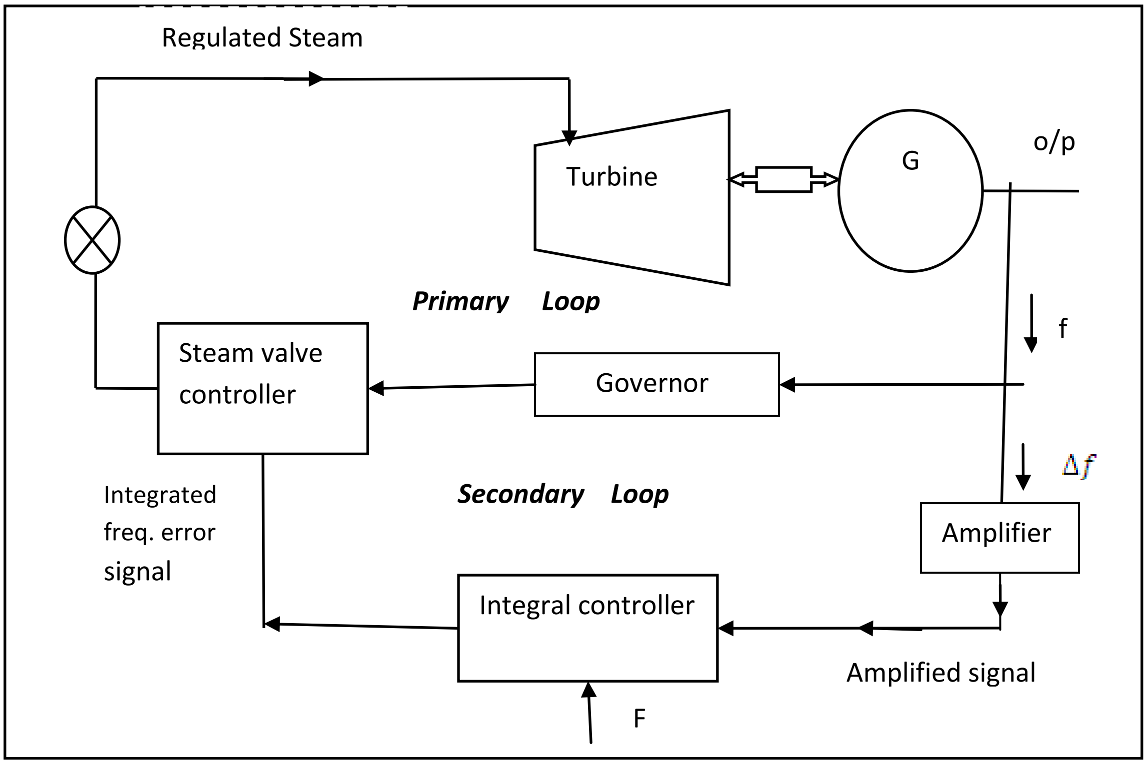
Real power generated = Real power demanded by load + Real power lost in the system

$$P_g = P_d + P_L$$

- As electricity cannot be stored, this equation should be satisfied for balanced operation and stability of the system. If above 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 generator run synchronously and generate together the power that at each moment is being drawn by all load plus the real transmission losses
- If there is sudden drop or rise in load demand or fault occurred or failure of generator then unbalanced 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.
- Thus imbalance in real power flow can be sensed at any point in the power system.

Q3.b) **(Primary loop -2marks: secondary loop -2marks)**

Automatic frequency control system



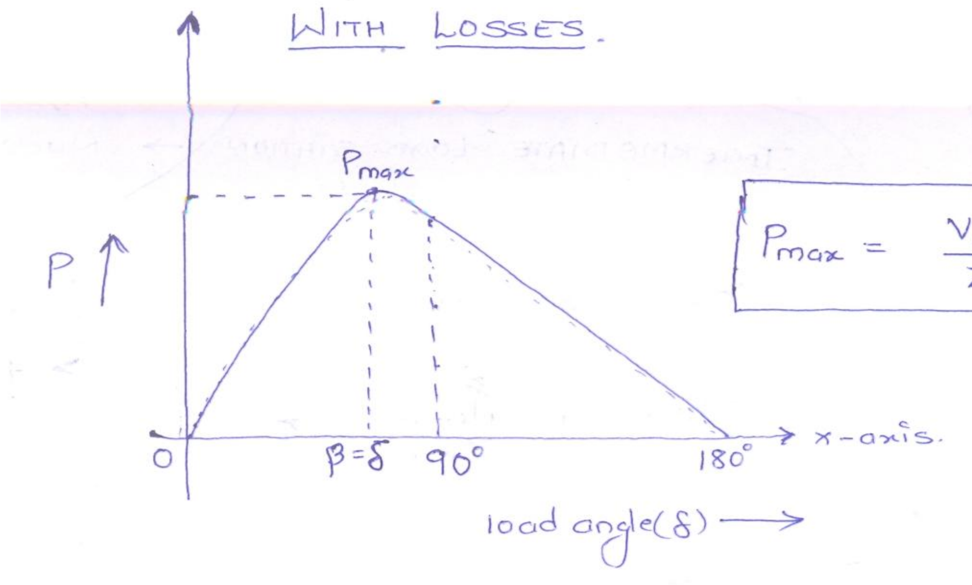
Q3.c) (Any four points -1 mark for each)

Data obtained from the load flow studies is as follows -

(1) We get MW and MVAR flow in the various parts of the system network.
(2) We get information about voltages at various buses in the system.
(3) We get information about optional load distribution.
(4) Impact of any change in generation (increase or decrease) on the system.
(5) Influence of any modification or extension of the existing circuits on the system loading.
(6) It also gives information for choice of appropriate rating and tap-setting of the power transformer in the system.
(7) Influence of any change in conductor size and system voltage level on power flow.

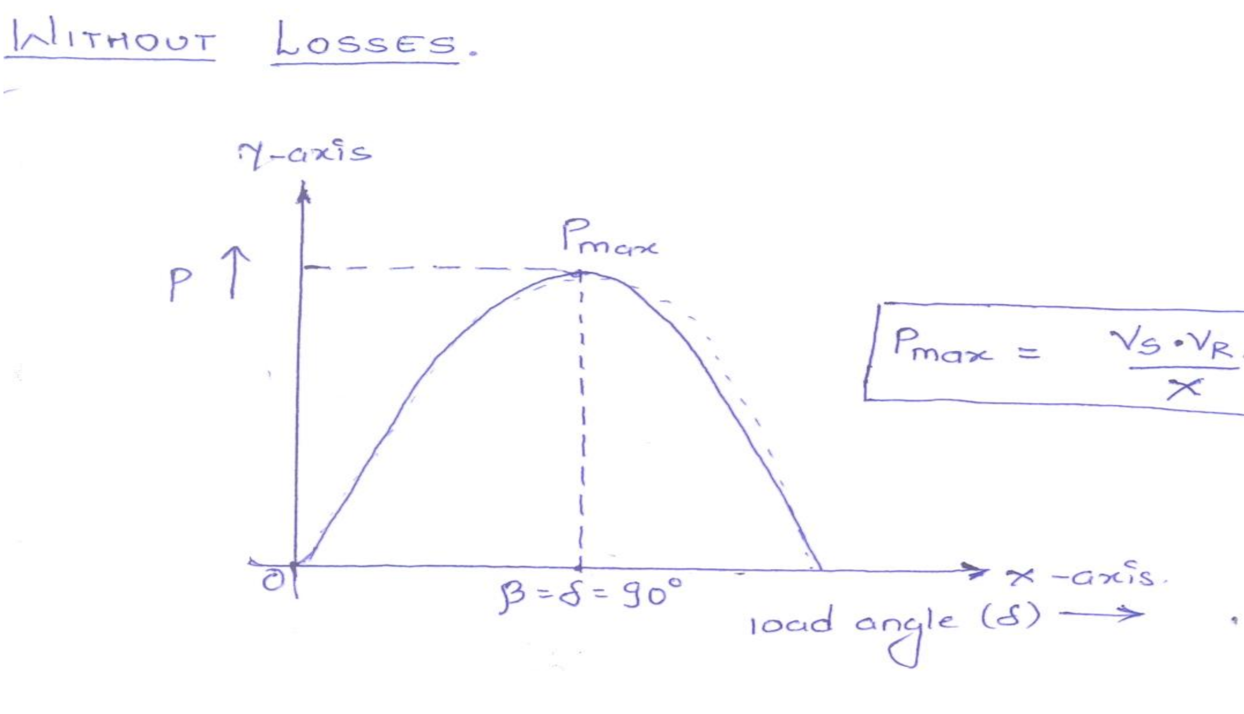
Q.3d) Power angle diagram: **(1½ Mark for each Diag. and ½ Mark for each equation)**

i. Considering losses in the system:



$$P_{max} = \frac{V_R^2}{Z}\left(\frac{V_S}{V_R}\cdot Z - R\right)$$

ii. Neglecting losses in System



$$P_{max} = \frac{V_S \cdot V_R}{X}$$

Q.3e) **(any four points , 1mark for each)**

Need of inter connection of power system network:

The connection of several generating stations in parallel is known as **interconnected grid system.**

Several Advantages

(*i*) *Exchange of peak loads* : An important advantage of interconnected system is that the peak load of the power station can be exchanged. If the load curve of a power station shows a peak demand that is greater than the rated capacity of the plant, then the excess load can be shared by other stations interconnected with it.

(*ii*) *Use of older plants* *:* The interconnected system makes it possible to use the older and less efficient plants to carry peak loads of short durations. Although such plants may be inadequate when used alone, yet they have sufficient capacity to carry short peaks of loads when interconnected with other modern plants. Therefore, interconnected system gives a direct key to the use of obsolete plants.

(*iii*) *Ensures economical operation* *:* The interconnected system makes the operation of concerned power stations quite economical. It is because sharing of load among the stations is arranged in such a way that more efficient stations work continuously throughout the year at a high load factor and the less efficient plants work for peak load hours only.

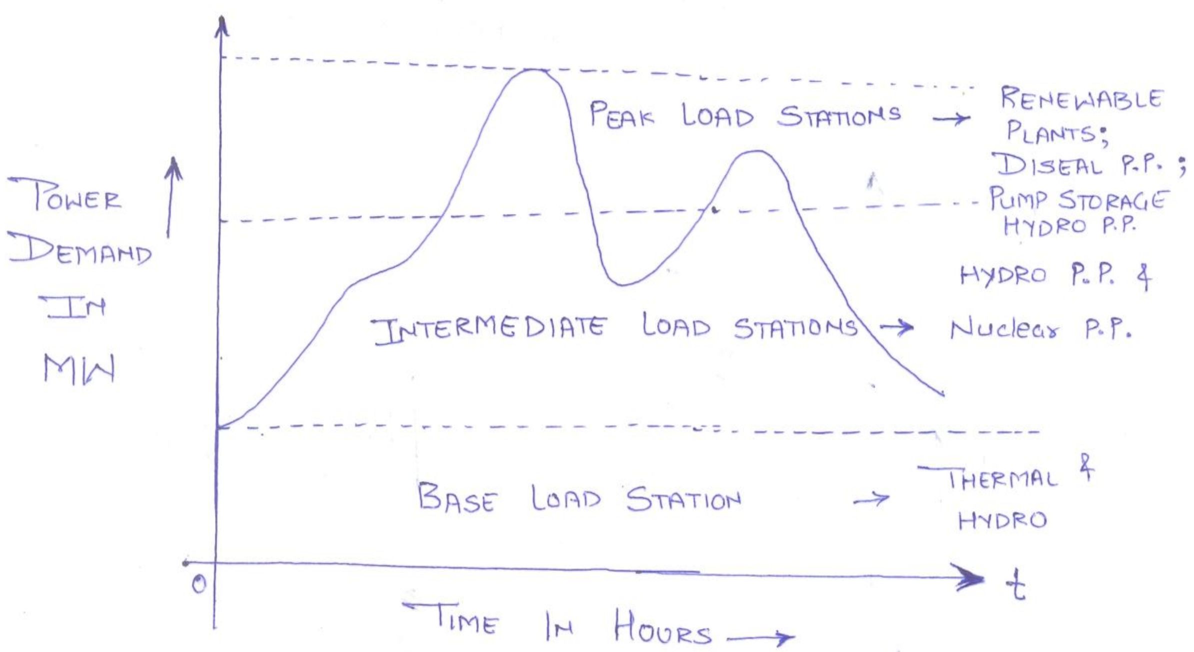
(*iv*) *Increases diversity factor* *:* The load curves of different interconnected stations are generally different. The result is that the maximum demand on the system is much reduced as compared to the sum of individual maximum demands on different stations. In other words, the diversity factor of the system is improved, thereby increasing the effective capacity of the system.

(*v*) *Reduces plant reserve capacity* : Every power station is required to have a standby unit for emergencies. However, when several power stations are connected in parallel, the reserve capacity of the system is much reduced. This increases the efficiency of the system.

(*vi*) *Increases reliability of supply* : The interconnected system increases the reliability of supply. If a major breakdown occurs in one station, continuity of supply can be maintained by other healthy stations.

Q..3 –f) **(Any four points , 1mark for each)**

Significance of Generation mix:

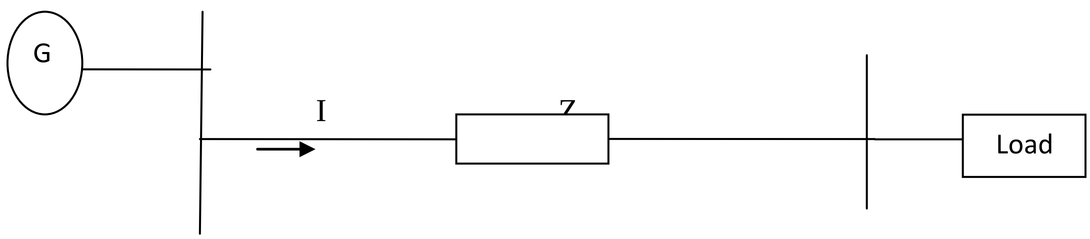


- In modern power system the demand on the system is continuously varying and in order to meet this demand 4the generating stations various their output continuously. The above load curve shows the variation in load demand for 24hrs. This curve changes for a week, a month and for a year.
- To meet the power demand, power is generated at different generating stations using conventional fuels as well as non-conventional fuels. Each generating station has more than one generating unit (main unit & auxiliary unit).
- So to have a economical & optimum power generation new technique is used i.e. ‘Generation Mix’. In this method to meet the power demand the load on the system is divided among different generating stations and different generating units, considering their incremental fuel cost for generation of power. So, the cost of power generation at any moment is same even the fuel input is varied.
- The best generation mix for any country or any nation consist of economical power generation which can control the load curve with adequate security and reliability. The pattern for generation in each country depends on resources available and other constraints like public acceptance and available investment.

- In Indian power generation scenario, power is generated at most of the time using Hydro and Thermal power stations and during peak loads, power is generated by using non-conventional resources.
- The power generation scheme should be decided by following the load curve throughout the day, week and year.

Q.NO.4 –A) Relation between reactive power flow and voltage level:

Consider a simple two bus system represented by a single line diagram as ..



Bus 1 Bus 2 1 Mark

Let $V_1 < \delta_1$ - be the voltage at bus-1 and $V_2 < \delta_2$ - be the voltage at bus-2

$S_1 = V_1 I_1$ $S_2 = V_2 I_2$

S_1= complex power that flows from bus 1 to bus 2 $= V_1 I_1 * = \left[\frac{V_1 < -\delta 1 - V_2 < -\delta 2}{-j X}\right]$

$= \frac{V_1 V_2 \sin\delta}{X} + j\left(\frac{V_1{}^2 - V_1 V_2 \cos\delta}{X}\right)$ = $P_1 + jQ_1$ ½ Mark

$\therefore Q_1 = \frac{V_1{}^2 - V_2 I_2 \cos\delta}{X}$..............(1)

S_2 = Complex power that flows from by bus 2 to bus 1

$= (V_2 I_2) * = V_2 < \delta_2 \left[\frac{[V_2 < -\delta_2 - V_1 < -\delta_1]}{-j X}\right]$ ½ Mark

$= \frac{V_2 V_1 \sin\delta}{X} + \left(\frac{(V_2 V_1 \cos\delta - V_2{}^2)}{X}\right)$

$= P_2 + Q_2$

$\therefore Q_2 = \frac{V_2 V_1 \cos\delta - V_2^{\ 2}}{X}$..................(2) ½ Mark

To maintain the stability of system the angle δ is maintained at lower value. For small value of δ, the value of cos $\delta \approx 1$

Rewriting the equations (1) & (2)

$Q_1 = \frac{V_1^{\ 2} - V_2 V_1}{X} = \frac{V_1 (V_1 - V_2)}{X}$ $Q2 = \frac{V_2 V_1 - V2^2}{X} = \frac{(V_1 - V_2) V_2}{X}$ ½ Mark

This shows that the reactive power depends on voltage drop.i.e. Q$\propto V_1 - V_2$

∴ As reactive power flow increases the voltage drop across the line also increases. Reactive power flow through the system depends on voltage level at buses but independent of δ i.e. frequency. 1Mark

Q.NO.4 –B) **(Any four points – 1 mark for each)**

❖ **IMPORTANT ASPECTS OF LOAD FLOW ANALYSIS**

(1) The total amount of real power flow thro' the network generates at generating stations whose size and location are fixed. At each moment power generation must be equal to power demand as electrical power can not be stored. Hence the load on the system has to be divided between no. of generators in a unique ratio in order to achieve optimum economic power generation. Hence the generator output must be closely maintained at predetermined set closely maintained at predetermined set points. It is important to remember that the power demand under goes slow but wide variation throughout the 24 hrs. of the day. Therefore we must change these set points slowly or continuously or in discrete step as the hours wear on. This means that load flow configuration that fits the demand of a certain hr. of the day may look quite different next hour.

(2) Transmission lines can carry only certain amount of current and we must make sure that we do not operate these links too close to their stability or thermal limits. Load flow analysis help to know the amount current flowing thro' various lines in the network.

(3) Due to flow of reactive power voltage profile of certain buses changes. It is necessary to keep the voltage levels of these buses within close tolerances. This can be achieved by proper scheduling of reactive power flow and that can be studied by load flow analysis.

(4) To meet power demand it is necessary to inter connect the networks through tie lines. Then both networks must fulfill certain contractual power scheduling commitments via its tie lines to neighboring system. Hence power flow through tie lines can be monitored with the help of load flow solution.

(5) The disturbances in network leads to a massive network fault and sometime it can cause system outages. The effect of system outage can be minimized by proper pre-fault power flow strategies. These strategies can be decided based of on load flow analysis.

(6) Load flow analysis is very important in the planning stages of new system networks or additions to existing ones.

Q.NO.4 –c) **(1 mark for each type & 1mark for example of each)**

BUS CLASSIFICATION:

In a power system each bus or node is associated with four quantities magnitude of voltage

- P, Q, V and its phase angle ‘δ’,

In load flow studies two out of four quantities are specified and remaining two are required to be obtained thro load flow solutions. Depending upon which quantities have been specified, the buses are classified as follows.

<u>I Load Bus</u>: - At this bus power is injected or delivered to load. Hence real & reactive component of power is specified. At this bus voltage is allowed to vary within the permissible limit and phase angle ‘δ’ is not important from consumers point of view. This is also called as PQ bus. Power ejected from bus is considered as – ve

<u>II Generator bus</u>: - At this bus power generated is injected into the system. Hence the magnitude of voltage corresponding to its rating are specified from load flow solution and it is required to find out Q & S.This is also called as PV bus

<u>III Slack Or Swing Or Reference Bus</u> : - In power system power is injected by generator bus and power is delivered or ejected at Load bus. So whatever losses takes place in the system remains unknown, until the load flow solution is complete. Hence one of the generator bus is made to take additional real and reactive power to supply transmission losses. This bus is known as **Slack Or Reference Bus.** As the power demand varies, variation in real power flow and reactive power flow results into variation in load angle (frequency) and bus voltage profiles. Hence it is also called as **Swing bus.**

At this bus the magnitude of bus voltage and phase angle are specified while P & Q are obtained through the load flow solution.

Type Of Bus	Specified quantities specification	Quantities Obtained Unknown Quantities
Load bus	P,Q	V, δ
Generator bus	P, V	Q, δ
Slack bus	V, δ	P,Q

Q.NO.4 –d) (def. or technical meaning -1mark & 1 mark for each factor –any three)

Definition of **load shedding**: Load shedding is an intentionally-engineered electrical power outage.

A **rolling blackout**, also referred to as **load shedding**, is an intentionally-engineered electrical power outage. Rolling blackouts are a last resort measure used by an electricity utility company in order to avoid a total blackout of the power system. They are usually in response to a situation where the demand for electricity exceeds the power supply capability of the network. Rolling blackouts may be localized to a specific part of the electricity network or may be more widespread and affect entire countries and continents. Rolling blackouts generally result from two causes: insufficient generation capacity or inadequate transmission infrastructure to deliver sufficient power to the area where it is needed.

- **Load shedding governing factors:**

1. The imbalance between power demand and power generation due insufficient resources. To reduce effect of imbalance intentionally supply to some load are cut off.
2. 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.
3. Due to major faults like three phase short circuit fault, line to ground fault, failure of switch gears or major equipment’s instability condition occurs in the system. To reduce effect of instability load shedding is carried out.

4. To reduce wastage of energy and to adopt energy conservation techniques supply to selective loads (mostly lighting loads) are shut off.
5. 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.
6. 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.
7. 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.
8. To share power, the UPS switches off selected devices to increase run time of critical loads.
9. 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 core.

Q.NO.4 –e) Importance of load forecasting in power generation: (1 Mark for each. Any 4)

- Due to advancement in technology demand for electricity tends to grow more rapidly due to population growth, growth per capita income, migration to urban areas and increase in energy using products. So power system planning has to be done which starts with load forecasting.
- Load forecasting includes future demands and energy. Demands forecast are used to determine the capacity of generation, transmission and distribution system. An energy forecast is used to determine the type of generation required.
- Load forecasting is very crucial activity in supply system. It is required for operation, planning and control in following time frame.
  - Exploration of natural fuel and water resources
  - Planning of generation, transmission, distribution equipments.
  - Development of trained human
  - Establishment of future fuel power requirements.
  - Deciding tariff structure for billing of different consumers
  - Annual planning and budgeting for fuel requirement.
  - Scheduling of capital Plant.

- Maintenance schedule
- Short term forecast like optimization of fuel stock, load management, and system securities

  Thus load forecasting in power generation helps to generate optimum and economical power and can be transmitted more economically to the consumers.

f) Optimum Operation of Power System: **(1 Mark for each point)**

A business is said to be successful when a return or profit is obtain on capital investment. Similarly the power utilities also decide about the profit on capital invested in the system and that profit can be obtained by optimum and economical operation of system.

The tariff structure of power is decided by regulatory bodies and hence the efficient operation of system and conservation of fuel are only the ways to achieve maximum profit or max return. If the system is operated with maximum efficiency, the cost of power to the consumer and cost of power deliver reduces even though there in cost of fuel or rise in cost of labour or cost of maintenance.

Optimum operation of power system involves two techniques:-

1. The one deals with economy in power generation
2. Optimum operation deals with economy in power transmission or delivery.
3. The operation economy which deals with cost of power generations is called as economic dispatch. This economic dispatch focuses on co-ordination between generating units which are connected to grid system and overall cost of power generation to meet the demand.
4. The operational economy deals with power delivery with minimum losses to the loads. This minimum loss delivery focuses on control of power flow through grid network and cost of power delivered.

Considering these two techniques the problem in power system can be solved by optimum power flow strategy.

NOTE: Any additional point related to the answer should also be considered

Q.5.a) **(2 mark for each constraints)**

Constraints of SLFE

(1) **Generator Constraints** - Active power generated by generators are restricted to lie within the min. & max. Limits. For example in steam turbine plants, boiler operation condition lays the max. & min. Limitation for power generation.

$$P_{G\,min} < P_G < P_{G\,max}$$

Similarly the reactive power limits of the generator also lie within max. & min limits. Usually at generating stations voltage is controlled by exaltation control method. I.e. by varying amount of reactive power produced by generators but the reactive power generated is function of generator design. Hence manufacturer gives max. and min. Power generation limits on the rating plate of generator.

$$Q_{g\,min} < Q_g < Q_{g\,max}.$$

(2) **Bus Constraints -** In order to satisfy statutory legal requirements and design limitations the bus voltage magnitude is restricted to limits. It is expressed as

$$IV_i I_{min} < IV_i I < IV_i I_{max}. \quad : \quad i = 1, 2, \text{---}\ n - \text{no. of buses}$$

(3) **In – Phase Tap Transformer Constraints -** on many power systems the transformer are provided with taps that can be changed under load, taps of automatic tap changing transformer must also lie within the range. The tap limits are expressed as

$$A_{t\,min}. < A_t < A_{t\,max.} \qquad t = 1, 2, 3 \text{---}\ \text{no. of transformers}$$

OR

Phase – Shifting Transformer Constraints - The angular position of phase shifters must not be allowed outside a given range. The constraints may be expressed as

$Q_{s\,min}. < Q_s < Q_{s\,max.}$ Where Q_s – angular position of phase shifter.

(4) **Transmission Line Constraints -** limits on the power transfer through the lines must be within the limits. The constraints may be expressed as

$S_m < S_m max.$ Where S_m- MVA capacity of the line m - 1,2,3,---no. of line.

Limits on the transfer of power through tr. Lines can also be achieved by the angular displacement between the bus bars concerned. Thus for a transmission line between buses i and j we have the constraints

$$I\ \delta_i - \delta_j\ I < I\ \delta_i - \delta_j\ I\ max$$

In addition to the above limits network security limits might be superimposed. These are unplanned circuit outages and thus cause violations of the limits. The type of limits imposed would depend on the degree of intended circuit security. (Thus we arrive at, that in the course of solving a particular load flow problem; these limiting values should not be violated.) That means after solving a particular load flow problem, we should follow security limits. Provisions must be made in solution procedures for efficiently leading with these constraints.

Q.5.b) (Causes of steady state stability---2 marks causes of Transient state stability---2 marks)

(Def. of Steady state stability limit ---2 marks Def. of Transient state stability limit –2 marks)

- **Causes Steady state stability:-**

The power system is said to be steady state stable for a particular steady state operating condition if, following a small disturbance it returns to its essentially the same steady state operating conditions.

Small Disturbance:-

- Change in load conditions: - if there is any small change in demand of power from consumer and if this change is changing gradually then it causes unbalance in steady state operation of the system.
- Due to improper tap settings of transformers, Automatic voltage regulators, exciters
- Small variation in one or more system parameters such as voltage, current, load angle, power factor at any point in the system network.
- Operation of circuit breakers due to Temporary faults as short circuiting by birds and lightening surges.

Def. of Steady state stability limit: The steady state stability limit is the maximum possible flow of power, without loss of stability, when the power is changed slowly.

- **Causes of Transient state stability:-**

Transient state stability is the ability of the system to return to its normal operating condition of same equilibrium or new equilibrium position after experiencing sudden and large disturbance in the network.

Large disturbance means

- occurrence of major faults such as L-L, L-L-G, faults
- sudden increase in large amount of power demand
- faults following isolation of circuits / system
- Failure of major components of power system (Generators, transformer, transmission lines, circuit breakers etc).
- Switching off or ON of major transmission and distribution lines
- Transients and harmonics

Def. of Transient state stability limit

It is refer to maximum possible flow of power through a point without loss of stability when a large sudden disturbance occurs.

Q.5.c) (any 8 points similar to following points can be considered ---- 1 mark for each point)

Functions of state Load dispatch centre

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 ay 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 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.

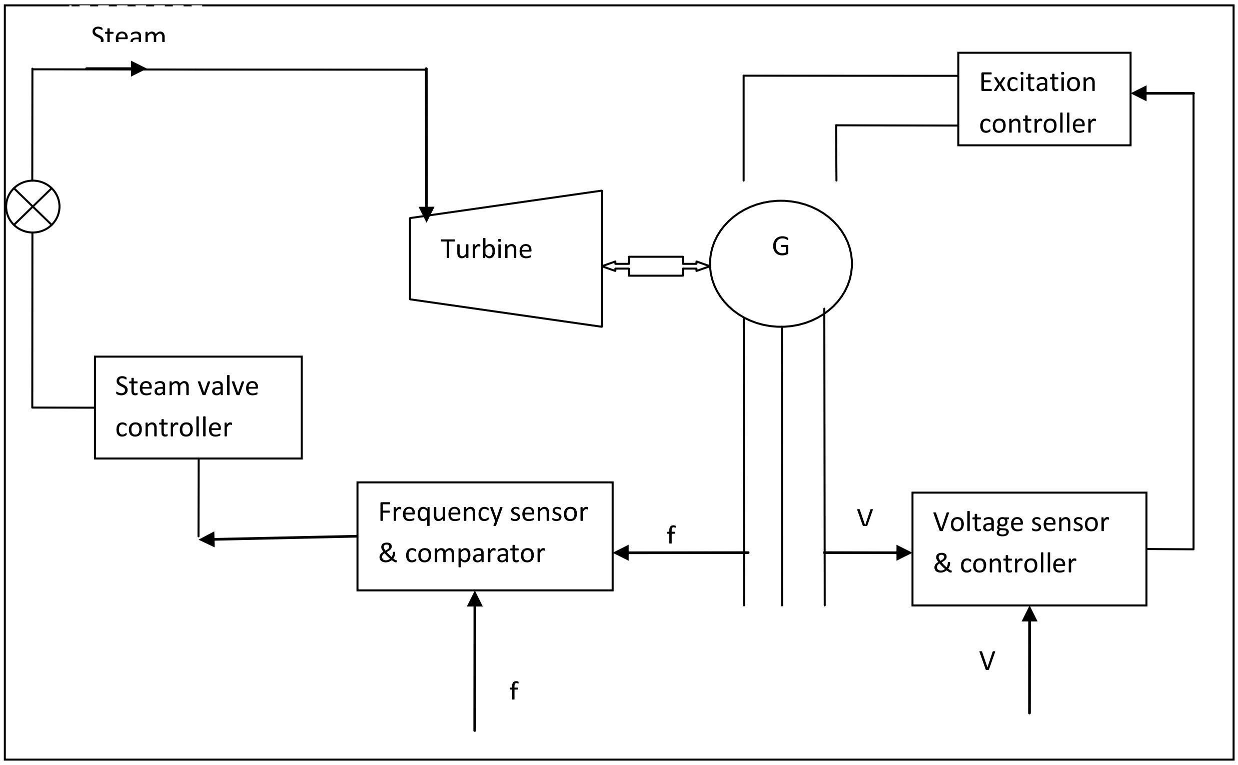
7. The State Load Dispatch Centre may collect such fee and charges from the generating companies and licensees engaged in intra-State transmission of electricity as may be specified by the State Commission.

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.

Q.6.a) **(2 marks for labeled diagram & 2 marks for explanation)**

Automatic Excitation system



- Power demand is never steady and it is continually changing with rising or falling trend, Therefore steam input to turbo-generators or water input to hydro generator must be continuously regulated to match the active power demand. If it fails to meet the demand. Then difference the active power is reflected in variation of generator speed which results in variation in frequency and this is undesirable. Max permissible variation in frequency is ±0.5 Hz
- Also to meet the reactive power demand with reactive power generation, excitation of generators must be continuously regulated. If it fails then voltages at various system buses may vary beyond the prescribed limit
- In modern power system, automatic generation OR voltage regulation equipment is installed in each generating stations. In this system, controllers are set for a particular operating condition and they take care of small changes in load demand without frequency and voltage exceeding the prescribed limits. For large variation in demand, the controllers must be reset manually or automatically.
- Variation in real power is reflected/depend on internal machine angle or load angle ‘δ’ and is independent of bus voltage where as bus voltage depends on machine excitation and is of load angle ‘δ’.
- Momentary variation in δ is caused by momentary variation in generator speed. Therefore, load frequency and excitation voltage controls are non-interactive for small changes and can be modeled and analyzed independently. Excitation control is fast acting and depends on generator field whereas power frequency control

is slow acting and depends on generator and turbines moment of inertia. Hence transient in excitation voltage control vanish, much faster than and do not affect the dynamics of power frequency controller.

Q.6.b) (what is RPC -2 marks and equipments & field of application -any 2 -1 mark each)

Reactive power compensation

Generators generate real power as well as reactive power. Real and reactive power is transmitted at the same time from generating station to load centers. Since electrical power cannot be stored, it has to be consumed at same time when it is generated so at every moment power generated should be equal to power demanded. In order to maintain the voltages at their prescribed values at all times, it is necessary to maintain the balance of reactive power in the system. That means the reactive power generated should be exactly equal to reactive power absorbed. Any mismatch in the reactive power balance affects the bus voltage magnitudes without much affecting the system frequency.

Practically it is difficult to maintain the reactive power balance as demand is continuously varying, hence an unbalance always exits between the supply and demand conditions of reactive power which results in voltage levels at certain buses. To overcome this problem, the reactive power can be locally generated near the load centers and can be fed to the consumers. This method of generating reactive power locally instead of generating at generating stations and meeting the consumers demand is called “Reactive Power Compensation”.

The equipments used for this are called reactive power compensating equipments. These equipments are classified as,

1. Shunt compensation
    - Shunt reactors
    - Shunt capacitors
    - Static VAR system (SVS)

2. Synchronous compensation
    - Synchronous phase modifiers

3. Series compensation
    - Series capacitors

Application of compensation equipments:-

- Shunt reactors:-
  - Under light load condition there causes Ferranti effect on EHV and UHV lines, so shunt reactors are used to compensate capacitive VAR of the line and to regulate the voltage within the prescribed limits.
  - Shunt reactors are also installed on EHV and UHV lines at an interval of 300KM in intermediate sub stations, receiving end sub-stations and sending end sub-stations to limit the voltage levels.
  - They are also located at tertiary windings of power transformer.

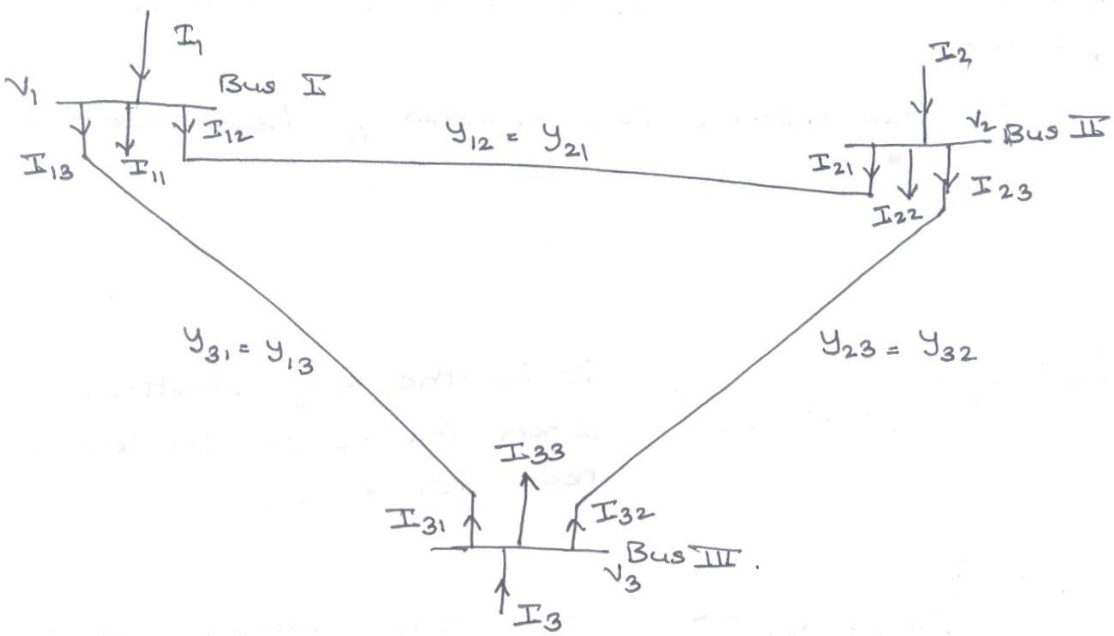
- Shunt Capacitors:-
  - Near the load terminals in receiving end sub-station, distribution sub-station and in switching sub-station.
  - In transmission lines they are connected either to the tertiary winding of the power transformer or to the bus bar
- **Static VAR system:-**
  - For continuous supply of controlled leading / lagging vars independently**.**
- **Synchronous phase modifier:-**
  - They are connected in parallel with the loads at the receiving end of the transmission system.

- **Series compensation:-**
  - The series compensators may be located at the sending end or receiving end or at the centre of the line. They are distributed at two or more no. of points along the line.

Q.6.c)

Single line diagram of 3-bus System.

Q.6.C.



From above figure we get,

$$Y_{Bus} = \begin{vmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{vmatrix} \Rightarrow \text{is called as admittance matrix.}$$

Where,

$$Y_{11} = y_{11} + y_{12} + y_{13} \quad \&$$
$$Y_{22} = y_{21} + y_{22} + y_{23} \quad \&$$
$$Y_{33} = y_{31} + y_{32} + y_{33}.$$

Also,

$$Y_{12} = Y_{21} = -y_{12} = -y_{21} \quad \&$$
$$Y_{13} = Y_{31} = -y_{13} = -y_{31} \quad \&$$
$$Y_{23} = Y_{32} = -y_{23} = -y_{32}.$$

where
y_{11} = line changing admittance of bus I
y_{22}, y_{33} are line changing admittances of bus II & III resply
$y_{12} = y_{21}$ – line admittance connecting bus I & bus II
IIIly $y_{13} = y_{31}$
$y_{23} = y_{32}$

SIGNIFICANCE :-

1) Diagonal elements are self admittance & off-diagonal elements are transfer admittance.

2) Y_{BUS} is $n \times n$ matrix where $n \to$ no. of buses

3) Y_{BUS} symetric matrix, if the regulating xmer are not involved, $Y_{ik} = Y_{ki}$ for $k \neq i$.

4) $Y_{ik} = 0$ if i^{th} & k^{th} buses are not connected.

In power network each bus is connected only to a few other buses (2 or 3). Hence in Y_{BUS} of large network has large no. of zero elements.

5) $Z_{BUS} = Y_{BUS}^{-1}$. Diagonal Elements are short ckt. driving point impedences & OFF-diagonal Elements are short circuit transfer admittance.

6). Z_{Bus} is full matrix. Zero Elements of Y_{Bus} becomes non-zero Elements.

Definations ⇒

$Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2 = V_3 = 0}$ → it is the self admittance of Bus-1 when Bus-2 is shorted to reference node i.e. $V_2 = 0$.

$Y_{12} = \left.\frac{I_1}{V_2}\right|_{V_1 = V_3 = 0}$ → it is the mutual admittance by injecting current I_2 in Bus 2 & shorting bus 1 to reference bus. Since I_1 is Zero & I_2 that flows in opposite direction of I_1, so this admittance is considered with negative sign.

$Y_{13} = \left.\frac{I_1}{V_3}\right|_{V_1 = V_2 = 0}$ → mutual admittance.

[matrix with labelling of parameter & diagram (optional) } – 1 marks
Definations – 1 mark.]

Significance – any Four – 2 marks.

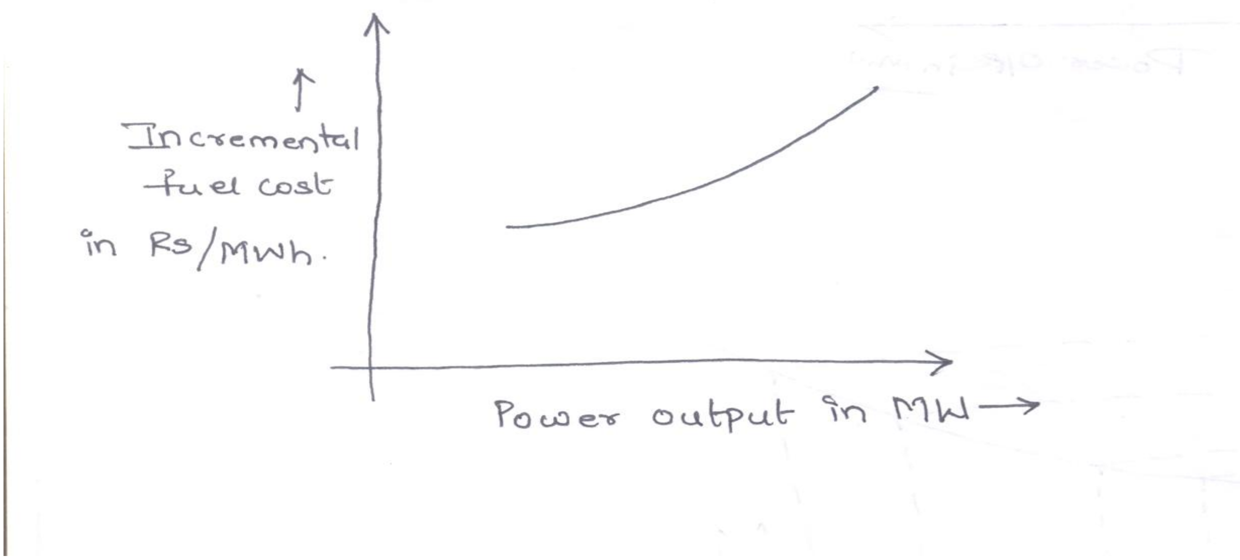
Q.6.d) Incremental fuel cost curve **(2 marks for diagram & 2 marks for explanation)**

Incremental fuel rate is defined as the ratio of small changes in fuel input to the corresponding change in the power output. Incremental fuel rate = $\frac{dF}{dP}$ …….Kcal/MWH

Incremental fuel cost = incremental fuel rate * fuel cost

$= \frac{Kcal}{MWH} * \frac{Rs}{Kcal}$……………Rs/MWH

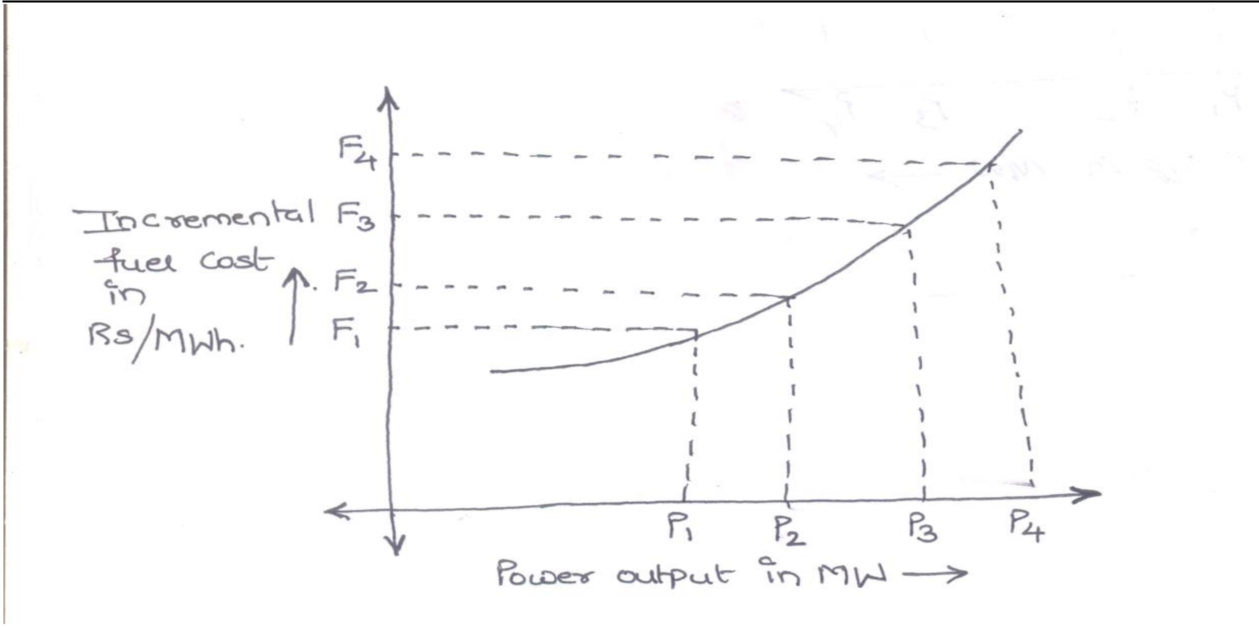
Incremental fuel cost curve can be drawn as



Incremental production cost of the energy = incremental fuel cost + incremental labour cost + incremental maintenance cost + incremental auxiliary fuel (water) cost + ……

These costs are very difficult to express as function of power output and also they are very small compared to fuel cost. Hence incremental fuel cost is approximately equal to incremental production cost.

Incremental fuel cost curve can be also shown as,



The graph shows that, for lower range of power output, variation in incremental fuel cost curve is less. Where as in higher range of power output the variation in incremental fuel cost is considerable for corresponding variation in power output.

Q. 6 e) ***NOTE: In this question the data is incomplete and what should be calculated and by which method is also not mentioned.***

Q. 6 f)

Soln:

Bus.	Z in p.u.	Y in p.u. ($Y = 1/Z$).	Bus Code	Line charging admittance in p.u.
1 – 2	0.075+j0.23	$y_{12} = y_{21}$ 1.281 – j3.93	1	y_{11} = j0.01
1 – 3	0.03+j0.06	$y_{13} = y_{31}$ 6.667 – j13.33	2	y_{22} = j0.02
2 – 3	0.06+j0.18	$y_{23} = y_{32}$ 1.667 – j5	3	y_{33} = j0.00

∴ Calculating 'Y_{mm}' (self admittance) of the buses.

∴ $Y_{11} = y_{11} + y_{12} + y_{13}$

$= (j0.01) + (1.281 - j3.93) + (6.667 - j13.33)$

∴ $\boxed{Y_{11} = 7.948 - j17.25\ \mho}$ —— (1)

∴ $Y_{22} = y_{21} + y_{22} + y_{23}$

$= (1.218 - j3.93) + (j0.02) + (1.667 - j5)$

∴ $\boxed{Y_{22} = 2.948 - j8.91\ \mho}$ —— (2)

∴ $Y_{33} = y_{31} + y_{32} + y_{33}$

$= (6.667 - j13.33) + (1.667 - j5) + (j0.00)$

∴ $\boxed{Y_{33} = 8.334 - j18.33\ \mho}$ —— (3)

Equations – 1 mark.
&
Calculations ½ mark

Now, calculating the 'Y_{mn}' (mutual admittance) of the buses,

∴ $Y_{12} = Y_{21} = -y_{12} = -y_{21}$; $Y_{13} = Y_{31} = -y_{13} = -y_{31}$;

$Y_{23} = Y_{32} = -y_{23} = -y_{32}$.

1 mark.

∴ $\boxed{Y_{12} = Y_{21} = -(1.281 - j3.93)\ \mho}$

∴ $\boxed{Y_{13} = Y_{31} = -(6.667 - j13.33)\ \mho}$

∴ $\boxed{Y_{23} = Y_{32} = -(1.667 - j5)\ \mho}$

—— (4)

1 mark.

Calculations
1/2 mark