KINGS

COLLEGE OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

QUESTION BANK

NAME OF THE SUBJECT: EE 1351 POWER SYSTEM ANALYSIS
YEAR / SEM : III / VI

UNIT – 1
THE POWER SYSTEM – AN OVER VIEW AND MODELLING
PART – A (2 MARKS)

1. What is single line diagram?
A Single line diagram is diagrammatic representation of power system in which the components are represented by their symbols and the interconnections between them are shown by a single straight line (even though the system is 3- phase system). The ratings and the impedances of the components are also marked on the single line diagram.

2. What are the components of power system?
The components of power system are Generators, power Transformers, Transmission lines, Substation Transformers, Distribution Transformers and Loads.

3. Define per unit value.
The per unit value of any quantity is defined as the ratio of the actual value of the quantity to the base value expressed as a decimal. The base value is an arbitrary chosen value of the quantity.

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

4. What is the need for base values?
The components or various sections of power system may operate at different voltage and power levels. It will be convenient for analysis of power system if the voltage power, current and impedance ratings of components of power system are expressed with reference to a common value called base value. Hence for analysis purpose a base value is chosen for voltage, power, current and impedance. Then all the voltage power, current

and impedance ratings of the components are expressed as a percent or per unit of the base value.

5. Write the equation for converting the p.u. impedance expressed in one base to another.

$$Z_{pu,new} = Z_{pu.old} \times \frac{KV_{b,old}^2}{KV_{b,new}^2} \times \left(\frac{MVA_{b,\,new}}{MVA_{b,\,old}} \right)$$

6. What are the advantages of per-unit computations?
   (i) Manufacturers usually specify the impedance of a device or machine in per unit on the base of the name plate rating.
   (ii) The p.u values of widely different rating machines lie within a narrow range, even though the ohmic values has a very large range.
   (iii) The p.u. impedance of circuit element connected by transformers expressed on a proper base will be same if it is referred to either side of a transformer.
   (iv) The p.u. impedance of a 3-phase transformer is independent of the type of winding connection (Y or Δ).

7. If the reactance in ohms is 15 ohms, find the p.u. value for a base of 15 KVA and 10 KV.

Solution:

$$\text{Base impedance, } Z_b = \frac{(kV)^2}{MVA} = \frac{(kV)^2}{KVA/1000} = \frac{10^2}{15/1000} = 6666.67\Omega$$

$$\text{p.u. value of reactance} = \frac{\text{Reactance in ohms}}{\text{Base impedance}} = \frac{15}{6666.67} = 0.0022\text{p.u.}$$

8. A generator rated at 30 MVA, 11 kV has a reactance of 20%. Calculate its p.u. Reactance's for a base of 50 MVA and 10kV.

Solution:

$$\text{New p.u. reactance if generator} = X_{pu,old} \times \left(\frac{kV_{b,old}}{kV_{b,\,new}} \right)^2 \times \frac{MVA_{b,\,new}}{MVA_{b,\,old}}$$

Here, $X_{pu,old}$ = 20% = 0.2 p.u. ; $kV_{b,old}$ = 11 kV, $MVA_{b,\,old}$ = 30 MVA

$kV_{b,new}$ = 10 kV ; $MVA_{b,\,new}$ = 50 MVA

$$\text{New p.u. reactance of generator} = 0.2 \times \left(\frac{11}{10}\right)^2 \times \frac{50}{30} = 0.403 \text{ p.u.}$$

9. What is impedance and reactance diagram?

The impedance diagram is the equivalent circuit of power system in which the various components of power system are represented by their approximate or simplified equivalent circuits. The impedance diagram is used for load flow studies. The reactance diagram is the simplified equivalent circuit of power system in which the various components are represented by their reactance. The reactance diagram can be obtained form impedance diagram if all the resistive components are neglected. The reactance diagram is used for fault calculations.

10. What are the factors that need to be omitted for an impedance diagram to reduce it to a reactance diagram?

(or)

What are the approximations made in reactance diagram?

The following approximations are made in reactance diagram.

1. The neutral reactances are neglected.
2. Shunt branches in the equivalent circuits of transformer are neglected
3. The resistances are neglected.
4. All static loads and induction motors are neglected.
5. The capacitances of the transmission lines are neglected.

11. What is a bus?

The meeting point of various components in a power system is called a bus. The bus is a conductor made of copper or aluminum having negligible resistance. The buses are considered as points of constant voltage in a power system.

12. What is bus admittance matrix?

The matrix consisting of the self and mutual admittances of the network of a power system is called bus admittance matrix. It is given by the admittance matrix Y in the node basis matrix equation of a power system and it is denoted as Y_{bus}. The bus admittance matrix is symmetrical.

13. What is bus impedance matrix?

The matrix consisting of driving point impedances and impedances of the network of a power system is called bus impedance matrix. It is given by the inverse of bus admittance matrix and it is denoted as Z_{bus}. The bus impedance matrix is symmetrical.

14. Write the four ways of adding an impedance to an existing system so as to modify bus impedance matrix.

To modify a bus impedance matrix, a branch of impedance Z_b can be added to original system in the following four different ways.

Case 1: Adding a branch of impedance Z_b from a new bus-p to the reference bus.
Case 2: Adding a branch of impedance Z_b from a new bus-p to the existing bus-q.
Case 3: Adding a branch of impedance Z_b from an existing bus-q to the reference bus.
Case 4: Adding a branch of impedance Z_b between two existing buses h and q.

15. How the Z_{bus} is modified when a branch of impedance Z_b is added from a new bus-p to the reference bus?

When a branch of impedance Z_b is added from a new bus-p to the reference bus, the order of the bus impedance matrix increases by one.

Let the original bus impedance matrix have an order of n and so the new bus impedance matrix have an order of (n+1). The first n x n sub matrix of new bus impedance matrix is the original bus impedance matrix. The elements of $(n+1)^{th}$ column and row are all zeros except the diagonal. The (n+1) diagonal element is the added branch impedance Z_b.

16. What are symmetrical components?

An unbalanced system of N related vectors can be resolved into N systems of balanced vectors. The N – sets of balanced vectors are called symmetrical components. Each set consists of N – vectors which are equal in length and having equal phase angles between adjacent vectors.

17. What are sequence impedance and sequence networks?

The sequence impedances are impedances offered by the devices or components for the like sequence component of the current .
The single phase equivalent circuit of a power system consisting of impedances to the current of any one sequence only is called sequence network.

PART - B

1. Draw the reactance diagram for the power system shown in Fig.1. Neglect resistance and use a base of 100 MVA, 220 kV in 50 Ω line. The ratings of the generator, motor and transformer are given below.

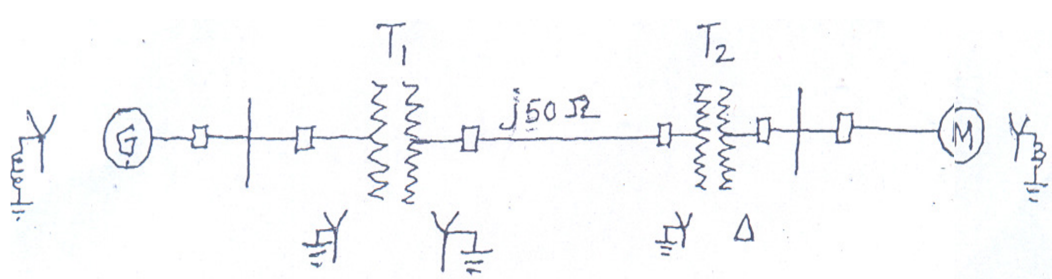

Fig. 1

Generator: 40 MVA, 25 kV, X" = 20%
Synchronous motor : 50 MVA, 11 kV, X" = 30%
Y – Y Transformer : 40 MVA, 33/220 kV, X = 15%

Y - Δ 30 MVA, 11/220 kV, (Δ/Y), X = 15%
(16)

2. Draw the structure of an electrical power system and describe the components of the system with typical values
(16)
3. Obtain the per unit impedance (reactance) diagram of the power system shown in Fig.3

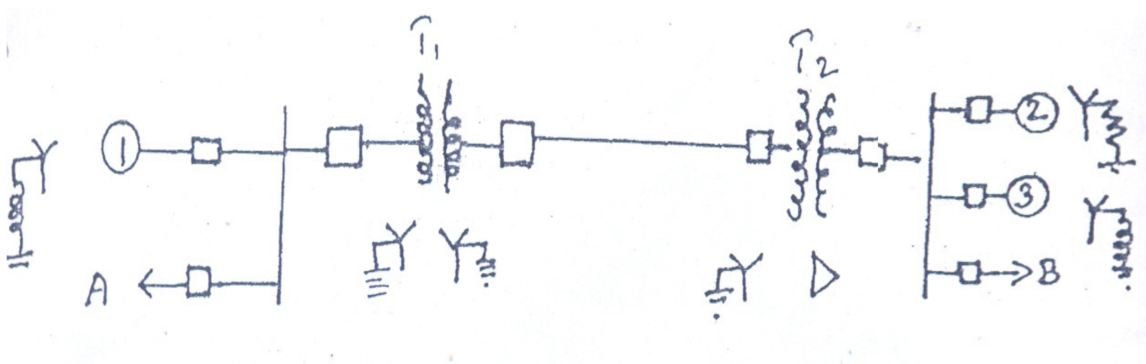

Fig. 3
One-line representation of a simple power system.

Generator No. 1: 30 MVA, 10.5 kV, X" = 1.6 Ohm
Generator No. 2: 15 MVA, 6.6 kV, X" = 1.2 Ohm
Generator No. 3: 25 MVA, 6.6 kV, X" = 0.56 Ohm
Transformer T_1 (3phase) : 15 MVA, 33/11 kV, X = 15.2 Ohm per phase on HT side
Transformer T_2 (3phase) : 15 MVA, 33/6.2 kV, X = 16 Ohm per phase on HT side
Transmission line : 20.5 Ohm/phase
Load A : 15 MW, 11kV, 0.9 p.f. lagging
Load B : 40 MW, 6.6 kV, 0.85 lagging p.f.
(16)

4. Explain the modeling of generator, load, transmission line and transformer for power flow, short circuit and stability studies.
(16)

5. Choosing a common base of 20 MVA, compute the per unit impedance (reactance) of the components of the power system shown in Fig.5 and draw the positive sequence impedance (reactance) diagram.

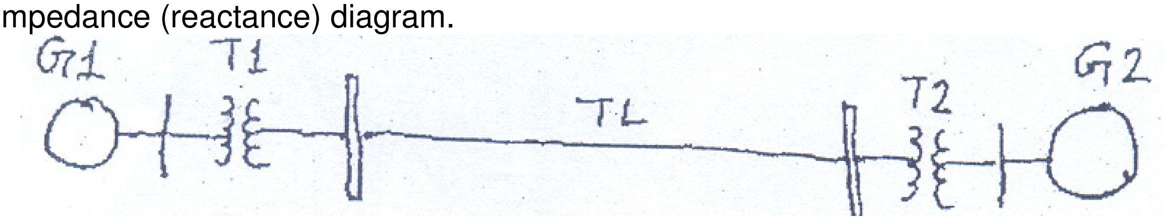

Fig. 5
Gen 1 : 20 MVA, 10.5 kV, X" = 1.4 Ohm
Gen 2 : 10 MVA, 6.6 kV, X" = 1.2 Ohm
Tr 1 : 10 MVA, 33/11 kV, X = 15.2 Ohm per phase on HT side

Tr 2 : 10 MVA, 33/6.2 kV, X = 16.0 Ohm per phase on HT side
Transmission line : 22.5 Ohms per phase
(16)

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6. (i) What are the step by step procedures to be followed to find the per-unit impedance diagram of a power system? (4)
   (ii) Draw the structure of an electrical power system and describe the components of the system with typical values. (12)
7. Write short notes on:
   (i) Single line diagram (5)
   (ii) Change of base. (5)
   (iii) Reactance of synchronous machines. (6)
8. A 120 MVA, 19.5 kV Generator has a synchronous reactance of 0.15 p.u and it is connected to a transmission line through a Transformer rated 150 MVA, 230/18 kV (star/delta) with X = 0.1 p.u.
   (i) Calculate the p.u reactance by taking generator rating as base values (5)
   (ii) Calculate the p.u reactance by taking transformer rating as base values. (5)
   (iii) Calculate the p.u reactance for a base value of 100 MVA and 220 kV on H.T side of transformer. (6)

UNIT – 2

POWER FLOW ANALYSIS
PART – A (2 MARKS)

1. What is power flow study or load flow study?

The study of various methods of solution to power system network is referred to as load flow study. The solution provides the voltages at various buses, power flowing in various lines and line-losses.

2. What are the works involved in a load flow study? or How a load flow study is performed?

The following work has to be performed for a load flow study.

(i) Representation of the system by single line diagrams.
(ii) Determining the impedance diagram using the information in single line diagram.

(iii) Formulation of network equations.
(iv) Solution of network equations.

3. List the quantities specified and the quantities to be determined to be determined from load flow study for various types of buses.

The following table shows the quantities specified and to be obtained for various types of buses.

Bus type	**Quantities specified**	**Quantities to be obtained**
Load bus	P,Q	$\lvert V \rvert$, δ
Generator bus	P, $\lvert V \rvert$	Q, δ
Slack bus	$\lvert V \rvert$, δ	P,Q

4. Define Voltage controlled bus.

A bus is called voltage controlled bus if the magnitude of voltage $\lvert V \rvert$ and real power (P) are specified for it. In a voltage controlled bus the magnitude of the voltage is not allowed to change. The other names for voltage controlled bus are generator bus and PV bus.

5. What is PQ-bus?

A bus is called PQ-bus or load bus when real and reactive components of power are specified for the bus. In a load bus the voltage is allowed to vary within permissible limits.

6. What is swing bus (or slack bus)?

A bus is called swing bus for (or slack bus) when the magnitude and phase for bus voltage are specified for it. The swing bus is the reference bus for load flow solution and it is required for accounting line losses. Usually one of the generator bus selected as the swing bus.

7. What is the need for slack bus?

The slack bus is needed to account for transmission line losses. In a power system the total power generated will be equal to sum of power consumed by loads and losses. In a power system only the generated power and load power are specified for buses. The slack bus is assumed to generate the power required for losses. Since the losses are unknown the real and reactive power are not specified for slack bus. They are estimated through the solution of load flow equations.

8. Write the expression for complex power injected to a bus.

The complex power injected to bus-p of a n-bus system is given by

$$S_p = P_p - jQ_p = V_p^* \sum^{n} Y_{pq} V_q$$

q=1

The complex power S_p is the difference between power injected by generators connected to the bus and power drawn by the loads connected to the bus. In a pure generators bus, only generators will be connected to the bus and so P_p and Q_p corresponds to power injected by generators. (In this case P_p and Q_p are positive). In a pure load bus, only loads will be connected to the bus and so P_p and Q_p corresponds to power drawn by loads (In this case P_p and Q_p are negative).

9. Write the load flow equation of Gauss and Gauss-Seidel method.

The load flow equation of Gauss method is given by equ (A).

$$V_p^{k+1} = \frac{1}{Y_{pp}} \left[\frac{P_p - jQ_p}{(V_p^{k})^*} - \sum_{\substack{q=1 \\ q \# p}}^{n} Y_{pq} V_q^{k} \right] \quad \text{....(A)}$$

The load flow equation of Gauss-Seidal method is given by equ (B)

$$V_p^{k+1} = \frac{1}{Y_{pp}} \left[\frac{P_p - jQ_p}{(V_p^{k})^*} - \sum_{q=1}^{p-1} Y_{pq} V_q^{k+1} - \sum_{q=p+1}^{n} Y_{pq} V_q \right] \quad \text{....(B)}$$

Where V_q^{k+1} and V_q^{k} = (k+1) and K^{th} iteration voltage of bus-p respectively.
V_q^{k+1} and V_q^{k} = (k+1) and K^{th} iteration voltage of bus-p respectively.

10. Write the load –flow equations of Newton-Raphson method.

The load flow equations of Newton – Raphson method are given below.

$$P_P = \sum_{q=1}^{n} \left[e_p(e_q G_{pq} + f_q B_{pq}) + f_p (f_q G_{pq} - e_q B_{pq}) \right]$$

$$Q_P = \sum_{q=1}^{n} \left[f_p(e_q G_{pq} + f_q B_{pq}) - e_p (f_q G_{pq} - e_q B_{pq}) \right]$$

$$|V|^2 = e^2_p + f^2_p$$

11. Discuss the effect of acceleration factor in the load flow solution algorithm. How will you account for voltage controlled buses in this algorithm?

In load flow solution by iterative methods, the number of iterations can be reduced if the correction voltage at each bus is multiplied by some constant. The multiplication of the constant will increase the amount of correction to bring the voltage closer to the value it is approaching. The multipliers that accomplish this improved convergence are called acceleration factors. An acceleration factor of 1.6 is normally used in load flow problems. Studies may be made to determine the best choice for a particular system.

The acceleration factor is a real quantity and it modifies the magnitude of voltage alone. Since in voltage controlled bus (generator bus), the magnitude of bus voltage is not allowed to change, the acceleration factor is not used for voltage controlled bus. (i.e acceleration factor is used only for load bus)

12. Why do we go for iterative methods to solve flow problems?

The load (or power) flow equations are nonlinear equations and so explicit solution is not possible. The solution of nonlinear equations can be obtained only by iterative numerical techniques.

13. What will be the reactive power and bus voltage when the generator bus is treated as load bus?

When the generator bus is treated as load bus the reactive power of the bus is equated to the limit it has violated, and the previous iteration value of bus voltage is used for calculating current iteration value.

14. Compare the G-S and N-R methods of load flow solutions.

G-S method	N-R method
1. Variable is expressed in rectangular coordinates.	Variables are expressed in polar coordinates.
2. Computation time per iteration is less.	Computation time per iteration is more
3. It has linear convergence characteristics.	It has quadratic convergence characteristics.
4. The number of iterations required for convergence increases with size of the system.	The numbers of iterations are independent of the size of the system.
5. The choice of slack bus is critical.	The choice of slack bus is arbitrary.

15. How the convergence of N-R method is speeded up?

The convergence can be speeded up in N-R method by using Fast Decoupled Load Flow (FDLF) algorithm. In FDLF method the weak coupling between P-δ and Q-V are decoupled and then the equations are further simplified equations are further simplified using the knowledge of practical operating conditions of a power system.

16. How the disadvantages of N-R method are overcome?

The disadvantage of large memory requirement can be overcome by decoupling the weak coupling between P-δ and Q-V. (i.e., using decoupled load flow algorithm). The disadvantage of large computational time per iteration can be reduced by simplifying the decoupled load flow equations. The simplifications are made based on the practical operating conditions of a power system.

17. What is the need for voltage control in a power system?

The various components of power system (or equipments connected to power system) are designed to work satisfactorily at rated voltages. If the equipments are not operated at rated voltages then the performance of the equipments will be poor and the life of the equipment will reduce. Hence the voltages are various points in a power system should be maintained at rated value. (Specified value).

18. Mention the various methods of voltage control employed in power system.

The various methods of voltage control in a power system are.

1. Voltage control by adjusting the excitation of generators.
2. Voltage control using shunt capacitors.
3. Voltage control using series capacitors.
4. Voltage control by synchronous capacitors.
5. Voltage control by tap-changing transformer.
6. Voltage control by regulating and booster transformer.

19. What is infinite bus?

A bus is called infinite bus if its voltage remains constant and does not alter by any changes in generator excitation.

20. How the reactive power of a generator is controlled?

The reactive power of a generator is controlled by varying the magnitude and phase of induced emf, which in turn varied by varying excitation. For an increase in reactive power the magnitude of induced emf is increased and its phase angle is decreased. For a reduction in reactive power the magnitude of induced emf is decreased and its phase angle is increased.

21. What are the drawbacks in voltage control using generator excitation?

The generators have a limit for excitation variation. Reducing the excitation below a certain limit may result in instability and increasing the excitation above a limit may result in over heating of the generator rotor. Hence larger reactive power demand cannot be met by excitation control. Also, the voltage regulation by varying excitation is limited to permissible voltage rise at the sending end.

22. What is the disadvantage in reactive power compensation by shunt capacitors and how it is overcome?

The disadvantage in reactive power compensation by shunt capacitors is that with the fall in bus voltage the reactive power supplied by capacitor reduces. Similarly on light loads, when the reactive power required is less the capacitor output will be large. This disadvantage can be eliminated by connecting number of capacitors in parallel and then the capacitance can be varied by switching ON or OFF depending on the requirement.

23. What is the drawback in series connected capacitor?

The drawback in series connected capacitor is the high voltage produced under short circuit (fault) conditions. This high voltage may damage the capacitor. Therefore the capacitor has to be protected using a spark gap with a high speed contactor.

24. Compare the reactive power compensation by shunt and series capacitors.

1. The voltage boost due to a shunt capacitor is evenly distributed over the transmission line whereas the series capacitor provide a sudden change in voltage at the point where it is connected.
2. It can be proved that for same voltage boost the reactive power capacity of shunt capacitor is greater than that of a series capacitor.
3. The shunt capacitor improves the power factor of the load but the series capacitor has little effect on the power factor.
4. The series capacitors are effective in improving the system stability when introduced in long transmission lines.

25. What are the advantages of synchronous capacitors over static capacitors?
    1. In synchronous capacitors the reactive power can be smoothly varies whereas in static capacitors only stepped variation is possible.
    2. The synchronous capacitors can deliver or absorb reactive power but the static capacitors can only deliver reactive power and cannot absorb reactive power.
    3. The synchronous capacitors can be overloaded for short periods, whereas the static capacitors cannot be overloaded.
    4. For large reactive power outputs synchronous capacitors are less costlier than the static capacitors.

26. What is the main difference in voltage control by capacitors and transformers?

When capacitors are employed the voltage control is achieved by injecting or absorbing reactive power at appropriate points in power system. But in voltage control by transformers, the voltage is regulated by providing a small boost or buck to the transmission line voltages by altering the voltage ratios of the transformer.

27. What is regulating transformer and booster transformer?

A type of transformer designed for small adjustment of voltage rather than for changing the voltage levels is called a regulating transformer.

The booster transformer (or series transformer) is a transformer used for boosting or bucking the voltages in a transmission line by connecting one of the winding in series with the line. Usually the other winding of booster transformer is excited by regulating transformer.

28. What is off-nominal transformer ratio? Draw the equivalent circuit of a transformer with off-nominal transformer ratio connected to a transmission line.

When the Voltage or turns ratio of a transformer is not used to decided the ratio of base kV then its voltage or turns ratio is called off-nominal turns ratio. Usually the voltage ratio of regulating transformer will be off-nominal ratios.

The equivalent circuit of a transformer with off-nominal ratio, ά and connected to a transmission line of admittance y is shown below

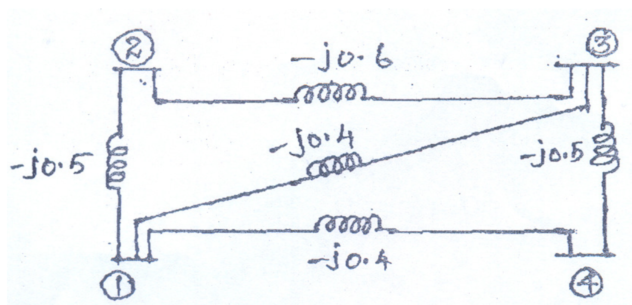
PART – B

1. Derive load flow algorithm using Gauss – Seidel method with flow chart and discuss the

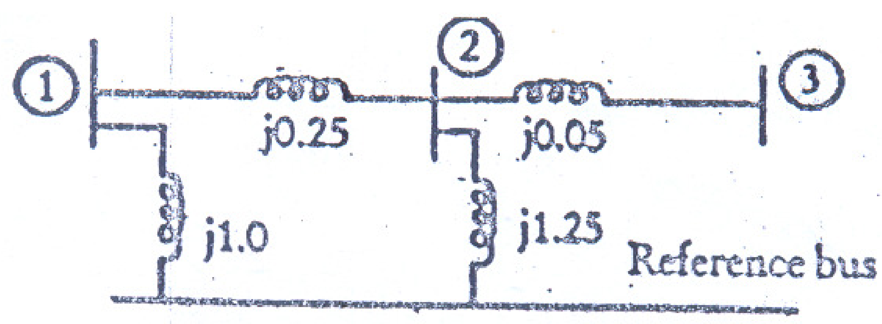
advantages of the method. (16)

2. Derive load flow algorithm using Newton-Raphson method with flow chart and state the importance of the method. (16)
3. Explain clearly the algorithmic steps for solving load flow equation using Newton – Raphson method (polar form) when the system contains all types of buses. Assume that the generators at the P-V buses have adequate Q Limits. (16)
4. Explain the step by step procedure for the NR method of load flow studies. (16)

5. Find the bus admittance matrix for the given network. Determine the reduced admittance matrix by eliminating node 4. The values are marked in p.u. (16)



6. Find the bus impedance matrix for the system whose reactance diagram is shown in fig. All the impedances are in p,u. (16)



7. (i) Derive the power flow equation in polar form. (8)
(ii)Write the advantages and disadvantages of Gauss-Seidel method and Newton-Raphson method. (8)
8. The parameters of a 4-bus system are as under:

Bus code	Line impedance (pu)	Charging admittance (pu)
1-2	0.2 + j 0.8	j 0.02

2-3	0.3 + j 0.9	j 0.03
2-4	0.25 +j 1.0	j 0.04
3-4	0.2 + j 0.8	j 0.02
1-3	0.1 + j0.4	j 0.01

Draw the network and find bus admittance matrix.
(16)

9. With a flow chart, explain the NR Iterative method for solving load flow problem.
(16)

10. (i) Compare Gauss-Seidel method and Newton-Raphson method of load flow studies (6)

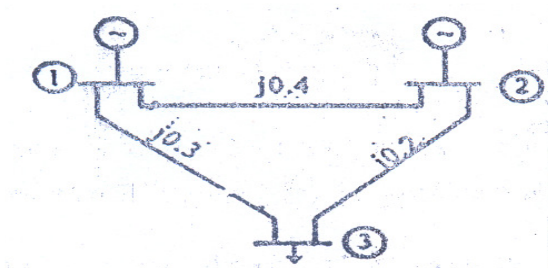
(ii) Fig.12 shows a three bus power system.

Bus 1 : Slack bus, $V = 1.05/0^0$ p.u.

Bus 2 : PV bus, V = 1.0 p.u. $P_g = 3$ p.u.

Bus 3 : PQ bus, $P_l = 4$ p.u., $Q_l = 2$ p.u.

Carry out one iteration of load flow solution by Gauss Seidel method. Neglect limits on reactive power generation.



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UNIT – III

SYMMETRICAL FAULT ANALYSIS
PART – A (2 MARKS)

1. What is meant by a fault?

A fault in a circuit is any failure which interferes with the normal flow of current. The faults are associated with abnormal change in current, voltage and frequency of the power system. The faults may cause damage to the equipments if it is allowed to persist for a long time. Hence every part of a system has been protected by means of relays and circuit breakers to sense the faults and to isolate the faulty part from the healthy part in the event of fault.

2. How the faults are classified?

In one method of classification, the faults are classified as shunt and series faults. The shunt faults are due to short circuits in conductors and the series faults are due to open conductors.

In another method of classificat6ion, the faults are classified into symmetrical and unsymmetrical faults. In symmetrical faults the fault currents are equal in all the phases and can be analyzed on per phase basis. In unsymmetrical faults the fault currents are unbalanced and so they can be analyzed only using symmetrical components.

3. List the various types of shunt and series faults.
   The various types of shunt faults are
   (i) Line-to-ground fault
   (ii) Line-to-line fault
   (iii) Double line-to-ground fault
   (iv) Three phase fault.
   The various types of series faults are
   (i) One open conductor fault
   (ii) Two open conductor fault.

4. Name the main differences in representation of power system for load flow and short circuit studies.
   (i) For load flow studies both the resistances and resistances are reactance are considered whereas for fault analysis the resistances are neglected.
   (ii) For load flow studies the bus admittance matrix is useful whereas for short circuit studies bus impedance matrix is used.
   (iii) The load flow study is performed to determine the exact voltages and currents whereas in short circuit studies the voltages can be safely assumed as 1 pu and the pre-fault current can be neglected.

5. For a fault at a given location, rank the various faults in the order of severity. In a power system relatively the most severe fault is three phase fault and less severe fault is open conductor fault.
   The various faults in the order of decreasing severity are given below.
   (i) 3-Phase fault
   (ii) Double line-to-ground fault
   (iii) Line-to-line fault
   (iv) Single line-to-ground fault
   (v) Open conductor faults.

6. What is the need for short circuit studies or fault analysis?

The short circuit studies are essential in order to design or develop the protective schemes for various parts of the system. The protective scheme consists of current & voltage sensing devices, protective relays and circuit breakers. The selection (or proper choice) of these device mainly depends on various currents that may flow in the fault conditions.

7. What is the reason for transients during short circuits?

The faults or short circuits are associated with sudden change in currents. Most of the components of the power system have inductive property which opposes any sudden change in currents and so the faults (short circuit) are associated with transients.

8. What is meant by doubling effect?

If a symmetrical fault occurs when the voltage wave is going through zero then the maximum momentary short circuit current will be double the value of maximum symmetrical short circuit current. This effect is called doubling effect.

9. What is synchronous reactance?

The synchronous reactance is the ratio of induced *emf* and the steady state *rms* current (i.e. it is the reactance of a synchronous machine under steady state condition). It is the sum of leakage reactance and the reactance representing armature reaction.

10. Define sub transient reactance.

The sub transient reactance is the ratio of induced *emf* on no-load and the sub transient symmetrical *rms* current, (*i.e*, it is the reactance of a synchronous machine under transient condition)

11. What is the significance of sub-transient reactance in short circuit studies?

The sub-transient reactance can be used to estimate the initial value of fault current immediately on the occurrence of the fault. The maximum momentary short circuit current rating of the circuit breaker used for protection or fault clearing should be less than this initial fault current.

12. How symmetrical faults are analyzed?

The symmetrical faults are analyzed using per unit reactance diagram of the power system. Once the reactance diagram of the power system is formed then the fault is simulated by short circuit (or by connecting the fault impedance at the fault point). The currents and voltages at various parts of the system can be estimated by any one of the following method.

(i) Using Kirchoff's laws
(ii) Using Thevenin's theorem
(iii) By forming bus impedance matrix.

13. What are the main factors to be considered to select a circuit breaker?

The choice of a circuit breaker for particular application depends on the following ratings of the circuit breaker.

i.) Normal working power level specified as rated interrupting current or rated interrupting MVA.
ii.) The fault level specified as either rated short circuit interrupting current or rated short circuit interrupting MVA.
iii.) Momentary current rating.
iv.) Speed of circuit breaker.

14. Why the circuit breaker interrupting current is asymmetrical?

The interrupting current of circuit breaker is the sum of symmetrical short circuit current and dc-offset current. The presence of dc-offset current makes the interrupting current as asymmetric.

15. What is momentary current rating of circuit breaker? How it si estimated?

The momentary current rating is the maximum current that may flow through a circuit breaker for a short duration. It is estimated by multiplying the symmetrical sub-transient fault current by a factor of 1.6 (The factor 1.6 accounts for dc-offset current during sub-transient period).

16. Define short circuit interrupting MVA of a circuit breaker.

The short circuit interrupting MVA of a circuit breaker is the volt-amperes (power) flowing through it at the moment of opening its contacts due to a fault.

It is estimated by the following equations.

Short circuit interrupting MVA = $\sqrt{3}|V_{pL}|\,|I_{fL}|$ or

Short circuit interrupting MVA = $|V_{pfL,pu}|\ \ I_{fL,pu}|$ x MVA_b

Where $|V_{pfL}|$. = Magnitude of line voltage at the fault point in kV.

$|I_{fL}|$ = Magnitude of line value of short circuit interrupting current at the fault in kA.

$|V_{pfL,pu}|$. = Magnitude of pre-fault voltage at the fault point in p.u.

$|I_{fL,pu}|$ = Magnitude of short circuit interrupting current at the fault in p.u.

PART – B

1. A generator is connected through a transformer to a synchronous motor the sub transient reactance of generator and motor are 0.15 p.u. and 0.35 p.u. respectively. The leakage reactance of the transformer is 0.1 p.u. All the reactances are calculated on a common base. A three phase fault occurs at the terminals of the motor when the terminal voltage of the generator is 0.9 p.u. The output current of generator is 1 p.u. and 0.8 p.f. leading. Find the sub transient current in p.u. in the fault, generator and motor. Use the terminal voltage of generator as reference vector.
(16)

2. Explain the step by step procedure for systematic fault analysis using bus impedance matrix.
(16)

3. A 60 MVA, Y connected 11 KV synchronous generator is connected to a 60 MVA, 11/132 KV Δ/Y transformer. The sub transient reactance X''_d of the generator is 0.12 p.u. on a 60 MVA base, while the transformer reactance is 0.1 p.u. on the same base. The generator is unloaded when a symmetrical fault is suddenly placed at point p as shown in Fig. 3 Find the sub transient symmetrical fault current in p.u. amperes and actual amperes on both side of the transformer. Phase to neutral voltage of the generator at no load is 1.0 p.u.
(16)

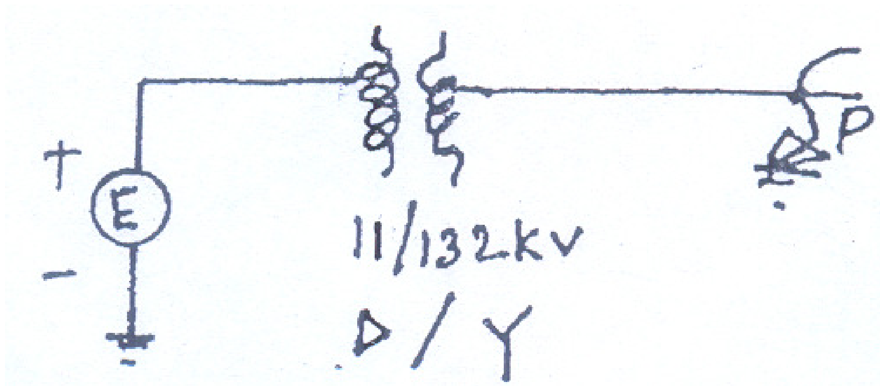
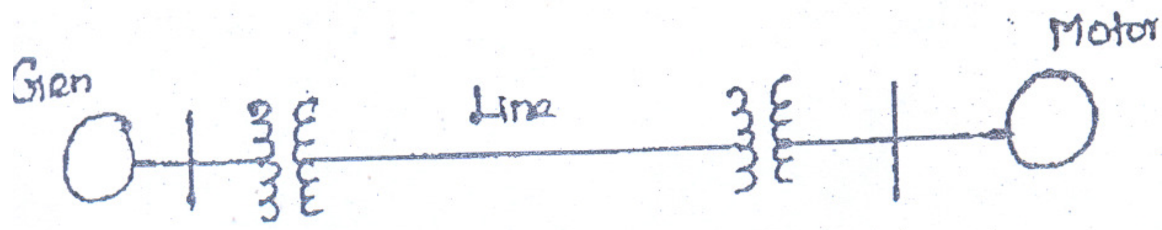


Fig. 3

4. A three –phase transmission line operating at 33 KV and having a resistance and reactance of 5 Ohms and 15 Ohms respectively is connected to the generating station bus-bar through a 5000 KVA step up transformer which has a reactance of 0.05 p.u. Connected to the bus-bars are two alternators, are 10,000 KVA having 0.08 p.u. reactance and another 5000 KVA having 0.06 p.u. reactance. Calculate the KVA at a short circuit fault between phases occurring at the high voltage terminals of the transformers.

(16)

5. A synchronous generator and a synchronous motor each rated 25 MVA, 11 KV having 15% sub-transient reactance are connected through transformers and a line as shown in fig. The transformers are rated 25 MVA< 11/66 KV and 66/11 KV with leakage reactance of 10% each. The line has a reactance of 10% on a base of 25 MVA, 66 Kv. The motor is drawing 15 MW at 0.5 power factor leading and a terminal voltage of 10.6 KV. When a symmetrical 3 phase fault occurs at the motor terminals. Find the sub-transient current in the generator, motor and fault.



(16)

6. A three phase power of 700 MW is to be transmitted to a substation located 315 kM from the source of power. For a preliminary line design assume the following parameters:

V_s = 1.0 p.u., V_r + 0.9 p.u. ^ = 5000 km ; z_c = 320 Ώ, and Ś = 36.87^0 .

(i) Based on the practical line load ability equation, determine a nominal voltage level for the transmission line.

(8)

(ii) For the transmission voltage level obtained in (i) Calculate the theoretical maximum power that can be transferred by the transmission line.

(8)

7. A 25,000 KVA, 13.8 kV generator with X''_d = 15% is connected through a transformer to a bus which supplies four identical motors as shown in Fig. 7 The sub transient reactance X''_d of

each motor is 20% on a base of 5000 KVA, 6.9 kV. The three-phase rating of the transformer is 25,000 KVA, 13.8/6.9 kV, with a leakage reactance of 10%. The bus voltage at the motors is 6.9 kV when a three-phase fault occurs at point p. for the fault specified, determine (i) the sub transient current in the fault (ii) the sub transient current in breaker A and (iii) the symmetrical short-circuit interrupting current in the fault and in breaker A.

(16)

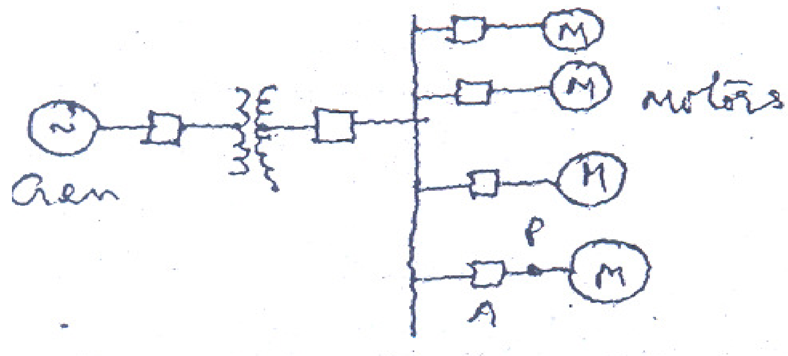


Fig.7 one line diagram

8 Determine Z_{bus} for the network shown below in Fig. 8 where the impedances labeled 1 through 6 are shown in per unit. Preserve all buses.
(16)

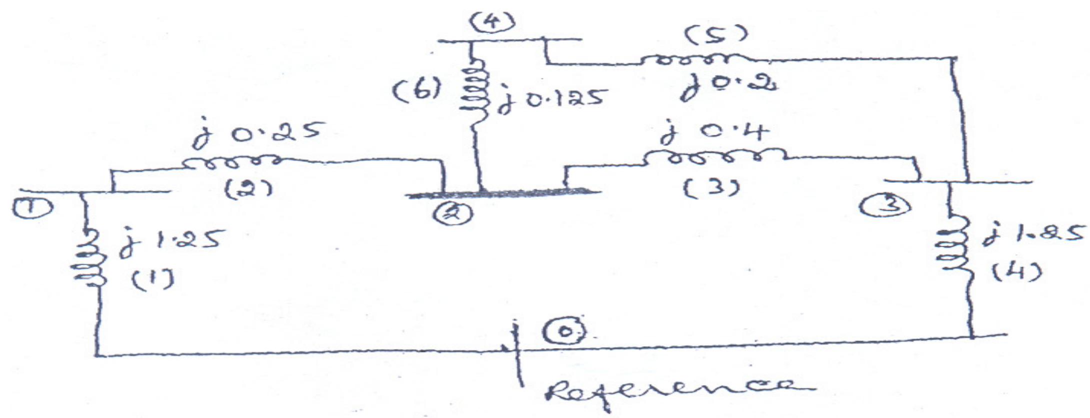
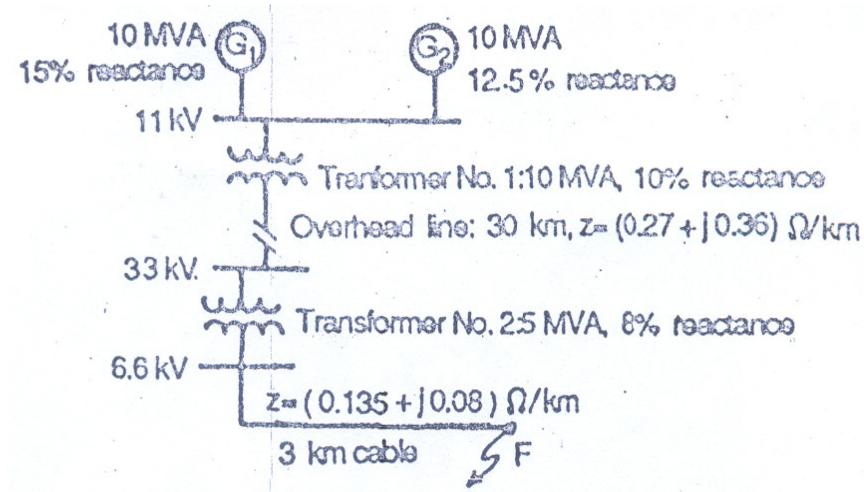


Fig. 8

Fig. 8 Branch impedances are in p.u. and branch numbers are in parentheses.

8. With a help of a detailed flowchart, explain how a symmetrical fault can be analyzed using Z_{bus} ?
(16)

8. (i) For the radial network shone below a three phase fault occurs at F. Determine the fault current and the line voltage at 11 kV bus under fault conditions.
(6)



(ii) Explain the procedure for making short-circuit studies of a large power system networks using digital computers.
(10)

9. Two synchronous machines are connected through three phase transformers to the transmission line shown in Fig.11 the ratings and reactance of the machines and transformers are

   Machine 1 and 2 : 100 MVa, 20kV; $X''_d = X_1 = X_2 = 20\%$
   $X_0 = 4\%$, $X_n = 5\%$
   Transformers T_1 and T_2 : 100 MVA, 20 Δ/345 YkV ; X = 8%.
   On a chosen base of 100 MVA, 345 kV in the transmission line circuit the line reactances are $X_1 = X_2 = 15\%$ and $X_0 = 50\%$. Draw each of the three sequence networks and find the zero sequence bus impedance matrixes by means of Z_{bus} building algorithm. (16)

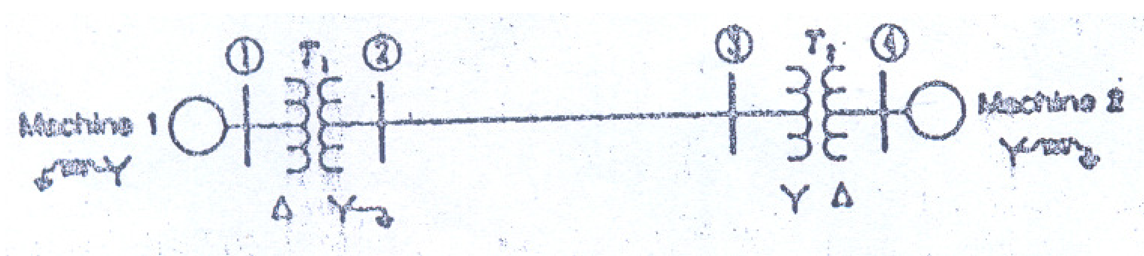


Fig.11

UNIT-IV

UNSYMMETRICAL FAULT ANALYSIS
PART – A (2 MARKS)

1. Name the various unsymmetrical faults in a power system.

The unsymmetrical faults in a power system are.

(i) Single line –to-ground fault
(ii) Line–to-line fault
(iii) Double line-to-line ground fault
(iv) Open conductor fault.

2. Name the faults which the zero sequence currents flowing

   In line to line faults the zero sequence current do not flow.

3. Define positive sequence impedance.

The positive sequence impedance of an equipment is the impedance offered by the equipment to the flow of positive sequence currents.

4. Draw the connection of sequence networks for a double line-to-ground fault at the terminals of an unloaded generator.

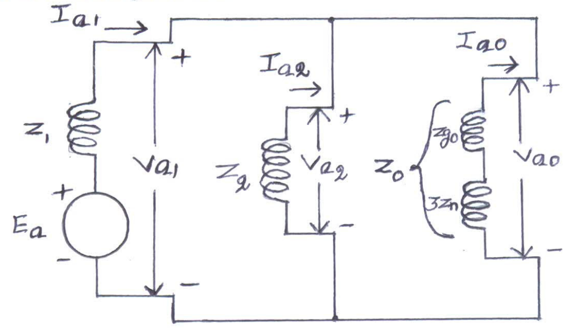


Fig F1: Connection of the sequence
Networks of an unloaded generator for
A double line to-ground fault on phase b and c

5. Draw the connection of sequence networks for line-to-line fault without fault impedance.

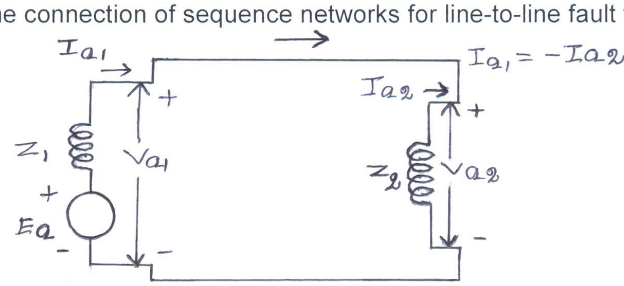


Fig F 2: Connection of the sequence networks
For a line-to-line fault in power system.

6. Draw the connection of sequence networks for double line-to-ground fault without fault impedance.

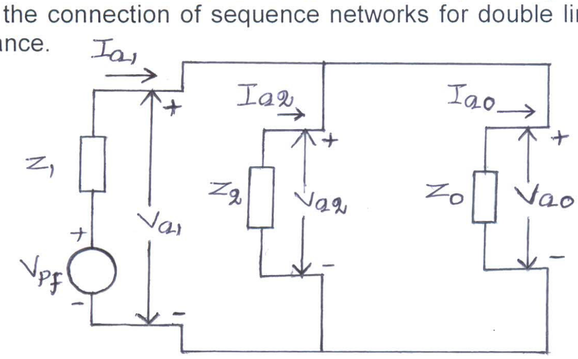


Fig F 3: Connection of the sequence Networks for a double line-to-ground fault

7. Draw the connection of sequence networks for in-to-ground fault through impedance Z_f.

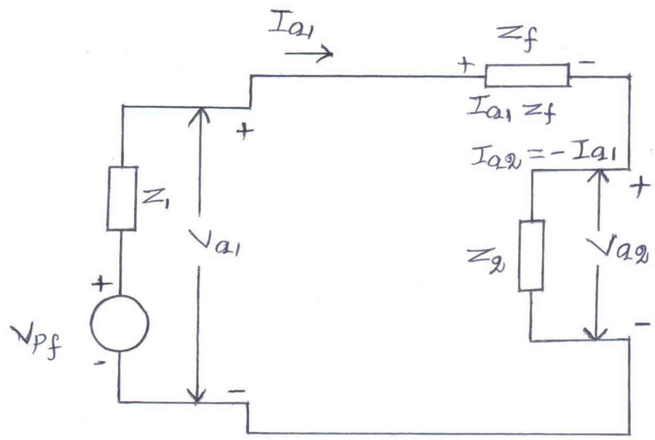


Fig F 4: Connection of sequence networks for Line-to-line fault through impedance Z_f.

8. Draw the connection of sequence networks for double line-to-ground fault through an impedance Z_f.

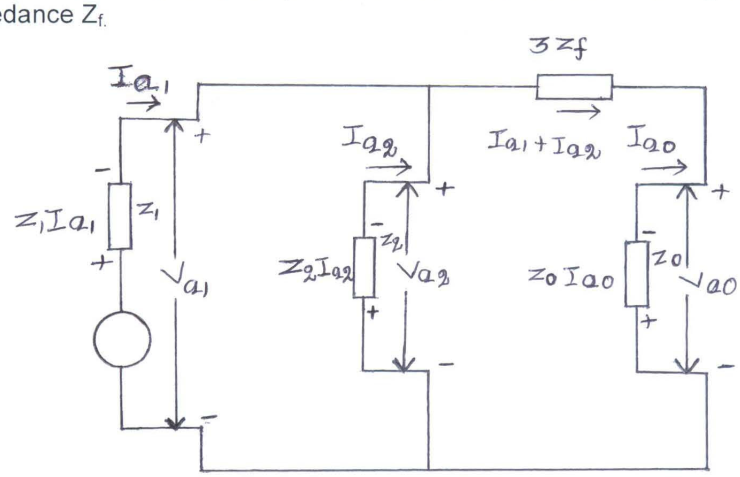


Fig F5: connection of sequence networks for a double Line-to-ground fault through an impedance

PART- B

1. Derive the expression for fault current in Line-to-Line fault on an unloaded generator in terms of symmetrical components.
   (16)

2. Determine the fault current and MVA at faulted bus for a line to ground (solid) fault at bus 4 as shown in Fig.2

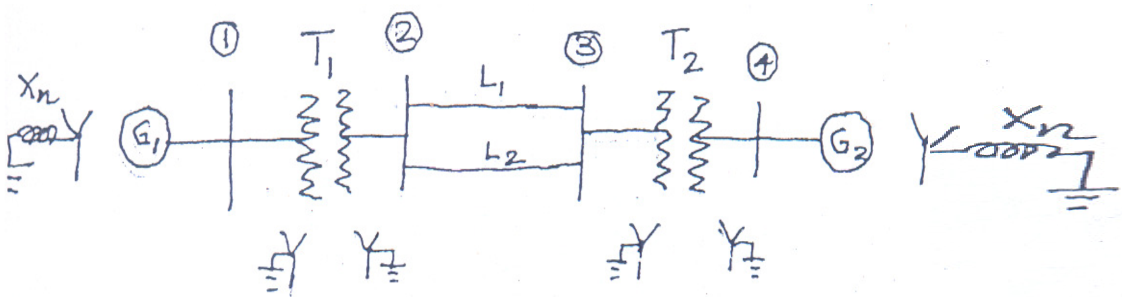


Fig.2

G_1, G_2 : 100 MVA, 11kV, $X^+ + X^- = 15\%$, $X^0 = 5\%$, $X_n = 6\%$
T_1 T_2 : 100 MVA, 11kV/220 kV, $X_{l\backslash leak} = 9\%$
L_1, L_2 : $X^+ = X^- = 10\%$, $X^0 = 10\%$ on base of 100 MVA. Consider a fault at phase a'.

(16)

3. A single line to ground fault occurs on bus 4 of the system shown in Fig.3
   (i) Draw the sequence networks and
   (12)
   (ii) Compute the fault current.
   (4)

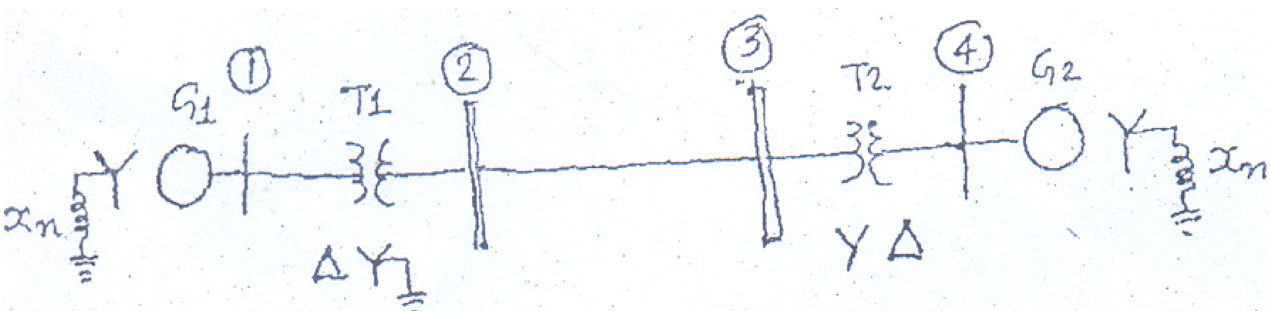
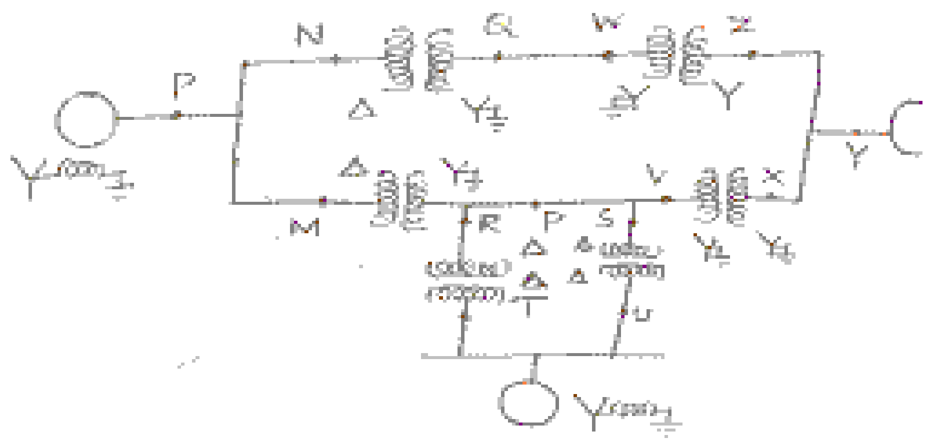


Fig. 3

Gen 1 and 2 : 100 MVA, 20kV; $X' = X''$ 20% ; $X_0 = 4\%$; $X_n = 5\%$.
Transformer 1 and 2 : 100 MVA, 20/345 KV; $X_{leakage} = 8\%$ on 100 MVA
Tr. Line : $X' = X' = 15\%$ $X_0 = 50\%$ on a base of 100 MVA, 20 kV.

4.. Draw the Zero sequence diagram for the system whose one line diagram is shown in fig.



(16)

5. Two synchronous machines are connected through three-phase transformers to the transmission line as given below in Fig. 5. The ratings and reactance of the machines and transformers are

Machines 1 and 2 : 100 MVA, 20 Kv; $X''_d = X_1 = X_2 = 20\%$

$X_0 = 4\%$; $X_n = 5\%$.

Transformers T_1 and T_2 : 100 Mva, 20y/345 YkV ; X= 8%

Both transformers are solidly grounded on two sides. On a chosen base of 100 MVA, 345 kV in the transmission line circuit the line reactance are $X_1 = X_2 = 15\%$ and $X_0 = 50\%$. The system is operating at nominal voltage without prefault currents when a bolted (Z_f = o) single line-to-ground fault occurs on phase A at bus (3) Using the bus impedance matrix for each of the three sequence networks, determine the sub transient current to ground at the fault. (16)

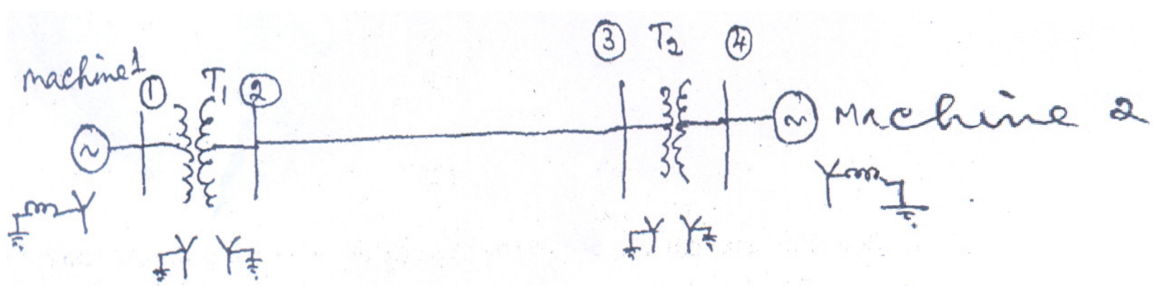
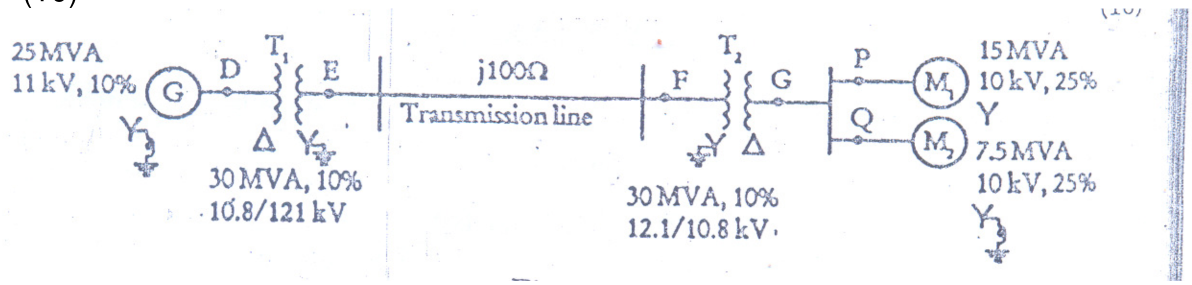


Fig.5

6. Determine the positive, negative and zero sequence networks for the system shown in Fig. 6. Assume zero sequence reactance for the generator and synchronous motors as 0.06 p.u. current limiting reactors of 2.5 Ώ are connected in the neutral of the generator and motor No.2 The zero sequence reactance of the transmission line is j 300 Ώ. (10)



7. Develop the connection of sequence network when a line to line fault occurs in a power network.
(16)
8. Derive the expression for fault current in double line to ground fault on unloaded generator. Draw an equivalent network showing the inter connection of networks to simulate double line to ground fault
(16)

UNIT – V

STABILITY ANALYSIS
PART – A (2 MARKS)

1. Define Steady state stability.

The steady state stability is defined as the ability of a power system to remain stable (i.e, without loosing synchronism) for small disturbances.

2. Define transient stability.

The transient stability is defined as the ability of a power system to remain stable (i.e., without loosing synchronism) for large disturbances.

3. What is steady state stability limit?

The steady stability limit is the maximum power that can be transmitted by a machine (or transmitting system) to a receiving system without loss of synchronism. In study state the power transferred by synchronous machine 9or power system) is always less than the steady state stability limit.

4. What is transient stability limit?

The transient stability limit is the maximum power that can be transmitted by a machine 9or transmitting system) to a fault or a receiving system during a transient state without loss of synchronism. The transient stability limit is always less than the steady state stability limit.

5. How stability studies are classified, what are they?

The stability studies are classified depending on the nature of the disturbance. Depending on the nature of disturbance the stability studies can be classified into the following three types.

1. Steady state stability
2. Dynamic stability
3. Transient stability.

6. In a 3- machine system having ratings G_1, G_2 and G_3 and inertia constants M_1, M_2 and M_3, what is the inertia constants M and H of the equivalent system.

$$M_{eq} = \frac{M_1 G_1}{G_b} + \frac{M_2 . G_3}{G_b} + \frac{M_3 G_3}{G_b}$$

Where, G_1, G_2, G_3 = MVA ratings of machines 1,2,3, respectively

G_b = Base MVA or MVA rating of system.

$$H_{eq} = \frac{\pi f M_{eq}}{S_b}$$

7. Define synchronizing coefficient. For what value of synchronizing coefficient the system remains stable.

The term $P_{max} \cos \delta_o$ is called synchronizing coefficient is positive. It is positive when $O \leq \delta_o \geq \pi /2$.

8. Define swing curve. What is the use of swing curve?

The swing curve is the plot or graph between the power angle δ and t.

It is usually plotted for a transient state to study the nature of variation in δ for a sudden large disturbance. From the nature of variations of δ the stability of a system for any disturbance can be determined.

9. Give the simplified power angle equation and the expression for P_{max}

The simplified power angle equation for a generator feeding energy to infinite bus is given by, δ

$$P_e = P_{max} \sin \delta$$

Where, $$P_{max} = \frac{|E|\ |V|}{X}$$

$|E|$ = Magnitude of internal *emf* of generator.

$|V|$ = Magnitude of infinite bus voltage

X = Transfer reactance between generator and infinite bus

δ = Power angle or torque angle.

10. Define power angle.

The power angle (or torque angle) is defined as the angular displacement of the rotor from synchronously rotating reference frame.

11. Define critical clearing time and critical clearing angle and give equations for both.

The critical clearing angle, δ_{cc} is the maximum allowable change in the power angle δ before clearing the fault, without loss of synchronism. The time corresponding to this angle is called critical clearing time, t_{cc}. The critical clearing time, t_{cc} can be defined as the maximum time delay that can be allowed to clear a fault with out loss of synchronism.

12. List the methods of improving the transient limit of a power system.

The following are the methods used to improve the transient stability of a system.

(i) Increase of system voltage and use of AVR (Automatic Voltage Regulation)
(ii) Use of high speed excitation systems.
(iii) Reduction in system transfer reactance.
(iv) Use of high speed enclosing breakers.

13. State equal area criterion.

The equal area criterion for stability states that the system is stable if the area under $P_a - \delta$ curve reduces to zero at some value of δ.

This is possible only if the positive (accelerating) area under $P_a - \delta$ curve for a finite change in δ. Hence this stability criterion is called equal area criterion.

14. A 50H_z, 4 pole turbo generator of rating 20 MVA, 13.2 kV has an inertia constant of H = 9 kW – sec/kVA. Find the kinetic energy stored in the rotor at synchronous speed.

SOLUTION:

$$\text{Kinetic energy, } E_{ke} = \frac{1}{2} M w_s$$

$$\text{Where, } M = \frac{HS}{\pi f} \text{ and } w_s = 2\pi f$$

$$\therefore E_{ke} = \frac{1}{2} \frac{HS}{\pi f} 2\pi f = HS = 9x20 = 180 \text{ MJ. (Mega Joules)}$$

15. Find the frequency of oscillation for a synchronizing coefficient of 0.6, inertia constant, H = 4 and system frequency of 50 H_z .

SOLUTION:

$$\text{Frequency of oscillation} = \sqrt{\frac{C}{\ }}$$

M

Where, C = synchronizing coefficient ; M = Inertia constant in p.u.

Given that, C = 0.6

$$M \text{ in p.u.} = \frac{H}{\pi f} = \frac{4}{\pi \times 50} = 0.0255 \text{ p.u.}$$

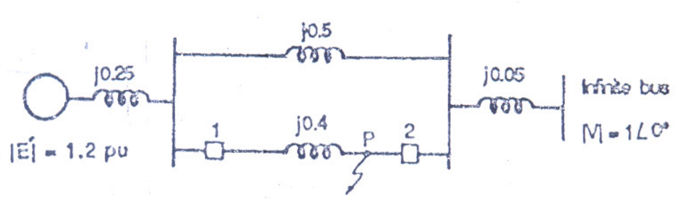
$$\therefore \text{Frequency of oscillation} = \sqrt{\frac{0.6}{0.0255}} = 4.85 \text{ rad/sec} = \frac{4.85}{2\pi} = 0.7719 H_z$$

PART- B

1. Derive swing equation used for stability studies in power system. (16)
2. Explain the modified Euler method of analyzing multi machine power system for stability with a neat flow chart. (16)
3. (i) Derive swing equation for a synchronous machine. (8)

   (ii) A 50 H_z generator is delivering 50% of the power that it is capable of delivering through a transmission line to an infinite bus. A fault occurs that increases the reactance between the generator and the infinite bus to 500% of the value before the fault. When the fault is isolated, the maximum power that can be delivered is 75% of the original maximum value. Determine the critical clearing angle for the condition described. (8)

4. Find the critical clearing angle for clearing the fault with simultaneous opening of the breakers 1 and 2. The reactance values of various components are indicated on the diagram. The generator is delivering 1.0 p.u. power at the instant preceding the fault. The fault occurs at point p as shown in the figure.



(16)

5 In the system shown in Fig. 5 a three phase static capacitive reactor of reactance 1 p.u. per phase in connected through a switch at motor bus bar. Calculate the limit of steady state power with and without reactor switch closed. Recalculate the power limit with

capacitance reactor replaced by an inductive reactor of the same value.
(16)

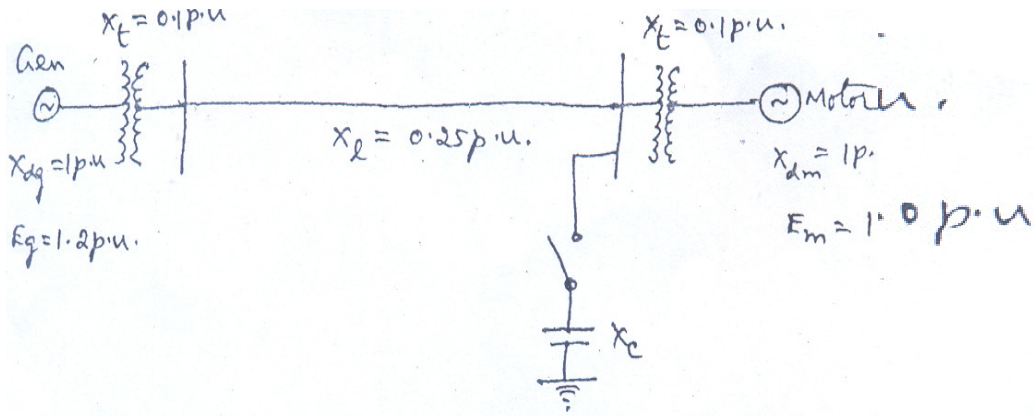


Fig.5

Assume the internal voltage of the generator to be 1.2 pu. and motor to be1.0 p.u.

6. Describe the Runge-Kutta method of solution of swing equation for multi-machine systems.
   (16)
7. (i) Derive the swing equation of a synchronous machine swinging against an infinite bus. Clearly state the assumption in deducing the swing equation.
   (10)
   (ii) The generator shown in Fig. 7 is delivering power to infinite bus. Take V_t = 1.1 p.u. Find the maximum power that can be transferred when the system is healthy.
   (6)

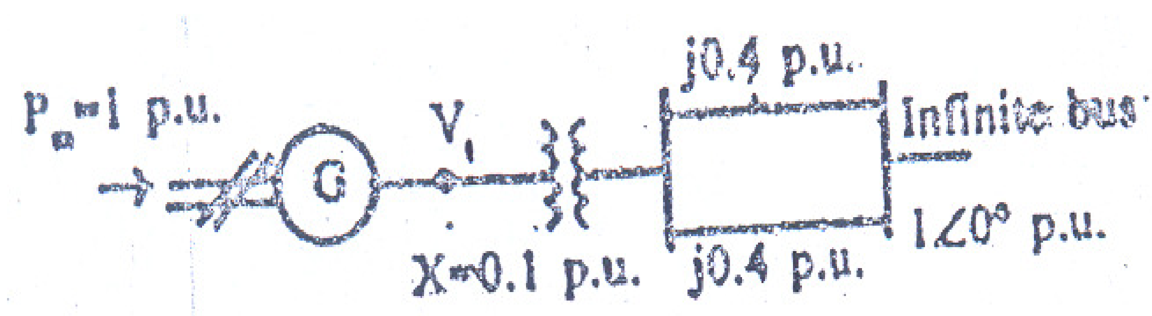
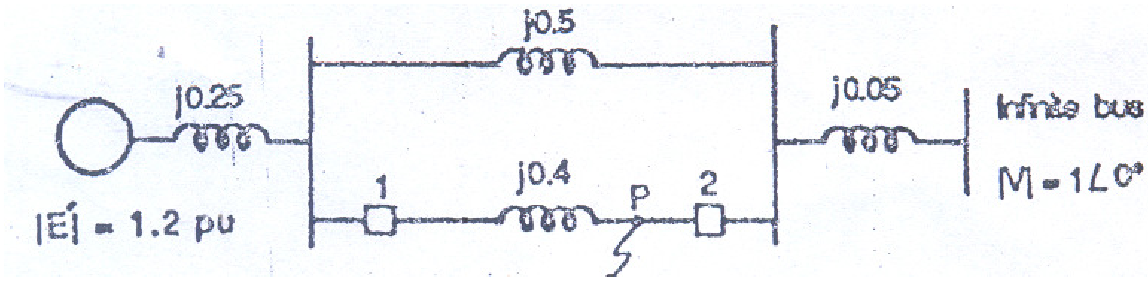


Fig. 7

9. (i) A 2-pole 50 Hz, 11kV turbo alternator has a ratio of 100 MW, power factor 0.85 lagging. The rotor has a moment of inertia of 10,000 kgm^2. Calculate H and M.
(6)
   (ii)A three phase fault is applied at the point P as shown below. Find the critical clearing angle for clearing the fault with simultaneous opening of the breakers 1 and 2. The reactance values of various components are indicated in the diagram. The

generator is delivering 1.0 p.u. power at the instant preceding the fault.
(10)



10. Describe the equal area criterion for transient stability analysis of a system.
(16)

----------- X ---------