GATE

2018

POWER SYSTEM

ELECTRICAL ENGINEERING

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GATE-2018: Power System| Detailed theory with GATE & ESE previous year papers and detailed solu ons.

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CONTENTS

CHAPTER - 1
BASIC CONCEPTS

1.1 INTRODUCTION

1. In electrical engineering the energy is studied in reference to charge (Q). Voltage and current are basic electrical circuit variables.

Voltage is defined as work done on unit charge i.e. $V = \frac{dW}{dQ}$ J / C or volts. (V).

Current is defined as time rate of change of charge i.e $I = \frac{dQ}{dt}$ c / s or Ampere (A)

Now, $v \times i = \frac{dW}{dQ} \times \frac{dQ}{dt} = \frac{dW}{dt}$

$\frac{dW}{dt}$ is time rate of charge of energy, which basically means power (p)

$p(t) = v(t) \times i(t)$ J/s or watts (w)

2. Current is taken positive in the direction of movement of positive charge and vice-versa.

The voltage at point A (V_A) is voltage with respect to ground.

The voltage between two points V_{AB} is equal to (V_A–V_B). Voltage V_{AB} is positive if positive charge looses energy in moving from A to B or negative charge gains energy in moving from A to B.

To calculate V_{AB} start from point B and go towards A, while doing so take voltage rises as positive and voltage drops as negative and add all such voltages.

3. The positive charge will have natural tendency to be repelled by positive charge and attracted by negative charge as shown in the figure (1.1), Q^+ will naturally move towards B and the direction of current will be from A and B as shown figure (1.2). In this case charge is losing energy and device is getting energy from charge such devices are called passive elements or load. Power in this case in positive.

Figure (1.1)

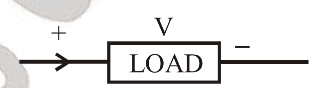


Figure (1.2)

4. In figure (1.3) as shown below Q^+ will have to be supply energy by external medium to move it from B to and direction of current will be from B to in this case charge is gaining energy and device is supplying energy such device are called active elements source or generator. Power in this case is negative.

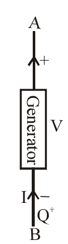


Figure (1.3)

ESE OBJ QUESTIONS

1. The three non-inductive loads of 5 kW, 3 kW and 2 kW are connected in a star network between R, Y and B phases and neutral. The line voltage is 400V. The current in the neutral wire is nearly

[ESE - 2017]

(a) 11 A (b) 14A
(c) 17 A (d) 21 A

2. A three-phase star-connected load is operating at a power factor angle ϕ with ϕ being the angle between

[ESE - 2017]

(a) Line voltage and line current
(b) Phase voltage and phase current
(c) Line voltage and phase current
(d) Phase voltage and line current

3. Consider the following statements regarding three-phase transformers in Open-Delta (V–V) connections;

1.Being a temporary remedy when one transformer forms of Delta-Delta system is damaged, and removed from service.
2.The Volt Ampere (VA) supplied by each transformer is half of the total VA, and the system is not overloaded.
3.An important precaution is that load shall be reduced by $\sqrt{3}$ times in this case.
Which of the above statements are correct?

[ESE - 2017]

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

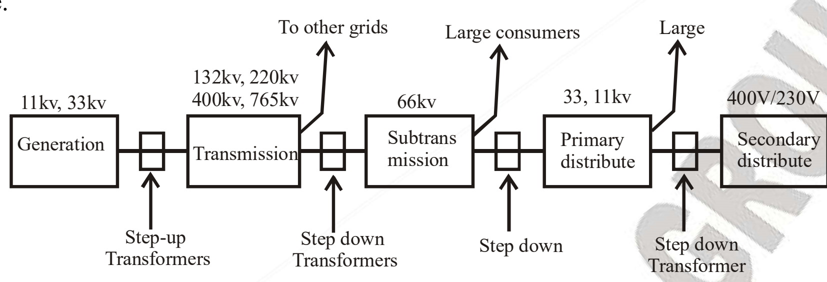
4. In a certain single-phase a.c. circuit the instantaneous voltage is given by
$v - V\sin(\omega t + 30°)$ p.u. and the instantaneous current is given by $i =$ $I\sin(\omega t - 30°)$ p.u. Hence the per unit value of reactive power is

[ESE - 2002]

(a) 1/4 (b) 1/2
(c) $\sqrt{3}/4$ (d) $\sqrt{3}/2$

CHAPTER - 2
SINGLE LINE DIAGRAM

2.1 INTRODUCTION
Power system is the study of generation, transmission and distribution of electric energy at very large scale.

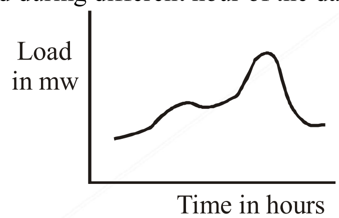


2.2 TRANSMISSION NETWORK
1. Transmission network connect generating plants to consumption point. Transmission is always in 3-ϕ, generally done through over head lines.
2. Transmission network interconnects power pools which are part of grid. Inter connecting power pools has following advantages.
(i) It reduces generation reserve and cost
(ii) It increases reliability
3. Transmission is done at High Voltage (HV). HV transmission has following advantages.
(i) High Voltage for fixed amount of power will have low current which leads to less losses, loss voltage drop.
(ii) Due to reduction in current density conductor cross section area is reduced which leads to less material for same amount of power.
(iii) High voltage also increase power transferable limit and steady state limit.
4. HVAC is called synchronous link
5. HVDC is asynchronous link
6. Voltage levels for HVAC are 765 kv, 400kv, 220 kv and 132kv. Voltage level > 220 kV are extra High voltage (EHV) and voltage levels ≥ 760kv are ultra high voltage (UHV).
7. HVDC up to 500kv is available in India.
8. High voltage needs expenditure on insulating equipments. Hence there is a limit of increasing voltage. High voltage also causes corona interference.
9. In transmission there are problems of corona loss, radio interference, voltage control, load frequency and problem of stability etc.
10. Transmission equipment are
(i) Step up power transformers
(ii) Step down power transformer
(iii) Power transformers are designed with high value of leakage reactance so as to reduce fault current.
(iv) Voltage regulators
(v) Phase shifters to control real power flow
(vi) Transmission lines
(vii) Shunt compensation to maintain voltage profile.

CHAPTER - 3
POWER GENERATION CONCEPT

3.1 INTRODUCTION

1. Load curve
Load curve is the variation of load during different hour of the day, shown on curve.



2. Maximum Demand
The peak load on system is called maximum demand.

3. Connected Load
The sum of the continuous rating of all electrical equipment connected to the supply system is know as connect load.

4. Average Load

$$\text{Daily average load } = \frac{\text{KWh supplied in day}}{24}$$

5. Load Factor

$$\text{Load factor} = \frac{\text{Average load}}{\text{max imum demand}}$$

6. Demand Factor

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

7. Diversity Factor

$$\text{Diversity factor} = \frac{\text{Sum of individual max demand}}{\text{max demand of power system}}$$

8. Plant Capacity Factor

$$\text{Capcity or plant factor} = \frac{\text{Averge demand}}{\text{Ratge capacity of plant}}$$

9. Plant Use Factor

$$\text{Plant operating or use factor} = \frac{\text{Total kwh generated}}{\text{Rated capacity } \times \text{number of operating hrs}}$$

CHAPTER - 4
TRANSMISSION LINE PARAMETERS

4.1 INTRODUCTION

4.1.1 Resistance

$$R = \frac{\rho\ell}{A}$$

Where ρ is the resistivity of conductor

ℓ is length of conductor

A is cross sectional area

Resistance changes with temperature

$$R_{T_2} = R_{T_1}\left[1+\alpha\left(T_2 - T_1\right)\right]$$

T_1 & T_2 are temperature is °C

R_{T_1} is resistance at temperature T_1

R_{T_2} is resistance at temperature T_2

α is temperature coefficient of resistance in Ω/°C

4.1.2 Inductance of line

AC flux linkages

$\lambda = N\phi = L I$

Where λ & I are in rms

$d\lambda = Nd\phi$

Voltage inducted due to alternating flux linkages

$$V(t) = \frac{d\lambda}{dt}$$

In frequency domain

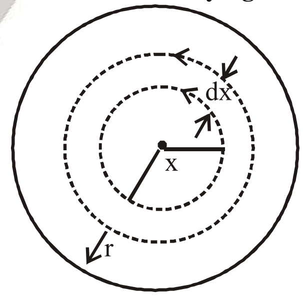
$V = j\omega\lambda = j\omega LI$

The mutual inductance M_{12} is defined as flux linkages of 1 due to current of 2 as follows

$$M_{12} = \frac{\lambda_{12}}{I_2}$$

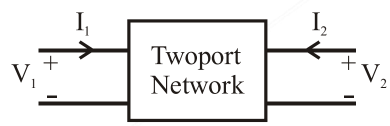
Voltage drop in circuit 1 due to current in circuits $V_1 = j\omega\lambda_{12} = j\omega M_{12}I_2$

4.1.3 Flux linkages and Inductance of Current carrying Conductor



CHAPTER - 5
CHARACTERISTICS AND PERFORMANCE OF POWER TRANSMISSION LINE

5.1 INTRODUCTION
Transmission line can be studies on phase basis under balanced conditions, in this case transmission line can be regarded as two port network. Input port is sending and output port is receiving end.



For transmission line parameter are

$V_1 = AV_2 - BI_2$

$I_1 = CV_2 - DI_2$

Here,

$V_1 = V_S$ and $I_1 = I_s$

$V_2 = V_R$ $\quad$ $I_2 = I_R$

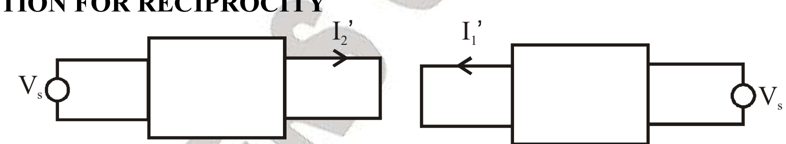
Condition for symmetry

$$\left.\frac{V_1}{I_1}\right|_{I_2=0} = \left.\frac{V_2}{I_2}\right|_{I_1=0}$$

$\Rightarrow \frac{A}{C} = \frac{D}{C}$

$\Rightarrow A = D$

5.2 CONDITION FOR RECIPROCITY



$V_s = +BI_2'$

$-I_1' = CV_s - \frac{A}{D}V_s$

$\Rightarrow I_1' = -CV_S + \frac{AD}{B}V_S$

For reciprocity $I_2' = I_1' \Rightarrow \frac{V_s}{B} = \frac{AD - BC}{B}V_s \Rightarrow AD - BC = 1$

$$\% \text{ Efficiency of line} = \frac{\text{Power delivered at receving end}}{\text{Power sent from sending end}} \times 100$$

$$\% \text{ Regulation of line} = \frac{V_{r0} - V_r}{V_r} \times 100$$

When V_{r_0} is receiving end voltage at no load

CHAPTER - 6
INSULATED CABLES

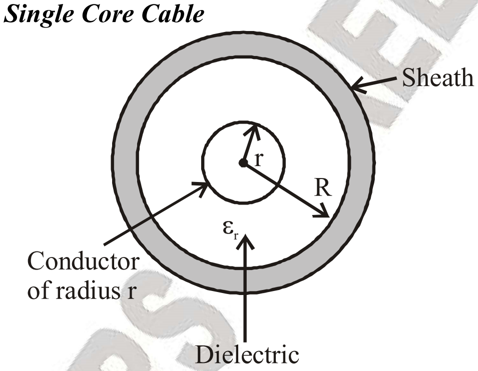
6.1 INTRODUCTION

6.1.1 Electric Cables Consist
1. Conductor for transmitting power
2. Insulation to insulate conductor from direct contact with earth.
3. External protection from mechanical damage etc.

6.1.2 Various Insulting Materials used For Cables
1. Vulcanized Rubber: used for wiring of houses etc for low power usage.
2. Butyl Rubber: More tough can be used for cables without sheath.
3. Neoprene: Used for sheathing material.
4. Poly vinyle chloride PVC:
5. Polythene used for high frequency
6. Impregnated paper

(i) Protective Coverings
These are to protect cable like lead alloy sheath, steel tapes, steel wires etc.

(ii) Electrostatic Stress in Single Core Cable



$$E = g = \frac{q}{2\pi \in x}$$

$$V = \int_r^R E \cdot dx$$

$$= \frac{q}{2\pi \in} \ln \frac{R}{r}$$

$$g = \frac{V}{x \ln(R/r)}$$

g will be maximum at the surface of conductor i.e. x = r

$$g_{max} = \frac{V}{r \ln \frac{R}{r}}$$

Gradient is minimum at the inner radius of the sheath

CHAPTER - 7
OVERHEAD LINE INSULATORS

7.1 INTRODUCTION
The insulators for overhead lines provide insulation to the power conductor from ground mainly made by glazed porcelain or toughened glass.

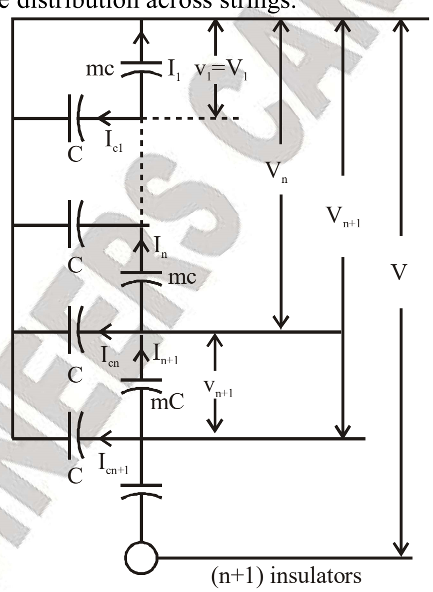
7.1.1 Types
1. Pin type
It is used up to 33kv

2. Suspension type
(i) Each insulator is designed for say 11kv and for higher operating voltages string of insulator disc is used.
(ii) In case of failure of one disc (string) only that need to be replaced.

3. Strain type
These are placed horizontally. These are used to take tension of conductors at line terminals, road crossings etc. They are also known as tension insulators.

4. Shackle type
Used for voltage < 11 kV

7.2 VOLTAGE DISTRIBUTION OVER A STRING OF SUSPENSION INSULATOR
Capacitances are formed between insulator strings and between string and metal parts of structure which causes unequal voltage distribution across strings.



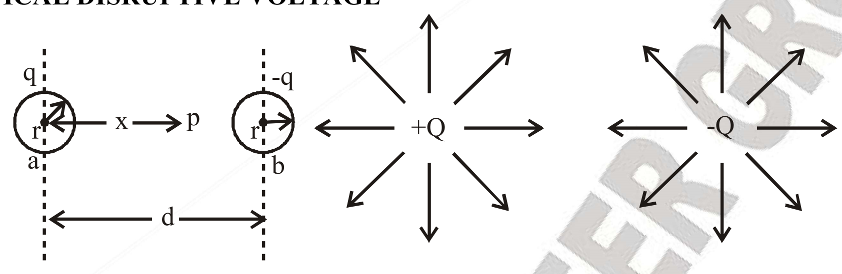
At junction n

$$I_{n+1} = I_{c_n} + I_n$$

CHAPTER - 8
CORONA

8.1 INTRODUCTION
Corona phenomenon is defined as self sustained electric discharge in which the field intensified ionization is localized over a portion of distance between electrodes.
When potential between conductors is increased the gradient around the surface of conductor increases above a voltage higher than critical voltage the nearby air is ionized and there is bluish white glow around the surface of conductor. A hissing noise is also heard along with formation of ozone gas.

8.2 CRITICAL DISRUPTIVE VOLTAGE



Gradient at x

$$E_x = \frac{q}{2\pi \in_0}\left[\frac{1}{x}+\frac{1}{d-x}\right] \text{ and } V_{ab} = \frac{q}{\pi \in_0}\ln\frac{d}{r}$$

After solving

$$E_x = \frac{Vd}{x(d-x)\ln d/r} \quad \text{where v in line to neutral voltage } V = \frac{V_{ab}}{2}$$

Gradient is max when x = r

$$g_{max} = E_r = E_{max} = \frac{Vd}{r(d-r)\ln(d/r)}$$

$$= \frac{V}{r\ln d/r}$$

or $V = r\,g_{max} \ln d/r$

Critical disruptive voltage is the voltage at which disruption or break down of dielectric occurs.
This voltage corresponds to the gradient at the surface of conductor equal to strength of air.
The deflective strength of air at 25°C and 76 cm of Hg pressure is

$g_0 = 30\text{kV/cm}$ Peak

At other temperature or pressure

$g_0' = g_0\delta$

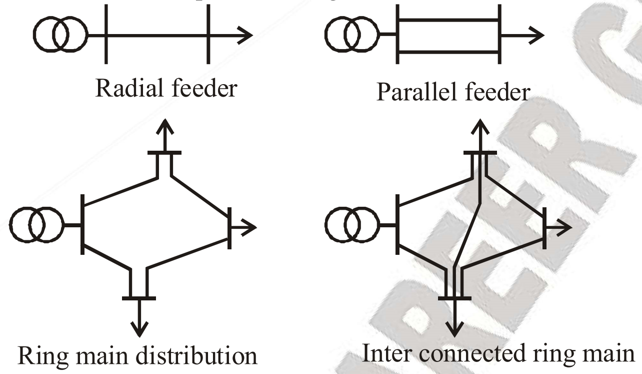
$\delta = \frac{3.92b}{273+\theta}$, where δ is called air density factor.

Where b is pressure in cm of Hg and θ is temperature in °C

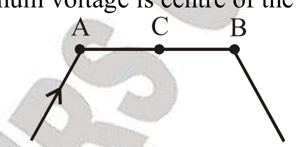
CHAPTER - 9
DISTRIBUTION SYSTEMS

9.1 INTRODUCTION
The conductor system by means of which electrical energy is converted from bulk power source to consumers is known as distribution system. Primary distribution is at voltage levels of 11kV, 6.6 kV and 3.3 kV and gives power to bulk consumers like industries.
Secondary distribution supply power to households at 400V, 3-ϕ and 230V, single phase.
The main criteria for designing of conductors for distribution are voltage drop and current carrying capacity.

9.1.1 Classification
Distribution systems are classified as per following



9.1.2 Uniform Loading
Load in considered uniformly distributed along the length of feeder. For feeder having equal voltage at both ends point of minimum voltage is centre of the feeder.



Max voltage drop from A that $V_{AC} = \frac{2rl^2}{8} = \frac{IR}{8}$

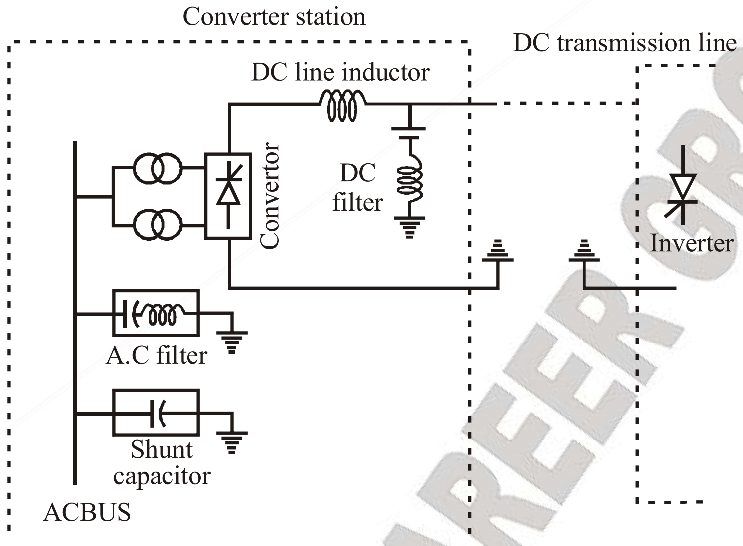
i is current in A/m
r is resistance Ω/m
l is the length of feeder
I = il
R = rl

Minimum voltage $V_C = \frac{V_A - IR}{8}$

CHAPTER - 10
HIGH VOLTAGE DC TRANSMISSION (HVDC)

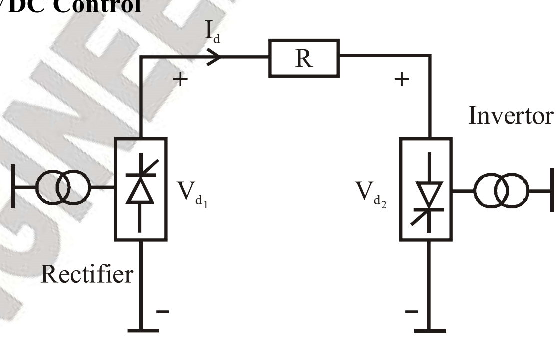
10.1 INTRODUCTION

HVDC transmission consists of two converter stations rectifier and inverter connected to each other by DC cable or overhead line. Main components and arrangement of HVDC transmission is shown below.



Transformer provides suitable voltage ratio to achieve the desired direct voltage, transformer also provide electrical separation between DC and AC systems.
DC line inductor also called smoothing inductor is used to reduce harmonics in current on DC side.
The control of converters introduces phase shift between current and voltage. Thus reactive power is consumed by converters; converter transformers two consume reactive power. This reactive power demand is almost 50-60% of transmitted reactive power. This reactive power at converter stations is supplied by shunt capacitor.

10.1.1 Principle of HVDC Control



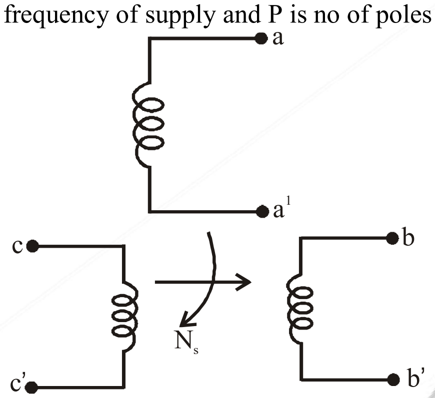
CHAPTER - 11
BASICS OF SYNCHRONOUS MACHINE & R-L CIRCUIT TRANSIENT

11.1 INTRODUCTION

1. When three windings are placed at 120° to each other in space and supply of 3-ϕ, displaced 120° in time to each other is given to such windings than a rotating magnetic field is produced which rotates with synchronous speed in the direction of positive sequence. The synchronous speed.

$$N_s = \frac{120f}{P}$$

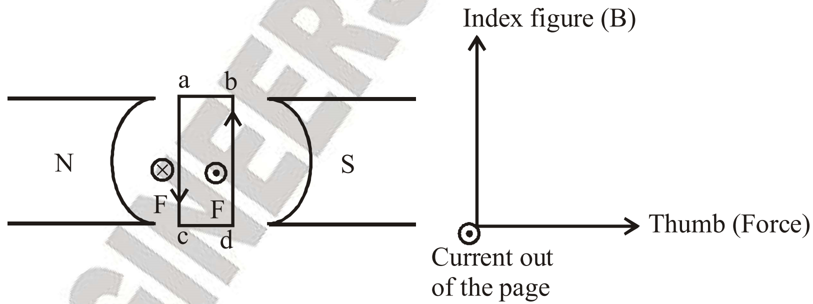
Where f is frequency of supply and P is no of poles



$V_a = V_m \sin\omega t$
$V_b = V_m \sin(\omega t - 120)$
$V_c = V_m \sin(\omega t + 120)$

2. If a conductor moves in a magnetic field than emf is induced in the conductor and if closed path is provided than due to emf current will start to flow in the conductor. The direction of current can be found by Fleming′s Right Hand Rule.

According to Fleming′s Right Hand Rule. Put the thumb of Right Hand in the direction of Force on conductor. The index figure shall be in the direction of magnetic field then middle figure will show direction of current induced.



The synchronous generator has 3-ϕ winding uniformly distributed in slots of stator. The winding are displaced in space 120° to each other.

The rotor is either cylindrical or salient pole type. The rotor is excited By D.C current. The rotor is made to run by prime mover.

CHAPTER - 12
LOAD FLOW

12.1 INTRODUCTION

Load flow is steady state solution of power system network. Load is considered as complex power and not as impedance. The variables are P, Q, |V| & δ at various buses as per nature of bus.
Load flow is useful for monitoring power system and for future planning.

Power injection at i[th] bus $S_i = S_{Gi} - S_{Di}$
Where S_{Gi} is generation at i[th] bus and S_{Di} is demand at that bus.
In general current injection at i[th] bus is

$$I_i = \sum_{k=1}^{n} Y_{ik} V_k \ i$$

Where $Y_{ik} = -y_{ik}$ $(i \neq k)$; where y_{ik} is admittance between i[th] & k[th] bus

$$Y_{ik} = \sum_{k=1}^{n} y_{ik}$$ When i = k And y_{ii} is admittance between bus and ground or datum bus

$I_{Bus} = Y_{Bus} V_{Bus}$

$$Y_{Bus} = \text{admittance bus matrix} = \begin{bmatrix} Y_{11} & Y_{11} & ....Y_{1n} \\ Y_{21} & Y_{22} & ....Y_{2n} \\ \vdots & & \\ Y_{n1} & Y_{n2} & ....Y_{nn} \end{bmatrix}$$

Y_{BUS} is a symmetric matrix hence only $\frac{n^2 - n}{2} + n = \frac{n(n+1)}{2}$ terms are to be saved.

Y_{BUS} is generally a sparse matrix i.e. having very few non-zero terms.

12.2 BUS INCIDENCE MATRIX

Bus incidence matrix is formed by graph theory and by singular transformation of primitive Y_p matrix if A is Bus incidence matrix then.

$Y_{BUS} = A^T Y_p A$

12.2.1 Effect of Adding or Removing Extra Lines in Y_{BUS}

Assuming no mutual coupling between transmission lines addition of admittance y effects four element if connected between i[th] & j[th] bus

Y_{ii} new = $y_{ii\ old} + y$

Y_{jj} new = $y_{jj\ old} + y$

$Y_{ij\ new} = y_{ji\ new} = y_{ij\ old} - y$ and y_{ji} old – y

Addition of element between i[th] bus and ground effect only

Y_{ii} i.e.

$y_{ii\,new} = y_{ii\,old} + y$

CHAPTER - 13
VOLTAGE CONTROL

13.1 INTRODUCTION

As we have seen that

$$Q_r = \frac{|V_r|}{X}\Delta V$$

Voltage drop ΔV increases if reactive power demand is increased. Increase in ΔV means that for fixed supply voltage receiving end voltage is decreased.

As we have seen in previous chapter that if loading of line is equal to surge impedance loading (SIL) than voltage remains constant over the line if loading is more than SIL than $V_r < V_s$ and for loading less than SIL, $V_r > V_s$.

Basically the voltage at any node in power system can be controlled by controlling reactive power at that node. If lagging reactive power is supplied at the node by local generator than reactive power taken through line can be maintained at specified value and thus receiving end voltage can be maintained constant.

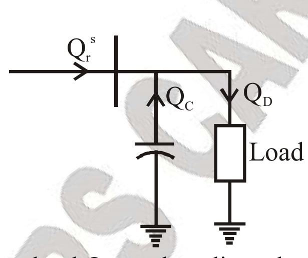
13.2 METHOD OF VOLTAGE CONTROL

1. By Changing Excitation of Generator

Sending end voltage V_s can be increased by increasing excitation of alternator.

2. By Static VAR Generators or Shunt Compensation

Capacitors known as shunt capacitors are connected at the receiving end. Capacitor is supplier of reactive power.



$Q_r^s + Q_c = Q_D$; when Q_D varies as per load Q_c can be adjusted to maintain Q_r^s constant.

For capacitor bank in Δ

$$Q_{C3-\phi} = \frac{3|V_r|^2}{X_c}\text{MVAR}$$

Where V_r is line voltage in kV

When capacitor bank in Y

$$Q_{c\,3-\phi} = \frac{|V_r|^2}{X_C}\text{MVAR}$$

Some times at light loads V_r becomes greater then V_s in such situations to keep V_r constant. Inductors are connected at receiving end to lower V_r

$$Q_{L3-\phi} = \frac{3|V_r|^2}{x_L}\text{MVAR} \quad \text{for } \Delta$$

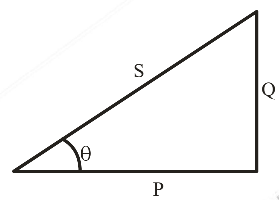
CHAPTER - 14
POWER FACTOR CORRECTION

14.1 INTRODUCTION

Almost 70% load on power system is inductive. The more the load is inductive the poorer the power factor becomes. Low power factor means high current for same amount of real power, High current causes over heating of conductors, large ohmic losers and considerable voltage drop. Hence it is desired to improve the power factor of load.

Inductive load absorbs reactive power. If required reactive power can be supplied locally to the load than power factor of such load will remain same but the power factor of current supplied will change because of less reactive power flow from supply to load.

In terms of powers the power factor angle is shown in power triangle below.



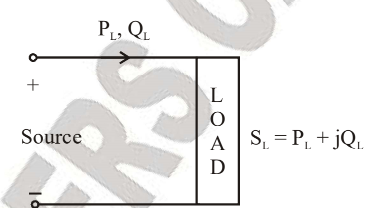
Here S is complex power, P is active or real power and Q is reactive power

$S = p + jQ$

The power factor angle $\theta = \tan^{-1}\dfrac{Q}{P}$

For large value of Q the angle θ will be more for same P $\Rightarrow$ Power factor cosθ ↓

Let us consider an inductive load demanding Q_L reactive power. Whole reactive power is supplied through source i.e. $Q_S = Q_L$



Now the power factor angle of source current is

$$\theta = \tan^{-1}\frac{Q_L}{P_L}$$

Capacitor is generator of reactive power. If capacitor is connected across load and supplies Q_C reactive power than p reactive power supplied from source $Q_S = Q_L - Q_C$ and for same real power of load the power factor angle of source current

$$\theta' = \tan^{-1}\frac{Q_L - Q_C}{P_L}$$

We can see $\theta' < \theta \Rightarrow \cos\theta' > \cos\theta$ and hence power of source current in improved.

Reactive power supplied by capacitor C at frequency f is

CHAPTER - 15
ECONOMIC LOAD DISPATCH

15.1 INTRODUCTION
Economic Load dispatch has the aspects

1. Unit commitment

This is pre dispatch issue where in it is required optimal selection of generating units out of pool of generators to meet expected load.

2. Dispatch

where in out of selected generating stations load is distributed in such a way so as reduce overall operating cost.
The cost of generation is not fixed for particular load demand but depend upon the operating constraints of the sources.

15.2 SYSTEM CONSTRAINT
15.2.1 Equality Constraint
$\Sigma P_{G_i} = \Sigma P_{D_i} + P_L$

$\Sigma Q_{G_i} = \Sigma Q_{D_i} + Q_L$

P_L and Q_L are real reactive power loss

15.2.2 Inequality Constraints
1. Generator Constraints

$P_i^2 + Q_i^2 \le S_p^2$

Where s_p is prespecipied KVA loadings
The max P_i is limited by temperature limits and minimum P_i by flame instability of boiler.

$P_{i_{min}} \le P_p \le P_{i_{max}}$

Max Q_i is limited by overheating of rotor winding and min Q_i due to stability limit.

$Q_{i_{min}} \le Q_i \le Q_{i_{max}}$

2. Voltage Constraints

$|V_{imin}| \le V_i \le |V_{imax}|$

$\delta_{imin} \le \delta_i \le \delta_{max}$

3. Running Spare Capacity Constraints

Total Generation $G \ge P_i + Ps_0$

4. Transmission Line Constraint

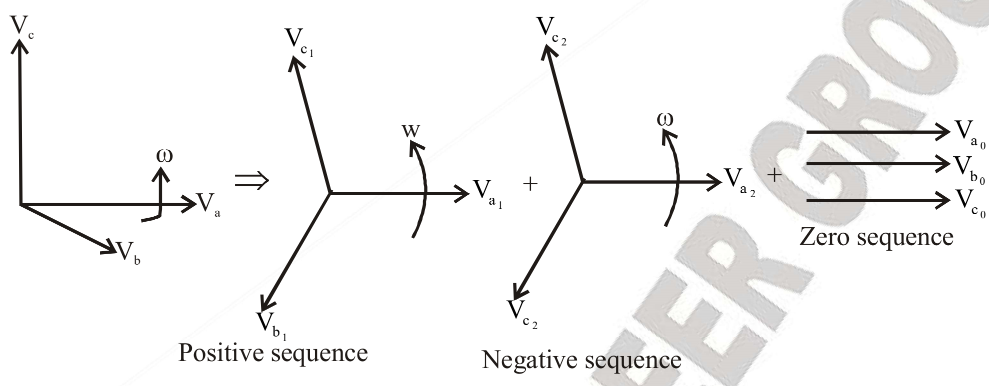
$C_i \le C_{i_{max}}$ where c_i is loading capacity of line

5. Transformer tap settings also are constraints

15.3 GENERATOR OPERATING COST
Only fuel cost for thermal & nuclear is considered. The input energy rate $Fi(P_{G_i})$ in Mkcal/h or cost of fuel $C_i(P_{G_i})$ Rs/h is function of P_G as sown

CHAPTER - 16
SYMMETRICAL COMPONENTS & SEQUENCE NETWORKS

16.1 FORTESCUE'S THEOREM
An unbalanced set of n phasors may be resolved into (n – 1) balanced n-phase system of different phase sequence and one zero sequence system. As per this theorem the unbalanced three phase may be resolved in 2 balanced 3-phase system one of which is positive sequence (Having same sequence that of unbalanced), Negative sequence (Having sequence positive to that of unbalanced) and zero sequence.



$V_a = V_{a1} + V_{a2} + V_{a0}$

$V_b = V_{b1} + V_{b2} + V_{b0}$

$V_c = V_{c1} + V_{c2} + V_{c0}$

The voltages V_{a1}, V_{a2} & V_{a0} etc are called symmetrical components. The calculation of symmetrical component phasor is made in terms of 'a' as the symmetric phase.

16.2 λ-OPERATOR
The phasor λ is an operator which when operates upon a phasor rotates it by + 120° without changing magnitude.

$\lambda = 1 \angle 120°$

16.2.1 Properties of λ
1. $\lambda = 1 \angle 120° = \cos 120 + j \sin 120$

$\Rightarrow \lambda = -0.5 + j\,\frac{\sqrt{3}}{2}$

2. $\lambda^2 = 1 \angle 240° = 1\angle -120° = -0.5 - j\frac{\sqrt{3}}{2}$

3. $\lambda^3 = 1 \angle 360° = 1 \angle 0° = 1$

4. $\lambda^3 - 1 = 0$

$\Rightarrow (\lambda - 1)(\lambda^2 + \lambda + 1) = 0$

$\Rightarrow \lambda^2 + \lambda + 1 = 0$

5. $\lambda^* = \lambda^2$

6. $\lambda^4 = \lambda$

CHAPTER - 17
SYMMETRICAL FAULT ANALYSIS

17.1 INTRODUCTION

Generally, the power system works is balanced condition. When a 3-ϕ short circuit occurs, then currents become very high and voltages reduce, still the system remains balanced, such fault are known as symmetrical fault and are severest.

17.1.1 Types of Symmetrical Fault

Symmetrical fault are of the two type.
1. 3-phases coming together or LLL fault.
2. 3-phase touching ground simultaneously or LLLG fault.

The circuit breakers are designed to the limit of short circuit of 3-ϕ.

17.1.2 Purpose of Fault Analysis

The purpose of fault analysis includes:
1. To determine fault voltage and current at different point of power system so that rating of circuit breakers may be determined.
2. Fault analysis helps is selecting appropriate scheme for protective relaying.

Faults may cause severe effects on power system like excessive currents cause heating and rupture of insulation.

In fault analysis certain assumptions are made, which include:
(i) Series resistances of components are neglected.
(ii) Shunt elements of transformers and lines are neglected.
(iii) Normal load currents are neglected i.e. before fault the system is considered open circuited and pre fault voltage at the fault point is taken as $1 \angle 0°$ p.u. This is known as flat profile.

17.2 SHORT CIRCUIT CAPACITY

Short circuit capacity of a network is defined as product of magnitude of pre fault voltage and post fault current.

$SCC \triangleq V^{\circ} |I_F| VA$.

For three phase

$\sqrt{3} V_{lb} I_F = SSC$ in all three phase

If Z_T is the impedance from voltage source to fault point then

$$Z_{T_{p.u}} = \frac{I_b Z_T}{V_b}$$

Now short circuit current $I_{sc} = \frac{V_b}{Z_T}$

$$\therefore \; Z_{T_{p.u}} = \frac{I_b Z_T}{V_b} = \frac{I_b}{I_{sc}} = \frac{V_b I_b}{I_{sc} V_b}$$

$I_{sc} V_b$ is SCC, hence

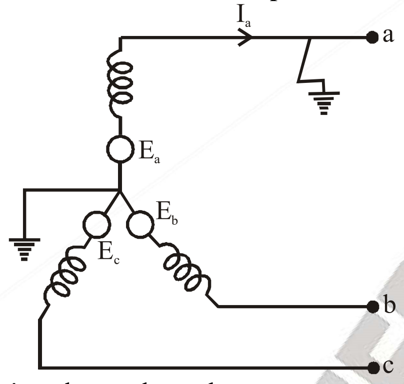
$$S.C.C = \frac{S_b}{Z_{T_{p.u.}}}$$

CHAPTER - 18
UNSYMMETRICAL FAULT ANALYSIS

18.1 INTRODUCTION

In unsymmetrical fault the system becomes unbalanced and symmetrical components are used for analysis.

18.1.1 Single Line to Ground Fault without Fault Impedance



Let fault takes place at phase 'a' as shown above then

$V_a = 0$

$I_b = I_c = 0$

Sequence network equation is

$V_{a_0} = -I_{a_0} Z_0$

$V_{a_1} = E_a - I_{a_1} Z_1$

$V_{a_2} = -I_{a_2} Z_2$

$$\begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda & \lambda^2 \\ 1 & \lambda^2 & \lambda \end{bmatrix} \begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix}$$

$$\Rightarrow I_{a_0} = \frac{I_a}{3} = I_{a_1} = I_{a_2}$$

$V_a = 0 = V_{a_1} + V_{a_2} + V_{a_0}$

$\Rightarrow E_a - I_{a_1} Z_1 - I_{a_2} Z_2 - I_{a_0} Z_0 = 0$

$$E_a = I_{a_1}\left(Z_1 + Z_2 + Z_0\right) \Rightarrow I_{a_1} = \frac{E_a}{Z_1 + Z_2 + Z_0}$$

$I_n = I_a = 3I_{a_0}$

If neutral is not grounded then $I_{a_0} = I_{a_1} = I_{a_b} = 0$

Hence if neutral is not grounded then fault current is zero

For neutral grounded through Z_n

CHAPTER - 19
POWER SYSTEM PROTECTION

19.1 INTRODUCTION

1. Protective Relay

A relay is an automatic device which senses an abnormal condition in an electric circuit and closes its contacts, which in turn close the circuit breaker trip coil circuit, thereby, it opens the CB and faulty part of the electric circuit is disconnected from system.

2. Pick up level

The value of actuating quantity above which relay operates.

3. Reset level

The value of actuating quantity below which relay comes in original position.

4. Operating time

The time between the instant when actuating quantity exceeds pick up value to the instant when relay contacts close.

5. Reach

The area of protection is called reach.

19.2 FUNCTIONAL CHARACTERISTIC OF RELAY

1. Reliability

Relay should operate when required.

2. Selectivity

Relay shall sense as to which part is faulty and which is not.

3. Speed

It must operate at required speed.

4. Sensitivity

It Shall be sensitive.

6. Unit system of protection

In this system protection responds to faults within its own zone and does not make note of condition elsewhere for example Protection of Generator, transformers and BUS bars.

7. Non unit system of protection

In this type selectivity is obtained by current and time grading of the relays at different location for example protection of feeders.

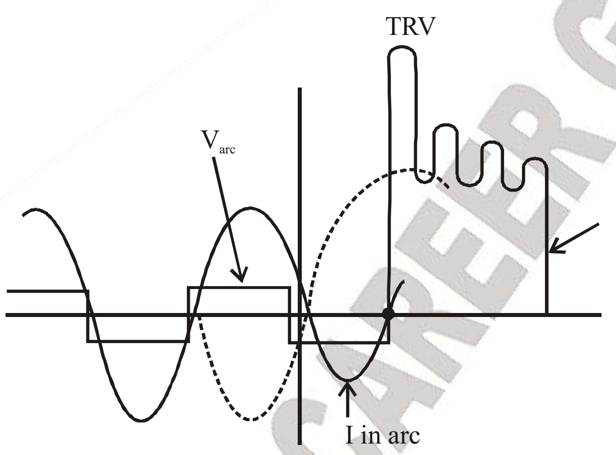
8. Universal torque equation

The universal torque equation for various relays is

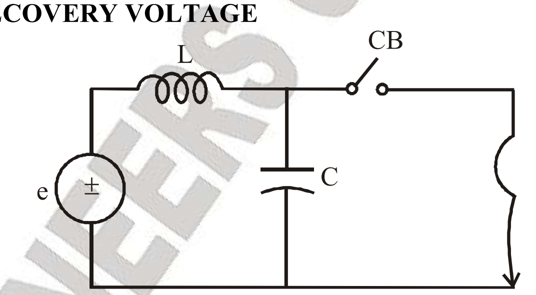
$T = K_1 I^2 + K_2 V^2 + K_3 VI\cos(\theta - \tau) + K_4$.

CHAPTER - 20
CIRCUIT BREAKERS

20.1 INTRODUCTION
During fault protective relay energizes the trip circuit of the circuit breaker causing its moving poles to separate from fixed poles. As poles separate electric arc is formed in the air gap feeding the current. For A.C. arc would extinguish at zero current and if it does not strike, the breaker opens successfully. The voltage across the breaker poles is almost constant during arcing phase and after arc is extinguished the ac system voltage appears across poles of circuit breakers.
The voltage opening across the poles when arc extinguishes is known as recovery voltage. Due to inductance and capacitance between source and fault point, transients appear at the time of interruption of current. The voltage across CB in transient period is called transient recovery voltage (TRV). The peak value of TRV may be doubled that of normal voltage, which may cause are to restrike.



20.2 TRANSIENT RECOVERY VOLTAGE



Voltage across CB is voltage across capacitor.
By Laplace transformation the network is redrawn below.

CHAPTER - 21
POWER SYSTEM STABILITY

21.1 INTRODUCTION
Power system stability is the ability of power system to return to normal operating condition after disturbance or in other words ability to remain in synchronism.

1. Steady State Stability
The maximum load which can be supplied when loading is increased gradually is the steady state stability of the system.

2. Dynamic Stability
Dynamic stability is the stability due to small disturbances, amplitude of oscillation is less and die out quickly No fear of loss of synchronism.

3. Transient Stability
Transient stability is under large sudden disturbance like faults. Due to severe disturbance there is fear of loss of synchronism if disturbance not resolved in very short time i.e. with 1 or 2 second.

21.2 DYNAMICS OF SYNCHRONOUS MACHINE
Kinetic energy of rotor

$$\text{K.E.} = \frac{1}{2}J\omega_{sm}^2$$

ω_{sm} is synchronous speed

$\omega_s = \frac{P}{2}\omega_{sm}$ where ω_s is speed in elect rad/sec

P = number of poles in the machine

$$\text{K.E} = \frac{1}{2}\left(J\left(\frac{2}{P}\right)^2 \omega_s\right)\omega_s$$

$$= \frac{1}{2}M\omega_S$$

Where $M = J\left(\frac{2}{P}\right)^2 \omega_s =$ moment of inertia in J-s/ elect read

Now inertial constant H such that

$$\text{K.E} = GH = \frac{1}{2}MW_s$$

Where G is Machine rating in VA

H = inertia constant in J/VA or W –s/VA

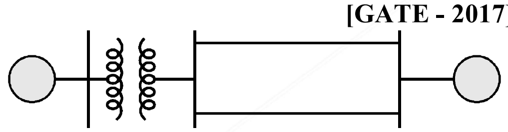
$$M = \frac{2GH}{\omega_s} = \frac{GH}{\pi f} \text{J} - \text{s / elect rad}$$

$$M = \frac{GH}{180f} \text{ J-s / elect degree}$$

GATE QUESTIONS

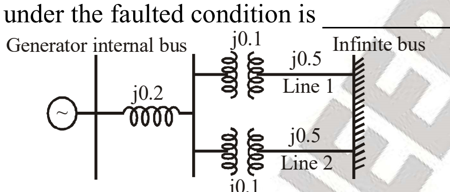
1. The figures shows the single line diagram of a power system with a double circuit transmission line. The expression for electrical power is 1.5 sinδ, where δ is the rotor angle. The system is operating at the stable equilibrium point with mechanical power equal to 1 pu. If one of the transmission line circuits is removed, the maximum value of δ, as the rotor swings is 1.221 radian. If the expression for electrical power with one transmission line circuit removed is P_{max} sinδ, the value of P_{max}, in pu is ________.

[GATE - 2017]



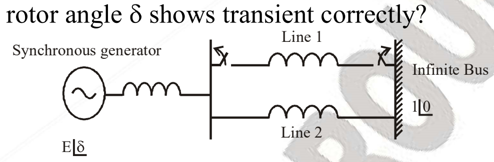
2. The single line diagram of a balanced power system is shown in the figure. The voltage magnitude at the generator internal bus is constant and 1.0 p.u. The p.u. reactances of different components in the system are also shown in the figure. The infinite bus voltage magnitude is 1.0 p.u. A three phase fault occurs at the middle of line 2.

The ratio of the maximum real power than can be transferred during the pre-fault condition to the maximum real power that can be transferred under the faulted condition is __________.

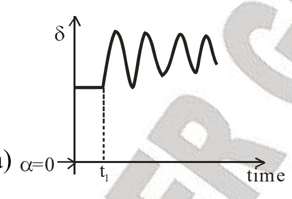


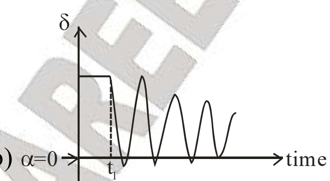
[GATE - 2016]

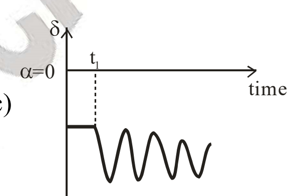
3. The synchronous generator shown in the figure is supplying active power to an infinite bus via short, lossless transmission lines, and is initially in steady state. The mechanical power input to generator and the voltage magnitude E are constant. if one line is tripped at time t_1 by opening circuit breakers at the two ends (although there is no fault), then it is seen that the generator undergoes a stable transient. Which one of the following waveforms of the rotor angle δ shows transient correctly?

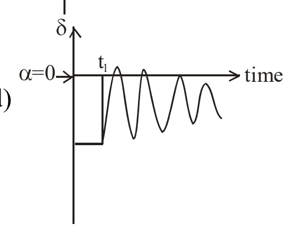


[GATE - 2015]

(a)


(b)


(c)


(d)


4. A sustained three phase fault occurs in the power shown in the figure. The current and voltage phasor during the fault (on a common reference), after the natural transients have died

CHAPTER - 22
LOAD FREQUENCY CONTROL

22.1 INTRODUCTION

Due to following reasons system frequency shall remain in striet limits.

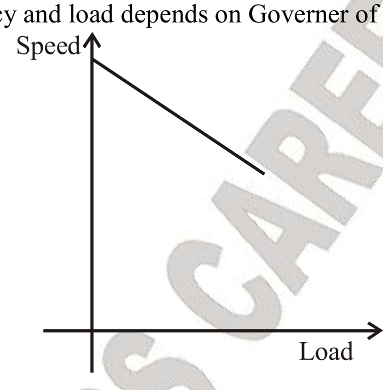
1. Speed of A.C. motors is directly related to frequency.
2. The electric clocks are driven by synchronous motors.
3. For frequency outside of range turbine blades may damage.
4. For low frequency the flux required in core increases in transformers and core may saturate.
5. In thermal power plant with reduced frequency the blast of fan decreases ⇒ generation ↓ and this again reduced blast of fan which becomes a cumulative process and the power system may shutdown consequently.

22.1.1 With Increase in Load

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

If P_e ↑ then acceleration ↓ and speed reduce thus frequency ↓. This is sensed by load frequency controller and steam input is increased by valve control mechanism thus meeting increased load.

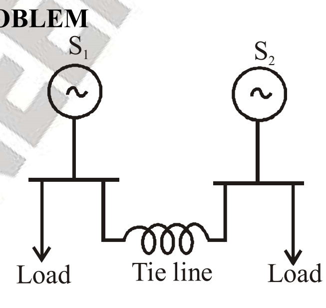
The control of system frequency and load depends on Governer of prime movers.



Governor Characteristic

Governor Characteristic is also called drop characteristic or droop characteristic.

22.2 LOAD-FREQUENCY PROBLEM



SOLUTIONS

Sol. 1. (a)

Sol. 2. (a)

Sol. 3. (b)
Using load frequency controller, the change in frequency and the tie-line real power are sensed which is a measure of the change in rotor angle θ. Hence, Option (b) is correct.

Sol. 4. (b)
$\Delta f_{pu} = -R\Delta P_{pu}$

$= -\frac{0.01}{50}\ R = 6\% = 0.06\ = -\frac{0.01}{50} = -0.06\times\Delta P_{pu}$

$\Delta P_{pu} = 3.33 \times 10^{-3}$ pu
$\Delta P = 120 \times 3.33 \times 10^{-3}$
= 0.4 MW
Hence, option (b) is correct.

Sol. 5. (d)

Sol. 6. (d)

Sol. 7. (b)
Unit of frequency bias coefficient is MW/Hz.

Sol. 8. (d)
Time constant of automatic load frequency control is about 20s.

Sol. 9. (d)

Sol. 10. (b)

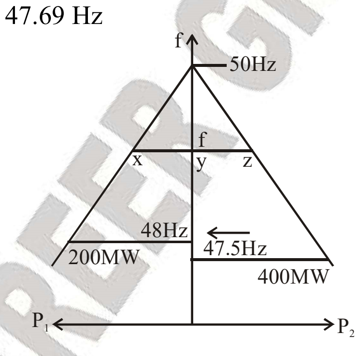
Xy + yz = 600 MW, $\frac{xy}{50-f} = \frac{200}{2}$

$\therefore$ xy = 100 (50 – f) …. (i)

$\frac{yz}{(50-f)} = \frac{400}{2.5} = 160$

$\therefore$ yz = 160 (50 – f) …. (ii)

From equation (i) and (ii),
Xy + yz = (50 – f) 260 = 600
$\Rightarrow$ f = 47.69 Hz



Sol. 11. (a)

$\Delta P_D = -\left(D + \frac{1}{R}\right)\Delta f$

$\therefore\ D + \frac{1}{R} = 2 + \frac{1}{0.025} = 42\,\text{MW/Hz}$

Where, Δf is change in frequency and ΔP_D is change in load demand.