

where,
 Torque = Torque due to mechanical losses
 Four-Motor output
 M = Mechanical power developed
 N = Motor speed.

4. THREE PHASE SYNCHRONOUS MACHINES

Voltage Regulation of Alternator or Synchronous Generator
Calculation of synchronous reactance
 open circuit voltage per phase
 short circuit armature current
 $X_s = \frac{V}{I_s}$
 % Regulation = $\frac{E_0 - V}{V} \times 100$
 For Varying Load = $\frac{E_0 - V}{V}$
 $Z_s = \frac{E_0 - V}{AC \text{ (in amperes)}}$
 No-load induced emf
 V = Terminal voltage

6. SINGLE PHASE TRANSFORMER

Self-Induction = $-L \frac{di}{dt}$
Mutual Induction = $-M \frac{di}{dt}$
E.M.F. Equation of A Transformer
 Let N_1 = No. of turns in primary
 N_2 = No. of turns in secondary
 Φ_m = Maximum flux in core in weber = $B_m X A$
 f = Frequency of a.c. input in Hz
 $E_1 = 4.44 N_1 \Phi_m = 4.44 N_1 B_m A \dots (i)$
 $E_2 = 4.44 N_2 \Phi_m = 4.44 N_2 B_m A \dots (ii)$
Voltage Transformation Ratio
 $\frac{E_1}{E_2} = \frac{N_1}{N_2} = K$
Transformer on No-Load
 Working or iron loss component $I_w = I_0 \cos \phi_0$
 magnetizing component $I_m = I_0 \sin \phi_0$
 No load current $I_0 = \sqrt{I_w^2 + I_m^2}$
Equivalent Circuit Parameter
 $R_1' = \frac{R_1}{K}$, $X_1' = \frac{X_1}{K}$, $R_2' = \frac{R_2}{K}$, $X_2' = \frac{X_2}{K}$
Test on Transformer:
Open-circuit or No-load Test
 $W = I_0^2 R_{oc}$, $\cos \phi_0 = W / I_0^2 V$
 $I_w = I_0 \cos \phi_0$, $I_m = I_0 \sin \phi_0$
 $X_0 = \frac{V}{I_m}$, and $R_0 = \frac{W}{I_w^2}$
 $X_0 = \sqrt{R_0^2 + R_{sc}^2}$
Short-circuit or Impedance Test
 $R_{sc} = \frac{W_{sc}}{I_{sc}^2}$, also $W = I_{sc}^2 R_{sc}$
 $R_{sc} = W / I_{sc}^2$
 $X_{sc} = \sqrt{R_{sc}^2 + R_0^2}$
Losses in a Transformer
 (1) Core or Iron Losses
 (a) hysteresis loss $W_h = \eta B^2 f$ watt
 (2) eddy current loss $W_e = \eta^2 B^2 f^2$ watt
 Total Cu loss = $I_1^2 R_1 + I_2^2 R_2 = I_1^2 R_1 + I_2^2 R_2$
Efficiency of A Transformer
 Efficiency = $\frac{\text{output}}{\text{input}}$
 $E = V + I R_1 + I X_1$
 $E = V + I R_2 + I X_2$
 $E = V + I R_0 + I X_0$
 E = EMF induced on load
 V = Terminal voltage, I is vectorially less than E_0 (no-load emf) by ϕ_0
 I = Armature current per-phase.
 ϕ_0 = Voltage drop in an alternator.

5. THREE PHASE SYNCHRONOUS MOTOR:

synchronous motor speed
 $N_s = \frac{120}{P}$
 • N_s = frequency of the AC current (Hz)
 • P = total number of poles per phase
Power Developed by a Synchronous Motor
 $P_g = \frac{E_f V}{X_s} \sin \delta$
 Where,
 V = Supply voltage
 E_f = back emf / phase
 δ = load angle
 $Z_s = R_s + j X_s$ = Synchronous impedance

Zero Power Factor or Potier Triangle Method
 $Z_s = \frac{V}{I_s}$
 $X_s = \frac{V}{I_s} \sin \delta$
 $R_s = \frac{V}{I_s} \cos \delta$
Unity Power Factor Load
 $E_0 = \sqrt{V^2 + I_a^2 X_s^2} + I_a R_s$
Lagging Power Factor Load
 $E_0 = \sqrt{V^2 + I_a^2 X_s^2} + I_a R_s + I_a X_s \cos \phi$
Leading Power Factor Load
 $E_0 = \sqrt{V^2 + I_a^2 X_s^2} + I_a R_s - I_a X_s \cos \phi$
Coil Span Factor or Pitch Factor:
 $K_p = \cos \frac{\alpha}{2}$
Distribution Factor or Breadth Factor
 $K_d = \frac{\sin \frac{m\alpha}{2}}{m \sin \frac{\alpha}{2}}$
relationship between induced emf E and the terminal voltage V
 $E = V + I_a R_s + I_a X_s$
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Weight of copper in autotransformer W_a is equal to $(1 - K) \times$ Weight of copper in two-winding transformer W_2 . Therefore, the weight of copper savings is,
 $W_2 - W_a = (1 - K) W_2$
 $W_a = K W_2$
 $K =$ Weight of copper in a two-winding transformer.
 $K = \frac{N_2}{N_1 + N_2}$
 $N_1 =$ No. of Stator poles (teeth)
 $N_2 =$ No. of Rotor poles (teeth)
 $m =$ No. of stator phases

Concept of S.M.R. and G.M.D
 Concept of S.M.R. and G.M.D for capacitance calculations
 $C = \frac{2\pi\epsilon_0}{\ln \frac{D}{r}}$
 Where,
 C = Line capacitance
 ϵ_0 = Permittivity of free space
 G.M.D = Geometrical Mean Distance
 G.M.D = Geometrical Mean Radius
Capacitance of three phase line with symmetrical spacing:
 $C_s = \frac{2\pi\epsilon_0}{\ln \frac{D}{r}}$ F/m
Unsymmetrical spacing:
 $C_s = \frac{2\pi\epsilon_0}{\ln \frac{D_{12} D_{23} D_{31}}{D^3}}$ F/m
 $d_1, d_2, d_3 =$ Conductor spacings
GMR (self GMD):
 • total no. of individual wires = $3n(1 + 1) + 1$
 • Where n = Number of Layers
 Inductance per conductor per meter
 $L = 10^{-7} (0.5 + 2.3 \log \frac{D}{r})$

For single circuit 3 phase line:
 Inductance per conductor per meter = $2 \times 10^{-7} \log \frac{D_m}{D_s}$
 Where, $D_m = 0.7788 r$ and $D_s = \sqrt[3]{D_{12} D_{23} D_{31}}$
Double circuit 3 phase line:
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3. OVERHEAD LINES UNDERGROUND
 For single phase line:
 Inductance per conductor per meter = $2 \times 10^{-7} \log \frac{D_m}{D_s}$
 Where, $D_m = 0.7788 r$ and $D_s = \sqrt[3]{D_{12} D_{23} D_{31}}$
 If w is the weight per unit length of the conductor, then,
 $\frac{1}{2} \frac{Tb}{w}$

String efficiency
 $\eta_s = \frac{1}{n} \frac{Tb}{w}$
Classification of Underground Cables:
 • Low-tension (L.T.) cables - up to 1000 V
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 • Insulation resistance of cable:
 $R = \frac{\rho}{2\pi l} \ln \frac{R_2}{R_1}$
 Where R_1 & R_2 inner & outer radius of cable m.
 l = Length of cable in m.

Power Flow in Silent pole SYNCHRONOUS Machine
 $P = \frac{E_f V}{X_s} \sin \delta$
 Where, $\frac{E_f V}{X_s} \sin \delta =$ Electromagnetic power
The reluctance power is given by,
 $P_{reluctance} = \frac{1}{2} \left(\frac{E_f}{X_s} \right) \sin 2\delta$
Stepper Motor - Step Angle β
 • $\beta = \frac{360}{N_s - N_r}$ is 90°
 • Most commonly used - $1.8^\circ, 2.5^\circ, 7.5^\circ, 15^\circ$
 $\beta = \frac{360}{N_s - N_r} \times 360^\circ$
 $N_s =$ No. of Stator poles (teeth)
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KVA Rating AUTOTRANSFORMER
 $\frac{S_{auto}}{S_{2w}} = \frac{1-K}{1}$
 $\frac{S_{auto}}{S_2} = \frac{1-K}{1}$
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POWER SYSTEM ANALYSIS
1. ECONOMICS OF POWER SYSTEM
 Demand factor = $\frac{\text{maximum demand}}{\text{connected load}}$
 Let N_1 = No. of turns in primary
 N_2 = No. of turns in secondary
 Φ_m = Maximum flux in core in weber = $B_m X A$
 f = Frequency of a.c. input in Hz
 $E_1 = 4.44 N_1 \Phi_m = 4.44 N_1 B_m A \dots (i)$
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6. PERFORMANCE OF TRANSMISSION LINES
Short transmission line:
 $A = D + 1 + \frac{2T}{D}$, $B = 2C \sqrt{1 + \frac{2T}{D}}$
Medium transmission line:
 1. "Nominal π " - The ABCD constant of the nominal π -circuit model of a medium line are:
 $A = D = 1 + \frac{ZY}{2}$
 $B = Z \left(1 + \frac{ZY}{4} \right)$
 $C = Y$
 ABCD parameters of a long transmission line
 $A = \cosh \gamma l$
 $B = Z_0 \sinh \gamma l$
 $C = \sinh \gamma l$
 $D = \cosh \gamma l$

2. TYPES OF POWER POTENTIAL
 Hydro Power Potential
 $P = \rho g Q H$
 Where
 P = Power available in watt
 Q = flow or discharge (m³/s)
 H = height of fall of water
 $P = 9.81 \times 1000 \times Q \times H \times \eta$
 $P = 9.81 Q H \eta$ kW
 where η = efficiency of the assembly
Specific speed of a turbine
 $N_s = \frac{N \sqrt{P}}{H^{5/4}}$
Comparison of Turbines

Turbine	Head (m)
Kaplan	30 to 70
Francis	40 to 400
Pelton	>400 m

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 ϵ_0 = Permittivity of free space
 G.M.D = Geometrical Mean Distance
 G.M.D = Geometrical Mean Radius
Capacitance of three phase line with symmetrical spacing:
 $C_s = \frac{2\pi\epsilon_0}{\ln \frac{D}{r}}$ F/m
Unsymmetrical spacing:
 $C_s = \frac{2\pi\epsilon_0}{\ln \frac{D_{12} D_{23} D_{31}}{D^3}}$ F/m
 $d_1, d_2, d_3 =$ Conductor spacings
GMR (self GMD):
 • total no. of individual wires = $3n(1 + 1) + 1$
 • Where n = Number of Layers
 Inductance per conductor per meter
 $L = 10^{-7} (0.5 + 2.3 \log \frac{D}{r})$

String efficiency
 $\eta_s = \frac{1}{n} \frac{Tb}{w}$
Classification of Underground Cables:
 • Low-tension (L.T.) cables - up to 1000 V
 • High-tension (H.T.) cables - up to 33,000 V
 • Super-tension (S.T.) cables - from 22 kV to 33 kV
 • Extra high-tension (E.H.T.) cables - from 33 kV to 66 kV
 • Extra super voltage cables - beyond 132 kV
 • Insulation resistance of cable:
 $R = \frac{\rho}{2\pi l} \ln \frac{R_2}{R_1}$
 Where R_1 & R_2 inner & outer radius of cable m.
 l = Length of cable in m.

Weight of copper in autotransformer W_a is equal to $(1 - K) \times$ Weight of copper in two-winding transformer W_2 . Therefore, the weight of copper savings is,
 $W_2 - W_a = (1 - K) W_2$
 $W_a = K W_2$
 $K =$ Weight of copper in a two-winding transformer.
 $K = \frac{N_2}{N_1 + N_2}$
 $N_1 =$ No. of Stator poles (teeth)
 $N_2 =$ No. of Rotor poles (teeth)
 $m =$ No.

Instrument Transformer
Nominal ratio: It is the ratio of rated primary winding current (voltage) to the rated secondary winding current (voltage).
For CT: $K_r = \frac{\text{rated primary winding current}}{\text{rated secondary winding current}}$
For PT: $K_r = \frac{\text{rated primary winding voltage}}{\text{rated secondary winding voltage}}$
Turns ratio: This is defined as the ratio of number of turns in secondary winding to number of turns in primary winding.
Burden of an Instrument Transformer:
The rated burden is the volt ampere loading which is permissible without errors exceeding the particular class of accuracy.
Total secondary wdg burden (secondary wdg induced voltage)² / Impedance of sec. wdg voltage / (secondary wdg induced voltage)² * Impedance of load on sec. wdg

MEASUREMENT OF POWER AND ENERGY
THREE PHASE REAL POWER MEASUREMENTS
The three phase real power is given by $P_{3\phi} = 3 V_{ph} I_{ph} \cos \theta$
 $P_{3\phi} = \sqrt{3} V_L I_L \cos \theta$
• Variation of wattmeter readings with load PF (lag)

Wattmeter	Reading	Power Factor
W1	$W_1 = V_L I_L \cos \theta$	1.0
W2	$W_2 = V_L I_L \cos \theta$	1.0
W3	$W_3 = V_L I_L \cos \theta$	1.0

DC & AC BRIDGES
DC Bridge
Wheatstone's Double Bridge Method

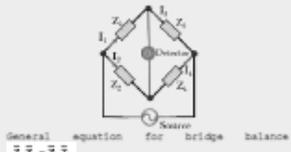
At balance: $R = \frac{P}{Q} \times S = \frac{P}{P+Q+R} \times \left(\frac{P}{Q}\right)$

Sensitivity of Wheatstone bridge
 $S_s = \frac{d}{dR} \left(\frac{S_1 R}{R+S_1} \right) \times \frac{1}{(R+S_1)^2}$
 $S_s = \frac{S_1 R}{Q^2 + 2 + \frac{R}{S_1}}$
Where, S_1 = Voltage sensitivity of galvanometer, mm/volt
 E = Bridge voltage
 R, Q = Branch resistance
 d = Deflection of galvanometer, mm
For a bridge with equal arms
 $S_s = \frac{S_1 E}{4}$
 $S_p = \frac{S_1 E}{4}$
Note: For maximum bridge sensitivity $\frac{P}{Q} = \frac{R}{S_1} = 1$

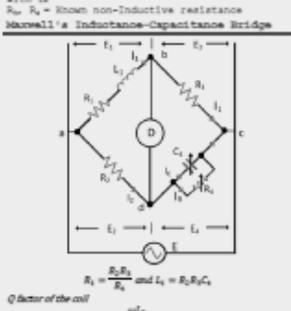
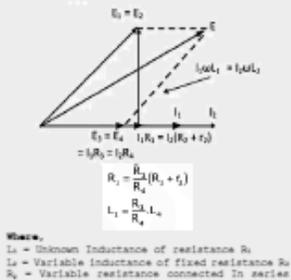
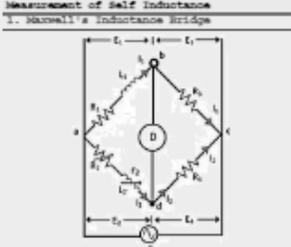
AC Bridges
Used to measure self inductance, Mutual inductance, capacitance, and frequency.
General equation for bridge balance
 $Z_1 Z_2 = Z_3 Z_4$
Magnitude condition $|Z_1| |Z_2| = |Z_3| |Z_4|$
Angle condition
Depending upon the frequency, different null detectors are used

Vibration galvanometer	5 Hz to 1 kHz
Head phones	150 Hz to 4 kHz
Tuned amplifier	1 kHz to 100 kHz
Detector	100
Galvanometer	frequency = 50 Hz

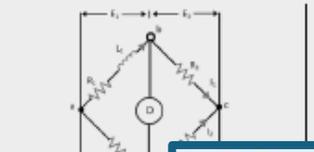
3. Ray's Bridge
 $Q \text{ factor of the coil} = \frac{\omega L}{R} = \omega C R_s$
 $Q = \frac{\omega L}{R_s} \text{ and } L_s = R_s R_2 C_s$



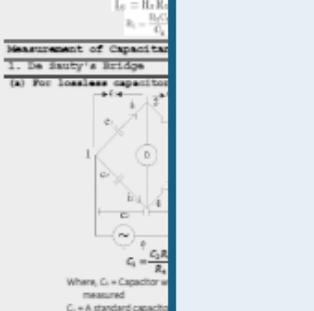
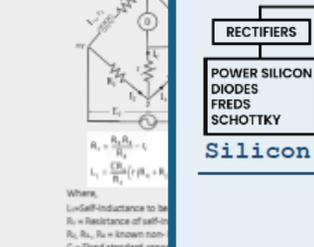
1. Maxwell's Inductance Bridge
Where, L_1 = Unknown inductance
 R_1, R_2, R_3 = known non-inductive resistances
 C_1 = Standard capacitor



3. Ray's Bridge
 $Q \text{ factor of the coil} = \frac{\omega L}{R} = \omega C R_s$
 $Q = \frac{\omega L}{R_s} \text{ and } L_s = R_s R_2 C_s$



4. Anderson's Bridge
Where, L_1 = Unknown inductance
 R_1, R_2, R_3, R_4 = known non-inductive resistances
 C_1 = Standard capacitor

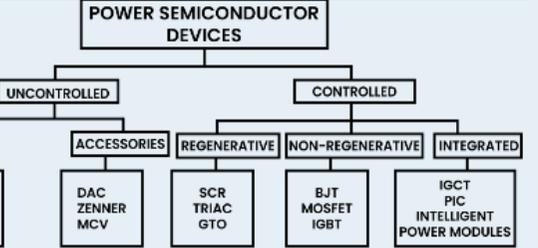


3. Ray's Bridge
 $Q \text{ factor of the coil} = \frac{\omega L}{R} = \omega C R_s$
 $Q = \frac{\omega L}{R_s} \text{ and } L_s = R_s R_2 C_s$

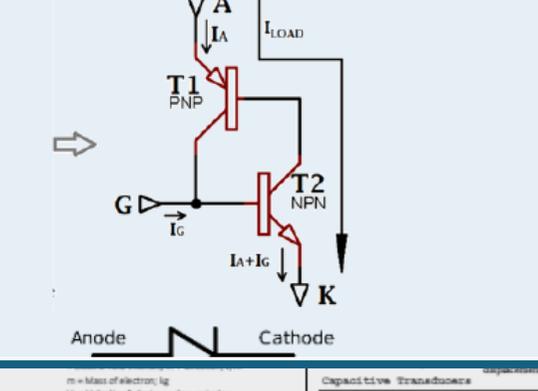
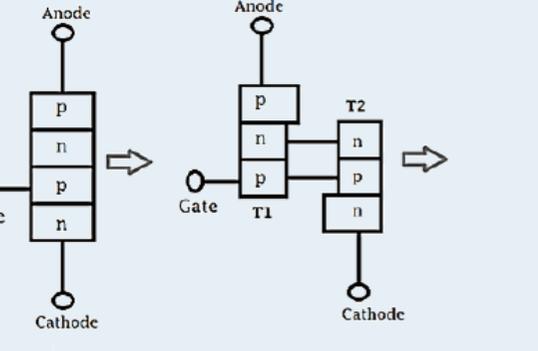
POWER ELECTRONICS

SILICON CONTROLLED RECTIFIER

Power Semiconductor Devices or Thyristor Family



Silicon Controlled rectifier

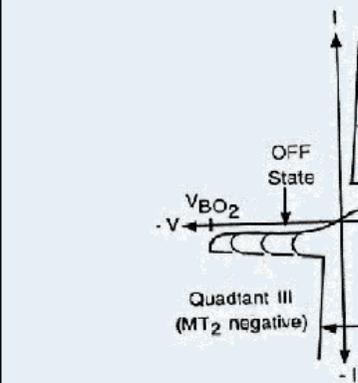


m = Mass of electron; h = Planck's constant
 v = Velocity of electron when entering the fields of deflecting plates; m/s

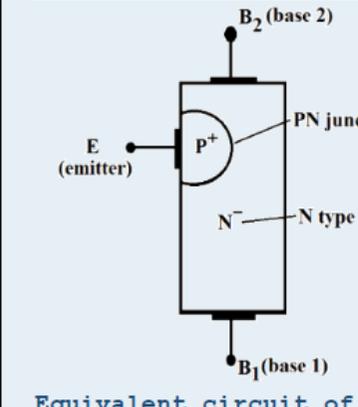
Capacitive Transformers
Capacitance
Capacitance of parallel plate capacitor

$E = \frac{1}{2} \epsilon_0 \epsilon_r \frac{Q^2}{A^2} = \frac{1}{2} \epsilon_0 \epsilon_r \frac{Q^2}{A^2} = \frac{1}{2} \epsilon_0 \epsilon_r \frac{Q^2}{A^2}$

Deflection
 x = Displacement in x-direction; m
Where,
 L = Distance between screen and the centre of deflecting plates; m
 L_p = Length of deflecting plates; m
 E_p = Potential between deflecting plates; V
 d = Distance between two plates
 E = Permittivity of medium
Capacitance of cylindrical capacitor
 $C = \frac{2\pi \epsilon_0 \epsilon_r l}{\ln \frac{r_2}{r_1}}$



UNI-JUNCTION TRANSISTOR (UJT)



Equivalent circuit of UJT

$R_{BB} = R_{B2} + R_{B1}$
Where
 R_{B2} - resistance between terminal B2 and E (fix resistance)
 R_{B1} - resistance between terminal E and B2 (variable resistance).

- Intrinsic standoff ratio (η)**: It is the ratio of R_{B1} to the sum of R_{B1} & R_{B2} . It can be expressed as $\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}$ or $\eta = \frac{R_{B1}}{R_{BB}}$
- The typical range of intrinsic standoff ratio is from 0.5 to 0.8.

Capacitive Transformers
Capacitance
Capacitance of parallel plate capacitor

$E = \frac{1}{2} \epsilon_0 \epsilon_r \frac{Q^2}{A^2} = \frac{1}{2} \epsilon_0 \epsilon_r \frac{Q^2}{A^2} = \frac{1}{2} \epsilon_0 \epsilon_r \frac{Q^2}{A^2}$

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