6 Edition
Revised & Updated

A Handbook on

Electrical Engineering

Contains well illustrated formulae & key theory concepts

for

ESE, GATE, PSUs

& OTHER COMPETITIVE EXAMS

MADE EASY
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Director's Message

B. Singh (Ex. IES)

During the current age of international competition in Science and Technology, the Indian participation through skilled technical professionals have been challenging to the world. Constant efforts and desire to achieve top positions are still required.

I feel every candidate has ability to succeed but competitive environment and quality guidance is required to achieve high level goals. At MADE EASY, we help you discover your hidden talent and success quotient to achieve your ultimate goals. In my opinion CSE, ESE, GATE & PSUs exams are tools to enter in to the main stream of Nation serving. The real application of knowledge and talent starts, after you enter in to the working system. Here at MADE EASY you are also trained to become winner in your life and achieve job satisfaction.

MADE EASY alumni have shared their winning stories of success and expressed their gratitude towards quality guidance of MADE EASY. Our students have not only secured All India First Ranks in ESE, GATE and PSUs entrance examinations but also secured top positions in their career profiles. Now, I invite you to become an alumnus of MADE EASY to explore and achieve ultimate goal of your life. I promise to provide you quality guidance with competitive environment which is far advanced and ahead than the reach of other institutions. You will get the guidance, support and inspiration that you need to reach the peak of your career.

I have a true desire to serve the Society and the Nation easing path of the education for the people of India.

After a long experience of teaching Electrical Engineering over a period of time, MADE EASY team realised that there is a need of a good *Handbook* which can provide the crux of Electrical Engineering in a concise form to the student to brush up the formulae and important concepts required for ESE, GATE, PSUs and other competitive examinations. This *handbook* contains all the formulae and important theoretical aspects of Electrical Engineering. It provides much needed revision aid and study guidance before examinations.

B. Singh (Ex. IES)
CMD, MADE EASY Group

A Handbook on

Electrical Engineering

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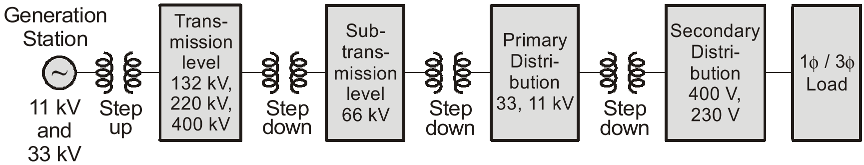
■■■■

Power Systems

1

I Supply System

Basic Structure of Power System



- Generating stations are interconnected by the lines.
- Transmission lines, when interconnected with each other, becomes transmission networks.
- The combined transmission and distribution network is known as the "power grid".

Effect of System Voltage on Transmission of Power

- Power loss in the line is inversely proportional to the system voltage and power factor both.
- Percentage voltage drop in resistance decreases with the increase in the system voltage.
- Weight of the conductor material for the line will decreases with the increase in supply voltage and power factor.
- Efficiency of transmission, increases with the increase of supply voltage and power factor.
- Higher supply voltages also enhances the system stability.
- The problems encountered with high voltages are the insulation of the equipment, corona, radio and television interference.
- The voltage level of a system is therefore governed by the amount of power to be transmitted and the length of the line.

Voltage Level

- Low voltage → 230 V (1-ϕ), 400 V (3-ϕ)
- High voltage → 11 kV, 33 kV

- Extra high voltage: 66 kV, 132 kV, 220 kV.
- Modern EHV: 400 kV
- Ultra high voltage: 765 kV and above.

Conductor Used for Transmission Line

- Copper conductor
- ACSR : Aluminium conductor steel reinforced.
- ACAR : Aluminium conductor alloy reinforced.
- AAAC : All Aluminium alloy conductor.
- Expanded ACSR conductor: Normally used for EHV lines.
- AAC : All Alluminium conductors.

Types of Conductor

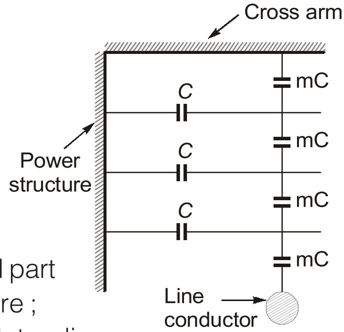
- Solid conductor: It has high skin effect.
- Hollow conductor: Preferred under heavy current, i.e., more than 1000 Amp.
- Stranded conductor.
- Composite standard conductor: used for voltage $\leq$ 220 kV.
- Bundle conductor: Used for voltage > 275 kV.

Advantage of Bundle Conductor

- Self distance (GMR) increased without change in mutual distance.
- Voltage gradient reduced so corona loss reduce.
- It reduces the interference with nearby communication line.
- Inductance (L) of transmission line reduces and capacitance (C) increases.
- Surge impedance, i.e., $Z_s = \sqrt{\frac{L}{C}}$ decreases.
- Power system stability increases.

Insulators

Over head line insulators provide the required insulation to the line conductors from each other and from the supporting structures electrically. Most commonly used materials are porcelain, toughened glass and steatite,



where, $C \rightarrow$ Capacitance between metal part of the insulator and tower structure ;
$mC \rightarrow$ Capacitance of each insulator disc.
$mC > C$

Note:

☑ The stress experienced by the disc near the power conductor is more than the stress experience by the disc near the cross-arm.

String Efficiency

$$\text{String efficiency} = \frac{\text{Voltage across the whole string}}{n \times (\text{Voltage across the unit adjacent to line conductor})}$$

where, $n \rightarrow$ Number of insulator discs in the string

String efficiency also defined as

$$\%\eta = \frac{\text{Flashover voltage of the string}}{n \times \text{flashover voltage of one string}} \times 100$$

Note:

☑ As the number of disc increases string efficiency decreases.

Methods of Equilising Potential Across Each Disc

- Increase the length of cross arm.
- Capacitance grading or grading of units.
- Use of grading rings or static shielding.

Remember:

☑ For static shielding the capacitance from the shield to the K_{th} link from the top

$$C_K = \frac{KC}{n-K} \qquad (\because n = \text{number of disc})$$

Types of Insulator

- **Pin type insulator:** Pin type insulator operate satisfactory upto 25 kV.
- **Multipine type insulator:** Operates upto 33 kV
- **Suspension type insulator:** A suspension insulator is designed to operate at 11 kV.
- **Strain type insulator:** Strain type insulator mechanically strong. It is used when direction of transmission line changes across river crossing and at the dead end of the transmission line.
- **Shackle type:** Shackle type insulator are used in low tension cable. These insulator can be operated either horizontally or vertically.

II Line Parameters

Transmission line is a carrier on which bulk amount of power from a remote generating station to the operative areas is being carried out.

Electrical Machines

2

I Transformers

It is a static device which transfers electrical energy from one circuit to another circuit without change in frequency. It works on electromagnetic induction principle.

Induced EMF

Direction of induced emf can be found by **"Lenz's law"** and magnitude of induced emf can be given by **"Faraday's law of electromagnetic induction"**.

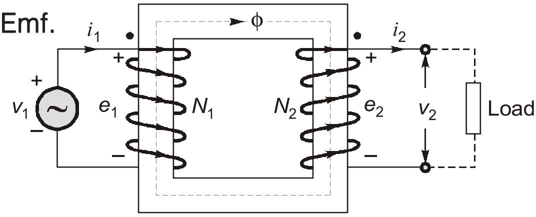
RMS value of induced Emf.

In primary winding

$$E_1 = \sqrt{2}\,\pi N_1 f \phi_m \text{ Volts}$$

In secondary winding

$$E_2 = \sqrt{2}\,\pi N_2 f \phi_m \text{ Volts}$$



where, N_1 = Number of turns in primary winding;

N_2 = Number of turns in secondary winding;

ϕ_m = Maximum value of the magnetic flux (in webers) = $B_m.A$

B_m = Maximum flux density; A = Area of cross-section

f = Supply frequency, in Hz

Remember:

- ☑ Emf per turn in primary = Emf per turn in secondary
- ☑ Compensating primary mmf = Secondary mmf

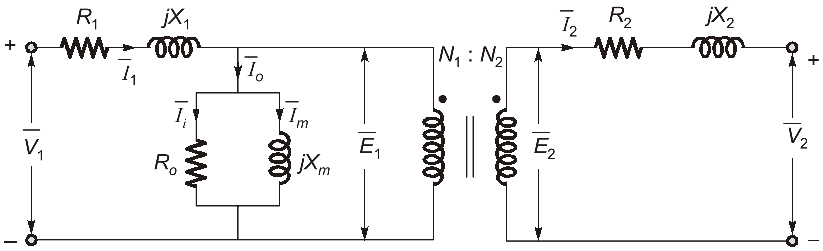
  $I_1' N_1 = I_2 N_2$ (where, I_1' = Load component of primary current I_1)
- ☑ Primary volt-amperes = Secondary volt-amperes.
- ☑ Transformer is a constant frequency and constant power device.
- ☑ Step up transformer : $N_1 < N_2$.
- ☑ Step down transformer : $N_1 > N_2$.

Ideal Transformer

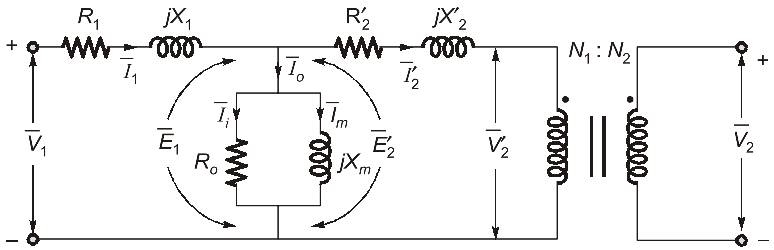
- The primary and secondary windings have zero resistance. So, there is no ohmic power loss and no resistive voltage drop.
- There is no magnetic leakage flux.

- The core loss considered to be zero.
- The core has infinite permeability.

Equivalent Circuit



Exact equivalent circuit of transformer



Equivalent circuit referred to primary side

where, $\bar{V}_1$ → Applied voltage to primary side.

$\bar{V}_2'$ → Secondary terminal voltage referred to primary side.

$\bar{E}_1, \bar{E}_2$ → Induced emf in primary and secondary side.

$\bar{E}_2'$ → Secondary induced emf referred to primary side.

$\bar{I}_o$ → No load current.

$\bar{I}_m, \bar{I}_i$ → Magnetizing and core loss component of exciting current.

$R_1,\ R_2$ → Primary and secondary winding resistances.

$X_1,\ X_2$ → Primary and secondary winding leakage reactances.

R_2', X_2' → Secondary resistance and leakage reactance referred to primary side.

R_o → Core loss equivalent resistance.

X_m → Magnetising reactance.

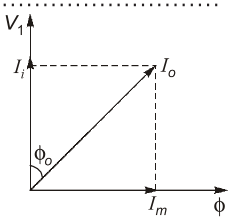
Note:

- At no load, current drawn from the supply is I_o

$\bar{I}_o = \bar{I}_m + \bar{I}_i = (2 \text{ to } 5\% \text{ of } I_{fl})$

$|\bar{I}_o| = \sqrt{I_m^2 + I_i^2}$

$\bar{I}_m = I_o \sin\phi_o$ = Magnetizing current



3

Power Electronics

I Power Electronics

- Power electronics is a subject that deals with the apparatus and equipment rated at high voltage, high current and high power (rather than signal level) working on the principle of electronics.

  Example: Thyristor, GTO, Power MOSFET, Power IGBT, TRIAC etc.

Power Device	Signal Device
1. Voltage and current rating is high	1. Voltage and current rating is low
2. Power handling capability is high	2. Power handling capability is low
3. Operate at power frequency	3. Operate at high frequency

Power Semiconductor Devices

- Semiconductor devices are used for high voltage, high current and high power applications.
- Power semiconductor devices have high efficiency due to low losses and high reliability.

  Power semiconductor devices can be classified based on their :
  - Turn-on and turn-off characteristics.
  - Gate signal requirements.

  (i) **Diodes** are uncontrolled rectifying devices and their ON state and OFF state are controlled by nature of power supply.

  (ii) **Thyristor** devices have controlled turned-on by a gate signal, these devices are also called as semicontrolled devices.

  (iii) **Controllable switches** turn-on and turn-off can be done by application of control signals.

Power Diodes

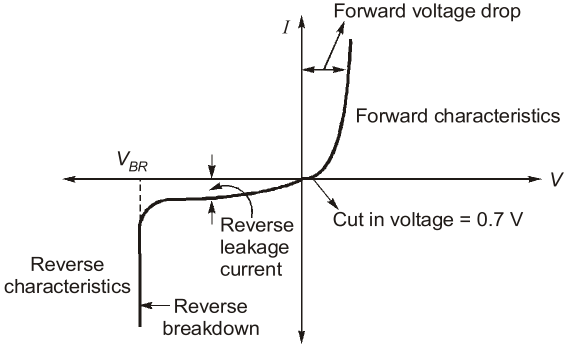
Power diode is a 2 layer, 2 terminal p-n junction semiconductor device. It has one p-n junction formed by alloying, diffusion or epitaxial growth.

Remember:

☑ When voltage rating is less than 400 V epitaxial process is used for diode fabrication.

☑ When voltage rating is greater than 400 V diffusion process is used for diode fabrication.

V-I Characteristics of Power Diodes :



Characteristics of Semiconductor Diode

Note:

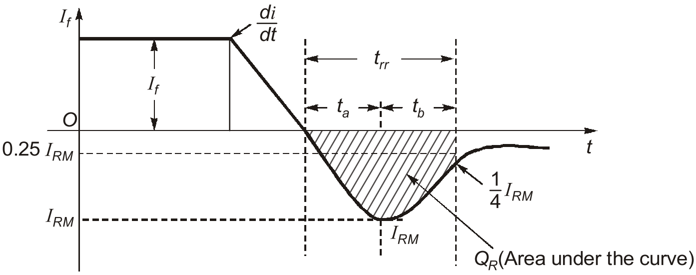
Peak inverse voltage (P.I.V.) specifies the maximum reverse voltage applied across diode by the source.

If P.I.V. < V_{BR}, diode remain in blocking state.

If P.I.V. > V_{BR}, breakdown occurs and diode starts conducting in reverse direction.

Reverse Recovery Characteristics of Power Diodes

- Due to the presence of excess stored charge carrier in the depletion region of diode, a reverse current immediately flow as soon as the forward diode current becomes zero.



Reverse Recovery Characteristics

$$t_{rr} = t_a + t_b = t_{off}$$

where, $t_{rr} \rightarrow$ Reverse recovery time

$t_a \rightarrow$ Time between $I_A = 0$ to $I_A = I_{RM}$

$t_b \rightarrow$ Time between I_{RM} to 25% of I_{RM}

$I_{RM} \rightarrow$ Reverse peak current.

$$t_{rr} = \left[\frac{2Q_R}{di/dt}\right]^{1/2} \quad \text{and} \quad I_{RM} = \left[2Q_R\left(\frac{di}{dt}\right)\right]^{1/2}$$

where, Q_R gives the amount of excess charge stored.

Measurements and Instrumentation

4

I Characteristics of Instruments and Measurement Systems

Measurements

Measurement is a process by which one can convert physical parameters to meaningful numbers. The measuring process is one in which the property of an object or system under consideration is compared to an accepted standard unit, a standard defined for that particular property.

Static Characteristics

Accuracy : It is the closeness with which an instrument reading approaches the true value of the quantity being measured.

Precision : It is a measure of the reproducibility of the measurements. It is a measure of degree of agreement within a group of measurements.

Remember:

- ☑ Precision is not the guarantee of accuracy.
- ☑ An instrument with more significant figure has more precision.

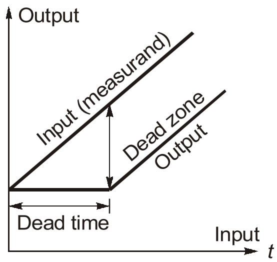
Sensitivity : It is the ratio of the magnitude of output signal to the magnitude of input signal applied to the instrument.

Note:

- ☑ An instrument requires high degree of sensitivity.
- ☑ Sensitivity $\propto \dfrac{1}{\text{Deflection factor}}$

Resolution : The smallest change in input which can be detected with certainty by an instrument is its resolution.

Linearity : Linearity is a behaviour of an instrument in which the output signal strength varies in direct proportion to input signal strength.



Dead Zone : It is the largest change of input quantity for which there is no output of the instrument.

Dead Time : Time required by an instrument to begin to respond to the change in a measurand.

Range and Span : The difference between the maximum and minimum values of the scale is called range. The maximum value of the scale is called span.

Errors : Measurement error is the difference between the measured value and true value.

$$\text{Error} = \text{Measured value} - \text{True value} = -\text{Accuracy}$$

Error Analysis

- Static error, $\delta A = A_m - A_t$

  where, $A_m \rightarrow$ Measured value of quantity or Actual value

  $A_t \rightarrow$ True value of quantity or Nominal value

- Relative static error, $\in_r = \dfrac{\delta A}{A_t}$

- Static correction, $\delta C = A_t - A_m = -\delta A$

- Static sensitivity $= \dfrac{\Delta q_0}{\Delta q_i}$

  where, $\Delta q_o \rightarrow$ Infinitesimal change in output

  $\Delta q_i \rightarrow$ Infinitesimal change in input

- Non-linearity (N.L.)

$$N.L. = \frac{(\text{Max. deviation of output from the idealized straight line})}{\text{Full scale deflection}} \times 100$$

$$\text{Error at desired value} = \frac{\text{Full scale value} \times \text{Error at full scale}}{\text{Desired value}}$$

Combination of Quantities with Limiting Errors

Sum or Difference of Two or more than Two Quantities

Let $X = \pm x_1 \pm x_2 \pm x_3 \pm x_4$

$$\frac{\delta X}{X} = \pm\left(\frac{x_1}{X}\frac{\delta x_1}{x_1} + \frac{x_2}{X}\frac{\delta x_2}{x_2} + \frac{x_3}{X}\frac{\delta x_3}{x_3} + \frac{x_4}{X}\frac{\delta x_4}{x_4}\right)$$

where $\pm\delta x_i \rightarrow$ Relative increment in quantity x_i

$\pm\delta X \rightarrow$ Relative increment in X

$\dfrac{\delta x_i}{x_i} \rightarrow$ Relative limiting error in quantity x_i

$\dfrac{\delta X}{X} \rightarrow$ Relative limiting error in X

Network Theory

5

I Basic Definitions and Circuits Element

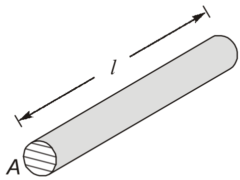
Definitions

1. **Charge:** It is an electrical property of an atomic particle of which the matter consists of and its unit is Coulombic (C).
   It can be positive or negative : Charge of $1e^- = 1.6 \times 10^{-19}$ C
2. **Current:** The flow of electron or the time rate of change of charge is called current.
   $$\boxed{i = \frac{dq}{dt}} \quad \text{Ampere}$$
3. **Voltage:** It is an external force required to move the electron from one point to another in a particular direction in an electrical circuit. This force is provided by the electromotive force (emf).
   $$\boxed{V = \frac{dw}{dq}} \quad \text{J/C or Voltage}$$
4. **Power:** It is the time rate of change of energy.
   $$\boxed{P = \frac{dw}{dt} = v(t) \cdot i(t)}$$
   Its unit is watts.
5. **Law of Conservation of Charge:** It states that the charge can neither be created nor be destroyed. It can only be transferred from one body to another body.
6. **Law of Conservation of Energy:** The sum of total instantaneous power in a circuit must be equal to zero.
   $$\Sigma P = 0$$

Electrical Network Components

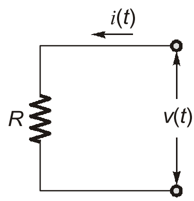
Resistor

It is the property of a substance due to which it opposes the flow of current (i.e., electrons) through it.



Resistance, $R = \rho \frac{l}{A}$, Ohm (Ω)

where, $l \rightarrow$ Length of conductor, metre (m)
$A \rightarrow$ Area of cross-section, m^2
$\rho \rightarrow$ Resistivity of the material, Ω-m



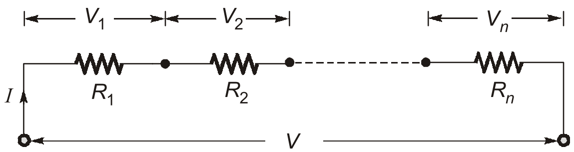
$v(t) = Ri(t)$; $i(t) = \frac{1}{R}v(t) \cdots$ in time domain

$V(s) = RI(s)$; $I(s) = \frac{1}{R}V(s) \cdots$ in s-domain

- Power loss in resistor, $p(t) = v(t)\, i(t) = i^2(t) = \frac{v^2(t)}{R}$
- Energy dissipated in resistor, $E_R = \int_{t_1}^{t_2} p(t)\, dt$

Combination of Resistors

Resistors in series

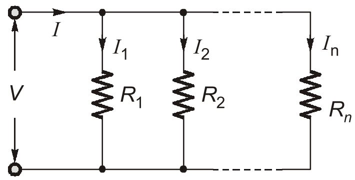


$$V = IR_{eq} \quad ; \quad R_{eq} = R_1 + R_2 + ... + R_n$$

Resistors in parallel

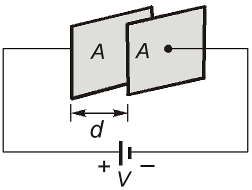
$$I = \frac{V}{R_{eq}}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ... \frac{1}{R_n}$$



Capacitor

The circuit element that stores energy in the form of electric field is a capacitor or capacitance.



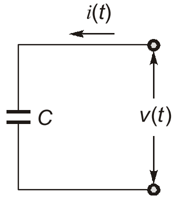
Capacitance $C = \frac{\epsilon_0 \epsilon_r A}{d}$ Farad(F)

where $\epsilon_0 \rightarrow$ Permittivity of free space, F/m ,
$\epsilon_r \rightarrow$ Relative permittivity of the dielectric ; $A \rightarrow$ Cross-sectional area of parallel plates, m^2
$d \rightarrow$ Separation of plates, m

Note:

When the capacitance is removed from source, the capacitor retains the charge and the electric field until a discharge path is provided.

$$v(t) = \frac{1}{C}\int_0^t i(t)\, dt \;;\; i(t) = C\frac{dv(t)}{dt} \cdots \text{in time domain}$$

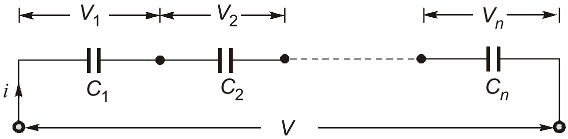


Power in capacitance, $p(t) = v(t)\, i(t) = Cv(t)\dfrac{dv(t)}{dt}$

Energy stored in capacitance, $E_c = \dfrac{1}{2}Cv^2$

Combination of Capacitors

- **Capacitors in series**

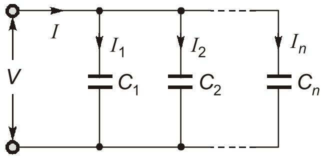


$$V = \frac{1}{C_{eq}}\int_0^t i\, dt \quad ; \quad \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots.. + \frac{1}{C_n}$$

- **Capacitors in parallel**

$$I = C_{eq}\frac{dv}{dt}$$

$$C_{eq} = C_1 + C_2 + C_3 + \ldots\ldots.. + C_n$$



Note:

☑ Under steady state condition for D.C. supply capacitor acts as open circuit.

☑ Capacitor doesn't allow sudden change of voltage, until impulse of current is applied.

☑ If unit impulse of current is applied then at $t = 0^+$ it stores $\dfrac{1}{2C}$ Joules energy.

☑ Power dissipation in ideal capacitor is zero.

Inductor

The circuit element that stores energy in the form of a magnetic field is an inductor or inductance.

Inductance $\quad L = \dfrac{\mu_0 N^2 A}{l}$ Henry (H)

where $\mu_0 \rightarrow$ Permeability of free space, H/m ; $N \rightarrow$ Total number of turns in coil ; $A \rightarrow$ Cross-sectional area of coil, m^2 ; $l \rightarrow$ Length of coil, m