

# ELECTRICAL | INSTRUMENTATION

Useful for

Engineering

# MAHAGENCO

## AE | JE<sub>EXAM</sub>

Comprehensive Theory With  
Important Questions

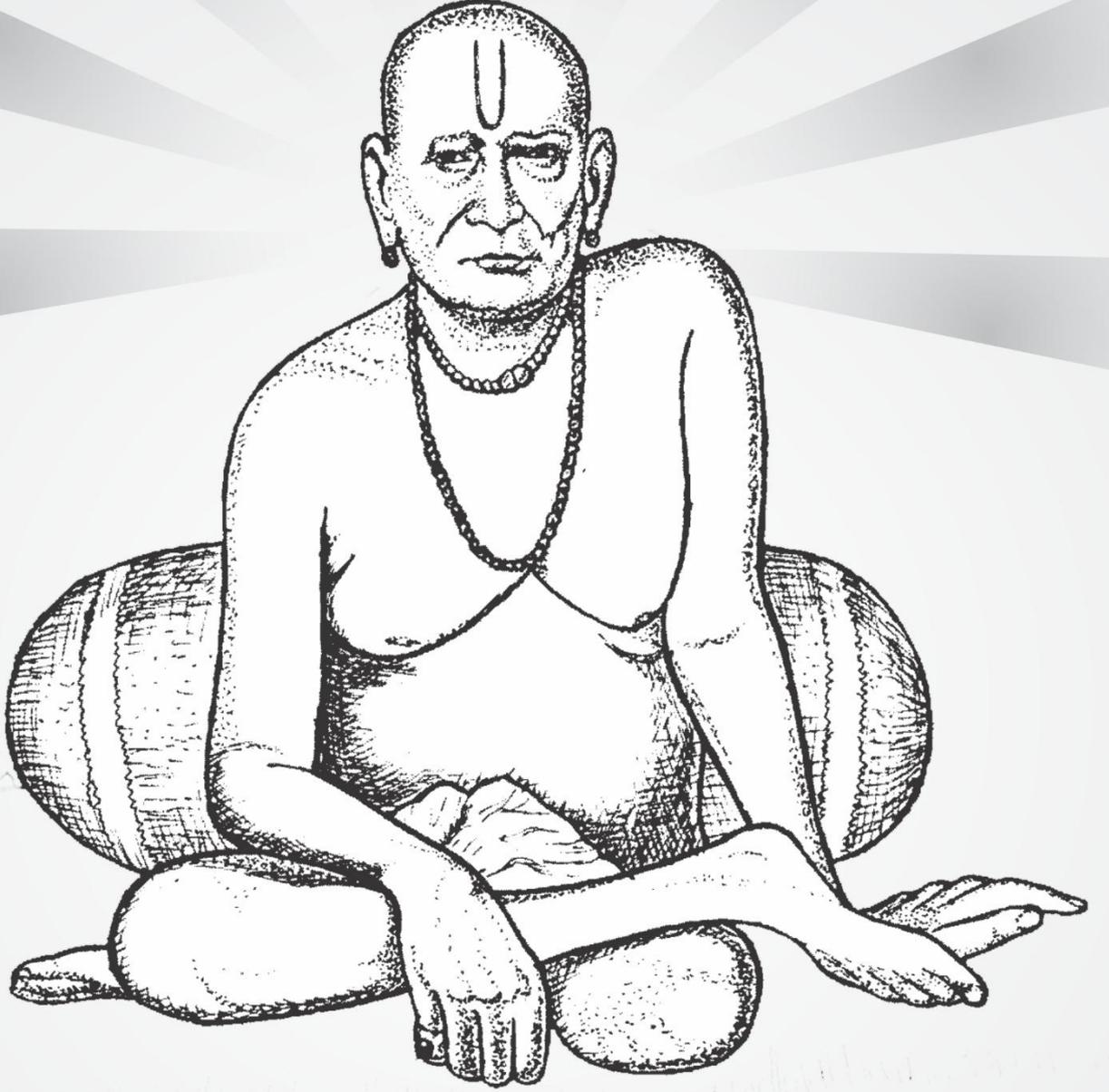
**Mr. Pramod Deshkari**

M.E (E & TC)

(17+ Teaching Experience)



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श्रीस्वामीसमर्थ...

स्वामींच्या चरणी अर्पण ...

# PREFACE

## **Dear Aspirants,**

We are extremely happy to present this book for Electrical and Electronics Engineering students those preparing for various competitive examinations especially for MAHAGENCO

This book covers Eleven most important technical subjects including important theory concepts and more than 2000+ multiple choice questions. Out of these 1500+ most important MCQs and 500+ most expected MCQs. This book is written considering previous year questions for said examinations.

We tried to represent the concepts in brain mapping format and more in pictorial form so that the topic understood properly. The topics within the chapters have been arranged in a proper sequence to ensure smooth flow of the subjects.

Number of MCQs been included so, we are sure that this book will cater all your needs for various examinations.

We are thankful to Infinity Academy and its Publication department for the encouragement and support that they have extended. We are also thankful to Directors and the staff members of Infinity Academy for their efforts to make this book as good as it is. We have jointly made every possible effort to eliminate all the errors in this book. However, if you find any, please let us know, because that will help us to improve further.

**P. B. Deshkari**  
(M.E. (E & TC))

# INDEX

## **1. BASIC ELECTRICAL ENGINEERING ..... 9**

1. BASICS OF ELECTRICAL ENGINEERING .....	9
2. DC CIRCUITS .....	14
3. AC FUNDAMENTALS .....	24
4. THREE PHASE CIRCUITS .....	40
5. MAGNETISM .....	47
6. IMPORTANT QUESTIONS .....	52

## **2. NETWORK THEORY ..... 62**

1. BASICS OF NETWORK .....	62
2. NETWORK THEOREMS: .....	70
3. ANALYSIS OF TRANSIENT RESPONSE .....	73
4. TWO PORT NETWORK .....	77
5. FILTERS .....	81
A. IMPORTANT QUESTIONS .....	83
B. IMPORTANT QUESTIONS WITH EXPLANATION .....	100

## **3. DC AND AC MACHINES ..... 105**

1. ELECTROMECHANICAL-ENERGY-CONVERSION PRINCIPLES .....	105
2. D.C. MACHINES .....	107
3. THREE PHASE INDUCTION MOTOR .....	118
4. THREE PHASE SYNCHRONOUS MACHINES .....	126
5. THREE PHASE SYNCHRONOUS MOTOR: .....	131
6. SPECIAL TYPES OF MOTORS .....	134
7. SINGLE PHASE TRANSFORMER .....	141

8. THREE PHASE TRANSFORMERS .....	153
A. IMPORTANT QUESTIONS.....	166
B. IMPORTANT QUESTIONS WITH EXPLANATION.....	177

## **4. POWER SYSTEM ANALYSIS..... 183**

1. STRUCTURE OF ELECTRICAL POWER SYSTEMS .....	183
2. TYPES OF POWER PLANTS .....	188
2. POWER STATION EQUIPMENT'S .....	210
3. OVERHEAD LINES AND UNDERGROUND CABLES .....	215
4. RESISTANCE & INDUCTANCE OF TRANSMISSION LINE .....	223
5. CAPACITANCE OF TRANSMISSION LINE.....	224
6. PERFORMANCE OF TRANSMISSION LINES .....	225
7. REPRESENTATION OF POWER SYSTEM .....	227
9. TRANSMISSION LINE FAULTS.....	232
A. IMPORTANT QUESTIONS.....	236
B. IMPORTANT QUESTIONS WITH EXPLANATION.....	242

## **5. SWITCH GEAR & PROTECTION..... 251**

1. CIRCUIT BREAKERS.....	251
2. PROTECTIVE RELAY .....	275
3. FEEDERS & BUSBARS PROTECTION.....	291
4. GROUNDING & ITS TYPES.....	303
5. PROTECTION AGAINST OVER VOLTAGES.....	313
A. IMPORTANT QUESTIONS WITH EXPLANATION .....	322

## **6. ANALOG ELECTRONICS .....338**

1. DIODES.....	338
2. APPLICATIONS OF DIODE .....	348
3. BJT (BIPOLAR JUNCTION TRANSISTOR) .....	352
4. AMPLIFIER.....	358
5. OPERATIONAL AMPLIFIER.....	364
6. TIMER IC555 .....	369
7. OSCILLATORS:.....	371
A. IMPORTANT QUESTIONS WITH EXPLANATION .....	373

## **7. DIGITAL CIRCUITS .....379**

1. NUMBER SYSTEM.....	379
2. LOGIC GATES .....	382
3. COMBINATIONAL CIRCUITS.....	389
4. SEQUENTIAL CIRCUITS.....	394
5. MICROPROCESSOR.....	396
A. IMPORTANT QUESTIONS.....	402
B. IMPORTANT QUESTIONS WITH EXPLANATION.....	417

## **8. POWER ELECTRONICS .....423**

1. SILICON CONTROLLED RECTIFIER .....	423
2. POWER ELECTRONICS DEVICES .....	429
3. RECTIFIER AND CHOPPERS .....	436
4. INVERTER .....	439
A. IMPORTANT QUESTIONS.....	443
B. IMPORTANT QUESTIONS WITH EXPLANATION.....	450

## **9. CONTROL SYSTEM ..... 456**

1. BASICS OF CONTROL SYSTEM .....	456
2. TIME RESPONSE ANALYSIS .....	468
3. STABILITY .....	480
4. PROCESS CONTROL SYSTEM.....	487
A. IMPORTANT QUESTIONS.....	496
B. IMPORTANT QUESTIONS WITH EXPLANATION.....	508

## **10. ELECTRICAL AND ELECTRONICS MEASUREMENTS ..... 518**

1. MEASURING INSTRUMENTS AND ERROR ANALYSIS.....	518
2. MEASUREMENT OF POWER AND ENERGY .....	524
3. POTENTIOMETERS & AC BRIDGES .....	526
5. THE OSCILLOSCOPE.....	528
A. IMPORTANT QUESTIONS.....	530
IMPORTANT QUESTIONS WITH EXPLANATION.....	536

## **11. UTILIZATION OF ELECTRICAL ENGINEERING ..... 541**

1. ILLUMINATION.....	541
2. ELECTRIC HEATING .....	567
3. ELECTRIC WELDING .....	579
4. ELECTRIC TRACTION.....	588
IMPORTANT QUESTIONS WITH EXPLANATION.....	596

## **12. MAHAGENCO JE ELECTRICAL EXAM 2016 ..... 601**

## **13. MAHAGENCO AE ELECTRICAL EXAM 2016.....607**

# 1. BASIC ELECTRICAL ENGINEERING





# 1. BASICS OF ELECTRICAL ENGINEERING

## 1.1 Basic Concept

### 1.1.1 Atomic structure

- Any substance is made up of matter, matter is made up of tiny particles called atoms and molecules.

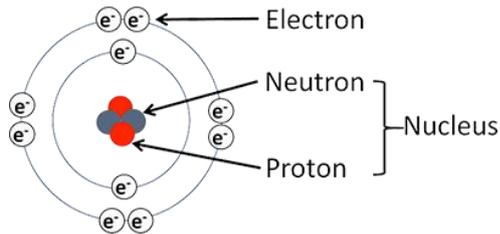


Fig: Atomic structure

- Atom can be broken down into three constituents parts – protons, neutron, and electrons.
- Each of these parts has an associated charge,
- with protons (p) carrying a positive charge,
- electrons ( $e^-$ ) having a negative charge,
- and neutrons possessing no net charge or electrically neutral
- Electrons are fundamental particles; however, protons and neutrons are made up of a different set of fundamental particles known as quarks.

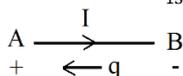
### 1.1.2 Charge (q) :

- Physical property of matter that causes it to experience a force when placed in an electromagnetic field
- Unit: charge is measured in coulomb (C)
- Electron is negatively charged particles revolving around nucleus in orbits.
- Proton is positively charged particles present in nucleus
- Charge on electron =  $-1.6 \times 10^{-19}$  C
- Charge on Proton =  $+1.6 \times 10^{-19}$  C

### 1.1.3 Electric Current (I)

- Measured in ampere (A)
- Flow of electrons or negatively charged particles in definite direction is current.
- Rate of flow of charge  $I = \frac{dq}{dt}$  Or

$$1 \text{ Ampere} = \frac{1 \text{Coulomb}}{1 \text{Second}}$$



- 1 Ampere current : 1 coulomb of charges flows through a conductor in 1 second

- Current is measured by ammeter
- Current is a scalar quantity even it has magnitude and direction because it do not obeys vector laws of addition.
- Electric current has two effect
  - Heating effect eg. Application -Water heater
  - Magnetic effect eg. Application-Electric Generator

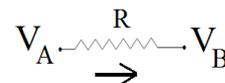
### 1.1.4 Potential difference:

- Amount of work needed to move a charge from a reference point.

$$\text{Voltage} = \frac{\text{Energy}}{\text{charge}}$$

$$1 \text{ volt} = \frac{1 \text{ J}}{1 \text{ C}}$$

- It is difference between energy level.
- Current only flows from higher potential to lower potential



- $V_A > V_B$  then current flows from terminal A to B .
- Potential difference is  $= V_A - V_B$
- Voltage drop across R is  $= \frac{V_A - V_B}{R}$
- potential difference is measured in volts (v)
- 1 volt potential difference - A voltage difference of one volt drives one ampere of current through a conductor that has a resistance of one ohm. Or
- One joule of work is required to move an electric charge of one coulomb across a potential difference of one volt. Or
- One volt is equivalent to one joule per coulomb.

### 1.1.5 Electric Power (P) :

- Electric power, like mechanical power,
- It is the rate, per unit time, at which electrical energy is transferred by an electric circuit.
- Electric power is usually produced by electric generators, but can also be supplied by sources such as electric batteries.
- It is supplied to businesses and homes by the electric power industry through an electric power grid.
- Electric power can be delivered over long distances by transmission lines and used for applications such as motion, light or heat with high efficiency
- It is the rate of doing work, represented by the letter P.

- The term wattage is used colloquially to mean "electric power in watts." The electric power in watts produced by an electric current  $I$  consisting of a charge of  $Q$  coulombs every  $t$  seconds passing through an electric potential (voltage) difference of  $V$  is

$$P = \frac{V \cdot Q}{t}$$

Where  $Q$  is electric charge in coulombs

$t$  is time in seconds

$I$  is electric current in amperes

$V$  is electric potential or voltage in volts

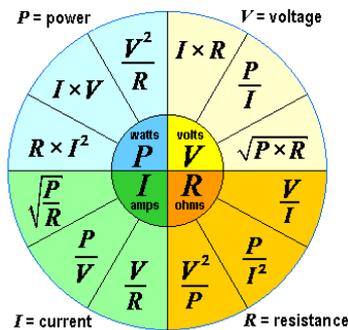
Since  $I = Q/t$

therefore  $P = V \times I$

Power = Voltage X current

- Electric power measured with SI unit watt, one joule per second.

### 1.1.6 Relation between various parameters:



### 1.1.7 Real power or true power or active power (P)

- The actual amount of power being used, or dissipated, in a circuit is called **Real power**
- it is measured in watts or kilowatts (kW) symbolized by the capital letter  $P$ . It is mathematically given by

$$P = V \cdot I \cos\theta$$

$$P = I^2 R$$

### 1.1.8 Apparent power: (S)

- The combination of reactive power and true power is called apparent power
  - it is the product of a circuit's voltage and current, without reference to phase angle.
  - It is measured in volt-ampere or kilo volt-ampere (VA or kVA)
  - symbolized by the capital letter  $S$ .
  - It is mathematically given by
- $$S = V \cdot I$$
- When the circuit is pure resistive, then **apparent power** is equal to real or true **power**.

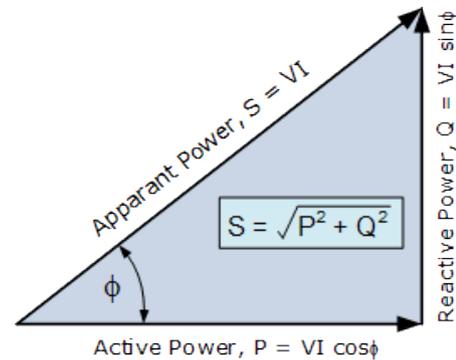
$$S = P$$

- In inductive or capacitive circuit with reactance then **apparent power** is greater than real or true **power**.

$$S > P$$

### 1.1.9 Reactive power: (Q)

- The power which flows back and forth that means it moves in both the directions in the circuit or reacts upon itself, is called **Reactive Power**.
  - It is measured in kilo volt-ampere reactive (kVAR) or MVAR.
  - Symbolized by the capital letter  $Q$ .
  - It is mathematically given by
- $$Q = V \cdot I \sin\theta$$
- $$Q = I^2 X_L$$
- Reactive power is also known as: phantom power.



- Reactive power gets energy moving back into the grid during the passive phases.
  - the relationship among real, reactive and apparent power is:
- $$S^2 = P^2 + Q^2 \text{ or } S = \sqrt{P^2 + Q^2}$$
- The relationship between real power, reactive power and apparent power can be expressed by representing the quantities as vectors.
  - This representation is often called the power triangle.
  - Real and reactive powers can also be calculated directly from the apparent power, when the current and voltage are both sinusoids with a known phase angle  $\theta$  between them:
  - The ratio of real power to apparent power is called power factor and is a number always between 0 and 1.
  - Where the currents and voltages have non-sinusoidal forms, power factor is generalized to include the effects of distortion.

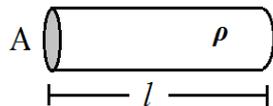
## 1.2. Important elements of electrical circuit/network

### 1.2.1. Resistance :

- It is property of material to oppose flow of current
- Measured in ohm ( $\Omega$ )
- Represented by R and symbol is



- Constructional value of resistance :
- Resistance of material is depends on various factor



- Resistors are passive components which opposes the flow of current.
- Resistance of material is given by

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

- Where  $\rho$  :- resistivity of material in  $\Omega\text{m}$   
 $l$  :- effective length of material in m  
 $A$  :- cross section area of material  $\text{m}^2$
- Its unit is ohm ( $\Omega$ ).
- Resistance value is directly proportional to length of material

$$R \propto l$$

- Resistance value is inversely proportional to cross sectional area of material

$$R \propto \frac{1}{A}$$

- Resistance value is depends on temperature of material .
- Resistivity value is depends on material used.

### 1.2.2 Resistivity of material

$$\rho = \frac{RA}{l}$$

- Unit of resistivity is ohm meter ( $\Omega\text{m}$ )
- Resistivity is reciprocal of conductivity

### 1.2.3 Conductance :

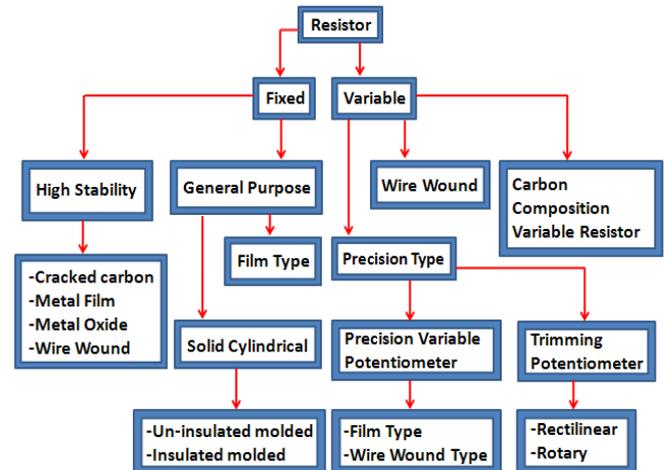
- Reciprocal of resistance is called conductance

$$G = \frac{1}{R}$$

- Property of material to allow current is called conductance

- It is represented by G
- It is measured in Siemen or mho ( $\text{S}$ )
- According to Ohm's law  $R = V/I$
- It is use to control the current.
- It is use to provide desired voltage.
- It opposes the flow of current.

### 1.2.4 Types of resistors :



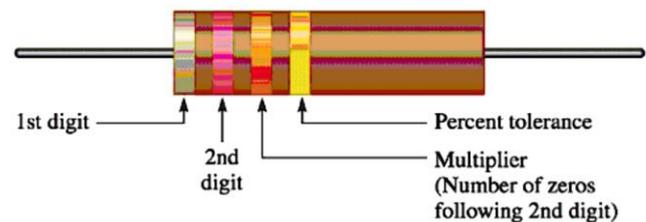
- There are two method to measure the value of resistor.

- Using digital multimeter
- Color Coding Method

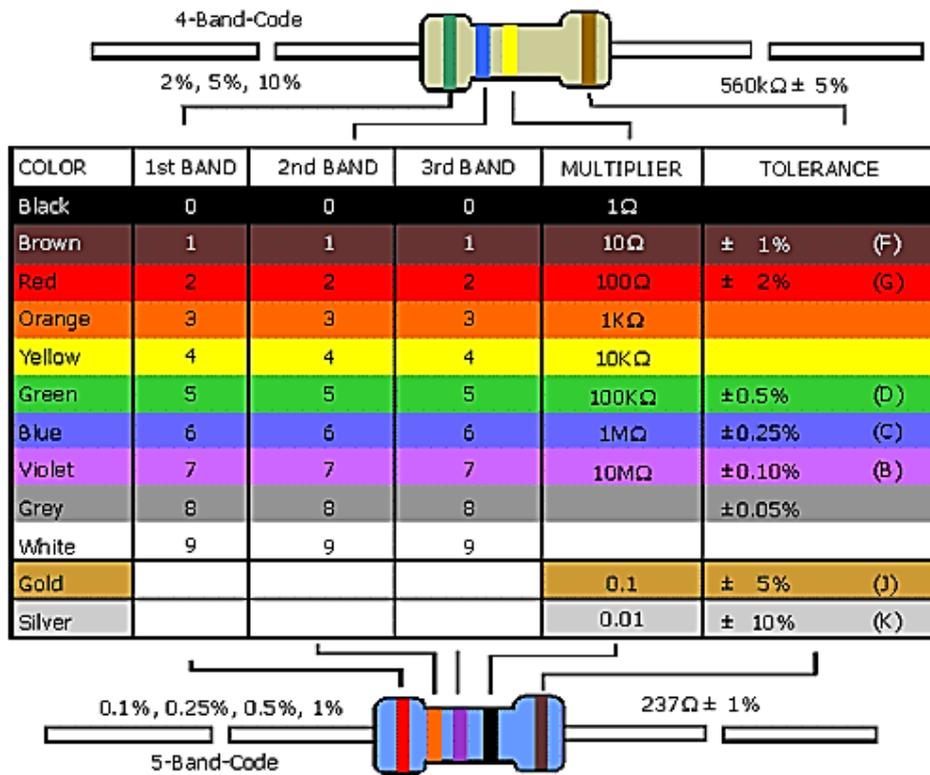
### 1.2.5 Color-code

#### Bands on a Resistor

- This coding is used for 5%, 10%, and 20% tolerance resistors
- 1st band is the first digit of the resistance value
- 2nd band is the second digit of the resistance value
- 3rd band is the multiplier (number of zeros)
- 4th band indicates the tolerance



**Key : B. B. ROY** Great Britain Very Good Wife



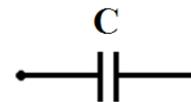
- Resistor values by Coding numbers
- R- used to indicate Ω
- K- used to indicate Kilo Ω.
- M- used to indicate Mega Ω.
- F- ±1%      G- ±2%
- J- ±5%      K- ±10%
- Position of alphabet indicate decimal point.
- E.g. 5M5

$$5.5 \text{ M} = 5.5\text{M} \Omega$$

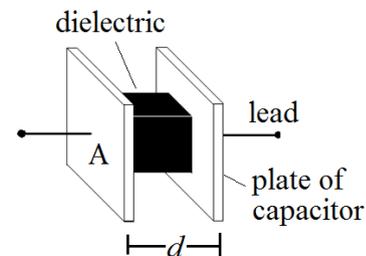
### 1.2.6 Capacitance (C)

- Capacitors are passive components which are able to store the charges.
  - Measured in farad (F)
  - Capacitance is property of capacitor.
  - Its unit is Farad, and it is given by
- $$C = \frac{Q}{V}$$
- Where Q-Charges on the plate in Coulomb,
  - V- Potential on capacitor in volts
  - Capacitor allows AC and block DC.
  - A capacitor consists of two metal plates separated by a dielectric.
  - The dielectric can be made of many insulating materials such as air, glass, paper, plastic etc.
  - A capacitor is capable of storing electrical charge and energy.

- Higher the value of capacitance, the more charge the capacitor can store.
- Represented by C and symbol is



- Depends on construction capacitor value is given by,



#### Structure of capacitor

- Capacitance value depends on various factor

$$C = \frac{\epsilon A}{d}$$

$$\epsilon = \epsilon_0 \epsilon_r$$

Where  $\epsilon$  -: dielectric constant ,

$\epsilon_0$  – Absolute permeability

$\epsilon_r$  – Relative permeability

A -: common area of plate in m<sup>2</sup>,

d -: Distance between two plates in m.

- Capacitance value is directly proportional to dielectric constant

$$C \propto \epsilon$$



Capacitance value is directly proportional to common area of plates

$$C \propto A$$

- Capacitance value is inversely proportional to distance between two plates

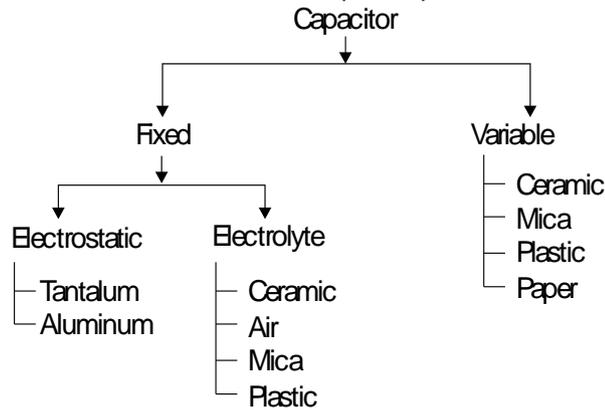
$$C \propto \frac{1}{d}$$

**1.2.7 Functions of Capacitors**

- It stores the charges.
- It allow the AC supply.
- It block DC supply.
- It removes ripples from dc source.
- It is use as a filter.

**1.2.8 Types of capacitors**

- Electrolytic capacitors have polarity (positive and negative terminals)
- Electrostatic do not have polarity



**1.2.9 Function of capacitors :**

- It is property of capacitor to store charges
- Pass AC and block DC signal

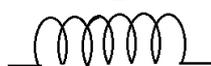
**1.2.10 Inductance (L)**

- measured in Henry (H)
- It is property of inductor to oppose any variation in current.
- It allow DC and block AC.
- Energy sored by inductor is given by

$$E = \frac{1}{2} LI^2$$

E- energy stored in Joules  
 L- inductance value in Henry  
 I -current flows in ampere

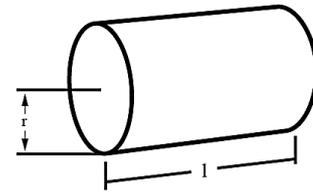
- Represented by L and symbol is



- Inductor: passive elements possesses inductance

$$L = \frac{N^2 \mu A}{l}$$

$$\mu = \mu_r \mu_0$$



Where,

L = Inductance of coil in Henrys

N = Number of turns in wire coil (straight wire = 1)

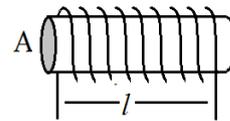
μ = Permeability of core material (absolute, not relative)

μ<sub>r</sub> = Relative permeability, dimensionless ( μ<sub>0</sub> = 1 for air)

$$\mu_0 = 4\pi \times 10^{-7} \text{ (H/m)}$$

A = Area of coil in square meters = πr<sup>2</sup>

l = Average length of coil in meters



- Inductance depends on various factor

$$L = \frac{\mu AN^2}{l}$$

Where L -inductance in henry

μ- permeability of core material (absolute)

A - cross sectional area of former in m<sup>2</sup>

N- number of turns in coil

l - average length of coil in m

μ = μ<sub>0</sub>μ<sub>r</sub> relative permeability μ<sub>r</sub> =1

μ<sub>0</sub> - absolute permeability

μ<sub>r</sub> -relative permeability

- Permeability-degree of magnetization of material
- Inductance value is directly proportional to cross sectional area of former

$$L \propto A$$

- Inductance value is directly proportional to square of number of turns of coil

$$L \propto N^2$$

- Inductance value is inversely proportional to average length of coil

$$L \propto \frac{1}{l}$$

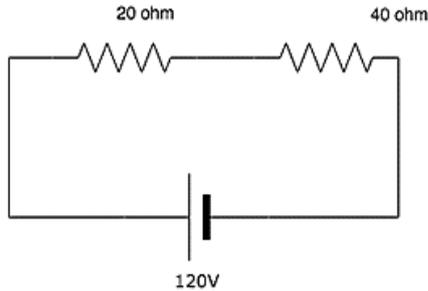
**Application:**

- Tuning circuits.
- Sensors.
- Store energy in a device.
- Induction motors.
- Transformers.
- Filters.
- Chokes.
- Ferrite beads.



## 6. IMPORTANT QUESTIONS

1. Find the current in the circuit.

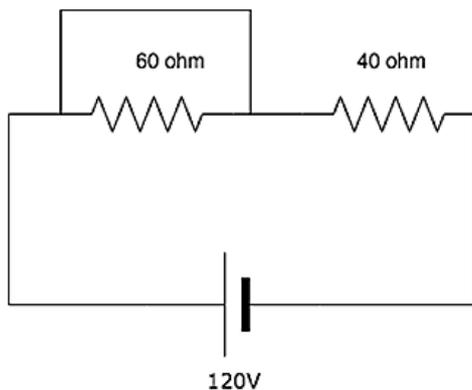


- A. 1 A      B. 2 A      C. 3 A      D. 4 A

2. In a series circuit, which of the parameters remain constant across all circuit elements such as resistor, capacitor and inductor etcetera?

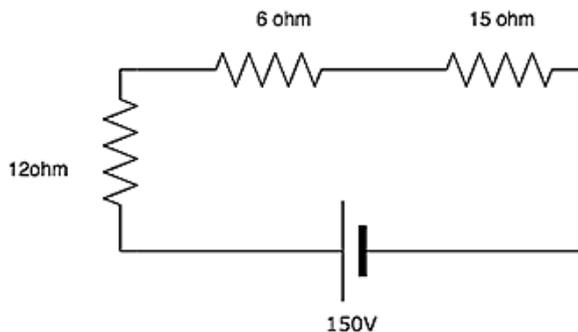
- A. Voltage  
B. Current  
C. Both voltage and current  
D. Neither voltage nor current

3. Voltage across the 60ohm resistor is \_\_\_\_\_



- A. 72V      B. 0V      C. 48V      D. 120V

4. Find the voltage across the 6 ohm resistor.



- A. 150V      B. 181.6V      C. 27.27V      D. 54.48V

5. If there are two bulbs connected in series and one blows out, what happens to the other bulb?

- A. The other bulb continues to glow with the same brightness  
B. The other bulb stops glowing  
C. The other bulb glows with increased brightness

D. The other bulb also burns out

6. Field lines move from \_\_\_\_\_

- A. North to south      B. South to north  
C. West to east      D. East to west

7. A voltage across a series resistor circuit is proportional to?

- A. The amount of time the circuit was on for  
B. The value of the resistance itself  
C. The value of the other resistances in the circuit  
D. The power in the circuit

8. Many resistors connected in series will?

- A. Divide the voltage proportionally among all the resistors  
B. Divide the current proportionally  
C. Increase the source voltage in proportion to the values of the resistors  
D. Reduce the power to zero

9. What is the voltage measured across a series short?

- A. Infinite  
B. Zero  
C. The value of the source voltage  
D. Null

10. What happens to the current in the series circuit if the resistance is doubled?

- A. It becomes half its original value  
B. It becomes double its original value  
C. It becomes zero  
D. It becomes infinity

11. If two bulbs are connected in parallel and one bulb blows out, what happens to the other bulb?

- A. The other bulb blows out as well  
B. The other bulb continues to glow with the same brightness  
C. The other bulb glows with increased brightness  
D. The other bulb stops glowing

12. Magnetic field lines \_\_\_\_\_ at the north pole.

- A. Emerge  
B. Converge  
C. Neither emerge nor converge  
D. Either emerge or converge

13. In a parallel circuit, with a number of resistors, the voltage across each resistor is \_\_\_\_\_

- A. The same for all resistors  
B. Is divided equally among all resistors  
C. Is divided proportionally across all resistors  
D. Is zero for all resistors

# 3. DC AND AC MACHINES





# 1. ELECTROMECHANICAL-ENERGY-CONVERSION PRINCIPLES

- The electromechanical-energy-conversion process takes place through the medium of the electric or magnetic field of the conversion device of which the structures depend on their respective functions.
  - Transducers: microphone, pickup, sensor, loudspeaker
  - Force producing devices: solenoid, relay, and electromagnet
  - Continuous energy conversion equipment: motor, generator

## Forces and Torques in Magnetic Field Systems

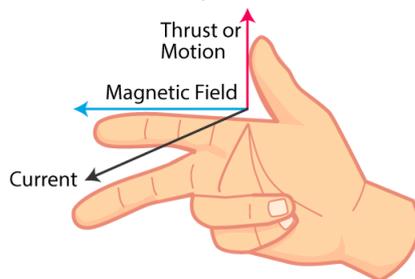
- The Lorentz Force Law gives the force  $F$  on a particle of charge  $q$  in the presence of electric and magnetic fields.

$$F = q(E + v \times B)$$

- Where,  $F$  : newtons,  $q$ : coulombs,  $E$ : volts/meter,  $B$  : teslas,  $v$ : meters/second
- In a pure electric-field system,
- In pure magnetic-field systems,

$$F = qE$$

$$F = q(v \times B)$$



- Figure : Right hand rule
- For situations where large numbers of charged particles are in motion,
 
$$Fv = \rho(E + v \times B)$$

$$J = \rho v \quad Fv = J \times B$$
- $\rho$  (charge density): coulombs/m<sup>3</sup>,  $Fv$  (force density): newtons/m<sup>3</sup>,  $J = \rho v$  (current density): amperes/m<sup>2</sup>.
- Most electromechanical-energy-conversion devices contain magnetic material.
- Forces act directly on the magnetic material of these devices which are constructed of rigid, non-deforming structures.

- The performance of these devices is typically determined by the net force, or torque, acting on the moving component. It is rarely necessary to calculate the details of the internal force distribution.
- Just as a compass needle tries to align with the earth's magnetic field, the two sets of fields associated with the rotor and the stator of rotating machinery attempt to align, and torque is associated with their displacement from alignment.
- In a motor, the stator magnetic field rotates ahead of that of the rotor, pulling on it and performing work.
- For a generator, the rotor does the work on the stator.

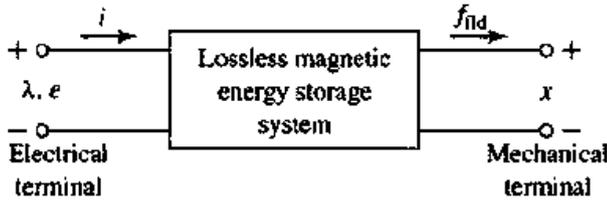
## The Energy Method

- Based on the principle of conservation of energy: energy is neither created nor destroyed; it is merely changed in form.
- Fig. shows a magnetic-field-based electromechanical-energy-conversion device.
- A lossless magnetic-energy-storage system with two terminals
- The electric terminal has two terminal variables:  $e$  (voltage),  $i$  (current).
- The mechanical terminal has two terminal variables:  $f_{fld}$  (force),  $x$  (position)
- The loss mechanism is separated from the energy-storage mechanism.
- Electrical losses: ohmic losses...
- Mechanical losses: friction, windage...
- Fig. a simple force-producing device with a single coil forming the electric terminal, and a movable plunger serving as the mechanical terminal.
- The interaction between the electric and mechanical terminals, i.e. the electromechanical energy conversion, occurs through the medium of the magnetic stored energy.
- $W_{fld}$  : the stored energy in the magnetic field

$$\frac{dW_{fld}}{dt} = ei - f_{fld} \frac{dx}{dt}$$

$$e = \frac{d\lambda}{dt}$$

$$dW_{fld} = i d\lambda - f_{fld} dx$$



(a) Schematic Magnetic Field-based Electromechanical Energy conversion Device

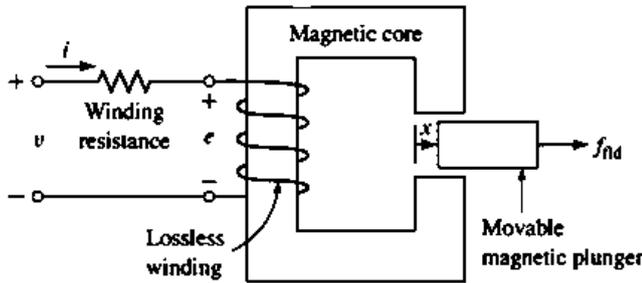


Fig.Schematic dia. Of Simple force producing device

- From the above equation force can be solved as a function of the flux  $\lambda$  and the mechanical terminal position  $x$ .
- The above equations form the basis for the energy method

### Energy Balance

- Consider the electromechanical systems whose predominant energy-storage mechanism is in magnetic fields. For motor action, the energy transfer can be accounted as

$$\left( \begin{matrix} \text{Energy input} \\ \text{form electric} \\ \text{sources} \end{matrix} \right) = \left( \begin{matrix} \text{Mechanical} \\ \text{energy} \\ \text{output} \end{matrix} \right) + \left( \begin{matrix} \text{Increase in energy} \\ \text{stored in magnetic} \\ \text{field} \end{matrix} \right) + \left( \begin{matrix} \text{Energy} \\ \text{converted} \\ \text{into heat} \end{matrix} \right)$$

- The ability to identify a lossless-energy-storage system is the essence of the energy method.
- This is done mathematically as part of the modeling process.
- For the lossless magnetic-energy-storage system of Fig. 1.2 can be rearranged and gives

$$dW_{elec} = dW_{mech} + dW_{fld}$$

where

$$dW_{elec} = id\lambda = \text{differential electrical energy input}$$

$$dW_{mech} = f_{id}dx = \text{differential mechanical energy output}$$

$$dW_{fld} = \text{differential change in magnetic stored energy}$$

- Here  $e$  is the voltage induced in the electric terminals by the changing magnetic stored energy. It is through this reaction voltage that the external electric circuit supplies power to the coupling

magnetic field and hence to the mechanical output terminals.

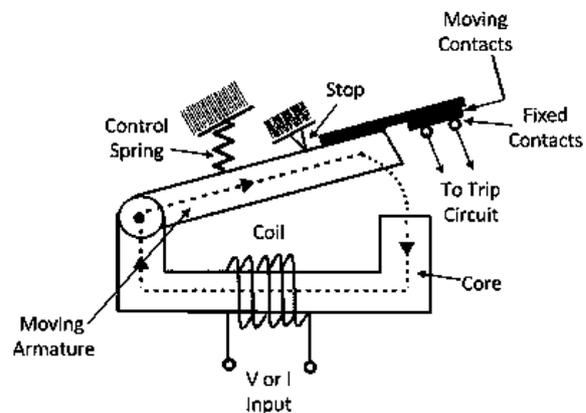
$$dW_{elec} = ei dt$$

- The basic energy-conversion process is one involving the coupling field and its action and reaction on the electric and mechanical systems.
- Combining above two equation -

$$dW_{elec} = ei dt = dW_{mech} + dW_{fld}$$

### Energy in Singly-Excited Magnetic Field Systems

- In energy-conversion systems the magnetic circuits have air gaps between the stationary and moving members in which considerable energy is stored in the magnetic field.
- This field acts as the energy-conversion medium, and its energy is the reservoir between the electric and mechanical system.
- Fig. 1.4 shows an electromagnetic relay schematically. The predominant energy storage occurs in the air gap, and the properties of the magnetic circuit are determined by the dimensions of the air gap.



$$\lambda = L(x)i$$

$$dW_{mech} = f_{id}dx$$

$$dW_{fld} = id\lambda - f_{id}dx$$

- $W_{fld}$  is uniquely specified by the values of  $\lambda$  and  $x$ . Therefore  $\lambda$  and  $x$  are referred to as state variables. Since the magnetic energy storage is lossless, it is conservative system.  $W_{fld}$  is the same regardless of how  $\lambda$  and  $x$  are brought to their final values. Fig shows where two separate the paths.

On path 2a,  $d\lambda = 0$  and  $f_{id} = 0$ . Thus  $df_{id} = 0$  on path 2a.

On path 2b,  $dx = 0$ . Therefore the following equation will result

$$W_{fld} = \int v \left( \int_{H_1}^{H_0} B \cdot dH \right) dV$$