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COMBINED TECHNICAL SERVICES EXAMINATION

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TAMIL NADU POWER DISTRIBUTION CORPORATION LIMITED

RECRUITMENT FOR THE POST OF

TECHNICAL ASSISTANT (ELECTRICAL)

PAPER-II

ELECTRICAL ENGINEERING

(DETAILED THEORY - DIPLOMA STANDARD)

Dr. Krishnasamy M.E., Ph.D.

SURA COLLEGE OF COMPETITION
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TECHNICAL ASSISTANT (ELECTRICAL) (PAPER II)

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- Measurements and Instruments
- Electronic Devices and Circuits
- Analog and Digital Electronics
- Generation, Transmission and Switch Gear
- Distribution and Utilisation
- Micro Processor and Micro Controller
- Power Electronics and Drives
- Electrical Estimation, Costing & Auditing
- Control of Electrical Machines

TNPSC

COMBINED ENGINEERING SUBORDINATE SERVICES EXAMINATION.

TNPDCL

TECHNICAL ASSISTANT (ELECTRICAL) (PAPER II)

SCHEME OF EXAMINATION:

Subject	Standard	No. of Questions	Duration	Maximum Marks	Type of Examination	Mode of Examination
Paper-I	SSLC	**100**	**3 hours**	**150**	**Objective**	**OMR**
Part A Tamil Eligibility Test						
Part B General Studies		**75**		**150**		
Part C Aptitude and Mental Ability		**25**				
Paper-II Subject Paper	**Diploma / ITI**	**200**	**3 hours**	**300**		**CBT**
Total (Part B & C of Paper-I and Paper-II)				**450**		

***Others - Candidates not belonging to SCs, SC(A)s, STs, MBCs/DCs, BC(OBCM)s and BCMs**

OMR - Optical Mark Recognition; CBT - Computer Based Test

TNPSC-CTSE

ELECTRICAL ENGINEERING / ELECTRICAL AND ELECTRONICS ENGINEERING (DIP./ITI STD.)

Duration : 2 Hours
Marks : 300

Solved Original Question Paper-2024

Held on : 16.11.2024

1. Synchronscope device is a electrodynamometer type or
- **A)** Moving coil type
- **B)** Power factor meter
- **C)** Moving Iron type
- **D)** Both (B)and (C) are correct

Ans : (D)

2. A bridge circuit works at a frequency of 2 kHz. The following can be used as detectors for detection of null conditions in the bridge
- **A)** Vibration galvanometer and headphones
- **B)** Headphones and tunable amplifiers
- **C)** Vibration galvanometer and tunable amplifiers
- **D)** Vibration galvanometers, headphones and tunable amplifiers

Ans : (B)

3. In synchronscopes the correct instant of synchronizing is when the bushbar and the incoming machine voltages
- **A)** Are equal in magnitude
- **B)** Are not equal in magnitude
- **C)** Does not have the same frequency
- **D)** Are in different phase

Ans : (A)

4. Example of absolute instrument
- **A)** Ammeter
- **B)** Voltmeter
- **C)** Tangent galvanometer
- **D)** Energy meter

Ans : (C)

5. Precision is defined as
- **A)** Reliability **B)** Accuracy
- **C)** Repeatability **D)** Uncertainty

Ans : (C)

6. Damping commonly used in moving Iron instrument is ..... damping.
- **A)** Air friction **B)** Eddy current
- **C)** Fluid friction **D)** None of these

Ans : (B)

7. Dynamometer type moving coil instrument can be used for
- **A)** DC Current and voltage only
- **B)** AC current and voltage only
- **C)** DC or AC currents and voltages only
- **D)** DC as well as AC circuit

Ans : (D)

8. The sensitivity of the voltmeter is
- **A)** $\frac{\Omega}{V}$ **B)** $\frac{V}{\Omega}$
- **C)** $\frac{\Omega}{A}$ **D)** $\frac{A}{\Omega}$

Ans : (A)

9. Maxwell's inductance - capacitance bridge is used for measurement of inductance of
- **A)** Low Q coils
- **B)** Medium Q coils
- **C)** High Q coils
- **D)** Low and medium Q coils

Ans : (B)

10. In Anderson bridge the unknown self inductance is measured in terms of a fixed ..... and ..... by comparison.
- **A)** Resistance and Capacitance
- **B)** Capacitance and Resistance
- **C)** Inductance and Capacitance
- **D)** Capacitance and Inductance

Ans : (B)

11. This measurement is not done by scheming bridge
- **A)** Capacitance **B)** Permittivity
- **C)** Dielectric loss **D)** High resistance

Ans : (D)

12. With help of ..... instrument can be used for measurement of high voltages and large currents.
- **A)** Voltage divider
- **B)** Transformer
- **C)** Transducer
- **D)** Potentiometer

Ans : (B)

13. ..... is the total power delivered (or) consumed over a time interval.
- **A)** Energy **B)** Power
- **C)** Voltage **D)** Current

Ans : (A)

14. Which transformer is used for measurement of high current?
- **A)** Potential Transformer
- **B)** Current Transformer
- **C)** Step up transformer
- **D)** Step down transformer

Ans : (B)

15. **Machine armature, series field winding examples of**
A) Low resistance
B) Medium resistance
C) High resistance
D) No resistance
Ans : (A)

16. **In a single phase energy meter the core of these electro magnet is made up of ..... steel lamination.**
A) Aluminium **B)** Silicon
C) Iron **D)** Gold
Ans : (B)

17. **In a CRT the focussing anode is located**
A) Between pre accelerating and accelerating anodes
B) After accelerating anode
C) Before pre accelerating anode
D) Before accelerating anode
Ans : (A)

18. **The main part of the cathode ray oscilloscope is**
A) Vertical Amplifier
B) Horizontal Amplifier
C) Cathode Ray Tube (CRT)
D) Time Base Generator
Ans : (C)

19. **An inverse transducers converts**
A) Electrical energy to any other form of energy
B) Electrical energy to light energy
C) Mechanical displacement in to electrical signal
D) Electrical energy to mechanical form
Ans : (A)

20. **RTD is a/an**
A) Active Transducer
B) Passive Transducer
C) Inductive Transducer
D) Capacitive Transducer
Ans : (B)

21. **Which one of the following is not DC system?**
A) Two wire DC system
B) Two wire system with mid point earthed
C) Three wire system
D) Four wire system
Ans : (D)

22. **Identify the type of HVDC scheme that uses only one conductor**
A) Monopolar
B) Bipolar
C) Homopolar
D) Back to back link
Ans : (A)

23. **If sag is an overhead line increases, tension in the line**
A) Decreases **B)** Increases
C) Remains same **D)** Zero
Ans : (A)

24. **Aluminium has a specific gravity of**
A) 1.5 **B)** 2.7
C) 4.2 **D)** 7.8
Ans : (B)

25. **Temperature increase produces which of the following effect on a transmission line?**
A) Tension of the conductor and it's sag increase
B) Tension of the conductor and it's sag decrease
C) Tension of the conductor decreases and it's sag increases
D) Tension of the conductor increases and it's sag decreases
Ans : (C)

26. **A ..... is provided over the insulation to protect the cable from moisture.**
A) Serving **B)** Metallic sheath
C) Bedding **D)** Armouring
Ans : (B)

27. **The most common and accurate method of locating earth fault or short - circuit fault in underground cables**
A) Murray loop test **B)** Open circuit test
C) Simple test **D)** Short circuit test
Ans : (A)

28. **Steel pipes arranged to take water to power house is called**
A) Penstock **B)** Surge tank
C) Spill ways **D)** Tail race
Ans : (A)

29. **Suspension type of insulator are used for voltages beyond**
A) 400 V **B)** 11 kV
C) 33 kV **D)** 240 V
Ans : (C)

30. **The most commonly used metal for cooling of nuclear reactors is .....**
A) Sodium **B)** Calcium
C) Mercury **D)** Zinc
Ans : (A)

31. **The maximum KVA demand of the consumer is ..... to power factor.**
A) inversely proportional
B) directly proportional
C) equal
D) double
Ans : (A)

32. Area under the daily load curve divided by 24 gives
- **A)** average load
- **B)** maximum demand
- **C)** units generated
- **D)** load factor

Ans : (A)

33. The another name for steam power station is .....
- **A)** Thermal Station
- **B)** Water Station
- **C)** Nuclear Station
- **D)** Diesel Station

Ans : (A)

34. In a Nuclear reactor, the moderator is used to
- **A)** slow down neutrons
- **B)** slow down electrons
- **C)** high accelerate neutrons
- **D)** high accelerate electrons

Ans : (A)

35. Which of the following Power Generation under conventional method?
- **A)** Hydro-electric
- **B)** Thermal
- **C)** Nuclear
- **D)** All of the above

Ans : (D)

36. A low utilisation factor for a plant indicates that
- **A)** Plant is under maintenance
- **B)** Plant is used for base load only
- **C)** Plant is used for standby purpose only
- **D)** Plant is used for base load as well as peak load

Ans : (C)

37. A fuse element should have ..... melting point.
- **A)** low
- **B)** high
- **C)** medium
- **D)** low or high

Ans : (A)

38. The voltage that appears across the contacts of the circuit breaker during the arcing period is .....
- **A)** Arc voltage
- **B)** Restriking voltage
- **C)** Recovery voltage
- **D)** Rate of Rise of Restriking Voltage

Ans : (A)

39. Function of a fuse is to
- **A)** Identify the fault
- **B)** Sense the fault and break the circuit
- **C)** Same that of a relay
- **D)** Same that of a circuit breaker

Ans : (B)

40. In equipment grounding, the enclosure is connected to ..... wire.
- **A)** Ground
- **B)** Neutral
- **C)** Phase
- **D)** Either phase or neutral

Ans : (A)

41. Regulation of a good transformer should be near
- **A)** 1%
- **B)** 10%
- **C)** 20%
- **D)** 30%

Ans : (A)

42. The main purpose of using core in a Transformer is to .....
- **A)** Reduce reluctance
- **B)** Prevent eddy current loss
- **C)** Decrease iron loss
- **D)** Eliminate magnetic hystersis

Ans : (A)

43. The leakage flux in a transformer depends upon the
- **A)** applied voltage
- **B)** frequency
- **C)** load current
- **D)** mutual flux

Ans : (C)

44. In a transformer EMF per turn in primary winding is
- **A)** less than EMF per turn in secondary winding
- **B)** greater than EMF per turn in secondary winding
- **C)** equal to EMF per turn in secondary winding
- **D)** equal to zero

Ans : (C)

45. A 200 KVA transformer has an iron loss of 1 KW and full load Cu loss of 4 KW. Its load KVA corresponding to maximum efficiency is
- **A)** 100 KVA
- **B)** 141.4 KVA
- **C)** 50 KVA
- **D)** 200 KVA

Ans : (A)

46. The load taken up by an alternator depends upon its ..... of its rotor.
- **A)** Controlling Torque
- **B)** Driving Torque
- **C)** Deflecting Torque
- **D)** Advancement

Ans : (B)

47. A 50 Hz alternator will run at the greatest possible speed if it is wound for ..... poles.
- **A)** 8
- **B)** 6
- **C)** 4
- **D)** 2

Ans : (D)

48. What is the frequency of voltage generated by an alternator having 10 poles and rotating at 720 rpm?
- **A)** 50 Hz
- **B)** 60 Hz
- **C)** 70 Hz
- **D)** 75 Hz

Ans : (B)

49. In an alternator when the load pf is unity
- **A)** the armature flux will be demagnetising
- **B)** the armature flux will be cross magnetising
- **C)** the armature flux will reduce to zero
- **D)** the armature flux will have square waveform

Ans : (B)

50. Turbo alternator are generally used to run at .....
A) Low speed
B) Medium speed
C) Low and medium speed
D) Very high speed
Ans : (D)

51. A 3-ø slip ring induction motor is fed from the rotor side with stator winding short circuited. The frequency of stator current is
A) Slip frequency
B) Supply frequency
C) Frequency corresponding to the rotor speed
D) Zero
Ans : (A)

52. An induction motor when started on load does not accelerate upto full load speed, but runs at 1/7th of the rated speed. The motor is said to be
A) Locking **B)** Plugging
C) Crawling **D)** Cogging
Ans : (C)

53. The slip at which maximum torque occurs in a 3ø induction motor is given as
A) $S = \frac{R_2}{X_2}$ **B)** $S = \frac{R_2}{X_2^2}$
C) $S = \frac{R_2^2}{X_2}$ **D)** $S = R_2 X_2$
Ans : (A)

54. Synchronous motor can operate at
A) Lagging p.f. only
B) Leading p.f. only
C) Unity p.f. only
D) Any of the above these
Ans : (D)

55. The range of efficiency for shaded pole motor is .....
A) 95% to 99% **B)** 80% to 90%
C) 5% to 35% **D)** 50% to 75%
Ans : (C)

56. A universal motors is used for driving
A) food mixers
B) ceiling fan
C) electric clocks
D) photocopying machines
Ans : (A)

57. The motor that provides high starting torque is
A) Capacitor run motor
B) Resistance start motor
C) Shaded pole motor
D) Capacitor start motor
Ans : (D)

58. The direction of rotation of induction motor can be reversed by
A) increasing the supply voltage
B) reversing the phase sequence
C) decreasing the supply voltage
D) reducing the frequency
Ans : (B)

59. In Switched Reluctance Motor, torque is produced due to
A) Variable reluctance principle
B) Self inductance principle
C) Mutual inductance principle
D) Constant reluctance principle
Ans : (A)

60. The speed of rotation of stepper motor depends on
A) magnitude of supply voltage
B) frequency of input pulse
C) torque
D) polarity of stator current
Ans : (B)

61. In PLC programme, a retentive timer function is .....
A) Defaults to the 'ON' state
B) Defaults to the OFF state
C) Comes last in the program
D) Not reset after a power cycle
Ans : (D)

62. The following elements are needed to make a star delta starter using Ladder diagram
A) Two push buttons, One timer, Three contactor
B) One push button, One timer, Three contactor
C) Two push button, Two timer, Two contctor
D) None of the above
Ans : (A)

63. A normally closed contact symbolize in ladder logic is
A) An open switch
B) A closed switch
C) A timer
D) A Counter
Ans : (B)

64. ..... are an example for output modules in the programmable logic controller.
A) Switches **B)** Alarms
C) Lamps **D)** Both (B) and (C)
Ans : (D)

65. The following process updates the status of PLC outputs .....
A) Full Scan **B)** Output scan
C) Input scan **D)** Process scan
Ans : (B)

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INTRODUCTION TO ELECTRICITY

Basic Concepts

- Electricity is the most conventional form of energy and has multiple applications like lighting, communication, heating, transportation, air conditioning, etc. The flow of electricity can be compared with the flow of water in a pipe. Flowing water is a good analogy of electricity. When water flows through a pipe, or down stream, there is a water current. Similarly, electric current or simply current is the flow of electrons in an electric circuit. The flow of current depends upon amount of charge or the number of electrons flowing. If we have to measure how fast the water is flowing in a pipe, we may say it is so many gallons per minute. When we measure how much current is flowing through a wire, it is based on the number of electrons flowing past that cross-section of wire in one second. There is a unit of measure called the **Coulomb**, which enables us to measure the amount of charge in an object (e.g. an electron). Since there are billions of electrons flowing through the wire, we instead measure the charge with unit Coulomb, which is 6,240,000,000,000,000,000 (6.24 billion-billion) electrons, flowing through the wire to measure electric current.
- **Ampere** is the basic unit of electric current. When one Coulomb of electrons passes through a wire in one second, we say that there is one Ampere of current. It is sometimes referred to as Amps. Hence, **I = Charge/Time, I = dq/dt.**
- Water flows through a pipe because of water pressure. Water pressure forces the water to flow. Likewise, **Electromotive Force (EMF)** is the pressure that forces electrons to flow through a circuit. Electromotive force is also known as voltage. The basic unit of electromotive force is Volt. In the same fashion as water flows down in the stream, through a pipe, current can flow in a circuit. Water is limited by the amount of friction it encounters as it flows. Electricity is limited by the amount of resistance it meets as it passes through a circuit. Resistance limits the current that flows through a circuit for a particular applied voltage. Hence, resistance acts as a friction in flow of current. However, if we increase the water pressure in a pipe, more water would flow. Similarly, if we turn up the voltage, then more current would flow.
- The material or the medium plays an important role. There are some materials in which electricity flows easily. These materials, thus, have very low or negligible resistance and are called **conductors**. Most metals are conductors. Three good electrical conductors are gold, silver and aluminum. **Insulators** are materials that do not let electricity flow through them and, thus, have very high or almost infinite resistance. Four good insulators are glass, air, plastic and porcelain.

Applications of Electricity

In the modern world, dependence on electricity is unavoidable. The ever increasing importance of electricity is due to its numerous applications for domestic and industrial purposes. A few important applications of electricity are discussed below :

Heating

- One of the important applications of electricity is its use for heating purposes in the domestic and industrial field. In all electric heating appliances, electrical energy is converted into heat by passing an electric current through a wire of high resistance.
- **Domestic Applications :** Electric press, heater, coffee percolator, toaster, electric kettle etc.
- **Industrial Applications :** Electric ovens, electric furnaces etc.

Lighting

- The other important application of electricity is its use for lighting purposes. In all such devices, electrical energy is converted into light energy by utilizing the effects of electricity.
- **Domestic Applications :** Electric bulbs, fluorescent tubes, discharge lamps (sodium lamp, mercury lamp) etc.
- **Industrial Applications :** All domestic lighting devices and lamps for cinema projectors, etc.

Electric Motors

- The main application of electricity is its use for running electric motors. In all electric motors, electrical energy is converted into mechanical energy.
- **Domestic Applications :** Hair drier, mixer, refrigerators, ceiling and table fans, air cooler, washing machine, etc.
- **Industrial Applications :** Lifts, cranes, tube-wells, concrete mixer, lathes, etc.

Electroplating

- Electricity is used for the process of electroplating, i.e. coating a layer of superior metal over inferior metal.
- **Domestic Applications :** Tin plating of utensils, etc.
- **Industrial Application :** Nickel plating of vehicles, watch cases, etc.

Current

Free Electron Theory

- As we are aware, the atom is most fundamental unit of matter. Generally, according to atomic structure, the atom consists of a nucleus and electrons. All electrons move around the nucleus in different orbits or shells. These orbits are energy levels. The electrons present in the outermost orbit are called valence electrons in

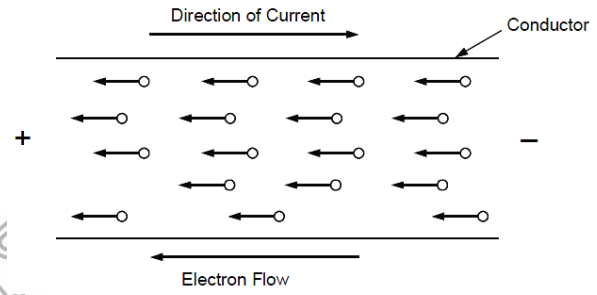
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modern physics, and the valence electrons that are able to move from one atom to another atom, in a random manner, are known as 'free electrons'. Free electrons, thus, work as charge carriers, and can carry charge from one point to another point, when an external field is applied.

- According to energy band theory, the forbidden energy gap is absent between valance and conduction band in good conductors. Thus metals, which work as good conductors, contain large number of free electrons at normal temperature without supplying any additional energy.
- Materials which are bad conductors possessing a higher energy gap between the valence and conduction bands are called insulators.

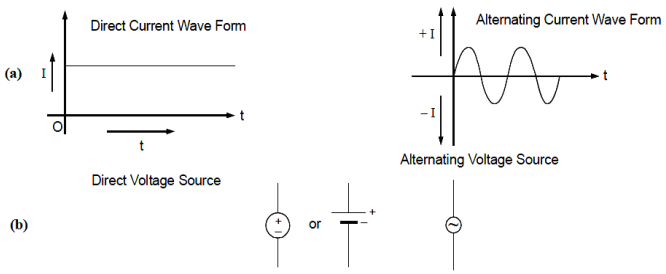
EMF and Current

- In the study of an atomic structure, a neutral atom contains equal number of protons in the nucleus and electrons in the shells. Protons are positively charged particles and electrons contain negative charge. Normally, an atom loses an electron when it becomes positively charged or positive ion. Similarly, after gaining an additional electron the atom becomes negatively charged and is known as negative ion.
- The ability of two oppositely charged bodies to produce a flow of electricity between them is the potential for the production of electric current. Thus, a positively charged body is said to be at positive potential and a "+" sign is used to identify this potential. Similarly, a negatively charged body is described at negative potential and a "–" sign is used to identify this potential. The arithmetic difference between the two is called "potential difference" between them. It is measured in volts (V) and a term "voltage" is applied for "potential difference". The magnitude of potential difference between two points is equal to the work done in moving a unit positive charge from one point to another. In electrical circuits, potential difference is provided by some external means like a cell or a battery. A cell or battery provides a electrical potential that tends to cause current to flow. It is also known as Electromotive Force (EMF) and is measured in "volts".
- When a suitable conductivity path or good conductor is used, then a current will flow as a result of electric pressure. The current flows from positive potential to negative potential. But actually the direction of flow of electrons is towards positive potential from negative potential, and may be considered as flow of equivalent positive charge in the opposite direction as shown in Figure below. Conventionally, the current, produced by flow of electrons, is supposed to be the flow of + ve charge and, thus, flows from positive potential to negative potential. SI unit of current is Ampere (A) and its symbol is I.



Electron Flow

- Current that flows continuously in one direction is known as direct current (DC).
- Direct current is supplied by voltage cell because the polarities of voltage cell do not reverse with passage of time. Thus, a voltage cell is termed as direct voltage source (DC voltage source) as shown in Figure below.



Direct and Alternating Voltage Source

- Alternating current (AC) is the current that flows first in one direction for a small time, and then reverses the flow in the opposite direction for a similar time. Voltage source capable of producing alternating current is called Alternating voltage source or AC voltage source.

Ohm's Law

The opposition to current flow that exists in every material is called 'Resistance'. It is the property of material by which we know how it resists flow of current. The property which supports flow of current is known as conductance. The reciprocal of resistance (R, symbol for a resistor) is conductance (G). The resistance is measured in ohms (Ω).

The conductance is given as,

$$\text{Conductance, } G = \frac{1}{\text{Resistance}} = \frac{1}{R}$$

Siemens (S) is the unit of conductance.

According to Ohm's law, the current (I) flows through a resistor due to electric pressure and is directly proportional to the magnitude of electrical pressure (V).

$$\therefore \quad \text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

$$\text{or,} \quad I = \frac{V}{R}$$

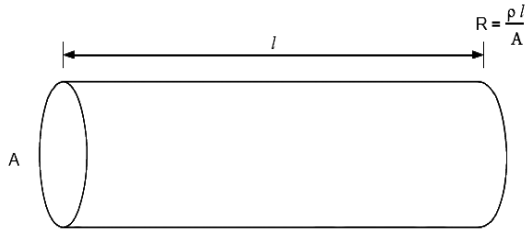
The resistance of a resistor depends on area, length and resistivity of material of resistor and is given by,

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

Here, ρ = Resistivity,

l = Length of resistor, and

A = Area of cross section.



Resistor

Resistivity is the property of material and depends upon the internal structure of a metal or a conductor. It is measured in ohm-m or ohm-cm.

Effects of Electric Current

When an electric current flows in a conductor, heat is dissipated as a result of work done in moving electrons. For example, work is performed in a lamp filament when the electric current is converted into light. The power (P) is the rate of doing work.

If work done is w, then

Power = w / t

The SI unit of power is Joules/second (J/s) termed as Watt (W).

In a resistance, heat is produced by flow of current due to work done in moving charge q across potential V, which is given by

$W = V \times q$

Thus, Power $= \frac{w}{t} = V \times \frac{q}{t} = V \times I$ = Voltage × Current

Therefore, $P = V \cdot I = I R \cdot I$ (using Ohm's law)

$P = I^2R$

The unit of electrical power is Watt (W) or kilo Watt (kW).

This power is wasted in electronic circuits but in order to protect the equipment, fuses are used. Fuses are designed in such a way that the current flow exceeds the design limit, the power is dissipated in fuse to cause it to melt and blow off to protect a device by interrupting the current flow in the circuit.

The electrical appliances are rated in W or kW consumed energy. Thus, the energy is the consumption of power in a specified time

$w = P \cdot t$

Its SI unit is kWh and is measured by energy meters.

Example: 1

Calculate current flow through the 5 Ω resistor when a 100 V battery is connected across it. Also calculate conductance of the resistor and the power dissipated by this resistor.

Solution:

We know $I = \frac{V}{R}$

So, $I = \frac{100}{5} = 20$ A

Power dissipated, $P = I^2 R = 20^2 \times 5 = 2000$ W

$= 2$ kW

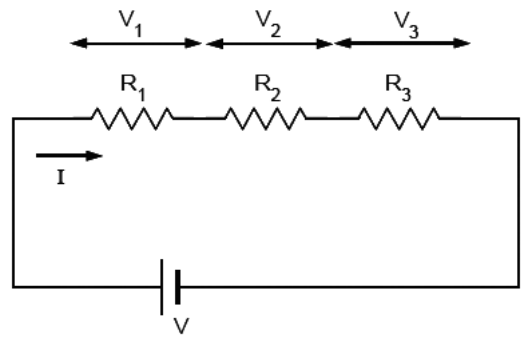
Now we know Conductance $= \frac{1}{\text{Resistance}} = \frac{1}{5}$

$= 0.2$ Siemens

Resistance of a Conductor

Resistance of Resistors in Series

Resistors are said to be in series when they are connected in such a way that there is only one path through which current can flow (Figure below). This means current in a series circuit is the same in all parts of the circuit. The voltage drop across each component in a series circuit depends on the current level and the component resistance.



Resistance of Resistors in Series

The total resistance across the voltage source in Figure below will be

$R_{eq} = R_1 + R_2 + R_3$

R_{eq} is called equivalent resistance of circuit for a series circuit with n resistors and

is given as,

$R_{eq} = R_1 + R_2 + R_3 + \ldots + R_n$

If the resistance of all resistors are same, then

$R_{eq} = n \cdot R$

The current flow in the circuit will be

$$I = \frac{E}{R_{eq}} = \frac{E}{R_1 + R_2 + \ldots + R_n}$$

The current in series circuit produces voltage drop across resistors as shown in Figure above:

$V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$.

Therefore, $V = V_1 + V_2 + V_3$

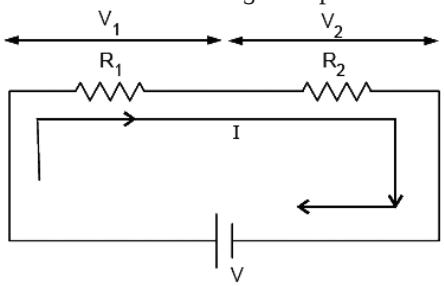
$V = I (R_1 + R_2 + R_3)$

$V = I \cdot R_{eq}$

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

Example: 2

A series combination of two resistors having resistances R_1 and R_2 is connected across a voltage cell of V volts as shown in Figure below. Find current flowing through the circuit and voltage drop across resistors.



Solution:

Here $R_{eq} = R_1 + R_2$

We know, current $I = \frac{V}{R_{eq}} = \frac{V}{R_1 + R_2}$

$\because$ Voltage drop across R_1 is $V_1 = I \cdot R_1$.

So, $\Rightarrow V_1 = \frac{V}{R_1 + R_2} \cdot R_1 = \frac{VR_1}{R_1 + R_2}$

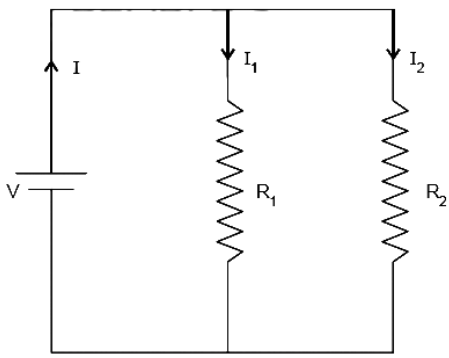
Similarly, voltage drop across R_2 is V_2

$\Rightarrow V_2 = \frac{VR_2}{R_1 + R_2}$

After illustration of above example, we know that in a series circuit the portion of applied emf developed across each resistor is the ratio of the resistor to the total series resistance. Thus, two or more series connected resistors, as shown in Figure (Resistance of Resistors in Series), can be used as a voltage divider. A potentiometer is a variable voltage divider. The series connected resistors are used for the purpose of voltage dropping or current limiting.

Resistance of Resistors in Parallel

Resistors are said to be connected in parallel when the same voltage appears across each component with different current flows through each resistor. The total current flow into and out of parallel combination is the sum of all the individual resistor currents as shown in Figure below.



Parallel Resistance

Two resistors connected in parallel may be used as a current divider.

The voltage V appears across each resistor

Then $I_1 = \frac{V}{R_1}$ and $I_2 = \frac{V}{R_2}$

But total current $I = I_1 + I_2$

For n resistors in parallel

$I = I_1 + I_2 + I_3 + \ldots + I_n$

Here, $I = I_1 + I_2$.

$= \frac{V}{R_1} + \frac{V}{R_2}$

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

Then, $\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2}$

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

For n resistors,

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

or $R_{eq} = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}\right)}$

Now $I_1 = \frac{V}{R_1}$

Using $V = I R_{eq}$, we get

$I_1 = \frac{I R_{eq}}{R_1}$

But here, $R_{eq} = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)} = \frac{R_1 R_2}{R_1 + R_2}$

$\Rightarrow I_1 = \frac{\frac{I \cdot R_1 R_2}{(R_1 + R_2)}}{R_1}$

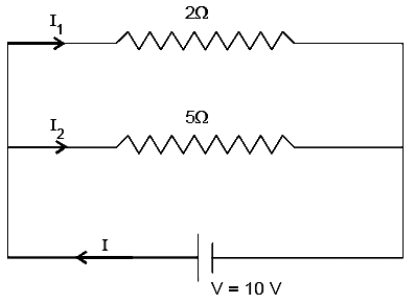
$I_1 = I\left(\frac{R_2}{R_1 + R_2}\right)$

Similarly $I_2 = I\left(\frac{R_1}{R_1 + R_2}\right)$

Thus, we see that two parallel connected resistors functioned as a current divider.

Example: 3

Determine current I_1, I_2 and total current in circuit shown in Figure below.



Solution:

We know $R_{eq} = \frac{R_1 R_2}{R_1 + R_2} = \frac{10}{7}$

$$I = \frac{V}{R_{eq}} = \frac{10}{\frac{10}{7}} = 7A$$

Now, $I_1 = I \cdot \frac{R_2}{R_1 + R_2} = \frac{7 \times 5}{2+5}$

$I_1 = 5A$

and, $I_2 = I - I_1$

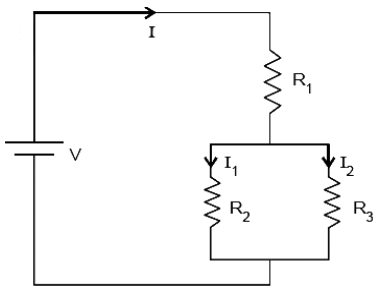
$= 7 - 5$

$= 2$ A

Also, $I_1 = I \cdot \frac{R_1}{R_1 + R_2} = \frac{7 \times 2}{2+5} = \frac{7 \times 2}{7} = 2A$

Series and Parallel Combination of Resistors

Generally, most of the circuits have series and parallel combinations. The simplest approach to analyse a series-parallel circuit is to resolve each purely series or purely parallel group into its single equivalent resistance till we arrive at a single equivalent resistance across voltage source.



Combination of Series and Parallel

Example: 4

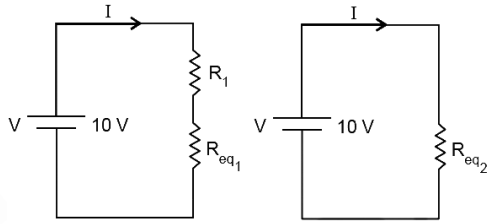
If $R_1 = 5\ \Omega$, $R_2 = 2\ \Omega$ and $R_3 = 3\ \Omega$ and voltage cell of 10 V connected across these for an arrangement shown in Figure below, then calculate the current in all three resistors.

Solution:

This circuit can be simplified by replacing parallel connected resistors with its equivalent resistance

$$R_{eq_1} = \frac{R_2 R_3}{R_2 + R_3}$$

The circuit can then be reduced by replacing series resistances R_1 and R_{eq_2} with R_{eq_2}.



Equivalent Circuit

Thus, $R_{eq_1} = \frac{R_2 R_3}{R_2 + R_3} = \frac{2 \times 3}{2+3} = \frac{6}{5}\Omega$

and $R_{eq_2} = R_1 + R_{eq_1} = 5 + \frac{6}{5} = \frac{31}{5}\Omega$

Now, $I = \frac{V}{R_{eq_2}} = \frac{10}{\frac{31}{5}} = \frac{50}{31}A$

Current I flows through R_1 and R_{eq_1}

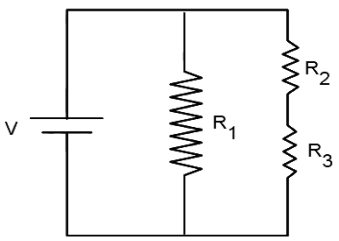
Now, find currents flowing through R_2 and R_3 by using current divider.

Current in R_2 is $I_1 = \frac{I \cdot R_3}{R_2 + R_3} = \frac{\frac{50}{31} \times 2}{5} = \frac{20}{31}A$

Current in R_3 is $I_2 = \frac{I \cdot R_2}{R_2 + R_3} = \frac{\frac{50}{31} \times 3}{5} = \frac{30}{31}A$

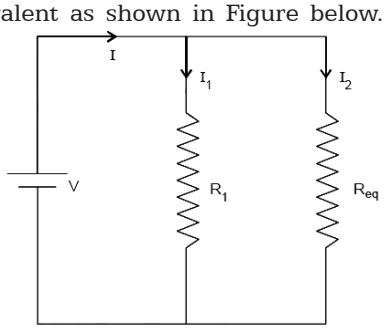
Example: 5

Using values given in above example, find currents in R_1, R_2 and R_3.



Solution:

To reduce above circuit, first replace series combination by its equivalent as shown in Figure below.



Equivalent Circuit (For example Parallel Resistance)

$R_{eq} = R_2 + R_3$
$= 2 + 3 = 5\ \Omega$

Now, the same voltage V appears across R_1 and R_{eq}

So, current in R_1, $I_1 = \frac{V}{R_1} = \frac{10}{5} = 2A$

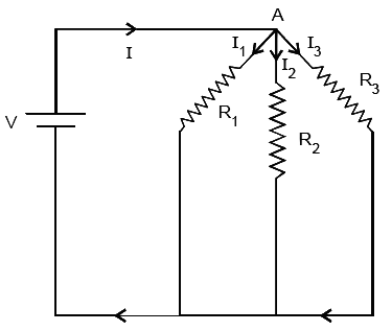
and current in R_2 and R_3, $I_2 \Rightarrow \frac{V}{R_{eq}} = \frac{10}{5} = 2A$

KIRCHHOFF'S LAWS

These laws are more comprehensive than Ohm's law and are used in solving the electrical circuits which may not be solved by the latter.

Kirchhoff's Current Law (KCL)

In any circuit, the algebraic sum of all the currents meeting at a point is zero. The total current leaving a junction or point is equal to total current entering that junction. It proves conservation of charge as charge is not stored at a point and the charge entering a point has to be equal to charge leaving that point, i.e. $\Sigma I = 0$ (at a point or junction) as shown in Figure below.



Kirchhoff's Current Law

Here 'I' enters at junction and I_1, I_2 and I_3 are leaving the junction.

Assuming incoming currents + ve and outgoing currents as – ve, we have, algebraic sum of currents meeting at junction A as,

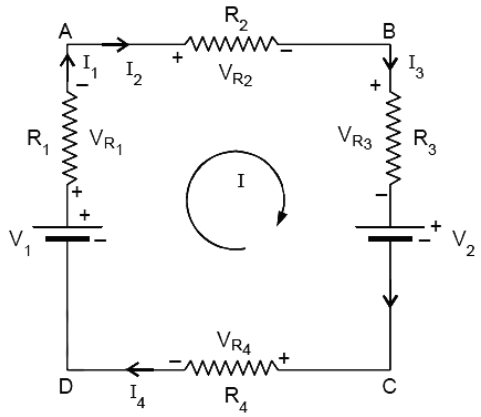
$I - I_1 - I_2 - I_3 = 0$
or $I - (I_1 + I_2 + I_3) = 0$
i.e. $I = I_1 + I_2 + I_3$.

Thus, KCL also implies that sum of incoming currents equals sum of outgoing current.

Kirchhoff's Voltage Law (KVL)

In any closed circuit the algebraic sum of the voltages reckoned in a particular direction is zero. Conventionally, voltage drop in the direction of traversal is taken as negative, while a rise in voltage is taken as positive. It may be remembered that across a resistor voltage drops in the direction of current while it rises in the opposite direction, as shown in Figure below.

Thus, $\Sigma V = 0$ (Round a mesh or path).

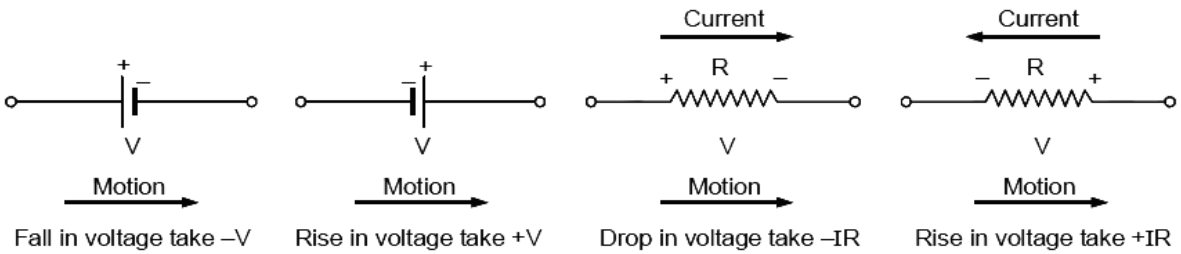


Kirchhoff's Voltage Law

In a closed circuit ABCDA, in the clockwise direction the voltage drops are $I_1 R_1$, $I_2 R_2$, $I_3 R_3$, $I_4 R_4$ and V_2, while the voltage rise is V_2.

In a path ABCDA, considering a rise in voltage is positive and fall in voltage is negative. The polarity of voltage drop appears across any resistor, as shown in Figure below.

The rise and fall in voltage should be as shown in Figure below.



Using these conventions, we have algebraic sum of voltages in clockwise direction as

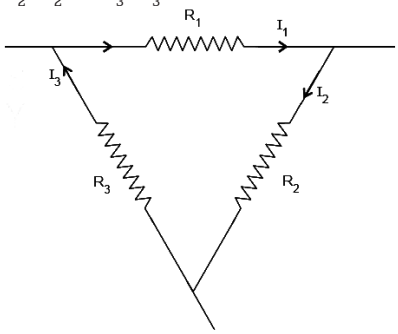
$-V_{R1} - V_{R2} - V_{R3} - V_2 - V_{R4} + V_1 = 0$
or, $-I_1 R_1 - I_2 R_2 - I_3 R_3 - I_4 R_4 - V_2 + V_1 = 0$
or, $I_1 R_1 + I_2 R_2 + I_3 R_3 + I_4 R_4 = V_1 - V_2$.
or, $\Sigma IR = \Sigma$ EMFs.

Thus, KVL also means that in a closed circuit total voltage drop across resistors is equal to algebraic sum of voltage sources reckoned in the direction of voltage drops across resistors.

In a closed circuit, if there is no source of EMF, then sum of voltage drops is equal to zero.

Thus, we get,

$I_1 R_1 + I_2 R_2 + I_3 R_3 = 0$



STORAGE BATTERIES

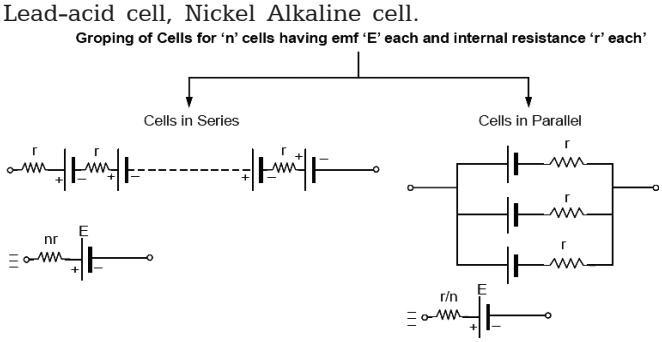
- A battery is a collection of two or more than two cells.
- A cell is the smallest unit of a battery, which converts chemical energy to electrical energy. A cell always gives DC voltage (emf) and DC current. Cells are of two kinds – Primary cell and Secondary cell.

Primary Cell

A cell based on irreversible reactions, whose components must be renewed (or the cell itself be replaced) when it is rundown, is known as a primary cell, e.g. simple voltaic cell, Daniel cell, Lechlanche cell and Dry cell.

Secondary Cell

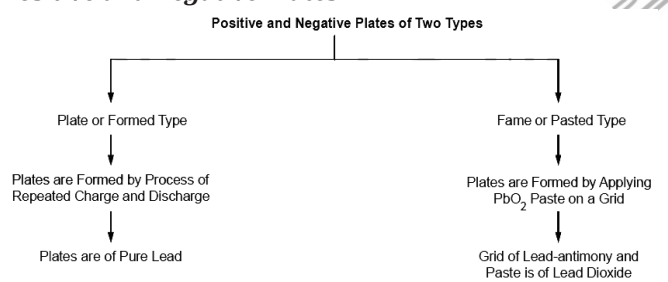
A cell based on reversible reactions, whose components (i.e. electrodes and electrolytes) can be brought back to normal state by passing a current through it in the opposite direction is known as a secondary cell, e.g. Lead-acid cell, Nickel Alkaline cell.



Different Types of Cell

Construction of Lead Acid Battery

Positive and Negative Plates



Types of Lead Acid Accumulator

Separators

They are used for insulating the negative and positive plates. They are made of thin sheets of perforated hard rubber or plastic material of fibre glass or wood.

Electrolyte

Diluted sulphuric acid fills the cell compartment to immerse the plates completely.

Container

Battery parts are placed within the container and protected. Partition walls are provided in the container for cells.

Bottom Blocks

The bottom-groved support blocks are placed at the bottom of the container, which converts the active materials, which fall from plates. In this way, it prevents the short-circuiting of the plates.

Plate Connector

It is a lead plate, which is assembled to a group of positive plates or to a group of negative plates. An upward connection of the plate connector forms a terminal of a cell.

Cell Connector

Various cells constitute a battery. The negative terminal of one cell is arranged close to the positive terminal of the next cell and connected together so that the cells can be connected in series. These connectors are either of pure lead or of a special lead alloy.

Terminal Posts

They are the upward extension of the two extreme plate-connectors. The connections for outside circuit are taken from these terminal posts. They are marked (+)ve or (–)ve.

Vent Plug or Filler Caps

These are made of rubber or polystyrene and screwed to the cover of the cell. Their function is to prevent escape of electrolyte but allow free exit of gases.

External Connecting Straps

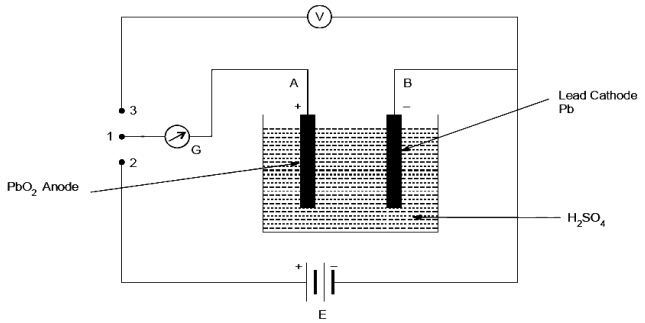
These are the antimony-lead alloy flat bars which connect the positive terminal post of one cell to the negative of the next across the top of the cover. These are of very solid construction, especially in starting batteries because they have to carry very heavy currents.

Active Materials of a Lead Cell

The active materials of a Lead-Acid Accumulator are

PbO_2 (Lead Peroxide)

It is a chocolate-brown coloured, hard and brittle rod, which forms the positive plate of the battery.



Pb (Sponge Lead)

It is pure lead in soft sponge or porous condition. It forms the negative plate of the battery.

Dilute H_2SO_4 (Dilute Sulphuric Acid)

Concentrated H_2SO_4 of specific gravity 1.84 is taken. One part of it is mixed with three parts of distilled water to prepare a diluted sulphuric acid of specific gravity 1.24.

Thus, the lead acid accumulator depends for its action in the presence of two plates of Pb / PbO_2 in a solution of diluted sulphuric acid of specific gravity 1.21 to 1.24 or near-about.

Chemical Reactions

Charging and Discharging of Lead Acid Batteries

In the process of manufacturing of cells, the plates are in the charged condition. In the charged condition, positive plate or anode consists of lead peroxide PbO_2 (dark chocolate brown) and the negative plates or cathode is in lead (Pb) (slate grey).

(a) During Charging, the following reactions occur:

$PbSO_4 + H_2 \rightarrow Pb + H_2SO_4$ . . . . . (at cathode)

$PbSO_4 + SO_4 + 2H_2O \rightarrow PbO_2 + 2H_2SO_4$ ..... (at anode)

At the end of charging (i.e. fully charged) :

(i) Anode becomes PbO2 (Colour : Chocolate brown)

(ii) Cathode becomes Pb (Colour : Slate grey)

(iii) Density of electrolyte (i.e. its specific gravity becomes 1.23 to 1.28)

(iv) Approximate value of emf is 2.3 volts

(v) Cell stores energy

(b) During Discharging, the following reactions occur:

$PbO_2 + H_2 + H_2SO_4 \rightarrow PbSO_4 + 2\ H_2O$ (at anode)

$Pb + SO_4 \rightarrow PbSO_4$ (at cathode)

During Discharging

(i) Both anode and cathode become $PbSO_4$, which is whitish in colour.

(ii) Due to formation of water, in the anode reaction, the specific gravity of the electrolyte decreases and may even reach as low as 1.15 or 1.05.

(iii) Voltage (emf) of the cell decreases.

(iv) Cell gives out energy.

Single Reaction :

$PbO_2 + 2H_2SO_4 + Pb \rightarrow PbSO_4 + 2H_2O + PbSO_4$

(+) ve Plate — Electrolyte — (–) ve Plate — (+) ve Plate — Water — (–) ve Plate

Initial Charging

Charging a new battery for the first time is called initial charging.

Steps

(a) Battery is cleaned.

(b) Electrolyte of specific gravity P = 1.23 is provided.

(c) Battery is allowed to cool for 14-16 days.

(d) Level of electrolyte, which decreases, is again brought back to the level by pouring more of it and again cooling for 3-6 days.

(e) Initial charging is done at a rate lower than the normal.

(f) At the end of charging (i.e. after 2-3 days), the 'P' is adjusted by adding distilled water.

Thereafter, the battery is discharged at a rate lower than normal for the first one or two times. The battery is put to the normal service after charging and discharging.

Testing of Lead Acid Battery

To know the latest charged position, testing of battery is done by measuring the specific gravity of electrolyte and the voltage with a cell tester.

For a fully charged battery, the voltage of each cell should be about 2 V to 2.07 V while the specific gravity should be about 1.26.

Care and Maintenance of Lead Acid Battery

There are some important points, as listed below, which help in care and maintenance of battery like :

(g) Lead acid batteries should be brought up to full charge at the earliest. Avoid continuously operating batteries in a partially charged condition. This will shorten their life and reduce their capacity.

(h) Inactivity can be extremely harmful.

(i) When not in use, remove electrical connections from the battery including series/parallel connectors.

(j) Store battery in a cool place.

(k) Extreme temperatures can substantially affect battery performance and charging.

(l) Batteries should be kept clean, free of dirt and corrosion at all times.

(m) New batteries should be charged properly.

Trickling Charge

Under idle condition, the battery discharges very slowly due to self leakage. To keep the battery fully charged under critical operating conditions, it is continuously charged at the same rate as that of discharge. This slow charging of battery is called **trickle charging**.

Thus, when the battery is charged at a very low rate, i.e. about 2-3 % of the normal rate for a long time, then it is said to be under 'trickling charge'. In electrical power-sub-stations (where these batteries are the "heart" of the system), trickling charge is used.

Advantages of Storage Battery

(a) Storing of energy in the battery can be done at any convenient rate but may be delivered at any other rate.

(b) It is the most efficient device for supplying of electrical energy in a portable form.

(c) Energy stored in the battery is available immediately without any lag of time.

Applications of Lead Acid Battery

In electrical power stations and sub-stations, relays are operated by supplying electrical energy by the lead-acid batteries (120 such batteries of 2 V each are connected in series to give 240 V).

Other applications of lead acid batteries are as follows :

(a) Emergency light and fans, inverters etc.
(b) Cars, trucks, jeeps etc.
(c) Industries and mining.
(d) Ships and submarines.
(e) Standby power supply for telephone exchange, radio stations, etc.

Power, Energy and Efficiency

We are interested in electricity because it can do useful work for us. Therefore, we want to quantify how much work can be derived from it. This capacity is defined in terms of Power and Energy.

Power

Remember that power P is the rate of doing work. In the case of electricity, we define it as the product of voltage and current. Power is used to produce real work.

- Measuring unit of power is joule/second or watt.
- Power = voltage × current
  $P = V \times I$
- 1 Watt = 1 Volt × 1 Ampere
  Bigger unit of power is kilowatt (kW)
  1 kW = 1000 Watt
- Similarly, 1000 kW = 1 MW (Mega Watt)

Energy

The capacity for doing the work is called energy. To say it differently, it is the rate of doing work (i.e. Power) multiplied by the time for which that power is applicable.

- Usual measuring unit of energy is kWh
- 1 kWh = 1000 watt for one hour = 36,00,000 Joule
- 1 kWh = 1 Unit of Electrical Energy
  It is also known as Board of Trade Unit (BOT)
- A larger unit is MWh, which is 1000 kWh

Efficiency

In an ideal situation and using a perfect machine, we should be able to convert every bit of the energy fed to the machine to useful work, as its output. Unfortunately, in any real life situation, a perfect machine does not exist. Hence the output of any machine is always less than the input energy. The difference is usually wasted as unrecoverable heat, due mainly to friction.

The efficiency is the ratio of desired form of energy obtains from a machine to the total energy fed to the machine.

(a) $\text{Efficiency} = \dfrac{\text{Output (useful) Energy}}{\text{Total Input Energy}}$

(b) $\text{Efficiency} = \dfrac{\text{Input Energy} - \text{Losses}}{\text{Input Energy}}$

(c) $\%\ \text{Efficiency} = \dfrac{\text{Output (useful) Energy}}{\text{Total Input Energy}} \times 100$

Efficiency of Power System

The efficiency of power system is maximized when the total combined load is purely resistive. Therefore, when the total load on the system approaches purely resistive, the total current requirements and losses are minimum. Total power that has to be produced is minimized. The total power becomes "real" power (i.e. minimum power required to serve all loads).

When efficiency is maximized then benefits are realized as

- Power losses of system are minimized.
- Extra capacity is made available in transmission lines, distribution lines and substation equipment because these are rated on the amount of current carrying capability. If the current flow is less, then more capacity available to serve additional load.

One way to measure the power system efficiency is by calculating the power factor.

Inductance, Capacitance and Impedance

We know that electrical property of a material, namely, Resistance. In the case of time-invariant (not changing with time) current, it may be the only electrical property of interest. However, if we consider currents, which keep changing with time, the word 'resistance' is to be replaced by the word impedance. This ever-changing current is called Alternating Current or AC.

Impedance has a resistive part and the remaining could be either capacitance or inductance or both,

Inductance

While inductance is associated with every conductor, it is easily manifested in the case of a conducting coil. When such a coil is exposed to changing magnetic force-field, an electromotive force (e.m.f.) (voltage) is generated at the terminal of the coil. In fact, this is how generators work.

Inductance is that property of a coil by virtue of which an e.m.f. is induced in the coil when the magnetic flux linked with that coil is changed. The change of flux may be due to Changing Current or AC. Frequency is the number of times the current completes the cycle of change in one second and is denoted by 'f'.

- The measuring unit of Inductance is Henry (H).
- It is denoted by L.

Inductive Reactance

Effective opposition offered by inductance.

- It is denoted by X_L and it is equal to $2\pi fL$, (where f is the frequency). The combination '$2\pi f$' is often replaced by the symbol 'ω'.
- Its measuring unit is ohms(Ω).

Capacitance

An assembly of two conducing plates separated by a dielectric is called a capacitor. A capacitor can store electrical charge and in this process offers impedance to the flow of changing current or AC, across it. Of course, a non-changing current (Direct Current or DC) cannot flow across a capacitor.

- The capacity to store charge is called Capacitance and is denoted by C.
- Its measuring unit is Farad.

Capacitive Reactance

Effective opposition offered by a capacitance is called capacitive reactance.

(a) It is denoted by X_c and it is equal to $\frac{1}{(2\pi f C)}$ (Where f is frequency).

Impedance

The total opposition offered by a series circuit containing resistance inductance and capacitance is called impedance.

- It is denoted by Z, where Z = R + j X
- Its measuring unit is ohm.

In this 'X' denotes reactance due to inductance or capacitance or a combination of both. 'R' is the resistance. 'j' is the symbolic representation of square root of – 1 or $\sqrt{-1}$. This is called imaginary number and is used in the calculation of complex equations in relation to electricity.

Using this representation of impedance, the associated current also has two components: Real and imaginary, or Active and reactive.

Three Types of Electrical Loads

Devices that are connected to the power system are referred to as electrical loads. The three load types are resistive, inductive, and capacitive.

Resistive Load

Units of electrical power associated with resistive load are watts. Light bulbs, toasters, electric hot water heaters, and so on are resistive loads.

Inductive Load

- Inductive load require a magnetic field to operate. All electrical loads that have a coil of wire to produce the magnetic field are called inductive loads. Examples of inductive loads are hair dryers, fans, blenders, vacuum cleaners, and many other motorized devices. The units (measurement) of inductance are called henrys.
- Regarding electrical motors, a load placed on a spinning shaft to perform a work function draws what is referred to as real power (i.e. rotating watts) from the electrical energy source. In addition to real power, reactive power is also drawn from the electrical energy source to produce the magnetic fields in the motor. The total power consumed by the motor is, sum of both real and reactive power. The units associated with reactive power are called positive VARs. VAR stands for volts-amps-reactive.

Capacitive Load

- A capacitor is a device made of two metal conductors separated by an insulator called a dielectric (i.e. air, paper, glass, and other non-conductive materials). Dielectric materials become charged when voltage is applied to the attached conductors. Capacitors can remain charged long after the voltage source has been removed.
- Examples of capacitor loads are TV picture tubes, long extension cords, and components used in electronic devices. The units (measurement) of capacitance are called farads.
- Similar to inductors, the power associated with capacitors is also called reactive power, but has the opposite polarity. Capacitors have negative VARs. Negative VARs of inductors can be cancelled by the positive VARs of capacitors; capacitors cancel out inductors in electrical circuits and improve system efficiency.

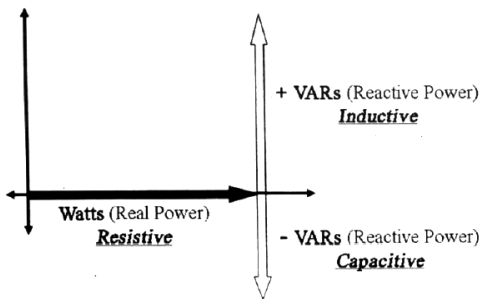
Active and Reactive Power

As we have learnt, every circuit current has two components:

- Active component, and
- Reactive component

Sometimes, it is easier to see this relationship graphically.

Basically, resistors dissipate energy in the form of heat. The power associated with resistive loads is expressed as watts.

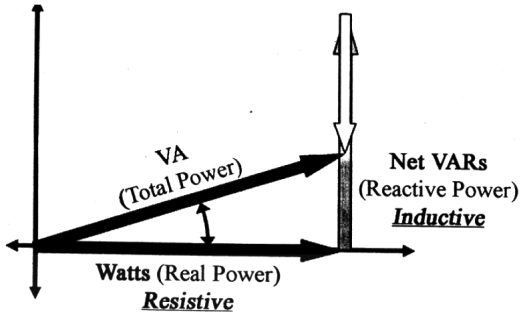


Active and Reactive Power Associated with Resistors, Inductors and Capacitors

The power associated with capacitive and inductive loads is expressed as VARs. As it is reactive power, the VAR is watt less power and does not contribute to real work functions. However, VARs are required in motors, transformers, and most coils to produce magnetic fields in order for the inductive load to function.

The interesting factor that exists in ac power systems is that inductive VARs are opposite of capacitive VARs and can cancel each other out if they are of the same value.

The graphical means of showing the relationship between the real and reactive power associated with resistors, inductors, and capacitors is shown in Figure below.



Electrical Power Triangle

Active Power or Real Power = V I cos θ

Reactive Power or Wattless Power = V I sin θ

The term 'cos θ' is called the power factor.

Power Factor

Efficiency of a power system can be viewed as: how much total power (i.e. "real power + reactive power") is required to get the "real" work done.

Typically, power factors above 95% are considered "good" (i.e. high).

The Power Factor (PF) may be defined as :

- Cosine of the angle between voltage and current
- Power Factor = $\frac{R}{Z} = \frac{\text{Resistance}}{\text{Impedance}}$
- Power Factor = Real Power/Total Power

If the reactive power component is made zero, the power factor becomes unity.

DC MACHINES

A DC machine is an electromechanical conversion device. The working of a DC machine as a generator or motor is as follows :

(a) By Faraday's induction law when a conductor cuts a magnetic field then an emf is induced in conductor (i.e. when the armature of DC machine rotates with any prime mover, an emf is induced in it, so it works as a DC generator).

(b) If a current carrying conductor is placed in a magnetic field perpendicularly, then a force acts on conductor and direction of force is determined by Fleming's left hand rule (i.e. when we provide the supply across armature of a DC machine then the armature rotates in the direction of force, so it works as DC motor).

(c) For a DC machine, either DC generator or DC motor, there should be a magnetic field and the rotating conductors. In a DC machine, magnetic field is provided by permanent magnets for small machines and by electromagnets in large machines because the strength of permanent magnets gets reduced with time or long use. From construction point of view, DC generator and DC motor both are same.

DC Generator

- The DC generator gets its name from the type of voltage it generates, which is DC voltage. It has two parts – a stator and a rotor. Stator is a cylindrical hollow part which always remains static and houses a rotating part, mounted on a bar through two bearings, called rotor. Although usually stator has magnetic poles, which can be of permanent magnet or electromagnets, and the rotor carries axially placed conductor wiring at its periphery called armature, but in principle either of them can serve as magnetic field producer and the other as armature. Usually, permanent magnet generators have armature on stator as no contact with rotating part is required for supply of electricity.
- The generator works on the principle laid down by Faraday's Law. When the rotor is rotated at a particular speed, there is continuous change of magnetic flux linked with each conductor on armature. This rate of change of flux gives rise to an induced voltage in each conductor, which when joined in series through the coils in armature add up to give the rated generated voltage. When armature is on rotor, the output voltage is taken through contact brushes on rotor.

EMF Equation

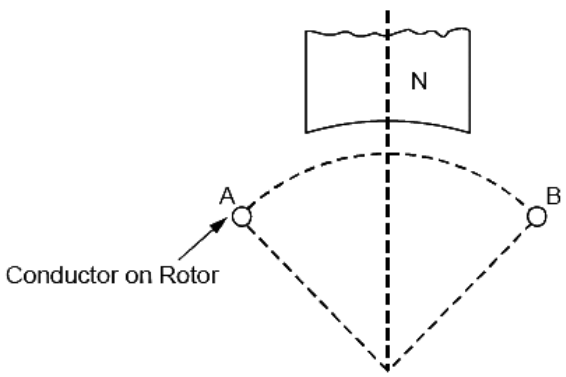
Let us now derive the expression for generated voltage at armature terminals.

Let ϕ = flux per pole in Webers,

P = No. of poles in machine, and

Z = Total number of armature conductors.

Let a conductor move from A to B (which is one pole pitch), then the flux linked or flux is ϕ Webers.



A Portion of Machine

If t = time taken for the conductor to move from A to B, then emf induced in the conductor,

e = Rate of change of flux = $\frac{\phi}{t}$ volts

Let N = RPM of the rotor

i.e. Time for N revolutions = 1 minute = 60 seconds

Time for 1 revolution = $\frac{60}{N}$ seconds

Time for 1 pole pitch $= \frac{60}{N} \times \frac{1}{P}$

(1 Pole Pitch is angular distance between two consecutive poles.)

or $t = \frac{60}{NP}$ seconds

Then emf is $e = \frac{\phi}{t} = \frac{\phi \times NP}{60}$ volts per conductor

The Calculation of emf Across Generator Terminals

Let A = No. of parallel paths and there are two types of windings – lap and wave.

For lap winding, A = P and for wave winding A = 2.

The conductors in series per path $= \frac{Z}{A}$

EMF induced per path across generator terminals

$= \frac{EMF}{Conductor} \times \frac{Z}{A} = e \times \frac{Z}{A}$

$= \frac{\phi NP}{60} \times \frac{Z}{A}$

or $E = \frac{\phi ZN}{60} \times \frac{P}{A}$ volts

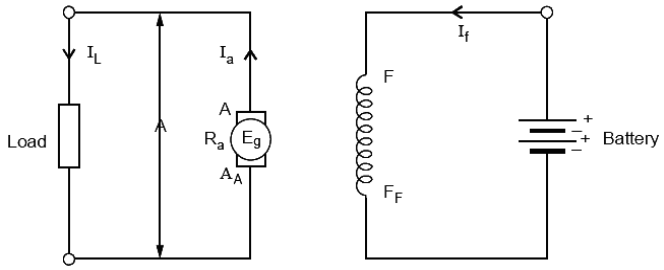
Types of DC Generator

The generators used for industrial applications have the magnetic field generated through current carrying coils wound onto poles. These coils connected in series with each other are collectively called field winding.

To provide the flux by Field system or Field coil, the field coils are excited by some external source or by the generator itself and thus there are two types of DC generator.

Separately Excited DC Generators

A DC generator whose field coils are energised by the external DC source, such as a battery etc., is called separately excited DC generator as shown in Figure below.



Separately Excited DC Generator

Self Excited DC Generators

A DC generator whose field windings are excited by the current flowing from the generator itself is called self excited DC generator. The current flowing through field winding depends on the connections of field winding. There are three possible connections of field winding so that self excited.

DC generators are classified as follows :

(a) Series wound DC generator

(b) Shunt wound DC generator

(c) Compound wound DC generator

Working of DC Generators

Some magnetic flux is always present in iron core of field coils or field system of self excited DC generators due to residual magnetism. When the armature cuts this flux then an emf is induced in armature conductors.

To buildup the rated voltage in any self excited DC generator :

(a) There should be residual magnetism in pole cores.

(b) The direction of rotation of armature should be correct or forward. If direction is reversed, then the flux produced by field current opposes the residual magnetic flux rather than aiding it.

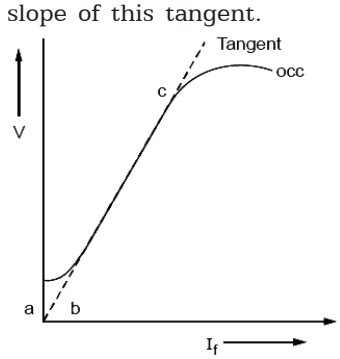
(c) The resistance of load for DC series generator or resistance of shunt field for DC shunt generator should not be more than a critical resistance.

In DC series generator, the voltage is built up at Rated Value when we connect the load across terminals because current flowing through armature is same as field current. Due to small induced emf, a field current flows through field coils so the magnetic flux rises. Due to this increased flux, the emf induced in armature is also increased so a large current flows through field coils due to this emf. This continues till iron core reaches saturation and rated voltage is reached.

For any magnetic material as per molecular theory of magnetism when we increase the field current gradually, then after some value of field current, saturation occurs. At that time rated emf is induced at the terminals of DC generator.

For DC shunt generator, if there is no load across terminals then the emf is induced because of field current in shunt winding, which is parallely connected across armature terminals who will induce emf across its terminals. Due to this emf, field current builds up through field coils.

If a curve is drawn between field current and armature open terminal voltage, then it is called open circuit or magnetic characteristics of DC generator. By drawing tangent on linear portion of OCC we find value of critical resistance as slope of this tangent.



Open Circuit Characteristics (OCC)

Operation of Different Types of Generator

Separately Excited DC Generator

Let Ra is armature resistance, Eg is induced emf in armature, and V is terminal voltage across armature. When a load is connected across terminals of generator then load current will be equal to armature current

So, $I_a = I_L$

By applying KVL in armature circuit, we get

$E_g = V + I_a R_a$

Here, V is voltage across load.

Power developed in armature $P_g = E_g I_a$ Watts

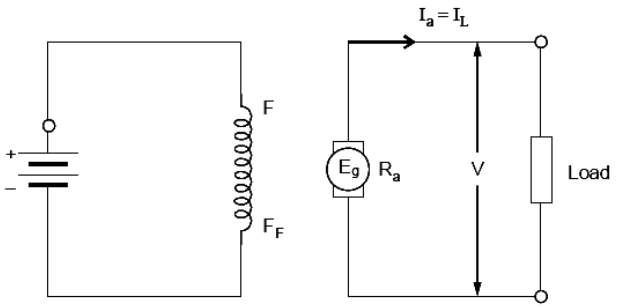
Power delivered to load $P_L = V I_L = V I_a$ watts

Power loss in the armature of machine,

$P_a = P_g - P_L$ watts

The expression for E_g is as derived earlier

$$E_g = \frac{\phi N Z P}{60 A} \text{ volts}$$



Separately Excited DC Generator

DC Series Generator

Similarly we can derive equations for DC series generator.

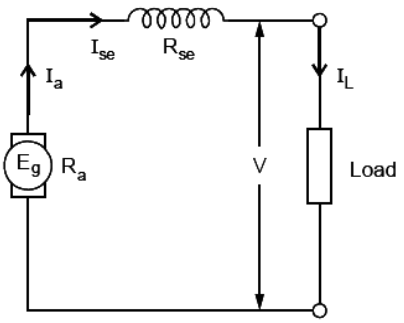
$I_a = I_{se} = I_L$

$E_g = V + I_a (R_a + R_{se})$

$P_g = E_g I_a$ watts

$P_L = V \cdot I_a$ watts

$P_a = P_g - P_L$ watts



DC Series Generator

DC Shunt Generator

In DC shunt generator, the shunt resistance R_{sh} is introduced across E_g.

$I_a = I_{sh} + I_L$

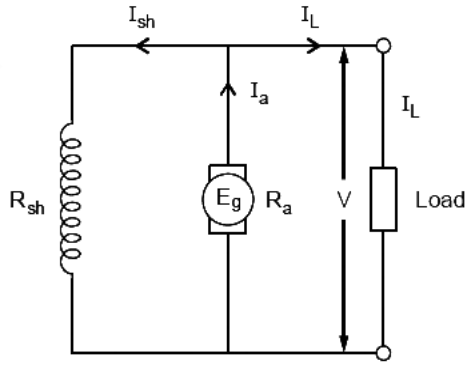
$$I_{sh} = \frac{V}{R_{sh}}$$

$E_g = V + I_a R_a$

$P_g = E_g \cdot I_a$ Watts

$P_L = V \cdot I_L$ Watts

$P_a = P_g - P_L$ Watts



DC Shunt Generator

DC Compound Generator

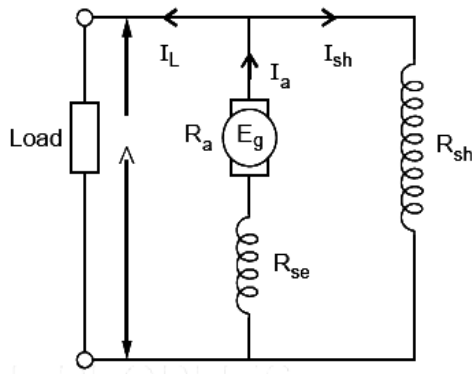
Long Shunt

There are of two types of compound generator :

(i) long shunt, and

(ii) short shunt.

The connections for long shunt compound generator is shown in Figure below.



Long Shunt

Equations of operation for long shunt are :

$I_a = I_L + I_{sh}$

$I_a = I_{se}$

$$I_{sh} = \frac{V}{R_{sh}}$$

$E_g = V + I_a (R_a + R_{se})$

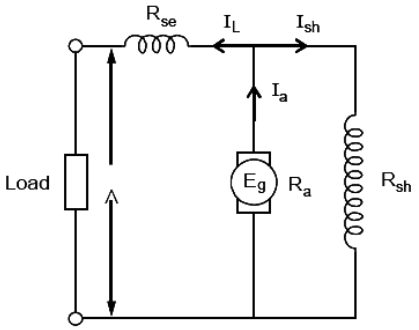
$P_g = E_g \cdot I_a$ Watts

$P_L = V \cdot I_L$ Watts

$P_a = P_g - P_L$ Watts

Short Shunt

The connections for short shunt compound generator is shown in Figure below.



Short Shunt

Equations of operation in short shunt compound generator are :

$I_a = I_L + I_{sh}$

$E_g = V + I_a R_a + I_L R_{se}$

$$I_{sh} = \frac{E_g - I_a R_a}{R_{sh}} = \frac{V + I_L R_{se}}{R_{sh}}$$

$P_g = E_g I_a$ Watts

$P_L = V \cdot I_L$ Watts

$P_a = P_g - P_L$ Watts

In all the above cases, if there is brush drop of Vb volts in the 2 brushes connected to armature, the voltage equation of generator has an additional drop term of 2 Vb added to Ia Ra term. For example, the voltage equation for short shunt compound generator would be

$E_g = V + I_L R_{se} + (I_a R_a + 2 V_b)$

DC MOTOR

Construction and Working of DC Motors

Motor is a device which converts electrical energy into mechanical energy. When a current carrying conductor is placed in a magnetic field then a force acts on the conductor and conductor starts moving in the direction of force. The construction of DC motor is similar to that of DC generator. When the DC machine is connected to DC supply, a current passes through the armature winding. When a conductor of armature winding carries outward current under North pole and incoming current under South pole then it experiences a force in clockwise direction according to Fleming's left hand rule. Due to this force, the conductor moves clockwise. When the conductors which were under North pole will come under South pole, they would have experienced a force in anticlockwise direction, if the direction of current is unchanged. So, there is a requirement to reverse the direction of current to make the conductor still move in clockwise direction. The direction of current is reversed by commutators in contact with brushes and, thus, armature conductors always experience a force in clockwise direction and rotate in same direction continuously.

Types of DC Motor

DC motors are also classified on lines similar to DC generators.

Working of DC Motors

In a DC motor, as in case of a DC generator, when armature rotates then an emf is induced in armature conductors known as back emf which opposes the applied voltages. The expression for this voltage is same as that for DC generator, i.e.

$$E_b = \frac{\phi Z N P}{60A} \text{Volts}$$

If R_a is armature resistance, then

$V = E_b + I_a R_a$

Here I_a is armature current and V is applied voltage.

So, $I_a = \frac{V - E_b}{R_a}$

Back emf makes a DC motor self regulating. When speed is low then back emf will be less as it is directly proportional to speed and armature current will be large because of above relation.

Power Equation

The voltage equation for separately excited or shunt motor is

$V = E_b + I_a R_a$

By multiplying Ia in this equation, we get

$VI_a = E_b I_a + I_a^2 R_a$

It is a power equation, where V Ia is input power, $E_b I_a$ is power developed in armature and $I_a^2 R_a$ represents power losses in armature.

So mechanical power developed by motor is

$P_m = E_b I_a = V I_a - I_a^2 R_a$

or, Pm = Input Power – Losses

On differentiating this equation with respect to I_a, we get

$$\frac{dP_m}{dI_a} = V - 2I_a R_a$$

For maximum power, put $\frac{dP_m}{dI_a} = 0$

so, $V - 2 I_a R_a = 0$

or, $V = 2 I_a R_a$

But $I_a R_a = V - E_b$

so, $V = 2 (V - E_b)$

or, $E_b = \frac{V}{2}$

Thus, in DC motor mechanical power developed in armature is maximum when back emf is half of applied voltage. This condition is avoided in practice due to large losses as efficiency in this case would be below 50%.

Speed Equation

The back emf in armature is

$$E_b = \frac{P\phi Z N}{60 A}$$

so, $N = \frac{E_b 60A}{P\phi Z}$

since P, Z and A are constant for a machine.

Then $N \propto \frac{E_b}{\phi}$

or, $N \propto \frac{V - I_a R_a}{\phi}$

For a shunt motor, field current and hence ϕ is constant, then

$N \propto E_b$ or $N \propto (V - I_a R_a)$

For a series motor I_f and hence ϕ is proportional to I_a.

So, $N \propto \frac{E_b}{I_a}$

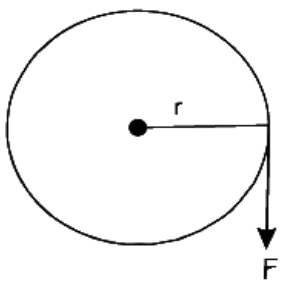
Percentage speed regulation $= \frac{N_0 - N_f}{N_f} \times 100$.

Here N_0 is speed at no load in RPM, i.e. at $I_a = 0$, and N_f is speed at full load in RPM, i.e. at $I_a = I_{FL}$.

Torque Equation of DC Motor

At a wheel of radius r metre if a force F acts on circumference, then

Torque $T = F \cdot r$



Work done per revolution $= F \cdot 2\pi r$

Work done per second $= F \cdot 2\pi r \cdot n$

Here, n is speed in revolutions per second, i.e. $n = \frac{N}{60}$ and N is speed of rotation in RPM.

So, power developed, P = Work done per second

or, $P = Fr \cdot 2\pi n$

or, $P = T \cdot \omega$

where, T = Torque, and ω = angular velocity.

Here, $\omega = 2\pi n = \frac{2\pi N}{60}$

But, power developed in armature $= E_b \cdot I_a$

So, $E_b I_a = T \cdot \omega$

or, $T = \frac{E_b I_a}{\omega} = \frac{E_b I_a}{2\pi N} \times 60 = 9.55 \frac{E_b I_a}{N} = \frac{9.55}{N} P_m$

Also, $T = \frac{E_a I_a}{\omega} = \frac{P\phi Z N}{60A} \frac{I_a}{\frac{2\pi N}{60}}$

or, $T = \frac{P\phi Z}{2\pi A} \cdot I_a = 0.159 \phi Z P \frac{I_a}{A}$

Shaft torque, $T_{sh} = \frac{9.55}{N} \times$ Mechanical power of shaft and it is also called armature torque.

Since Z, P and A are constant

$\therefore T \propto \phi I_a$

From this equation, it is clear that direction of DC motor can be reversed by reversing the direction of current either in armature or field winding. If current through both windings is reversed then direction of rotation will be same.

For DC shunt motor ϕ is constant

$\therefore T \propto I_a$

And for DC series motor, $\phi \propto I_a$,

$\therefore T \propto I_a^2$

Operation of Different Types of Motor

Separately Excited DC Motor

$E_b = V - I_a R_a$

$I_a = I_L$

Power drawn from supply

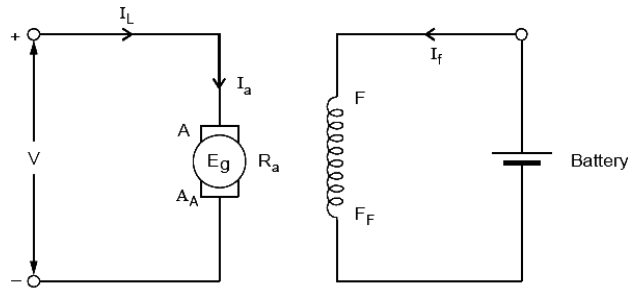
$P = V I_L$

Mechanical power developed

$P_m = E_b I_a$

$= I_a (V - I_a R_a)$

$= V I_a - I_a^2 R_a$



Series Wound DC Motor

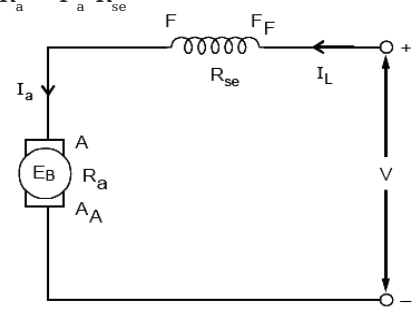
$I_a = I_{se} = I_L$

$E_b = V - I_a (R_a + R_{se})$

Power drawn from supply

$P = V I_a$

$P_m = E_b I_a = [V - I_a (R_a + R_{se})] \times I_a = V I_a - I^2_a R_a - I^2_a R_{se}$



Shunt Wound DC Motor

$I_L = I_a + I_{sh}$

$I_{sh} = V / R_{sh}$

$E_b = V - I_a R_a$

$P = V \cdot I_L$