2. Electrostatic Potential and Capacitance

Single Page Simple Synopsis
Chapter at a Glance

The two concepts **Electrostatic potential and Capacitance** form the foundation of energy storage in circuits.

1. **Electrostatic Potential (V)** is the work done (W) to bring a unit positive charge (q) from infinity to a specific point. **Formula:** $V = \frac{W}{q}$. It is a scalar quantity.

   SI Unit: Volt (V), equivalent to 1 Joule per Coulomb.

   • **Potential of a point charge (q)** at a distance r from a source is $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

2. **Capacitance** (C) measures how much charge a capacitor or conductor can store per unit of potential difference. It is the ratio of charge stored (Q) on a conductor to the potential difference (V) applied. **Formula:** $C = \frac{Q}{V}$

   SI Unit: Farad (F), equivalent to 1 Coulomb per Volt.

3. **Parallel Plate Capacitor:** An electrical device with two conductive plates separated by a distance d. Its capacitance depends on plate area A, distance between plates d and medium ε_0

   Formula: $C = \frac{\varepsilon_0 A}{d}$

4. **Energy Storage & Dielectrics**

   Capacitors act as temporary energy storage devices, holding electrical potential energy (U) in their electric fields. **Formula:** $U = \frac{1}{2}CV^2 = \frac{1}{2}QV$

5. **Circuit Combinations:**

   Capacitors are arranged in circuits to achieve a desired total capacitance:

   - **Parallel Combination:** When connected in parallel, the potential difference remains the same, and the total equivalent capacitance is simply the sum of the individual capacitances:

     $C_{eq} = C_1 + C_2 + C_3 + ...$

   - **Series Combination:** When connected in series, the charge on each capacitor is the same, and the inverse of the equivalent capacitance is the sum of the inverses.

     $$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$$

Real Life Examples

• **Camera flash batteries**, Computer Key boards, touch screens of Smart Phones,...

IMP. IPE POINTS

1. Electric potential is the work done in bringing a unit positive charge from infinity to a point. $V = W/q$.

SI unit: volt (V).

- A surface with constant potential at all points on it is called **equipotential surface**.

- Potential due to a point charge is $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

- Potential energy of two charge system is

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

- Relation between potential and field is $dV = -\vec{E}\cdot d\vec{r} = -E\,dr\cos\theta$

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2. Potential due to an **electric dipole** is

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$$

- Potential on the axial line of a **dipole** is

$$V_{ax} = \pm\frac{1}{4\pi\varepsilon_0}\frac{p}{r^2}$$

- Potential on the equatorial line of a **dipole** is $V_{eq} = 0$

- Potential energy of a **dipole** in a uniform electric field is $U = -pE\cos\theta = -\vec{p}\cdot\vec{E}$

- Work done in rotating a dipole in a uniform electric field is $W = pE(1-\cos\theta)$

3. Capacitance of a capacitor $C = \frac{Q}{V}$

SI unit: farad (F).

- Capacitance of a parallel plate capacitor is $C = \frac{\varepsilon_0 A}{d}$

For parallel combination of capacitors:

- Equivalent capacitance $C = C_1 + C_2$
  Here $Q \propto C$ and V is same.

For series combination of capacitors:

- Equivalent capacitance $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$

  Here $V \propto \frac{1}{C}$ and Q is same.

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4. Energy stored in a capacitor is $U = \frac{Q^2}{2C}$

or $U = \frac{1}{2}QV$ or $W = \frac{1}{2}CV^2$

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5. Dielectrics: Inserting an insulating material (dielectric) between the plates of a capacitor increases its capacitance by a factor known as the dielectric constant (K):

$$C = K\frac{\varepsilon_0 A}{d}$$

- When a dielectric of dielectric constant K is filled between the plates of a capacitor, its capacitance increases. $C_K = KC$

- If dielectric is filled in a capacitor keeping battery connected, its energy stored increases. $U_K = KU$

- If dielectric is filled in a capacitor after disconnecting the battery, its energy-stored decreases.

$$U_K = \frac{U}{K}$$