SEMESTER – V

Applications of Electricity & Magnetism

UNIT - II: Power Sources (Batteries)

BY

Dr. M.Surekha

Lectrurer in Physics

UNIT-II Power Sources (Batteries)

Part - A : Power Sources.

(1) * Types of power sources - DC & AC Sources.

A power source is a device that gives electricity to run a circuit or an electronic device.

There are two main types of power sources :

→ • DC (Direct Current) Sources.
→ AC (Alternating current) Sources.

1. DC Power Sources (Direct Current) :

→ In a DC source, the current flows in one direction only. The voltage remains constant over time.

Example of DC Power Sources :

→ Battery
→ Solar cell
→ DC Generator.
→ Mobile charger (output side) :
→ Power Bank.

Properties of DC Sources :

→ Supply constant voltage.
→ Current flows in one fixed direction.
→ Used in low voltage, Small devices.
→ Easy to store (e.g., in batteries).
→ Good for protable electronics.

2. AC power Sources (Alternating current) :

→ In an AC source, the current changes direction many times in a Second. The voltage alternates between positive and negative.

Examples of AC power Sources :

→ Household power supply (plug point).

→ AC Generator.

→ Power Plant.

→ Alternator in vehicles.

Properties of AC Sources :

→ voltage changes with time.

→ Current flows in both directions (alternates).

→ Used in homes, factories, and big machines.

→ Transmitted easily over long distances.

→ Frequency in India = 50 Hz (50 cycles per second).

Comparison of DC VS AC Power Sources.

Feature	DC Source	AC Source
Current Direction	One fixed direction	changes direction repeatedly.
Voltage	Constant	Alternating (positive & negative).
Source Examples	Battery, Solar cell, Power Bank	Household supply, Generator.
Use	Portable electronics, LED lights	Home appliances, industries.
Transmission	Not suitable for long distance	Best for long-distance transmission.

(2)

* Different Types of Batteries

Batteries are devices that store chemical energy and convert into electrical energy. They are used in many everyday devices like mobile phones, laptops, remote controls, vehicles, and more. Batteries provide DC power.

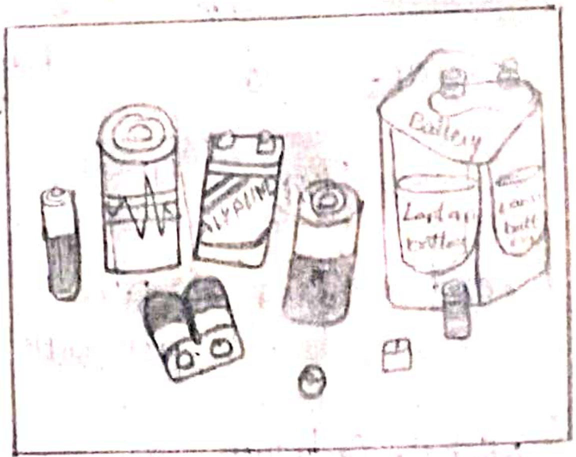
Batteries are mainly classified into two major types:

1. Primary batteries.
2. Secondary batteries.

1. Primary batteries:

→ Non-rechargeable batteries.

→ Once they are discharged (used), they cannot be reused or recharged.



→ These are also called disposable batteries.

→ They are low-cost and used in devices that need small amounts amounts of power.

Examples of Primary Batteries:

Battery Type	Typical voltage	Features	Applications.
Zinc - Carbon	1.5V	cheap, common, low power.	wall clocks, toys, remote
Zinc - chloride (Heavy Duty)	1.6V	Better than zinc-carbon	Radios, flashlights.
Alkaline (Manganese Dioxide)	1.5V	Longer life, better output.	cameras, toys, remotes

Mercuric oxide	1.35V	Small, stable voltage	Calculators, watches.
Silver Oxide	1.5V	High energy density, long shelf life	Hearing aids, small electronics.
Lithium Primary	3.0V	Lighweight, long shelf life	Watches, medical devices, Calculators.

2. Secondary Batteries :

→ Rechargeable batteries.

→ Can be charged and used again and again.

→ Suitable for devices that need frequent or long use.

→ Though constiler than primary batteries, they last much longer.

Examples of Secondary Batteries :

Battery Type	Typical voltage	Features	Applications.
Lead-Acid	2.0V per cell	Heavy, low cost, high current.	Invertes, UPS, automotive batteries.
Nickel-Cadmium (NiCd)	1.2V	Rechargeable, memory effect issue	Power tools, emergency lighting
Nickel-Metal Hydride (NiMH)	1.2V	Better than NiCd, more eco-friendly	Cameras, toys, poratable electronics.
Nickel-Iron (Edison cell)	1.2V	Long life, durable.	Solar and backup systems.
Nickel-zinc	1.6V	Higher voltage than NiMH	High-drain devices
Lithium-Ion (Li-Ion)	3.6-3.7 V	Light weight, fast charging, high	Phones, laptops, power banks, EVs

		energy.	
Solar cell (Photovoltaic)	0.5 V per cell	Converts light to electricity	Solar panels, solar lights, Calculators.

Difference Between Primary and Second. Batteries.

Feature	Primary Battery	Secondary Battery
Rechargeable	No	Yes
Cost	Low	High
Usage	One-time use	Reusable
Lifespan	Short	Long
Applications	Remotes, clocks	Phones, vehicles, laptops.

(5)

* Lead - Acid Batteries.

Lead-acid battery is a rechargeable battery that stores electrical energy using lead plates and dilute sulfuric acid as the electrolyte.

→ Lead-Acid battery is a very common rechargeable battery. It is one of the oldest battery types and is used in cars, inverters, and UPS systems.

→ A lead-acid battery is a secondary battery. That means it can be recharged and used again and again.

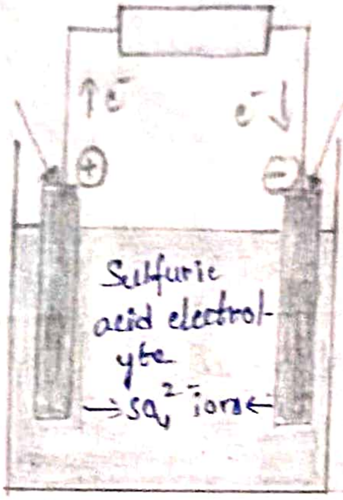
Parts of a Lead-Acid Battery :

A lead-acid battery contains :

→ Positive Plate : Lead dioxide (PbO_2)

→ Negative Plate : Spongy lead (Pb)
→ Electrolyte : Dilute sulfuric acid (H_2SO_4).
→ Container : Plastic case to hold all parts.
→ Separators : To keep positive and negative plates apart.

One cell gives 2 volts, and a 12V battery has 6 cells connected in series.

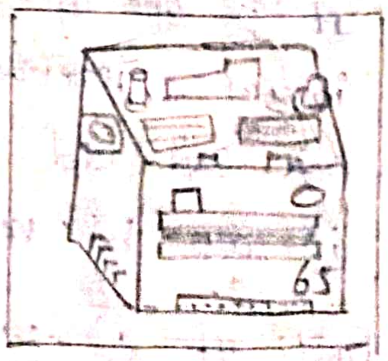


Lead acid charging

working of Lead-acid Battery :

1. During Discharging (Battery in Use).

→ The battery gives power to a device.
→ The sulfuric acid reacts with both electrodes.
→ Lead sulfate ($PbSO_4$) is formed on both plates.
→ water is formed, and acid becomes weaker.



Discharging Reactions :

At positive Plate (Cathode) :

$$PbO_2 + H_2SO_4 + 3H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$$

At Negative Plate (Anode) :

$$Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$$

Overall Reaction (Discharge) :

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

2. During charging (Battery Getting Power).

→ electrical energy is applied to the battery.
→ The chemical reaction is reversed.
→ Lead and lead dioxide are reformed.
→ Sulfuric acid concentration increases again.

Charging Reaction :

$$2PbSO_4 + 2H_2O \rightarrow Pb + PbO_2 + 2H_4SO_4$$

Applications of Lead - Acid Battery :

→ Cars and Bikes (to start the engine).
→ Inverters and UPS systems.
→ Solar energy storage.
→ Emergency lighting.
→ Electric wheel chairs, golf carts.

Advantages and Disadvantages of Lead - Acid Battery :

Advantages	Disadvantages.
Low cost and easily available	Heavy and bulky in size
Can be recharged many times	Requires regular maintenance
Provides high current output	shorter life compared to newer batteries.
Simple and rugged construction	Acid leakage is harmful and risky.
works well even in low temperature.	Takes longer time to charge.

(4)

* Lithium - Ion (Li-ion) Batteries

A Lithium-ion battery is a rechargeable battery that stores and releases electrical energy by the movement of lithium ions between a carbon anode and a lithium metal oxide cathode.

→ A lithium-ion battery is a type of secondary battery.

→ It can be charged and used again and again.

→ It stores energy using lithium ions that move between two electrodes.

→ It is widely used in mobile phones, laptops, electric vehicles, and other portable electronic devices between it is lightweight, long-lasting, and efficient.

Parts of a Lithium-ion Battery :

A lithium-ion battery contains.

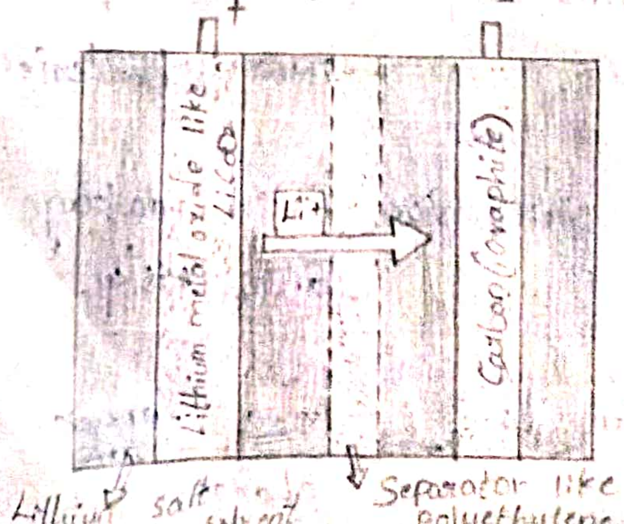
→ positive plate : Lithium metal oxide (like $LiCoO_2$)

→ Negative Plate : Carbon (graphite).

→ Electrolyte : Lithium salt solution like ($LiPF_6$)

→ Container : Plastic case to hold all parts.

→ Separators : A thin layer to separate the electrodes.



Working of Lithium - Ion Battery :

1. During Discharging :

→ The battery gives power to a device.
→ Lithium ions move from the anode to the cathode.
→ Electrons flow through the outer circuit, giving electrical energy.

Discharging Reactions:

$$LiC_6 + CoO_2 \longrightarrow C_6 + LiCoO_2$$

2. During charging (Battery Charging).

→ Electrical energy is given to the battery.
→ Lithium ions move from cathode back to anode.
→ The battery becomes ready to use again.

Charging Reaction :

$$C_6 + LiCoO_2 \longrightarrow LiC_6 + CoO_2$$

Applications of Lithium - Ion Battery:

→ Mobile phones and laptops.
→ Electric vehicles (EVs).
→ Power banks and tablets.
→ Smartwatches and cameras.
→ Solar energy storage.

Advantages and Disadvantages of Lithium - Ion Battery:

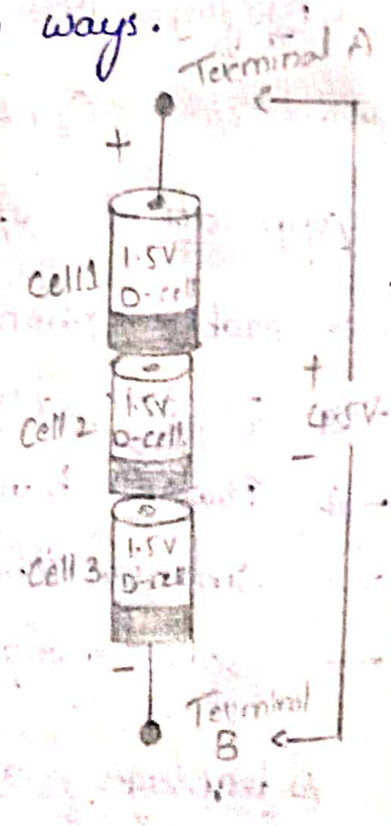
Advantages	Disadvantages.
Lightweight and compact	More expensive than lead-acid batteries.

High energy storage capacity	Can overheat if damaged and overcharged.
Fast charging and slow discharging.	Requires special circuits to protect it.
No memory effect.	Life reduces if overused or deeply discharged.
Long life and low maintenance	Not suitable for very high power needs.

(5)
* Battery configurations - Series, Parallel & series - Parallel configuration.

Batteries can be connected in three main ways. ~~They~~ These are :

1. Series Connection of Batteries.



→ In series, batteries are connected one after another.

→ The positive of one connects to the negative of the next.

→ The voltage adds up.

$$V = V_1 + V_2 + V_3 + \dots$$

→ The current stays the same.

$$I = I_1 = I_2 = I_3 = \dots$$

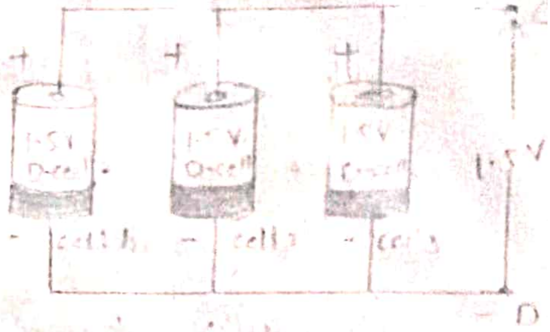
→ Used when we need higher voltage.

2. Parallel Connection of Batteries :

→ In parallel, all positives are joined together and all negative are joined together.

→ The voltage stays the same.

$$V\boxtimes = V_1 = V_2 = V_3 = \dots$$



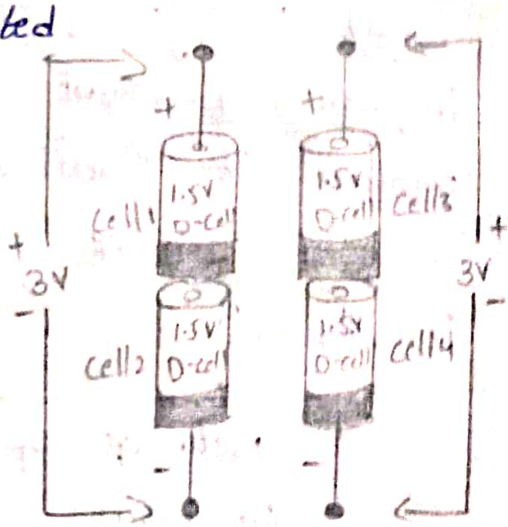
→ The current adds up.

$$I\boxtimes = I_1 + I_2 + I_3 + \dots$$

→ Used when we need more current or longer usage time.

3. Series - Parallel Connection of Batteries.

→ In this type, some batteries are connected in series, and then those group are connected in parallel.



→ This way, we get more voltage and more current.

→ Used in big systems like solar panels and electric vehicles.

Equations ;

→ voltage of each series set :

$$V\boxtimes = V_1 + V_2$$

→ Total voltage after parallel :

$$V\boxtimes = V\boxtimes$$

→ Total current (from parallel branches) :

$$I\boxtimes = I_1 + I_2$$

(6)

* Thevenin's theorem :

Statement : Thevenin's theorem states that any complex network of voltage sources and resistors can be reduced to a single voltage source (Vth) in series with a single resistor (Rth).

Definition: "The current in a load impedance connected to two terminals A and B of a network of generators & linear impedance is the same as if this impedance were considered to a single voltage generator whose em.f is the open circuit (when there is no load) voltage measure across A & B and whose internal impedance is equal to the impedance of the network between the terminals A and B when all the generators in the network have been replaced by their internal impedences."

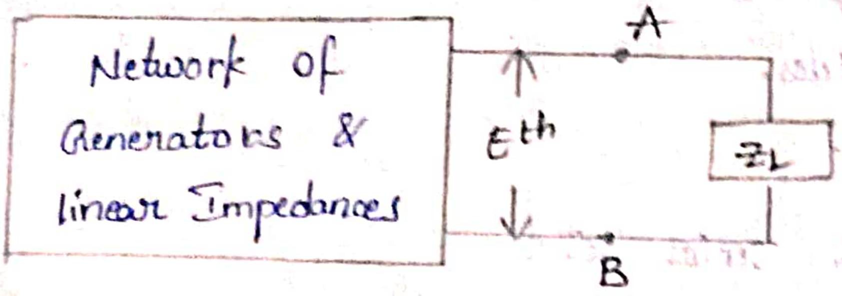


fig (A)

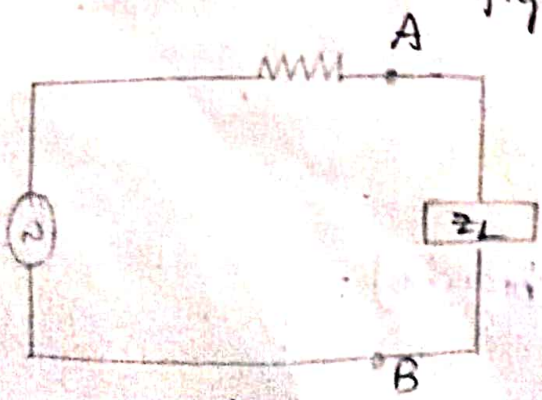


fig (b)

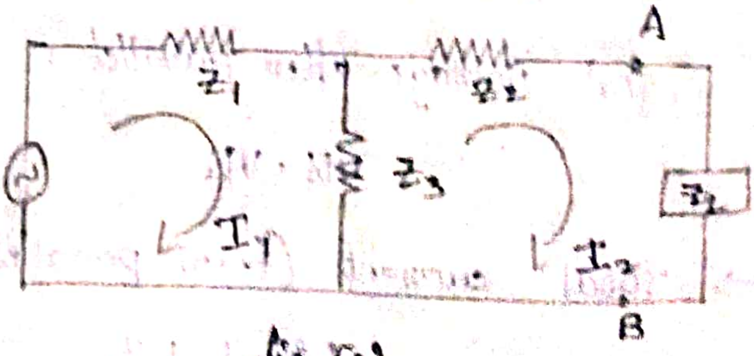


fig (c)

fig (a) N → Network containing a no. of generators & linear impedance with output terminals A and B.

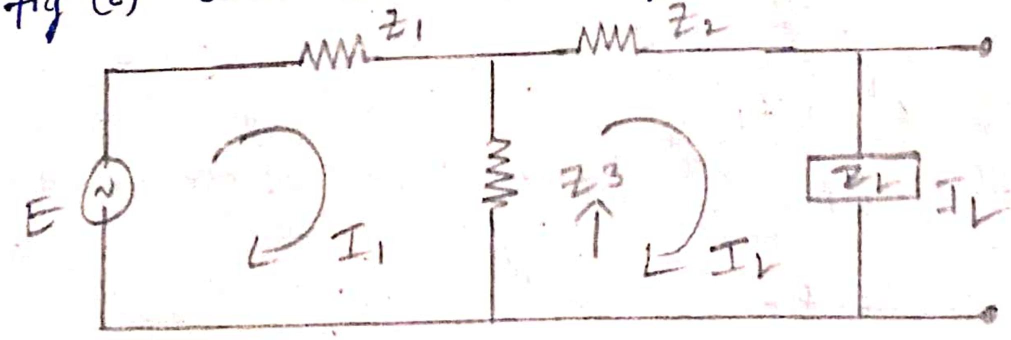
Let E^{th} → open-circuit voltage across A & B when all generators have been replaced by their respective internal impedances.

The Network 'N' will produce the Same current in an external load impedance Z_L Connected across A and B as Simple voltage generator of em.f E^{th} & internal impedance Z^{th} would do.

Proof : A network may be T-section arrangement of impedances Z_1 Z_2 & Z_3 & E is emf of source I_1 current Supplied Source & I_2 current flowing through load Z_L.

According to thevenin's theorem.

E^{th} & Z^{th} will be equivalent circuit of fig (b) with identical voltage and current at Z_L to fig (c)



from mesh I :

$$E = Z_1 I_1 + Z_3 I_1 - Z_3 I_L$$

$$I_L Z_3 + I_L Z_2 + I_L Z_L = Z_3 I.$$

$$I_L (Z_3 + Z_2 + Z_L) = Z_3 I_1$$

$$I_1 = I_L \left[\frac{Z_3 + Z_2 + Z_L}{Z_3}\right]$$

from mesh II

$$E = I_1 (Z_1 + Z_3) - Z_3 I_L$$

$$E = -I_L Z_3 + (Z_1 + Z_3) I_L \left[\frac{Z_3 + Z_2 + Z_L}{Z_3} \right]$$

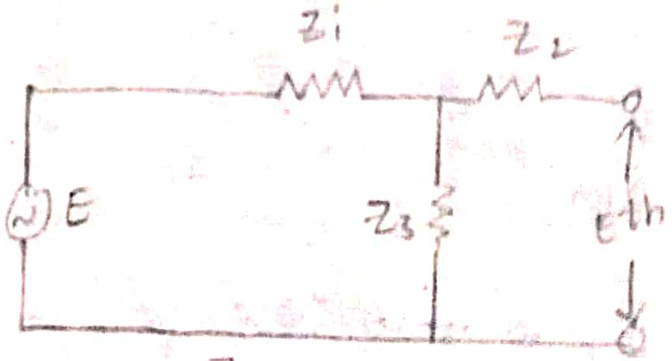
$$= I_L \left[\frac{-Z_3 + (Z_1 + Z_3)(Z_2 + Z_L) + Z_1 Z_3 + Z_3^2}{Z_3} \right]$$

$$I_L = \frac{E Z_3}{(Z_1 + Z_3)(Z_2 + Z_L) + Z_1 Z_3}$$

$$I_L = \frac{\left(\frac{E \cdot Z_3}{Z_1 + Z_3}\right)}{Z_2 + Z_L + \left(\frac{Z_1 + Z_3}{Z_1 + Z_3}\right)}$$

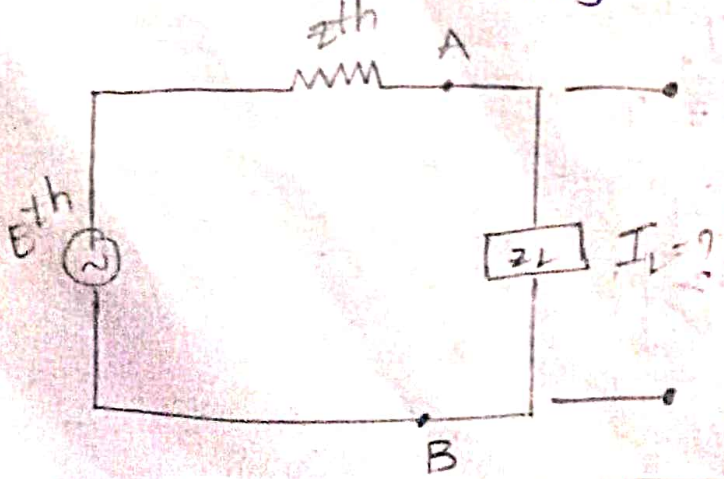
$$I_L = \frac{\left(\frac{E Z_3}{Z_1 + Z_3}\right)}{Z_2 + \left(\frac{Z_1 Z_3}{Z_1 + Z_3}\right) + Z_L}$$

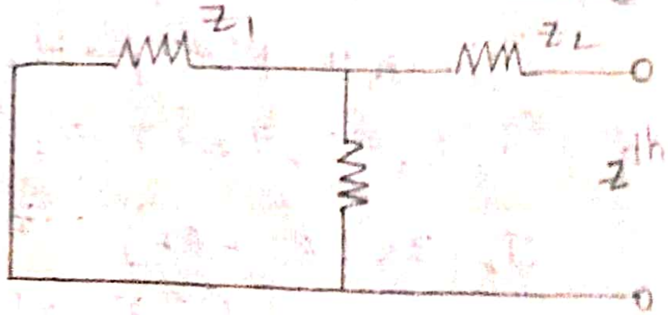
$$I_L = \frac{E^{th}}{Z^{th} + Z_L}$$



$$E^{th} = \frac{E Z_3}{Z_1 + Z_3}$$

$$Z^{th} = Z_2 + \frac{Z_1 Z_3}{Z_1 + Z_3}$$





* Norton's theorem :

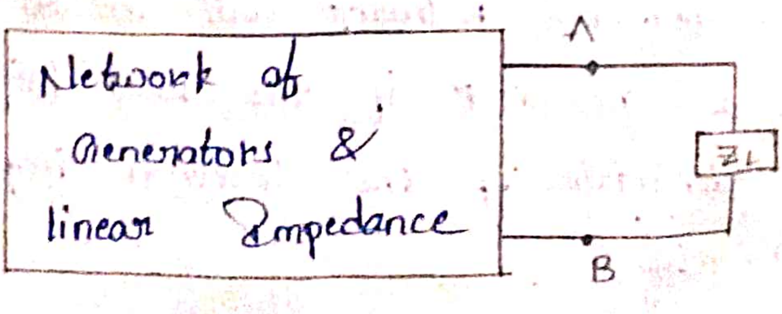
Statement : Norton's theorem states that any linear electrical network can be replaced by an equivalent circuit consisting of a single current source in parallel with a single resistor.

(Or)

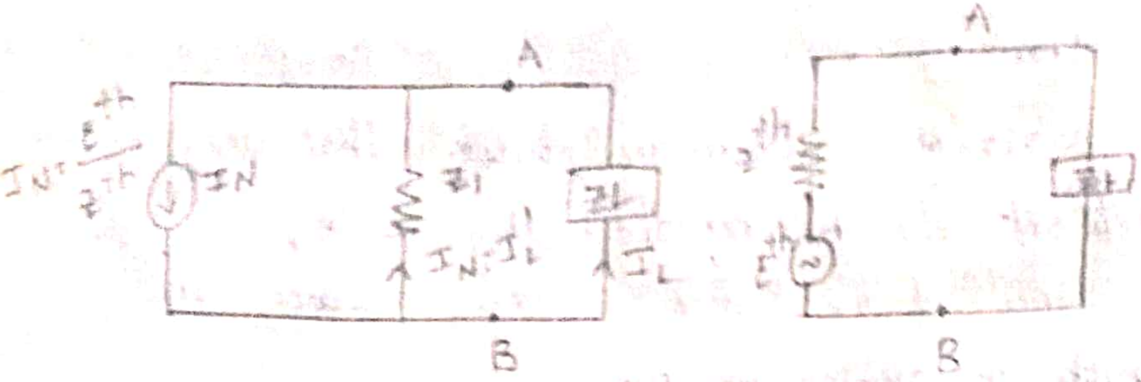
It is also enables a complicated network to be replaced by single generator & Impedance.

Thevenin's	Norton's
Generator is of constant voltage type having series impedance.	Generator is of constant current type having parallel impedance.

Definition : "The current in a load impedance connected to two terminals A and B of a network of generators & impedances is the same as if this impedances is the sames as if the impedance were connected to a constant current generator whose generated current is equal to the short circuit current at the terminals A, B & placed in ||le with an impedance equal to the impedance of the network b/w the terminals A and B when all the generators in the network have been replaced by their internal impedances".



(a)

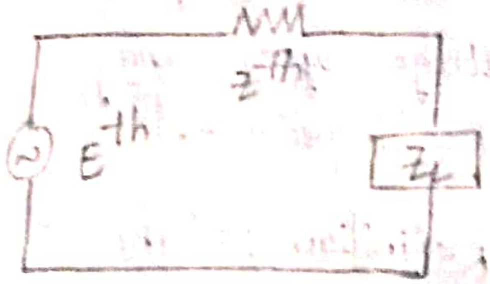


$I_N = \frac{E^{th}}{Z^{th}}$

$Z_N = Z^{th}$

The Norton's equivalent circuit in while the voltage generator E^{th} has been replaced by current generator $I_N = \frac{E^{th}}{Z^{th}}$ & the series impedance Z^{th} has been replaced by an equal parallel impedance current through Z_L in thevenin's current.

(a) $\longrightarrow$ $I_L = \frac{E^{th}}{Z^{th} + Z_L}$



(b) $\longrightarrow$ Current through Z_L in Norton's circuit.

$I_L' = \frac{Z^{th}}{Z^{th} + Z_L} I_N$ (by current division Law)

$(I_N - I_L') I_N = I_L' Z_L$

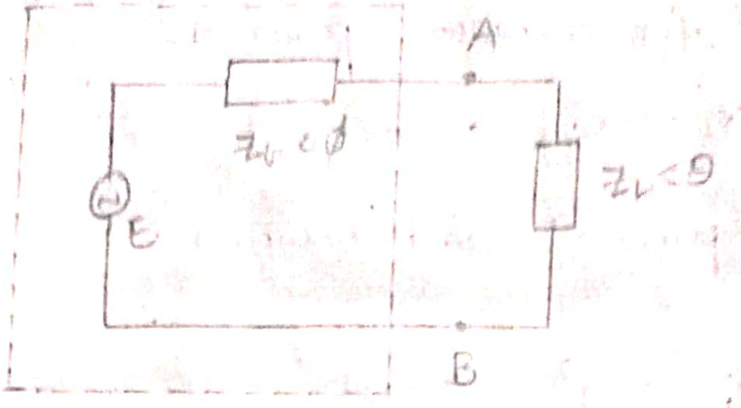
$= \frac{Z^{th}}{Z^{th} + Z_L} \times \frac{E^{th}}{Z^{th}}$

$= \frac{E^{th}}{Z^{th} + Z_L} = I_L$

(8)

* **Maximum power transfer theorem.**

"A two terminal network will absorb maximum power from a generator if the load impedance is the Complex conjugate of the internal impedance of the generator."



The generator impedance,

$$Z_G \angle \phi = R_G + jX_G$$

where phase angle is given by

$$\tan \phi = \frac{X_G}{R_G}$$

and the load impedance

$$Z_L \angle \theta = R_L + jX_L$$

where $\tan \theta = \frac{X_L}{R_L}$

The current I flowing in the circuit is

$$I = \frac{E}{(R_L + R_G) + j(X_L + X_G)}$$

The power 'P' in load is

$$P = I^2 R_L$$

$$P = \frac{E^2 R_L}{(R_L + R_G)^2 + (X_L + X_G)^2} \longrightarrow (1)$$

Power will be maximum when $\frac{dP}{dX_L} = 0$

$$\frac{dP}{dX_L} = \frac{-2E^2 R_L (X_L + X_G)}{\left[(R_L + R_G)^2 + (X_L + X_G)^2\right]^2} = 0$$

The condition for maximum power is

$$\boxed{X_L = -X_G} \longrightarrow (2)$$

Then the power in load becomes.

$$P_{max} = \frac{E^2 R_L}{(R_L + R_G)^2} \longrightarrow (3)$$

Again Power will be maximum when $\frac{dP}{dR_L} = 0$.

$$\frac{dP}{dR_L} = \frac{[(R_L+R_G)^2 + (X_L+X_G)^2]E^2 - E^2 R_L[2(R_L+R_G)^2]}{[(R_L+R_G)^2 + (X_L+X_G)^2]^2} = 0$$

$$(R_L+R_G)^2 + (X_L+X_G)^2 E^2 = E^2 R_L [2(R_L+R_G)]$$

$$(R_L+R_G)^2 + (X_L+X_G)^2 = 2R_L [(R_L+R_G)]$$

from eq (2) $X_L = -X_G$

$$(R_L+R_G)^2 = 2R_L^2 + 2R_L R_G.$$

$$R_L^2 + R_G^2 + 2R_L R_G = 2R_L^2 + 2R_L R_G$$

$$R_L^2 + R_G^2 = 2R_L^2.$$

∴ Power absorbed by load will be maximum when,

resistive components of load & Generators impedances are equal $R_L = R_G$.

and also.

The reactance of lead is equal that opposite in equal that opposite in sign to reactance of generator.

$$\boxed{X_L = -X_G}$$

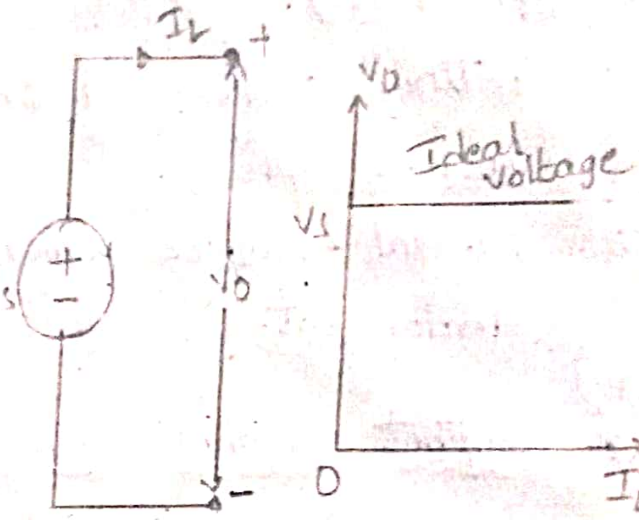
Hence, the theorem is proved P_{max} when load impedance $R_G - jX_G$ is Complex conjugate of generator internal impedance $R_G + jX_G$.

Resistance : opposite to a Current current.

Reactance : opposite two a charging current.

(9)

* Constant current Source :



A Constant voltage (CV) Source is a type of power supply designed to maintain a steady output voltage regardless of variations in the load current. Constant voltages source is to keep the voltage constant, even if the load changes or fluctuates. If there is no load or if the load is at maximum, the power supply will keep the output voltage at a constant level.

The typical graph shows the output voltage of a Constant voltage source. Graph shows that the output voltage remains constant, even with increasing current.

Characteristics of Constant voltage Sources :

→ It has zero internal resistance.

→ It always maintains a specified voltage across its terminal.

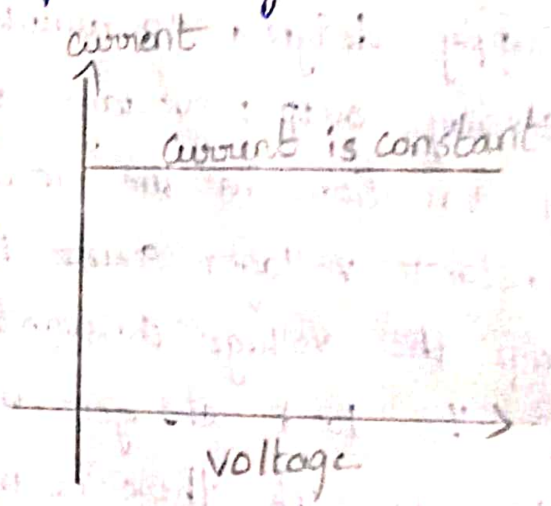
→ The output current changes depending on the load. As the resistance or impedance of the load changes, the changes current drawn by the load will adjust to maintain the same voltage.

Applications : Constant voltage sources are widely used in devices that require a stable voltage supply, such as:

1. Powering digital electronics (e.g., microcontrollers, sensors, processors).
2. Battery chargers (in CV mode, after the initial constant current phase).
3. General - purpose power supplies for testing and development.

(10)

* Constant current sources :



A constant current (cc) source is a type of power source designed to maintain a steady output current regardless of the voltage across its terminals. Constant current source is to keep the current constant, even if the load resistance changes.

The typical graph shows the output current of a constant current source. Graph shows that the output current remains constant, even with increasing current.

Characteristics of Constant Current Source :

→ It has infinite internal resistance.

→ It produces a fixed current that is independent of the load.

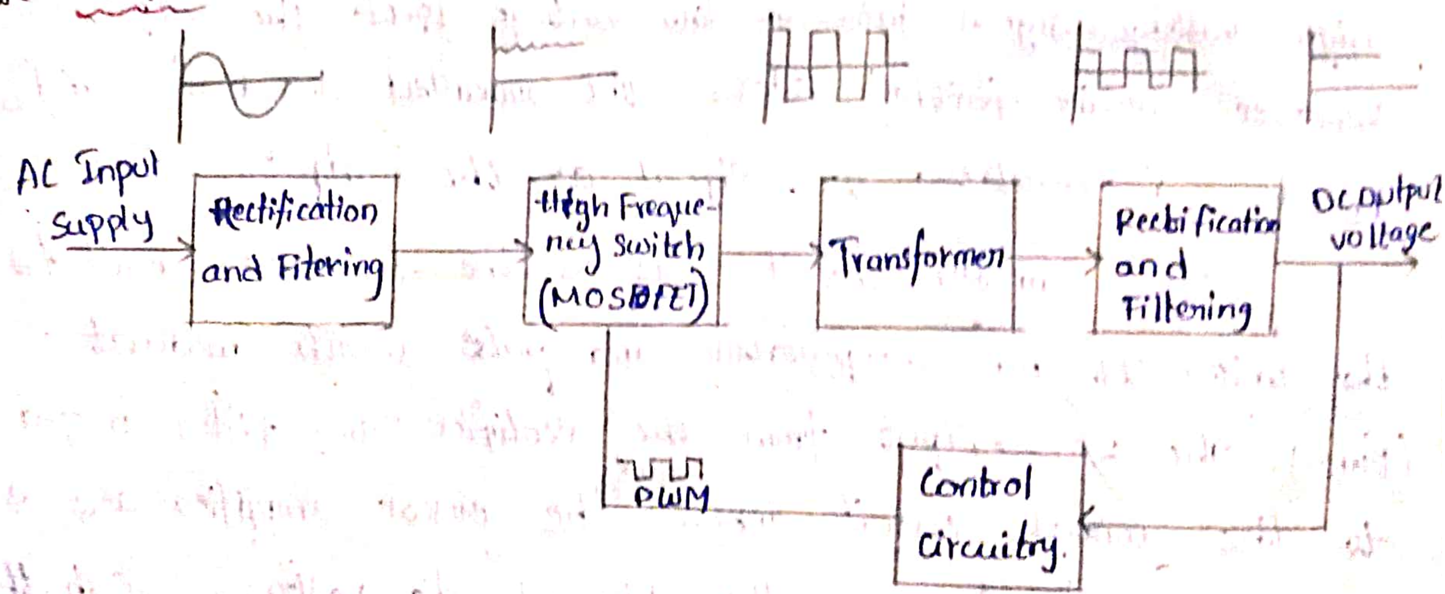
→ It can supply infinite voltage to maintain constant current.

Applications : Constant current that is independent of the load Sources are critical in applications where a precise current is needed, such as :

1. LED Drives : LEDs are current - sensitive devices that need a constant current for optimal brightness and lifespan.
2. Battery charging (initial stages) : In the early stages of charging, many batteries, like lithium - ion, are charged using constant current.
3. Electroplating and Electrophoresis : These processes require precise control of the current to ensure quality and consistency.

(11) :

* SMPS :



SMPS stands for Switch Mode Power Supply. It is used to convert alternating current in to direct current. It provides different voltage levels for digt different components.

Construction & working :

The unregulated A.C. input signal from the source is applied to the input rectifier and filter circuit. The A.C. input signal is rectified to generate a D.C. signal and further smoothened to remove high-frequency noise component from it. The D.C. output is fed to the power transistor that acts as a High-frequency switch. A chopping circuit acts as ideal switch between ON state and OFF state. Power MOSFET is used as chopper.

The output D.C. signal from the chopper circuit is then fed to the primary winding of high-frequency power transformer. The step-down transformer converts the high voltage signal into a low voltage level. The output rectifier circuit further filters the unwanted residuals and provides a regulated D.C. signal as the output.

The control circuit acts as the feedback circuit for the unit. It has comparator and pulse width modulator (PWM). The D.C. output from the rectifier and filter is fed to the control circuit where the error amplifier acts as a comparator, compares the obtained dc voltage with the reference value.

If the dc output is greater than the reference value then the chopping frequency is to be decreased. The decrease in chopping frequency will reduce the output power and so the dc output voltage.

~~Applications~~ Applications :

→ Computers : SMPS are essential for powering motherboards, CPUs, and hard drives by converting AC mains to multiple regulated DC voltages.

→ Televisions : They are used in LED TVs, set-top boxes, and other display devices.

→ Mobile Devices : Smartphones, laptops, tablets, tablets and wearable technology rely on SMPS for efficient and dependable power.

→ Home Appliances : Air conditioners, waching machines, and refrigerators also utilize SMPS for improved energy efficiency and compact design.

→ Power Plants and Factories : They are used to supply variable power and voltages in these environments.

→ Renewable Energy Systems : SMPS convert and regulate energy from sources like solar panels and wind turbines, making it usable and reliable.

→ Automotive Electronics : SMPS are used in navigation systems, entertainment systems, and ADAS.

→ Battery chargers : They are used for charging batteries in various devices, including electric vehicles.

→ Lighting : SMPS are used in LED Lighting systems to provide efficient and stable power.

→ Data Centers : SMPS help reduce energy consumption and cooling costs in data centers.

→ Railway Systems and Security Systems : SMPS are used in these systems for reliable and efficient power supply.