BEE Lab Manual

AY 2020-21

Department of Electrical Engineering

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Contents

"It is necessary to study and know about all the regulations to be maintained in the lab."

Instruction to Students

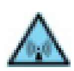
- Before entering to laboratory, the student should carry the following things.
  - i. Identity card issued by the college
  - ii. Class notes
  - iii. Lab observation book
  - iv. Lab Manual
  - v. Lab Record
- Student must sign in and sign out in the register provided when attending the lab session without fail.
- All students must follow a Dress Code while in the laboratory
- All bags must be left at the indicated place.
- The objective of the laboratory is learning. The experiments are designed to illustrate phenomena in different areas of Electrical Engineering and to expose you to measuring instruments, conduct the experiments with interest and an attitude of learning
- You need to come well prepared for the experiment.
- Work quietly and carefully
- Be honest in recording and representing your data.
- If a particular reading appears wrong repeat the measurement carefully, to get a better fit for a graph
- All presentations of data, tables and graphs calculations should be neatly and carefully done
- Graphs should be neatly drawn with pencil. Always label graphs and the axes and display units.
- If you finish early, spend the remaining time to complete the calculations and drawing graphs. Come equipped with calculator, scales, pencils etc.
- Do not fiddle with apparatus. Handle instruments with care. Report any breakage to the Instructor. Return all the equipment you have signed out for the purpose of your experiment.

"Your safety is our priority."

Safety Precautions

- Lather shoes are mandatory
- Do not touch if you do not know about
- You should inspect laboratory equipment for visible damage before using it. If there is a problem with a piece of equipment, report it to the technician or lecturer. DONOT return equipment to a storage area.
- You should not work on circuits where the supply voltage exceeds 40 volts without very specific approval from your lab supervisor. If you need to work on such circuits, you should contact your supervisor for approval and instruction on how to do this safely before commencing the work.
- Re-verify tour connection with the perfect circuit
- Make the connection tight
- Never strip insulation from a wire with your teeth or a knife, always use an appropriate wire-stripping tool.
- Shield wire with your hands when cutting it with a pliers to prevent bits of wire flying about the bench.

Important symbols

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
∿	Alternating current
≂	Both direct and alternating current
3∿	Three-phase alternating current
⏚	Earth (ground) terminal

"It is necessary to study and know about all the electrical equipment before handling those in the experiment."

[Expt: 01] Study of Electrical Equipment's

Aim of the Experiment

Familiar with the basic electrical components.

Theory

Basic Equipments:

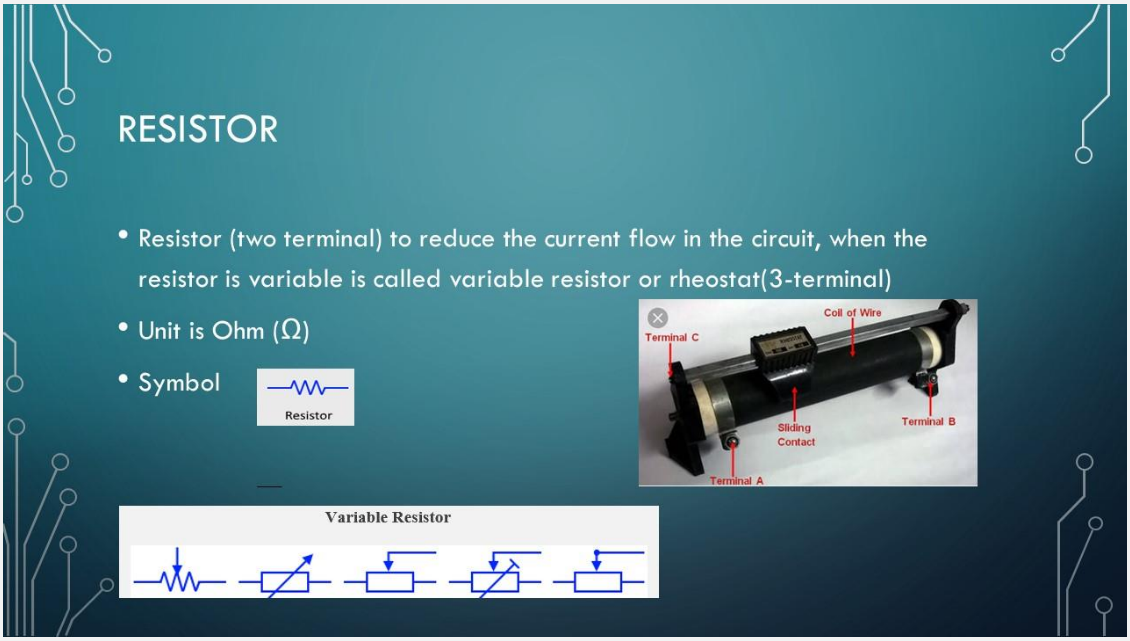
i. Resistor
ii. Inductor
iii. Capacitor
iv. Voltmeter
v. Ammeter
vi. Wattmeter
vii. Transformer
viii. Motor
ix. Variac / Auto-Transformer

Detail Explanation:

i. Resistor

Definition: A **resistor** is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. High-power resistors that can dissipate many watts of electrical power as heat, may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity. Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment. Practical resistors as discrete components can be composed of various compounds and forms. Resistors are also implemented within integrated circuits. The electrical function of a resistor is specified by its resistance: common commercial resistors are manufactured over a range of more than nine orders of magnitude. The nominal value of the resistance falls within the manufacturing tolerance, indicated on the component.

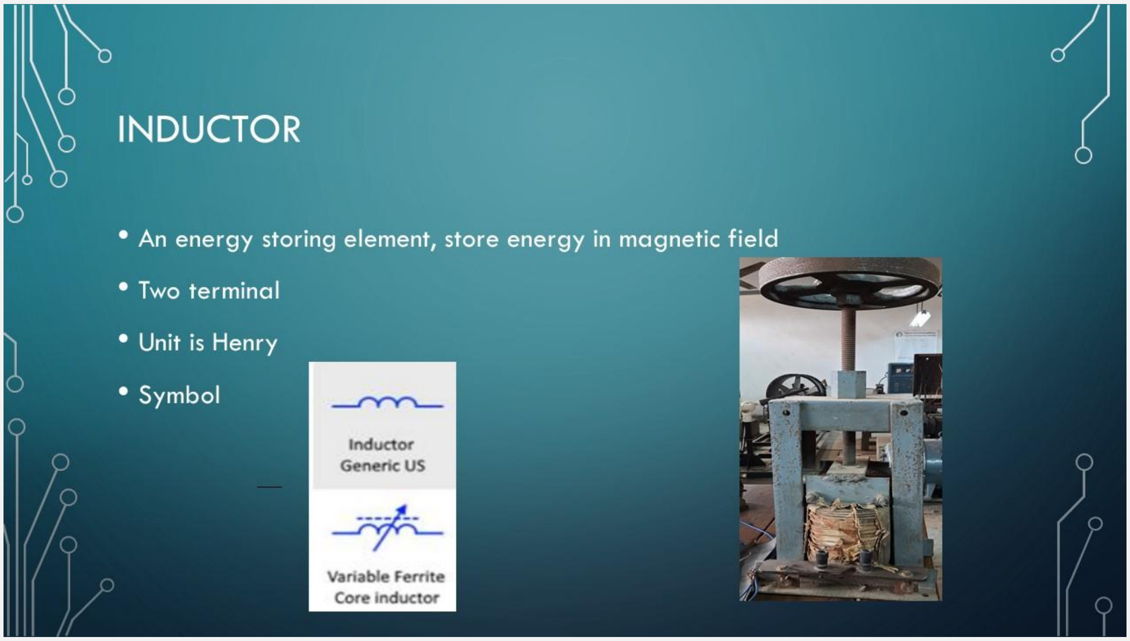
Diagram:



ii. Inductor

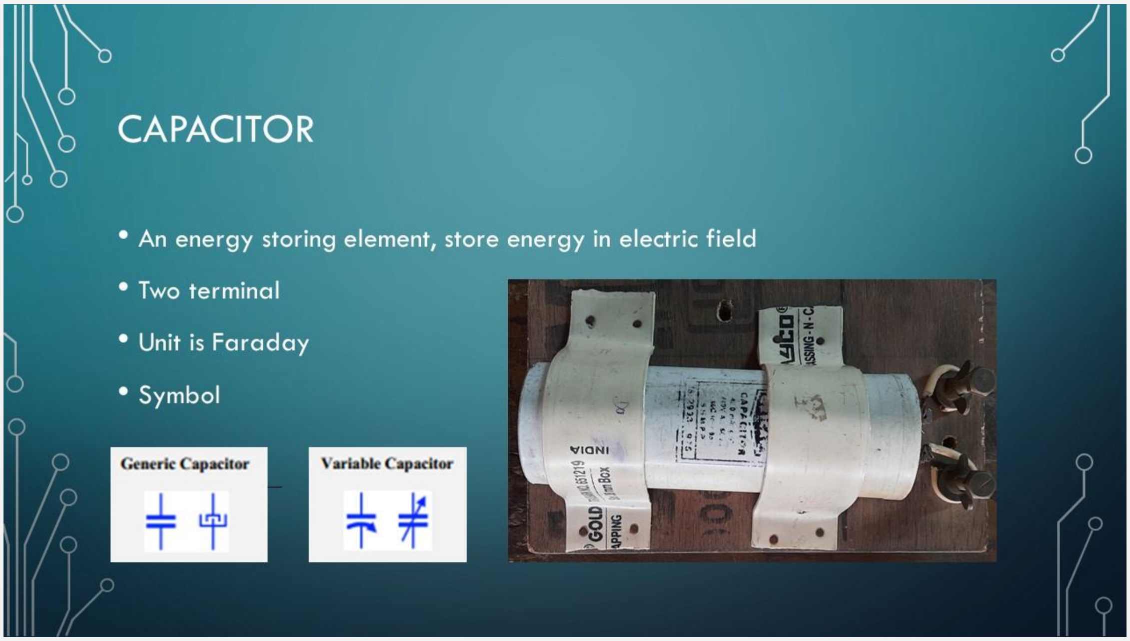
Definition: An inductor, also called a coil, choke, or reactor, is a passive two-terminal electrical component that stores energy in a magnetic field when electric current flows through it. An inductor typically consists of an insulated wire wound into a coil. When the current flowing through the coil changes, the time-varying magnetic field induces an electromotive force (*e.m.f.*) (voltage) in the conductor, described by Faraday's law of induction. According to Lenz's law, the induced voltage has a polarity (direction) which opposes the change in current that created it. As a result, inductors oppose any changes in current through them.

An inductor is characterized by its inductance, which is the ratio of the voltage to the rate of change of current. In the International System of Units (SI), the unit of inductance is the henry (H) named for 19th century American scientist Joseph Henry. In the measurement of magnetic circuits, it is equivalent to weber/ampere. Inductors have values that typically range from 1 µH (10^{-6} H) to 20 H. Many inductors have a magnetic core made of iron or ferrite inside the coil, which serves to increase the magnetic field and thus the inductance. Along with capacitors and resistors, inductors are one of the three passive linear circuit elements that make up electronic circuits. Inductors are widely used in alternating current (AC) electronic equipment, particularly in radio equipment. They are used to block AC while allowing DC to pass; inductors designed for this purpose are called chokes. They are also used in electronic filters to separate signals of different frequencies, and in combination with capacitors to make tuned circuits, used to tune radio and TV receivers.



iii. Capacitor

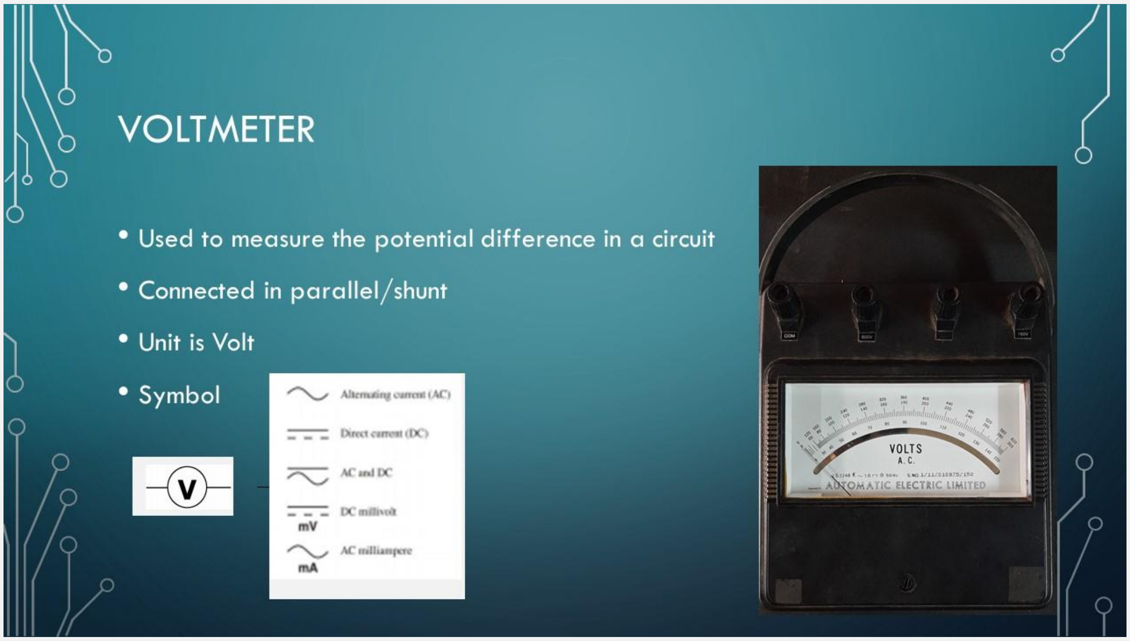
Capacitor is an electronic component that stores energy in its electric field.



iv. **Voltmeter**

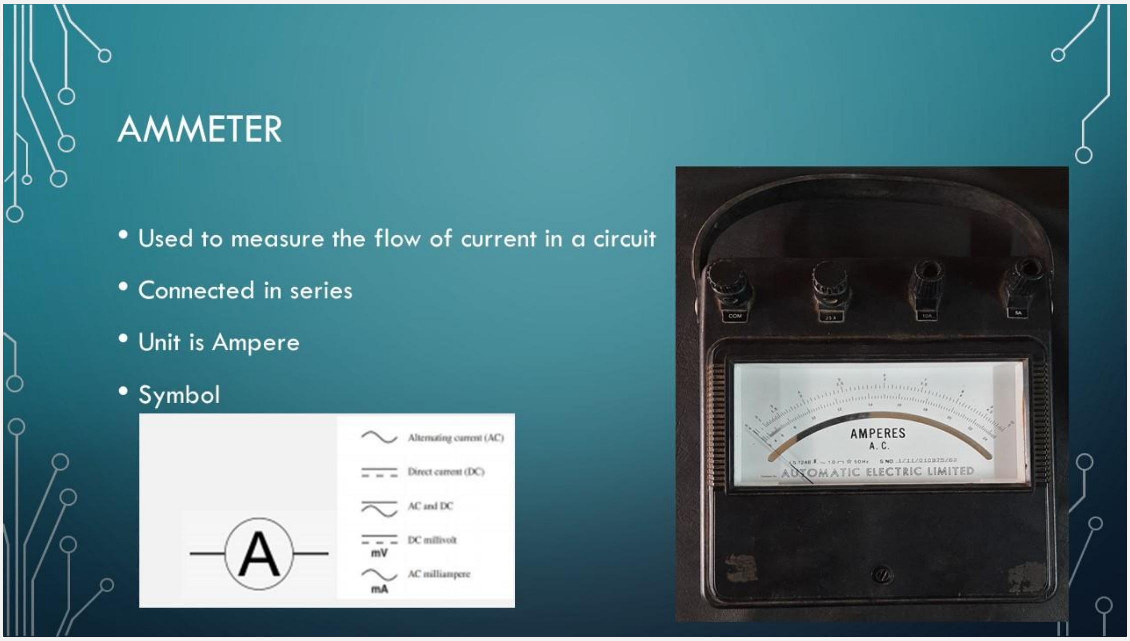
A voltmeter is an instrument used for measuring electric potential difference between two points in an electric circuit. A Voltmeter is also known as a Voltage Meter, it is an instrument used for measuring the potential difference or voltage between two points in an electrical or electronic circuit.

They can be used in AC/DC circuits. It is connected in parallel. It usually has a high resistance so that it takes a negligible current from the circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit; digital voltmeters give a numerical display of voltage by use of an analog-to-digital converter. Voltmeters are made in a wide range of styles. Instruments permanently mounted in a panel are used to monitor generators or other fixed apparatus. Portable instruments, usually equipped to also measure current and resistance in the form of a multimeter, are standard test instruments used in electrical and electronics work.



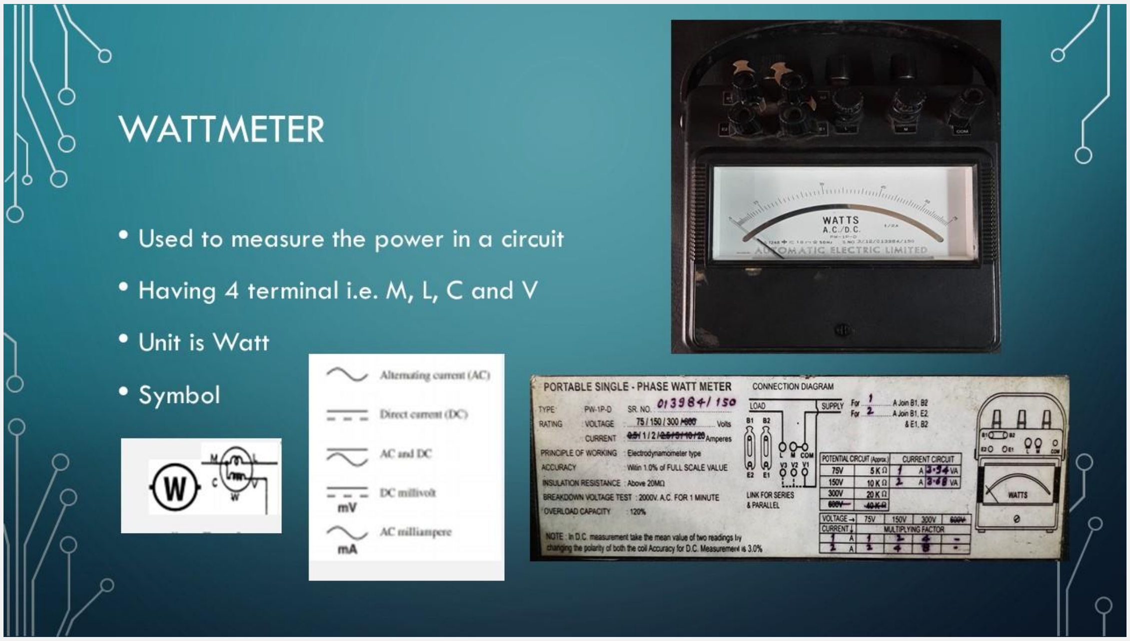
v. Ammeter

An **ammeter** (from ampere meter) is a measuring instrument used to measure the current in a circuit. Electric currents are measured in amperes (A), hence the name. The ammeter is usually connected in series with the circuit in which the current is to be measured. An ammeter usually has low resistance so that it does not cause a significant voltage drop in the circuit being measured. Instruments used to measure smaller currents, in the milliampere or microampere range, are designated as milliammeters or microammeters. Early ammeters were laboratory instruments that relied on the Earth's magnetic field for operation. By the late 19th century, improved instruments were designed which could be mounted in any position and allowed accurate measurements in electric power systems. It is generally represented by letter 'A' in a circuit.



vi. Wattmeter

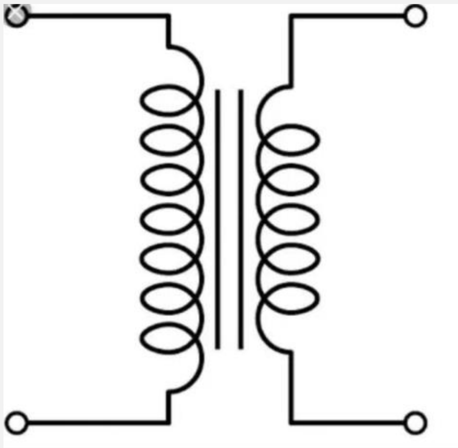
The wattmeter is an instrument for measuring the electric power (or the supply rate of electrical energy) in watts of any given circuit. Electromagnetic wattmeters are used for measurement of utility frequency and audio frequency power; other types are required for radio frequency measurements. A wattmeter reads the average value of the product v(t)i(t) = p(t), where v(t) is the voltage with reference polarity in the ± terminal with respect to the other terminal of the potential (pressure) coil, and i(t) is the current with reference direction flowing into the ± terminal of the current coil. The wattmeter reads $P = (1/T) \int_0^T v(t)i(t)\,dt$, which in sinusoidal steady-state reduces to $V_{rms} I_{rms} \cos(\varphi)$, where T is the period of p(t) and φ is the angle by which the current lags the voltage.



vii. Transformer

Definition: Transformer transfers electrical power from one electrical circuit to another electrical circuit. It does not change the value of power.

- A Transformer doesn't change the circuit frequency during operation.
- A Transformer works on the principle of electric i.e. mutual induction.
- A Transformer operates when both circuits take effect by mutual induction.
- A Transformer can't step-up or step-down the level of DC voltage or DC Current.
- A Transformer only step-up or step-down the level of AC voltage or AC Current.
- A Transformer doesn't change the value of flux.
- A Transformer won't operate on DC Voltage.

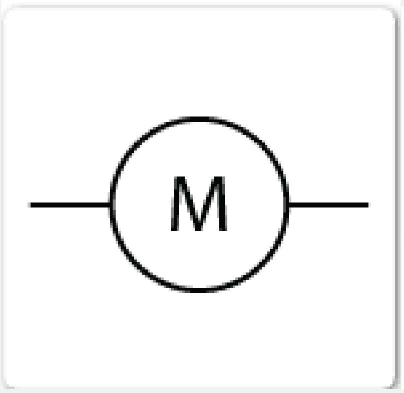


Symbol of transformer Air-cooled transformer

Power transformer used in power system

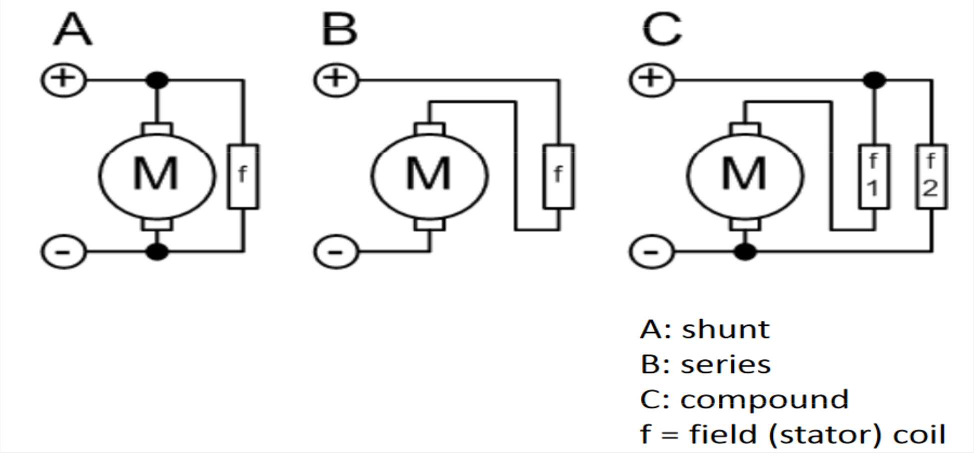
viii. Motor

Motor is an electro mechanical converter, converting electrical energy to mechanical energy (Rotational system.)A.C. motors are powered from alternating current (A.C.) while D.C. motors are powered from direct current (D.C.), such as batteries, D.C. power supplies or an AC-to-DC power converter. A.C. induction motors do not use brushes; they are very rugged and have long life expectancies.



Symbol

Practical motor



1). DC Shunt Motor

DC shunt motor works on DC and the windings of this electric motor like the armature windings and field windings are linked in parallel which is known as a shunt. This kind of motor is also called as shunt wound DC motor, where the winding type is known as a shunt winding.

2). Separately Excited Motor

In separately excited motor, the connection of stator and rotor can be done using a different power supply. So that the motor can be controlled from the shunt and the armatures winding can be strengthened to generate flux.

3). DC Series Motor

In DC series motor, rotor windings are connected in series. The operation principle of this electric motor mainly depends on a simple electromagnetic law. This law states that whenever a magnetic field can be formed around conductor & interacts with an external field to generate the rotational motion. These motors are mainly used in starter motors which are used in elevators and cars.

4). PMDC Motor

The term PMDC stands for "Permanent Magnet DC motor". It is one kind of DC motor which can be inbuilt with a permanent magnet to make the magnetic field necessary for the electric motor operation.

5). DC Compound Motor

Generally, DC compound motor is a hybrid component of DC series and shunt motors. In this type of motor, both the fields like series and shunt are present. In this type of electric motor, the stator and rotor can be connected to each other through a series & shunt windings compound. The series winding can be designed with few windings of wide copper wires, which gives a small resistance path. The shunt winding can be designed with multiple windings of copper wire to get the full i/p voltage.

AC Motors

The types of ac motors mainly include synchronous, asynchronous, induction motor.

1). Synchronous Motor

The working of the synchronous motor mainly depends on the 3-phase supply. The stator in the electric motor generates the field current which rotates in a stable speed based on the AC frequency. As well as the rotor depends on the similar speed of the stator current. There is no air gap among the speed of stator current and rotor. When the rotation accuracy level is high, then these motors are applicable in automation, robotics, etc.

2). Induction Motor

The electric motor which runs asynchronous speed is known as induction motor, and an alternate name of this motor is the asynchronous motor. Induction motor mainly uses electromagnetic induction for changing the energy from electric to mechanical. Based on the rotor construction, these motors are classified into two types namely squirrel cage & phase wound.

Special Purpose Motors

The special purpose motors mainly include servo motor, stepper motor, linear induction motor, etc.

1). Stepper Motor

The stepper motor can be used to offer step angle revolution, as an alternative to stable revolution. We know that for any rotor, the whole revolution angle is 180degrees. However, in a stepper motor, the complete revolution angle can be separated in numerous steps like 10 degree X 18 steps. This means, in a total revolution cycle the rotor will go stepwise eighteen times, every time 10 degree. Stepper motors are applicable in plotters, circuit fabrication, process control tools, usual movement generators, etc.

2). Brushless DC Motors

The brushless DC motors were first developed for achieving superior performance within a lesser space than brushed DC motors. These motors are lesser when compared with AC models. A controller is embedded into the electric motor to facilitate the process within the lack of a commutator and a slip ring.

3). Hysteresis Motor

The operation of the hysteresis motor is extremely unique. The rotor of this motor can be induced hysteresis and eddy current to generate the required task. The motor working can depend on the construction, 1-phase supply otherwise 3-phase supply. These motors give a very smooth process with stable speed, similar to other synchronous motors. The noise level of this motor is quite small, due to this reason they are applicable in numerous complicated applications wherever the soundproof motor is used such as sound player, audio recorder, etc.

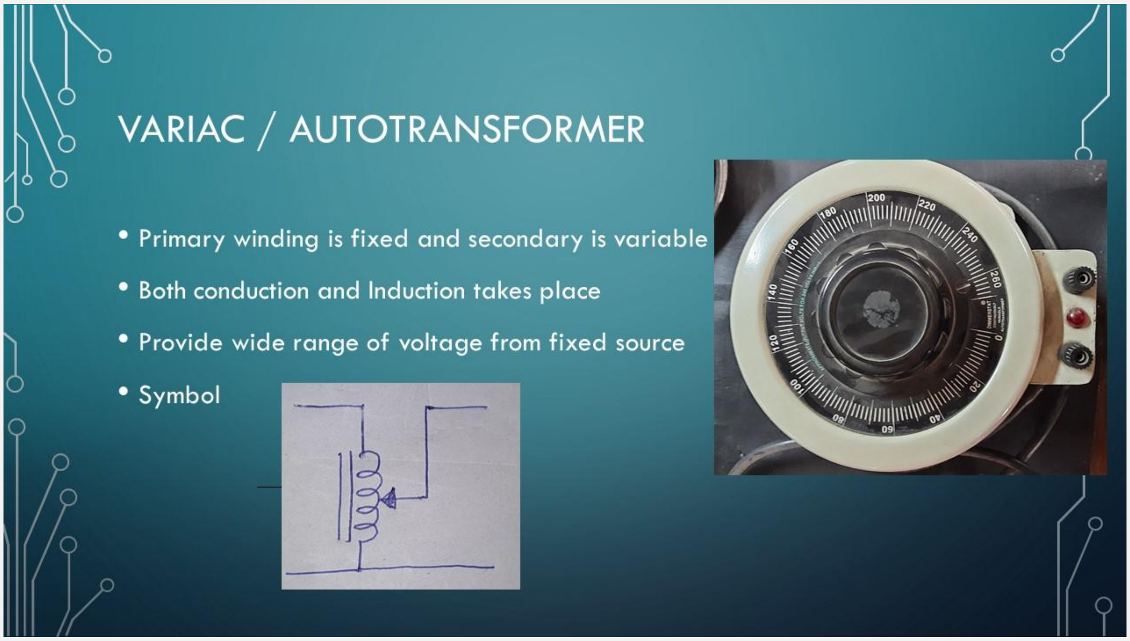
4). Reluctance Motor

Basically, reluctance motor is a 1-phase synchronous motor & this motor construction is quite same with induction motor like cage type. The rotor in the motor is like squirrel cage type & the stator of the motor include sets of windings such as auxiliary and main winding. The auxiliary winding is very useful at the beginning time of the motor. As they offer a level operation at a stable speed. These motors are commonly used in synchronization applications which include signal generators, recorders, etc.

5). Universal Motor

This is a special kind of motor and this motor works on single AC supply otherwise DC supply. Universal motors are series wound where the field and armature windings are connected in series and thus generates high starting torque. These motors are mainly designed for operating at high-speed above 3500 rpm. They utilize AC supply at low-speed and DC supply of similar voltage.

Variac / Autotransformer



NOTES

"Fluorescent is the emission of light by a substance that has absorbed light or other electromagnetic radiation"

[Expt: 02] Fluorescent Lamp

Aim of the Experiment

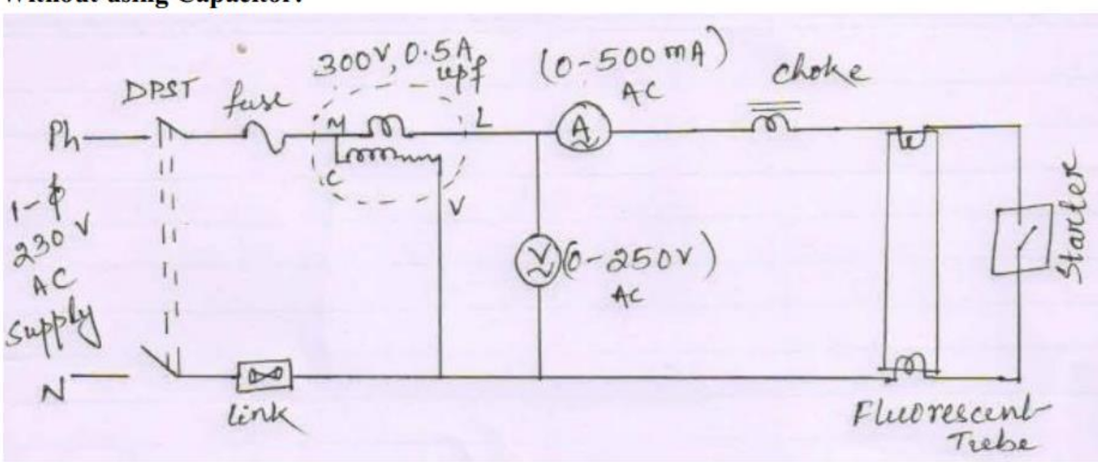
To study the connection and working of fluorescent lamp and to learn about the improvement of power factor using capacitor.

Apparatus Required

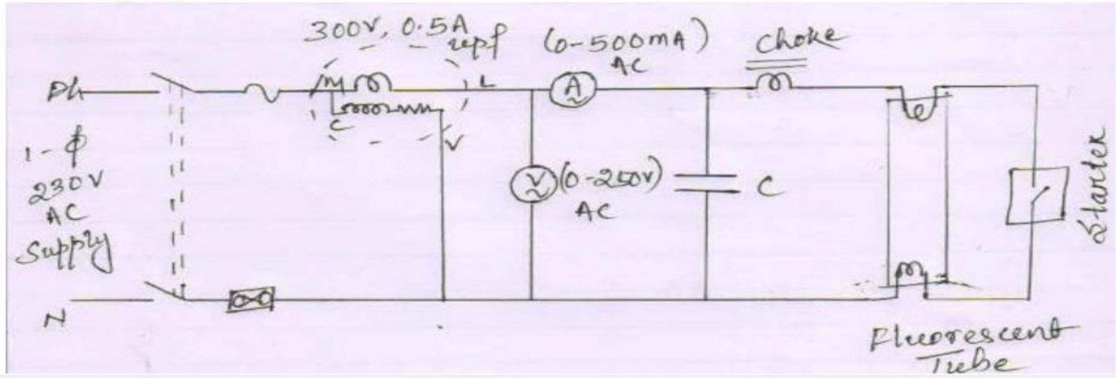
Sl. No.	Name of Equipment	Specification	Quantity
1	Wattmeter	300 V, 0.5 A , upf	01
2	Ammeter	(0-500) mA, AC	01
3	Voltmeter	(0-300) V, AC	01
4	Fluorescent Tube	40 W,250 V	01
5	Choke	40 W,250 V	01
6	Starter	40 W,250 V	01
7	Capacitor	4 µF +10 %, 250 V, 50 Hz	01
8	Connecting Wires	1.5 mm square PVC insulated Cu wire	As per reqirement

Circuit Diagram

Without using Capacitor:



With using Capacitor:



Theory

Procedure

- Make the connection as per the circuit diagram
- Connection should be tight and verified by the export available
- With all the safety precaution switch on the main
- Observe and tabulate the readings
- Switch off the supply and connect the capacitor
- Again repeat the process and take the reading and tabulate it
- Switch off the [power supply and remove the connection
- From the tabulation do the calculation and observe the power factor

Tabulation

(a) Without using Capacitor:

Sl. No.	P (in watt)	I (in mA)	V (in volt)	Power factor

(b) With using Capacitor:

Sl. No.	P (in watt)	I (in mA)	V (in volt)	Power factor

Calculation

$P = VI \cos\Phi$

$\cos\Phi$-Power factor

Result

After doing the experiment we found the power factor of the fluorescent lamp without capacitor is__________ and with capacitor is ___________.

"Theorems are very much necessary to reduce a complex circuit and to make is very simpler to solve."

[Expt: 03] Verification of theorems

Aim of the Experiment

To study and verify Superposition and Thevenin's Theorem.

Apparatus Required

For Superposition Theorem:

Sl. No.	Name of Equipment	Specification	Quantity
1	Ammeter	(0-2) A, DC	01
2	Rheostat	300 Ω, 1.7 A	01
		250 Ω, 3 A	01
		375 Ω, 2.5 A	01
3	Connecting Wires	1.5 mm square PVC insulated Cu wire	

For Thevenin's Theorem:

Sl. No.	Name of Equipment	Specification	Quantity
1	Ammeter	(0-2) A, DC	01
2	Rheostat	300 Ω, 1.7 A	01
		250 Ω, 3 A	01
		375 Ω, 2.5 A	01
3	Connecting Wires	1.5 mm square PVC insulated Cu wire	

Circuit Diagram

For Superposition Theorem:

Both sources are connected:

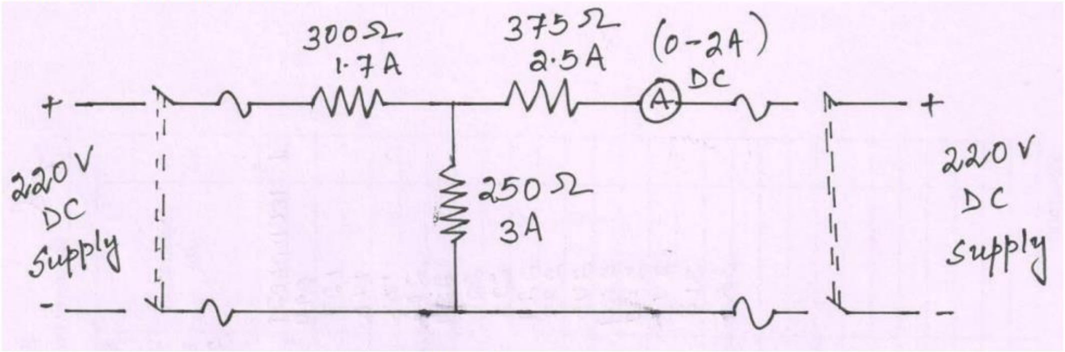


Fig. 1

First source is connected:

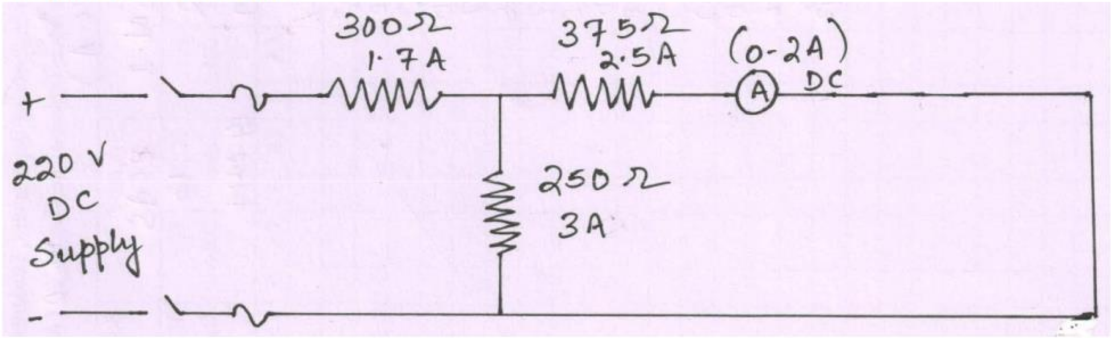


Fig .2

Second source is connected:

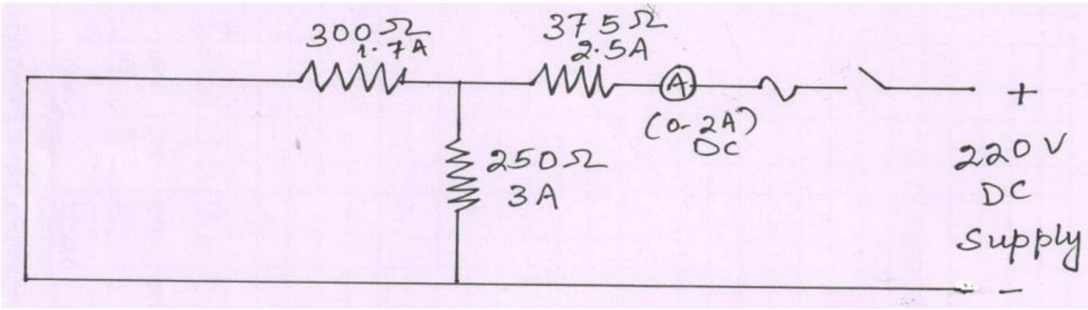
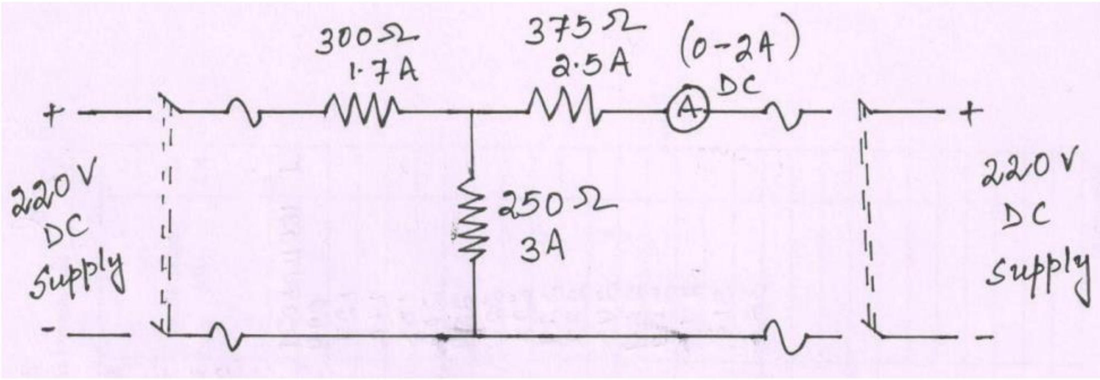
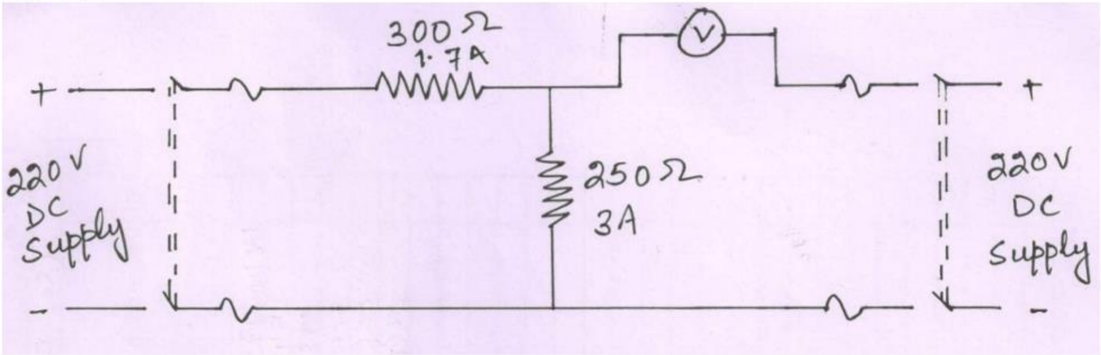


Fig.3

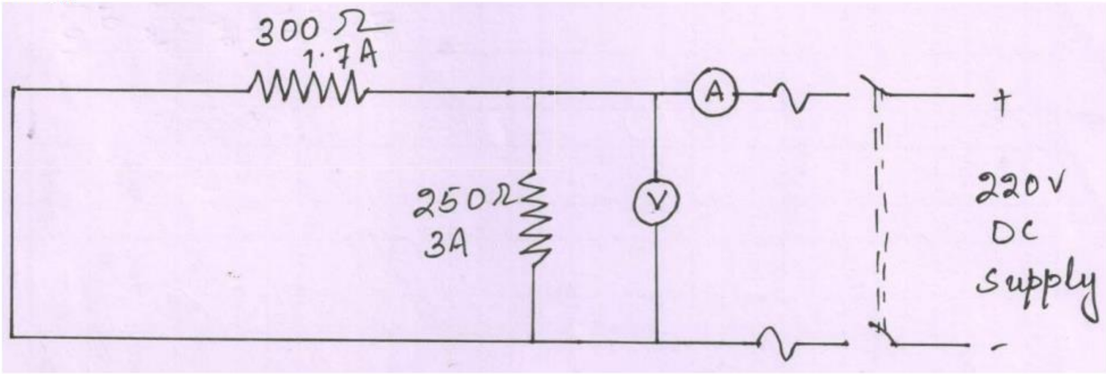
For Thevenin's Theorem:



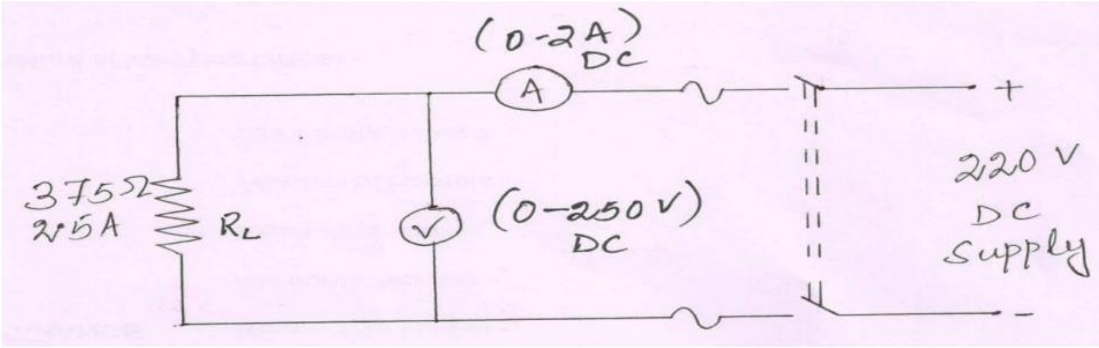
For V_t :



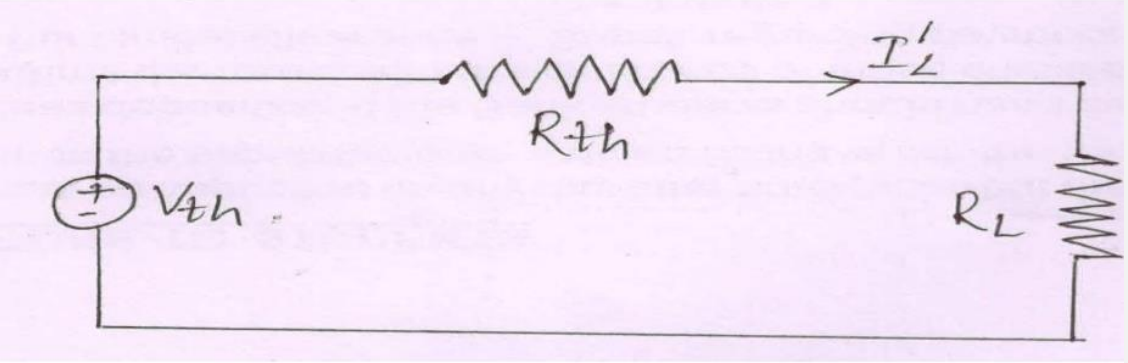
For $_{th}$:



For R :



Thevenin's Equivalent Circuit:



Theory

Procedure

- Make the connection as per the circuit diagram
- Connection should be tight and verified by the export available
- With all the safety precaution switch on the main
- Observe and tabulate the readings
- Switch off the supply and reconnect the circuit
- Again repeat the process and take the reading and tabulate it
- Switch off the power supply and remove the connection
- From the tabulation do the calculation

Tabulation

For Superposition Theorem:

Sl. No.	I_1 (in A)	I_2 (in A)	I (in A)	Remark
				$I = I_1 + I_2$

For Thevenin's Theorem:

Sl. No.	I_L (in A)	V_{th} (in volt)	R_{th} (in ohm)	I'_L (in A)	Remark
					$I_L = I'_L$

Calculation

Superposition theorem

THEORITICAL CALCULATIONS

From Fig(2)

$$I_1=V_1/(R_1+(R_2//R_3))$$

$$I_L^{I}=I_1*R_2/(R_2+R_3)$$

From Fig(3)

$$I_2=V_2/(R_2+(R_1//R_3))$$

$$I_L^{II}=I_2*R_1/(R_1+R_3)$$

$$I_L = I_L^{I} + I_L^{II}$$

Thevenin theorem :

To find the current flowing through load ,R_L is removed from ckt.

$V_{TH}=I.R_{TH}$

$R_{TH}=R_1R_2/(R_1+R_2)$

$I_L=V_{TH}/(R_L+R_{TH})$

Result

After doing the experiment, the theorems are verified and we found R_{th} is ________ohm and V_{th} is _____volt.

"Transformer in electrical network takes a vital role, by isolating the electrical circuit one with another without affecting power transmission"

[Expt: 04] Transformer polarity test

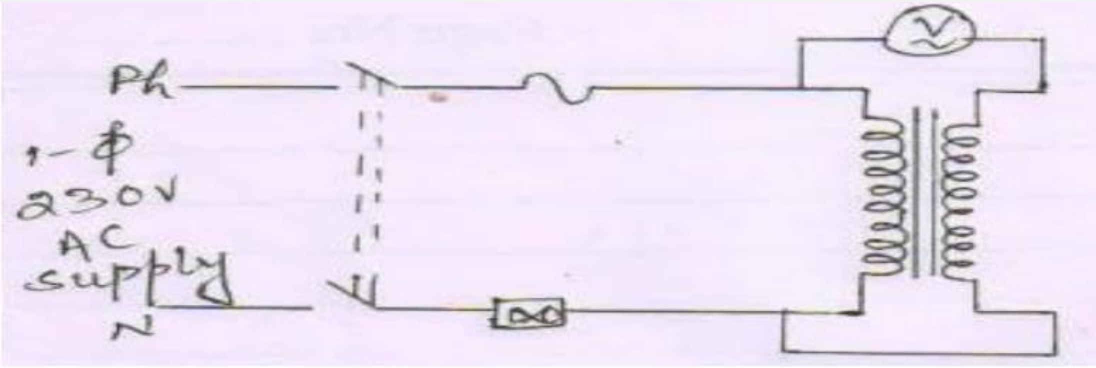
Aim of the Experiment

To study and find out the polarity of single phase transformer.

Apparatus Required

Sl. No.	Name of Equipment	Specification	Quantity
1	Transformer	1-ϕ, 1 KVA, 230V/230V	01
2	Voltmeter	(0-500) V, AC	01
3	Connecting Wires	1.5 mm square PVC insulated Cu wire	As per requirement

Circuit Diagram



Theory

Procedure

- Make the connection as per the circuit diagram
- Connection should be tight and verified by the export available
- Assume the polarity of the transformer terminals

- With all the safety precaution switch on the main
- Observe and tabulate the voltmeter readings
- From the tabulation verify the assumption

Tabulation

Sl. No.	V_1 (in volt)	V_2 (in volt)	V (in volt)	Remark

Result

After doing the experiment, the polarity of the transformer is found out and noted.

"Remember power consumption of any m-phase network can be measured by at least m-1 number of wattmeter."

[Expt: 05] Power measurement

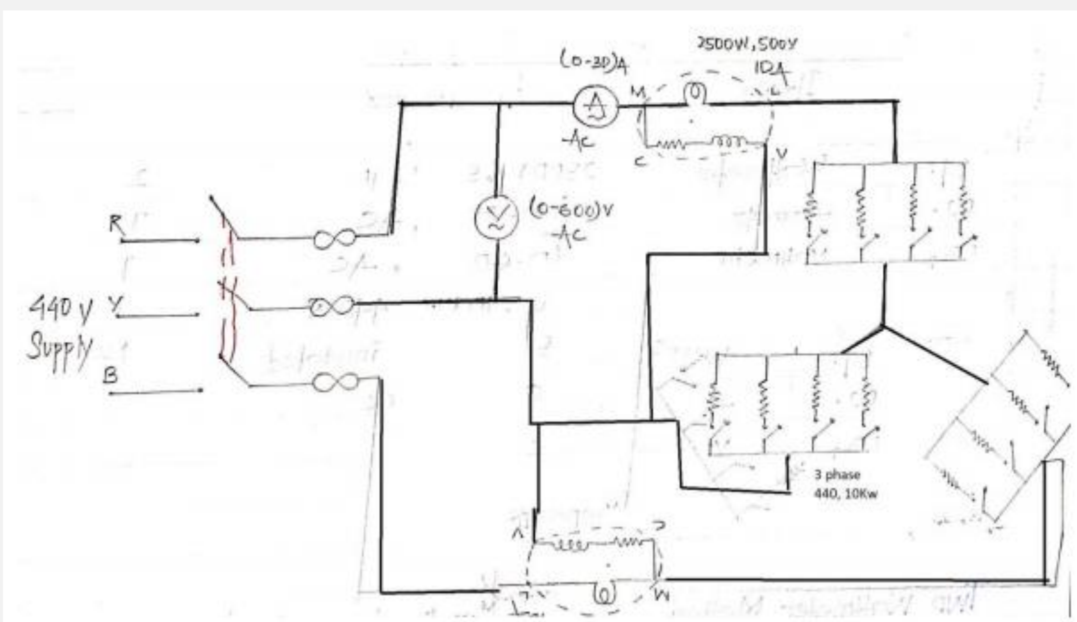
Aim of the Experiment

To study and measure the power consume by three phase resistive load by two-wattmeter method.

Apparatus Required

Sl.No	ITEMS	SPECIFICATION	Quantity
1	Wattmeter	2500W,500V,1A,UPF	02
2	Ammeter	(0-30)A, Moving Iron	01
3	Voltmeter	(0-600)V, Moving Iron	01
4	Load Box	3 phase, 10Kw, 440V	01
7	Connecting Wire	1.5mm^2 PVC Insulated Cupper Wire	As per needed

Circuit Diagram



Theory

Procedure

- Make the connection as per the circuit diagram
- Connection must be checked and verified and no loose connection
- Close the DPST switch with no load and not down the readings of all the meters
- Gradually increase the load and take the reading simultaneously
- After doing the experiment switch off the load and then switch off the power supply and remove the connection.
- From the reading do the calculation

Tabulation

Sl.No	Voltmeter Reading in Volt	Wattmeter 1 reading in Watt	Wattmeter 2 reading in Watt	Ammeter Reading in Amps	Total Power W1+W2

Calculation

Find the average power- Summing all the total wattmeter reading and divide by no of reading.

Result

The three phase power is found to be ______Watt.

“When the capacitive and inductive reactance are same the circuit is called resonant circuit and load become only resistive”

[Expt: 06] Series R-L-C circuit

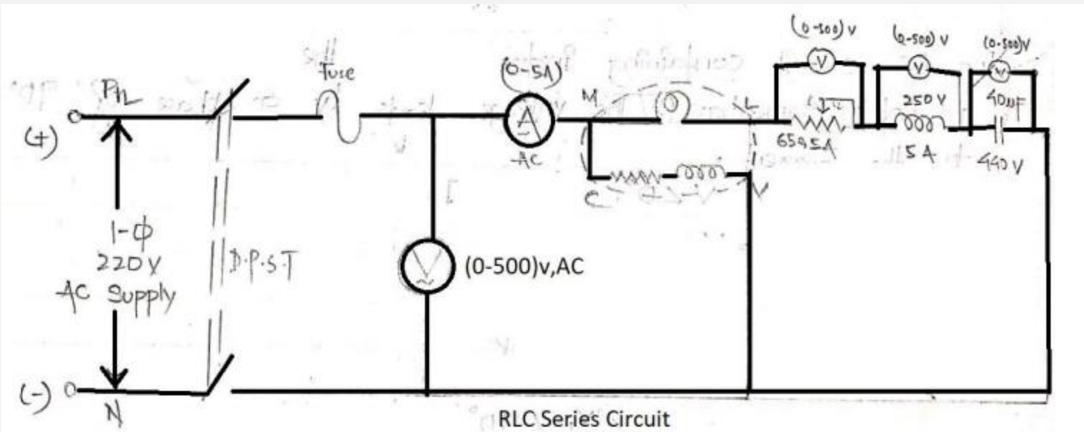
Aim of the Experiment

Determination of voltage, current, power and power factor of series RLC circuit.

Apparatus Required

Sl.No	ITEMS	SPECIFICATION	Quantity
1	Wattmeter	300V,5A,UPF	01
2	Ammeter	(0-5)A, Moving Iron	01
3	Voltmeter	(0-500)V, Moving Iron	01
4	Resistor	65 ohm,5A	01
5	Induction(Coil)	250v,5A	01
6	Capacitor	40 micro Fafraday,440V	01
7	Connecting Wire	1.5mm^2 PVC Insulated Cupper Wire	As per needed

Circuit Diagram



RLC Series Circuit

Theory

Procedure

- All the connections are made as per circuit diagram
- Power was supplied to the circuit
- Readings of all the meters are to be noted down in a table
- Rating of Resistor , Capacitor and Inductor also noted down
- Calculate the power factor

Tabulation

Serial No.	Voltmeter Reading (in Volt)	Ammeter Reading (IN Amps)	Wattmeter reading (in Watt)	V_R(V)	V_L(V)	V_C(V)	Power factor Cosφ

Calculation

$$P = VI . \cos\phi$$

$$\cos\phi = \frac{V_R}{\sqrt{(V_R)^2 + (V_L - V_C)^2}}$$

P=Wattmeter Reading in Watt

V=Total Voltage supplied to Ckt (Voltmeter Reading in Volt)

I=Ammeter Reading in Ampere

Vr,Vc,and VL are voltage across resister , capacitor and inductor respectively

Cosφ-Power factor of the circuit

Result

The voltage, current, power and power factor of series RLC circuit was found out and the values are _____, _______, ______and ______ respectively.

"If the field and armature windings are connected in parallel and tales DC supply for its operation then the machine is called DC shunt motor"

[Expt: 07] R_a and F_a of DC shunt motor

Aim of the Experiment

To measure the field resistance and armature resistance of a DC shunt motor.

Apparatus Required

For measuring field resistance

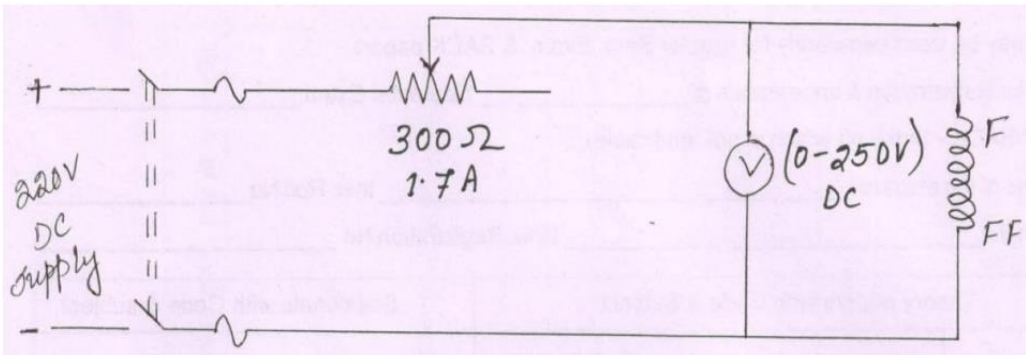
Sl No	Name of the Equipment	Specification	Quantity
1	Ammeter	(0-5A),DC	01
2	Voltmeter	(0-300V), DC	01
3	Rheostat	300Ω, 1.7A	01
4	DC Shunt Motor	5 H.P	01
5	Connecting wires	1.5 mm square PVC insulated Cu wire	

For measuring armature resistance

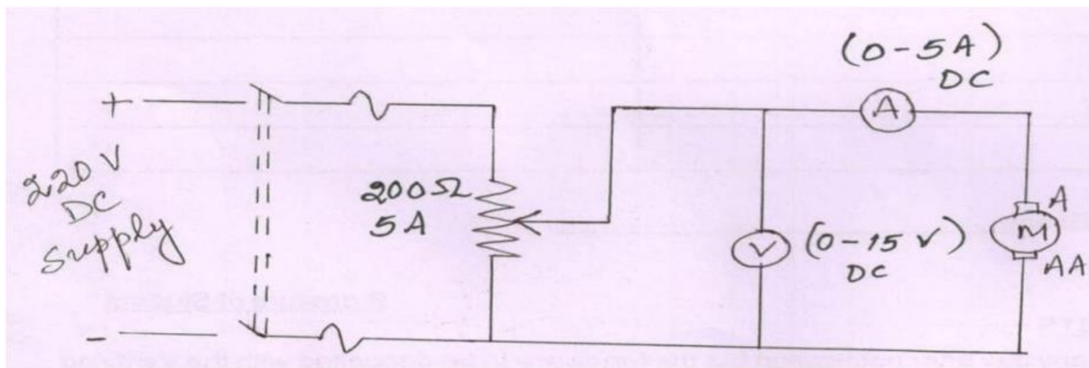
Sl No	Name of the Equipment	Specification	Quantity
1	Ammeter	(0-5A) ,DC	01
2	Voltmeter	(0-30V), DC	01
3	Rheostat	145Ω, 2.8A	01
4	DC Shunt Motor	5 H.P	01
5	Connecting wires	1.5 mm square PVC insulated Cu wire	

Circuit Diagram

For measuring field resistance:



For measuring armature resistance:



Theory

Procedure (Field resistance)

- Make the connection as per the circuit diagram
- Connection should be tight and verified by the export available
- Keep the rheostat at its maximum resistance position such that very low current will pass to the field while starting
- With all the safety precaution switch on the main
- Gradually reduce the rheostat resistance
- Observe and tabulate the readings with different value of rheostat

(Armeture resistance)

- Make the connection as per the circuit diagram
- Connection should be tight and verified by the export available
- Keep the rheostat at its minimum resistance position such that very low voltage will applied across the armature winding while starting
- With all the safety precaution switch on the main
- Gradually increase the rheostat resistance
- Observe and tabulate the readings with different value of rheostat

- Switch off the supply
- Switch off the [power supply and remove the connection
- From the tabulation do the calculation and observe the R_a and F_a

Tabulation

For measuring field resistance:

Sl No	Voltmeter reading(V)	Ammeter reading(A)	Resistance(Ω)	Average resistance(Ω)

For measuring armature resistance:

Sl No	Voltmeter reading(V)	Ammeter reading(A)	Resistance(Ω)	Average resistance(Ω)

Calculation

Result

After doing the experiment we found armature resistance and the field resistance of the shunt motor is _____ and ______ ohm respectively.

“Got something very important to point out to your readers? Use a sidebar to make it stand out.”

[Expt: 08] Study of BH curve

Aim of the Experiment

. To determine of B-H curve of core material of transformer

Theory

The rms voltage induced in a transformer is given by

$$E = 4.44\phi_m f N \tag{1}$$

where, ϕ_m is maximum value of the flux in the core, f is operating frequency and N is number of turns in the coil. This flux in the coil is given by

$$\phi_m = B_m A_c \tag{2}$$

where, B_m is the maximum flux density in core and A_c is the cross-sectional area of the core. So we have

$$E = 4.44 B_m A_c f N \tag{3}$$

The value of induced voltage E is thus dependent upon B_m which can be setup in the core.

2.1 DC Magnetization Curve

We know from Biot-Savart's law that a current carrying conductor produces magnetic field. “Magnetic field strength” **H** is proportional to the current which produces the field. From Ampere's Circuital law, it can be proved that **H** is proportional to current I. If a current carrying coil produces magnetic flux which traverses an average length of l in complete flux path, then

$$Hl = NI \tag{4}$$

In a magnetic circuit, this field is represented by *magnetomotive force*. It is analogous to the *electromotive force* in electrical circuit.

This field is responsible to “set up” certain flux, which in turn gives rise to certain flux density **B**. Note that, here **H** is cause and **B** is its effect. The amount of flux which *can be* setup in a material is determined by an inherent property of the material, called as *permeability*, denoted by μ.

$$\mathbf{B} = \mu \mathbf{H} \tag{5}$$

More details on analysis of magnetic circuits can be found in chapter 2 in [1].

Let us consider materials used in the laminations of transformers. They are called *ferromagnetic materials*. A piece of ferromagnetic material is composed of several “domains”. In each domain, magnetic moments of all atoms are aligned in one direction. In general, the domains are randomly oriented. When external magnetic field **H** is applied to a material, all the domains align in a particular direction, setting up “net flux” in the material. Due to domain alignment B (i.e. the magnitude of **B**) increases. However, after a certain value of B, the slope of $B - H$ curve starts reducing as shown in Fig. 1; $O - S_1$ represents the linear region and $S_1 - S_2$ represents the “saturation region”. Note that

$$\left.\frac{dB}{dH}\right|_{O-S_1} > \left.\frac{dB}{dH}\right|_{S_1-S_2} \tag{6}$$

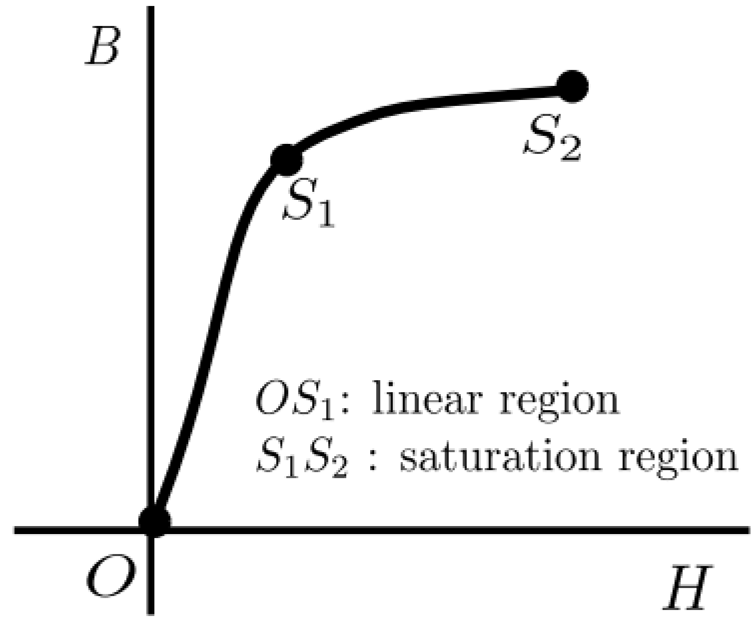


Figure 1: DC magnetization curve

In other words, for same increment in B, one has to apply more excitation in saturation region than in linear region. This is called as *DC Magnetization Curve* as both B and H have same sign. It is interesting to see what hapens when the external magnetic "excitation" is removed or reduced to zero. Discussion in the following section, applies to this case and also the case of AC circuits in general.

2.2 Hysteresis Loop

Removing external magnetic field is equivalent to reducing H from H_{max} to 0. Due to this, the domains which were aligned in the direction of external field, "become free" of the external magnetic force. However, now they do not attain completely random orientation as they had at $(B = 0, H = 0)$. Some domains maintain the direction of external magnetic field. This results in remanent magnetic flux density B_r. In short, while H traverses the trajectory $0 - H_{max} - 0$; magnetic flux density B traverses $0 - B_{max} - B_r$, as shown in Fig. 2. In order to reduce flux density to zero we have to apply external magnetic field in the opposite direction or on the negative $H-$axis.

If external field is increased in the *opposite* direction, the behaviour of magnetic material is seen analogous to that of the positive quadrant. Complete $B - H$ curve for is shown in Fig. 2. It is also called as "Hysteresis loop[1]" traced by the flux density in the material.

2.3 Determination of $B - H$ curve of a material

We cannot "measure" B and H directly. Further if we have transformer, we only have terminal measurements at our disposal. Hence, it is required to "process" the signals to get values of B and H.

From Faraday's law,

$$V = N\frac{d\phi}{dt} \tag{7}$$

Also, from equation 2, B is directly proportional to flux ϕ. A signal proportional to B can be obtained by integrating the voltage signal. The voltage can be integrated approximately by using an RC circuit. Care should be taken in the choice of R and C values. The transfer function of the circuit is given by

$$\frac{V_c(s)}{V_{in}(s)} = G(s) = \frac{1}{1+s\tau}$$

The time constant $\tau = RC$ should be chosen such that, in frequency domain $(1 + j\omega\tau) \approx j\omega\tau$

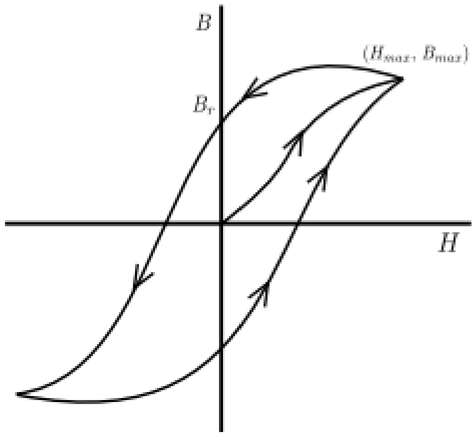


Figure 2: $B - H$ curve or Hysteresis loop

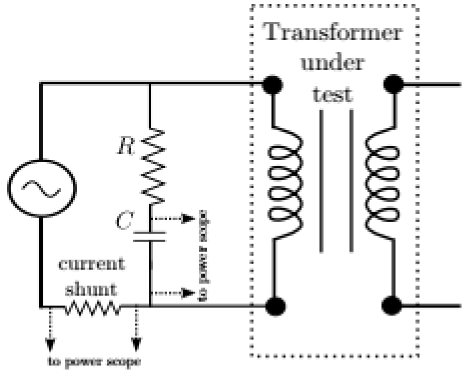


Figure 3: Connection diagram of circuit to trace $B - H$ curve measurement

Equation 4 tells that H is is proportional to current. The two signals can be given to two channels of a digital storage oscilloscope. $B - H$ curve of the material can be seen by plotting using *Lissajous*[2] plot settings of the oscilloscope.

Questions for discussion

1. Why is a ferromagnetic core required in transformers?
2. Permanent magnets exhibit a different type of $B - H$ curve. How does it differ from $B - H$ curve for ferromagnetic materials?
3. The material used for a transformer core is a steel variant with $\mu_r = 5000$. The average length of the magnetic path in the core is 50 mm. The number of turns in primary is 500. The cross sectional area of the core is 600 mm^2. The applied voltage is 230 V, 250 Hz. The secondary coil is open circuited. The $B - H$ curve of the material is as shown in Fig. 1. Is the transformer operating in saturation region? Why?
4. Note that flux density is inversely proportional to frequency (see equations 1 and 2). How would the design of a transformer be affected by the frequency? (Hint: What will be effect on cross sectional area of a core)
5. Consider two power supplies (adapters) shown in Figs. 5 and 6. Which has lower weight and size? Why?

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