EES51: Electrical Technology Lab

Tittle: To perform the open circuit test and short circuit test on a single-phase transformer

Expt. 4: Tests on 1Φ Transformer

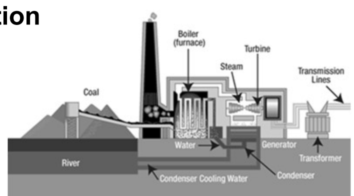
Electrical Power: Requirements

- ✓ Fluorescent Lamp
- ✓ Television
- ✓ Music System
- ✓ Battery Charger
- ✓ Battery Charger
- ✓ Rechargeable Torchlight
- ✓ Toaster
- ✓ Water Pump
- ✓ Electric Water Geyser
- ✓ Electric iron
- ✓ Air conditioner
- ✓ Air heater
- ✓ Refrigerator
- ✓ Cooking Heater
- ✓ Mixer Grinder
- ✓ Hair Dryer
- ✓ Electric Saver

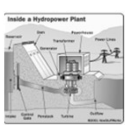
Expt. 4: Tests on 1Φ Transformer

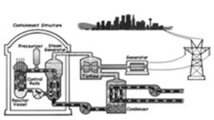
Electrical Power: Generation

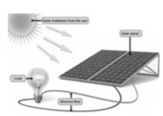
- ❑**Electric Power Station**
  - ❑**Thermal**
  - ❑**Hydroelectric**
  - ❑**Nuclear**
  - ❑**Non-Conventional**

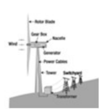


Thermal Power Station


Hydroelectric Power Station


Nuclear Power Station

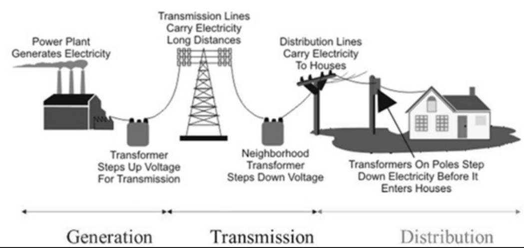

Solar Power Station


Wind Power Station

Expt. 4: Tests on 1Φ Transformer

Electrical Power: G to U

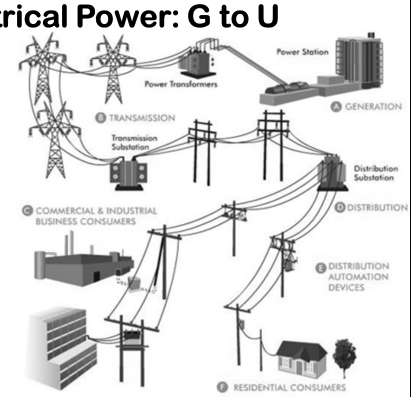
- ❑**Electrical Power**
  - ❑**Generation**
  - ❑**Transmission**
  - ❑**Distribution**
  - ❑**Utilization**



Expt. 4: Tests on 1Φ Transformer

Electrical Power: G to U

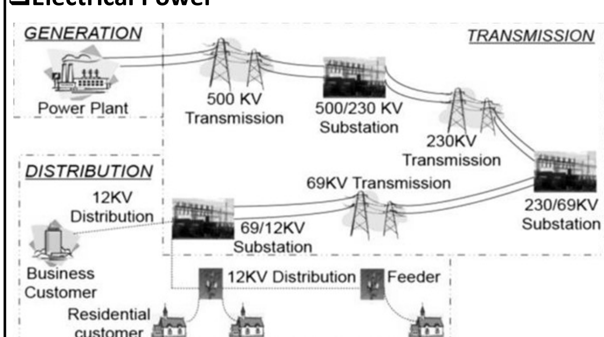
- ❑**Electrical Power**
  - ❑**Generation**
  - ❑**Transmission**
  - ❑**Distribution**
  - ❑**Utilization**



Expt. 4: Tests on 1Φ Transformer

Electrical Power: G to U

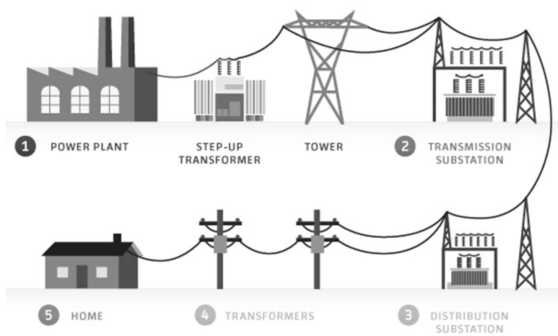
- ❑**Electrical Power**



Expt. 4: Tests on 1Φ Transformer

Electrical Power: G to U

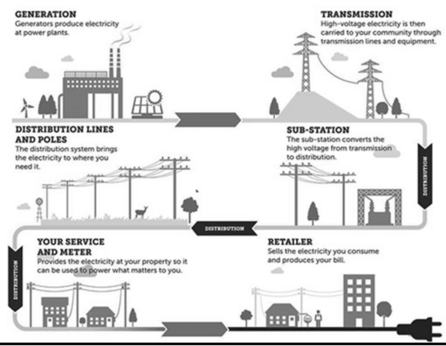
- Electrical Power



Expt. 4: Tests on 1Φ Transformer

Electrical Power: G to U

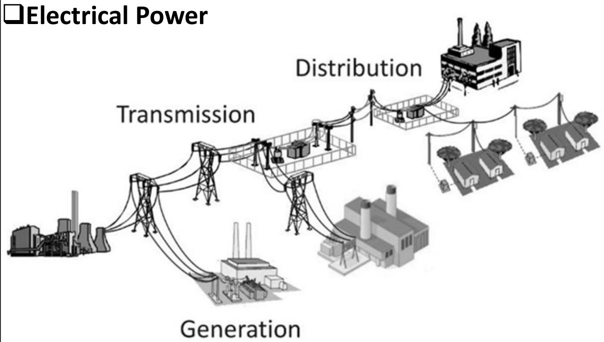
- Electrical Power



Expt. 4: Tests on 1Φ Transformer

Electrical Power: G to U

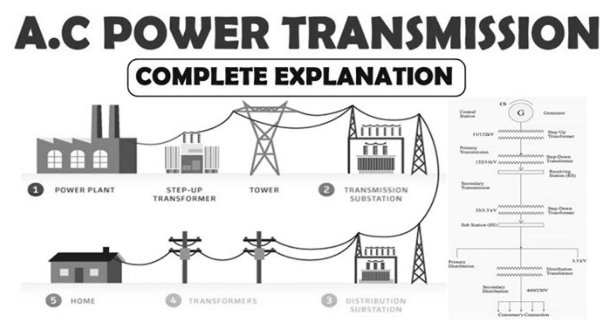
- Electrical Power



Expt. 4: Tests on 1Φ Transformer

Electrical Power: G to U

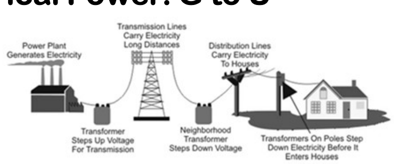
- Electrical Power



Expt. 4: Tests on 1Φ Transformer

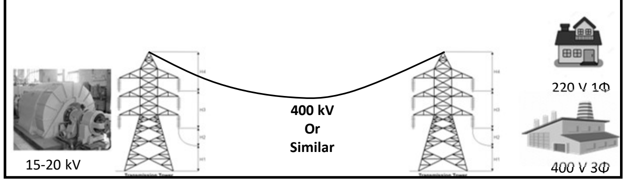
Electrical Power: G to U

- Electrical Power
  - Generation
  - Transmission
  - Distribution
  - Utilization



P = VI

For a constant amount of V ∞ 1/I **Loss = I^2R**



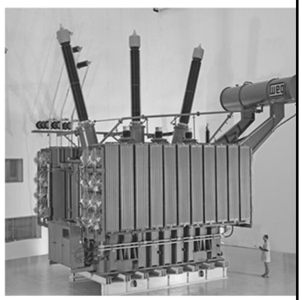
Expt. 4: Tests on 1Φ Transformer

Transformer: Where do we see these?

Varity of forms

Expt. 4: Tests on 1Φ Transformer

Transformer: How does it look?

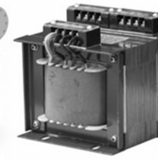


Expt. 4: Tests on 1Φ Transformer

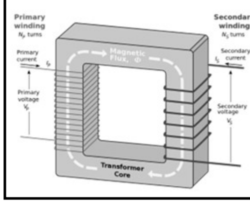
What is a Transformer?

Transformers are static electrical machines which are used to transfer the alternating electrical power from one circuit to an another circuit with a required change in the voltage and current levels keeping the power and frequency unchanged.

Transformer



Transformer



Generally,

- **Voltage Changes**
- **Current Changes**
- **Frequency dose not change**
- **Power dose not change** (rather reduced due to losses)

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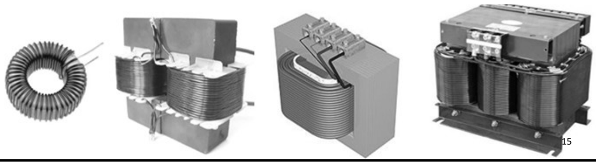
Expt. 4: Tests on 1Φ Transformer

Transformers Construction

Transformers are developed with copper windings wound over a magnetic core.

- **Core must be magnetic**
- **Copper wires are preferred for high conductivity and high ductility**



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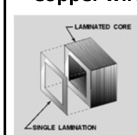
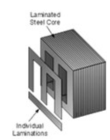
Expt. 4: Tests on 1Φ Transformer

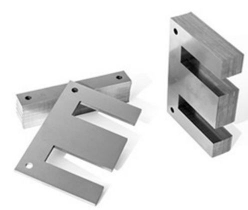
Transformers Construction: Laminated Iron Core

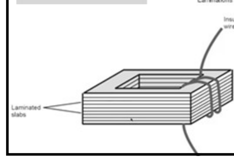
Transformers are developed with copper windings wound over a soft iron core (preferably CRGO).

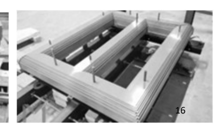
- **Core is laminated**
- **Copper wires are insulated**











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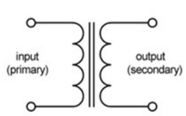
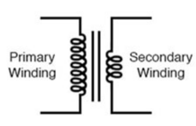
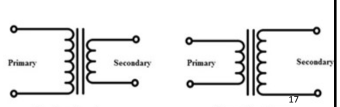
Expt. 4: Tests on 1Φ Transformer

Symbols and Names

- **Single Phase Transformers are represented as two inductive coils separated by two parallel lines representing the magnetic coupling.**
  - **Transformer Names: According to voltage variation**
    - **Step Up Transformer**
    - **Step Down Transformer**
    - **Isolation (1:1) Transformer**
  - **Winding Names**
    - **As per the connections**
      - **Primary**
      - **Secondary**
    - **As per the number of turns**
      - **HV**
      - **LV**







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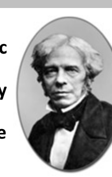
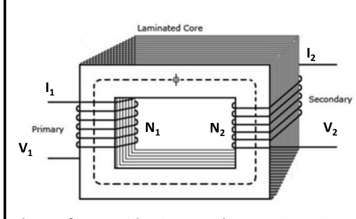
Expt. 4: Tests on 1Φ Transformer

Operation of Transformer

- **Transformer works as per the Faraday's electromagnetic induction principle.**
- **For an alternating current excitation, at the primary alternating flux is produced.**
- **Time varying flux links with both the winding and induce emf which is proportional to the number of turns.**





1Φ Transformer with primary and secondary windings

$$e = -N\frac{d\Phi}{dt}$$

$$\Phi = \Phi_m \sin \omega t$$

$$e = 4.44\Phi_m fN$$

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

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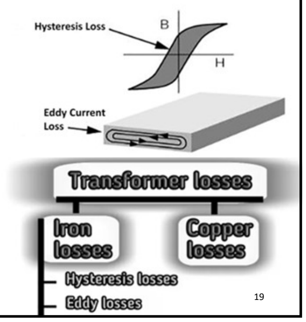
Expt. 4: Tests on 1Φ Transformer

❑Losses in the Transformers

- **There are two major types of losses are found in the transformers:**
  - ❖**Iron Loss**
    - ➢**Eddy Current Loss**
    - ➢**Hysteresis Loss**
  - ❖**Copper Loss**
    - ➢**Primary copper loss**
    - ➢**Secondary copper loss**



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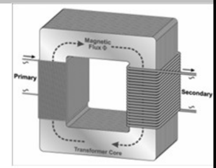
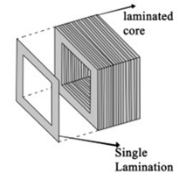
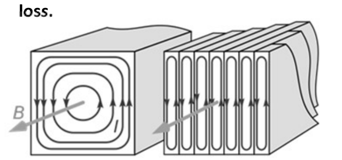
Expt. 4: Tests on 1Φ Transformer

- **Eddy Current Loss:**
- **Whenever the magnetic flux linking to conducting material changes, voltages are induced in all possible paths and hence the induced currents called eddy currents are set up throughout the volume of the conducting material.**
- **The electrical energy which is wasted in the form of heat due to eddy currents in the core material is called eddy current loss.**







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

ρ = resistivity
L = length
A = cross sectional area

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Expt. 4: Tests on 1Φ Transformer

- **Eddy Current Loss:**
- **Depends on the thickness.**

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

ρ = resistivity
L = length
A = cross sectional area

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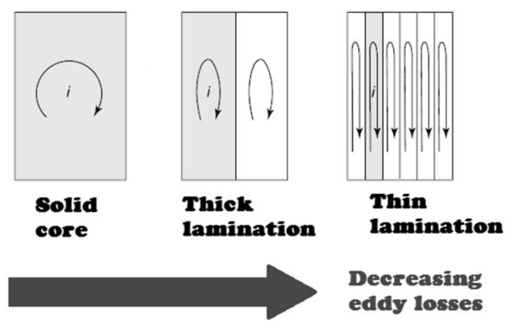
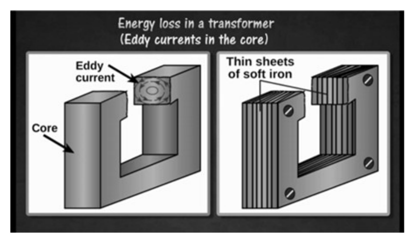


Expt. 4: Tests on 1Φ Transformer

- **Eddy Current Loss, $P_e = K_e B_{max}^2 f^2 t^2 V$** watts

Where K_e = constant
B_{max} = maximum flux density in Tesla
f = frequency of magnetic reversal in Hz
t = thickness of laminations in mm
V = volume of core in m^3



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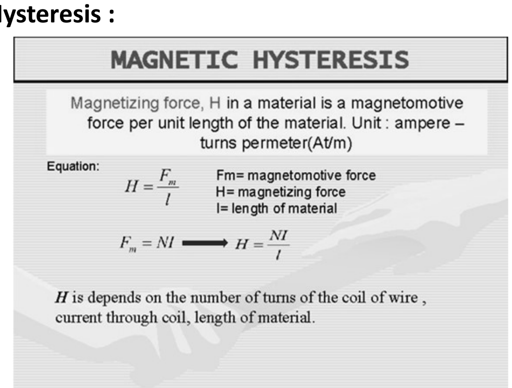
Expt. 4: Tests on 1Φ Transformer

- **Hysteresis :**
-



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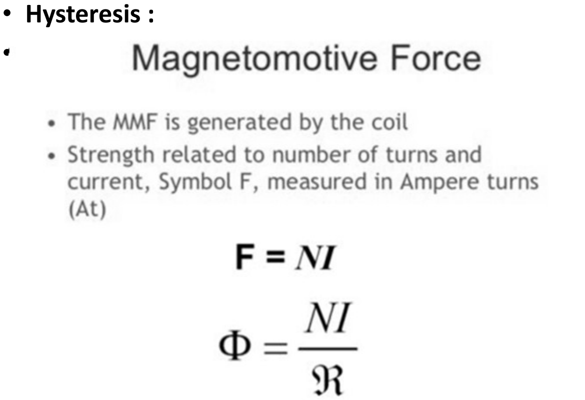
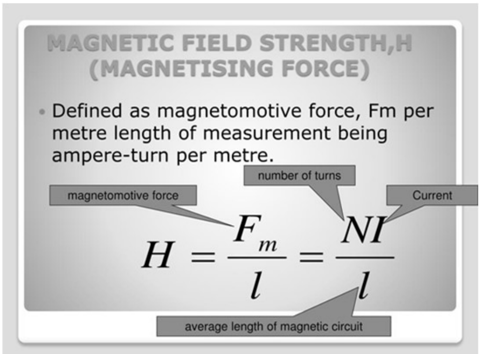
Expt. 4: Tests on 1Φ Transformer

- **Hysteresis :**
-



Expt. 4: Tests on 1Φ Transformer

- **Hysteresis :**
-



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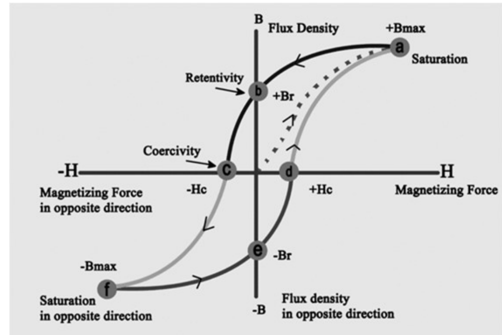
Expt. 4: Tests on 1Φ Transformer

- **Hysteresis :**
-



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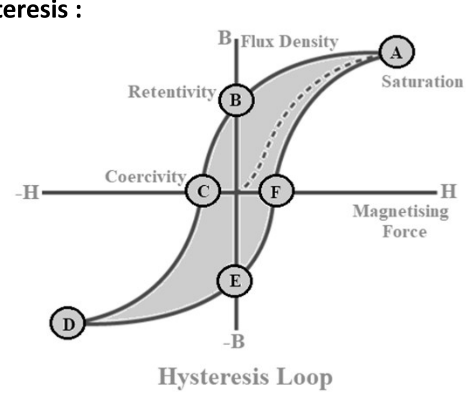
Expt. 4: Tests on 1Φ Transformer

- **Hysteresis :**
-



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Expt. 4: Tests on 1Φ Transformer

- H
-

Relationship between B-H

- Flux density (B) and magnetizing force (H) are related by the equation

$B = \mu H$

However, relative permeability is $\mu_r = \frac{\mu}{\mu_o}$ ⇒ $\mu = \mu_r \mu_o$

So, $B = \mu H = \mu_r \mu_o H$

B = flux density, Wb/m^2 or T

H = magnetizing force, At/m

μ = permeability of the medium, $Wb/At.m$

μ_o = permeability of free space, $Wb/At.m$

μ_r = relative permeability

μ_0, permeability of free space is given as $4\pi \times 10^{-7}$ $Wb/At.m$

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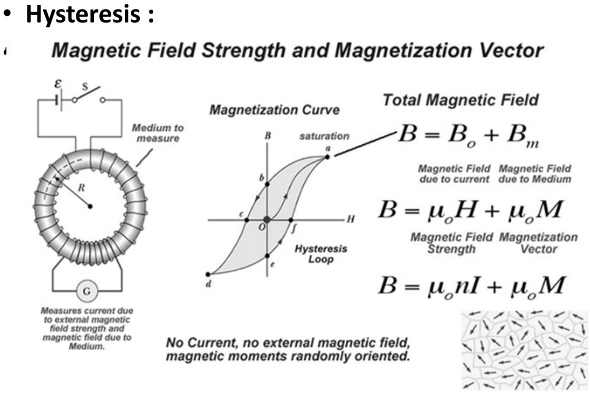
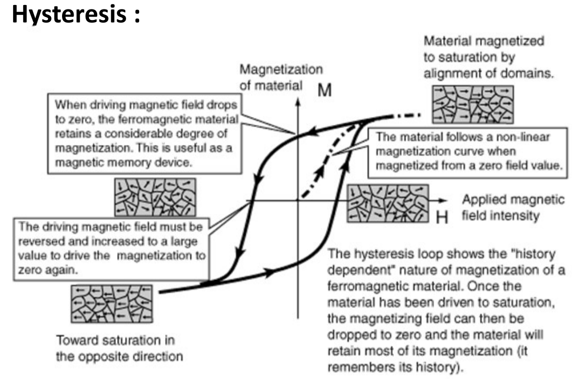
Expt. 4: Tests on 1Φ Transformer

- **Hysteresis :**
-



Expt. 4: Tests on 1Φ Transformer

- **Hysteresis :**
-



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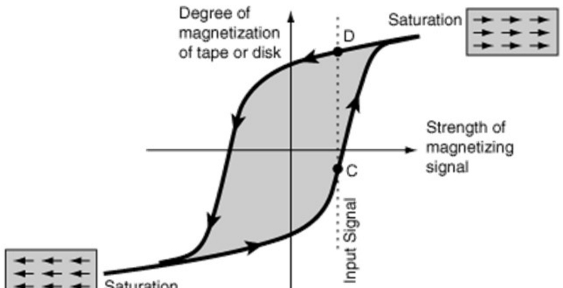
Expt. 4: Tests on 1Φ Transformer

- **Hysteresis :**
-



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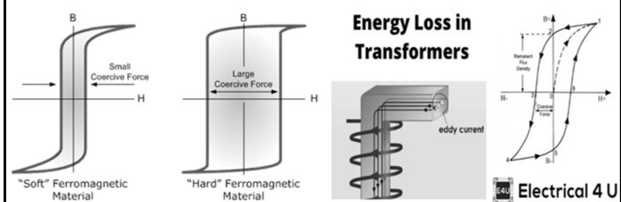
Expt. 4: Tests on 1Φ Transformer

- **Hysteresis loss:**
- The lag or delay of a magnetic material known commonly as **Magnetic Hysteresis**, relates to the magnetization properties of a material by which it firstly becomes magnetized and then demagnetized.
-



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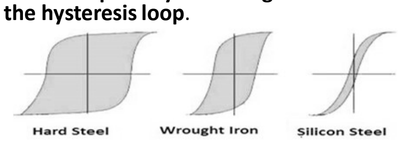
Expt. 4: Tests on 1Φ Transformer

Hysteresis loss, $\mathbf{P_h = \dot{\eta} B_{max}^{1.6} f V}$ **watts,**

- Where B_{max} = maximum flux density in Tesla,
- f = frequency of magnetic reversal in Hz,
- = NP/120 where N is in r.p.m,
- V = volume of the core material in m^3
- $\dot{\eta}$ = Steinmetz hysteresis coefficient.
- It can be proved that **the energy lost per unit volume of material in a complete cycle of magnetization is equal to the area of the hysteresis loop**.



Hysteresis Loops

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Expt. 4: Tests on 1Φ Transformer

Hysteresis loss, $\mathbf{P_h = \dot{\eta} B_{max}^{1.6} f V}$ **watts,**

- Where B_{max} = maximum flux density in Tesla,
- f = frequency of magnetic reversal in Hz,
- = NP/120 where N is in r.p.m,
- V = volume of the core material in m^3
- $\dot{\eta}$ = Steinmetz hysteresis coefficient.
- It can be proved that **the energy lost per unit volume of material in a complete cycle of magnetization is equal to the area of the hysteresis loop**.

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Expt. 4: Tests on 1Φ Transformer

TABLE I
CHARACTERISTICS OF ELECTRICAL STEEL SHEETS

Material	50A1300	50A470	20RMHF1200
Grade	Low	Middle	High
Thickness h (mm)	0.5	0.5	0.2
Conductivity σ (S/m)	7.14×10^6	2.56×10^6	1.96×10^6
K_e	3.10×10^{-4}	1.10×10^{-4}	3.04×10^{-5}
K_h	6.01×10^{-2}	2.71×10^{-2}	1.53×10^{-2}
κ	0.82	0.96	1.94

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https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5512834

Expt. 4: Tests on 1Φ Transformer

TABLE IV
SPECIFICATIONS OF IRON CORE (M47)

Parameter	Value	Description
K_h	273.2	Hysteresis loss factor
K_e	0.4786	Eddy current loss factor
d_t	0.65 mm	Lamination thickness
ρ_{fe}	390 nΩm	Resistivity
α	1.2558	MSE constant
β	1.685	MSE constant

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https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6584731

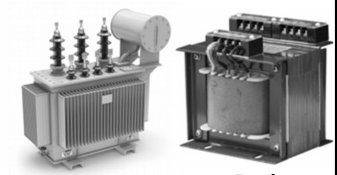
EES51: Electrical Technology Lab

Tittle: To perform the open circuit test and short circuit test on a single-phase transformer

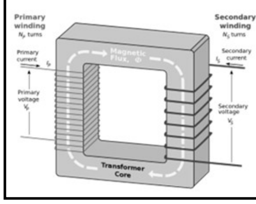
Expt. 4: Tests on 1Φ Transformer

What is a Transformer?

Transformers are static electrical machines which are used to transfer the alternating electrical power from one circuit to an another circuit with a required change in the voltage and current levels keeping the power and frequency unchanged.



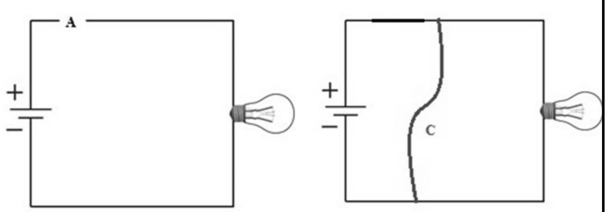
Transformer Transformer



Generally,

- **Voltage Changes**
- **Current Changes**
- **Frequency dose not change**
- **Power dose not change** (rather reduced due to losses)

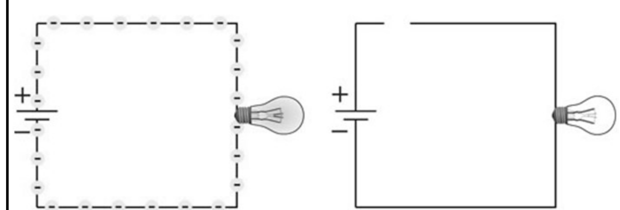
Expt. 4: Tests on 1Φ Transformer



open circuit Short Circuit

https://www.marinesite.info/2017/06/circuit-faults-open-circuit-short-circuit-Earth-Fault.html

Expt. 4: Tests on 1Φ Transformer



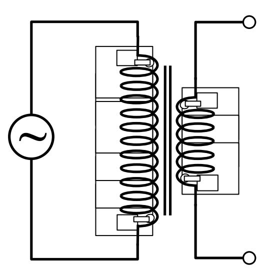
closed circuit open circuit

https://www.marinesite.info/2017/06/circuit-faults-open-circuit-short-circuit-Earth-Fault.html

Expt. 4: Tests on 1Φ Transformer

Transformer: Open and Short Circuit

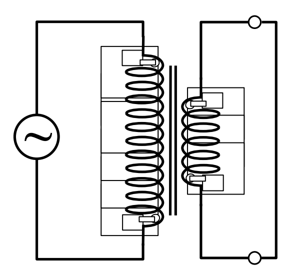
- **Transformer: Open circuit condition**
  - **Power will applied at the primary side.**
  - **No load will be connected.**
  - **No power will be taken from the secondary.**
  - **Input power = Losses of the transformer (Iron Losses).**



Expt. 4: Tests on 1Φ Transformer

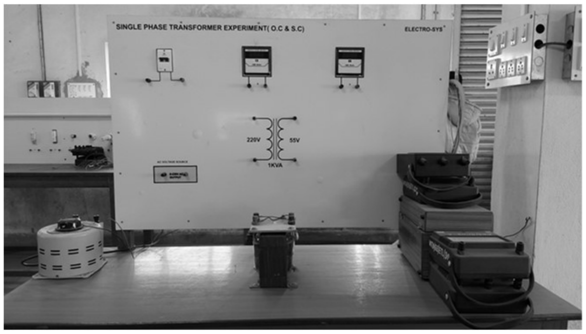
Transformer: Open and Short Circuit

- **Transformer: Short circuit condition**
  - **Power will applied at the primary side.**
  - **No load will be connected.**
  - **But the secondary terminal will be shorted.**
  - **No power will be taken from the secondary.**
  - **Input power = Losses of the transformer (Copper Losses).**



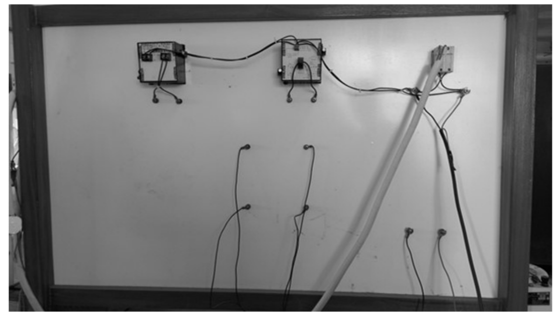
Expt. 4: Tests on 1Φ Transformer

- **Panel Board (Backside)**



Expt. 4: Tests on 1Φ Transformer

- **Panel Board (Backside)**

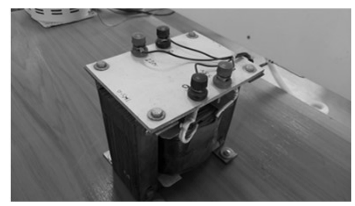


Expt. 4: Tests on 1Φ Transformer

- **Variac**

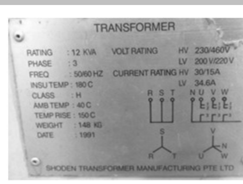
Expt. 4: Tests on 1Φ Transformer

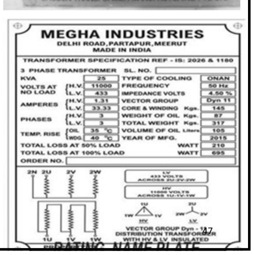
- **Variac**



Expt. 4: Tests on 1Φ Transformer

- **Transformer Ratings**
  - ➢**Rated Power (kVA)**
  - ➢**Rated Voltage (Volts)**
  - ➢**Rated Current (Amps)**
  - ➢**Rated Frequency (Hz)**





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Expt. 4: Tests on 1Φ Transformer

Transformer Used: 1 Φ Transformer

❑**Name Plate: 1 kVA, 55/230 V, 50 Hz 1 Φ Transformer…**

• **Rated Power**	**= 01 kVA = 1000 VA**
• **Rated Primary Voltage**	**= 55 V**
• **Rated Secondary Voltage**	**= 230 V**
• **Rated Primary Current**	**= 1000/55 A = 18.18 A**
• **Rated Secondary Current**	**= 1000/230 A = 4.35 A**
• **Rated Frequency**	**= 50 Hz**

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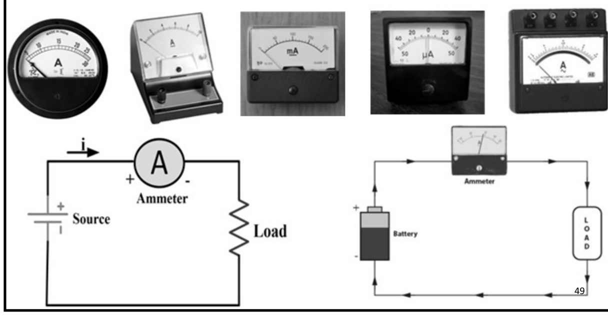
Expt. 4: Tests on 1Φ Transformer

Measuring Instruments: Ammeter

- Ammeter measures current
- Ammeter is connected in series



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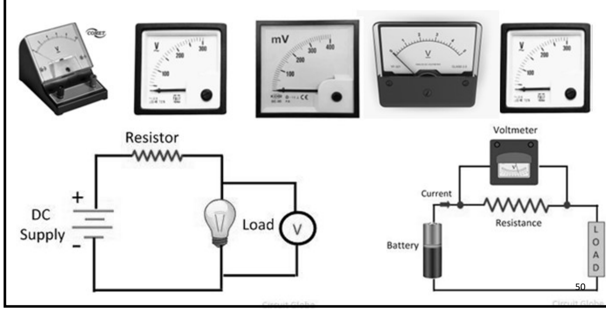
Expt. 4: Tests on 1Φ Transformer

Measuring Instruments: Voltmeter

- Voltmeter measures voltage
- Voltmeter is connected in parallel



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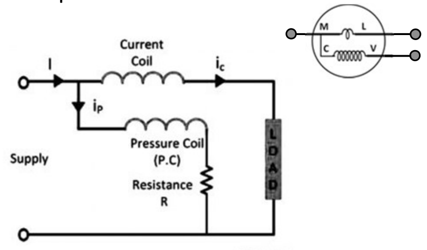
Expt. 4: Tests on 1Φ Transformer

Measuring Instruments: Wattmeter

- Wattmeter measures the power.
- Wattmeter is operated by connecting the current coil in series and pressure/voltage coil in parallel.



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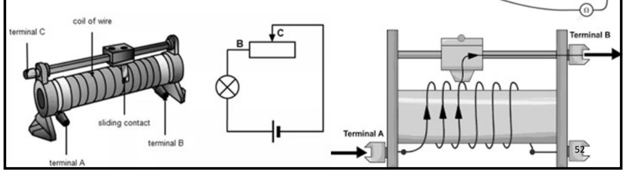
Expt. 4: Tests on 1Φ Transformer

Measuring Instruments: Rheostat

- Rheostat is a resistive load.
- Rheostat provides resistance of a required value (variable resistor)
- Rheostat is connected in series or parallel.



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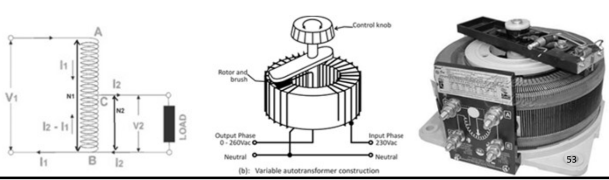
Expt. 4: Tests on 1Φ Transformer

Measuring Instruments: Auto Transformer

- Auto Transformer is used to obtain a required voltage value from a constant voltage supply.



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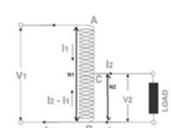
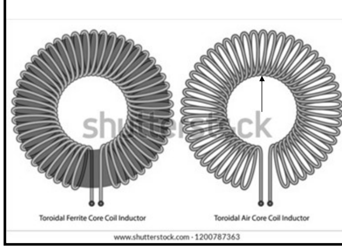
Expt. 4: Tests on 1Φ Transformer

Measuring Instruments: Auto Transformer

- Auto Transformer is used to obtain a required voltage value from a constant voltage supply.





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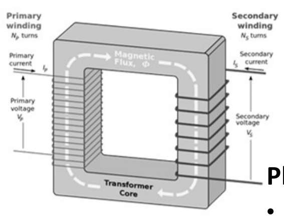
Expt. 4: Tests on 1Φ Transformer

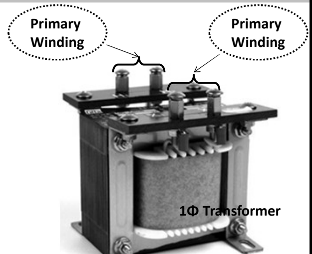
What are the tests?

Two tests are conducted:

- **Open Circuit Test (OCT)**
- **Short Circuit Test (SCT)**



1Φ Transformer with primary and secondary windings



Please remember

- **OCT: HV side is kept open**
- **SCT: LV side is short circuited**

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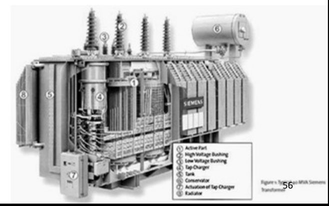
Expt. 4: Tests on 1Φ Transformer

- **Why OCT and SCT?**
- Open and short circuit tests are performed on a transformer to determine the:
  - **Losses and Efficiency of transformer**
  - **Equivalent circuit of transformer**
  - **Voltage regulation of transformer**



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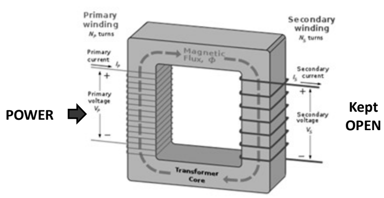
Expt. 4: Tests on 1Φ Transformer

- **PURPOSE OF OCT: To find the core loss or iron loss**
- The main purpose of this test are
  - **To find the iron loss**
  - **To calculate no load current**
  - **To calculate the core loss resistance (R_0)**
  - **To calculate the magnetizing reactance (X_0).**
- In O.C. test LV winding is connected to a.c. supply, keeping HV open (though the reverse is also possible).



- Note: Sometimes a voltmeter may be connected across secondary as voltmeter resistance is very high & voltmeter current is negligibly small so that secondary is treated as open circuit.

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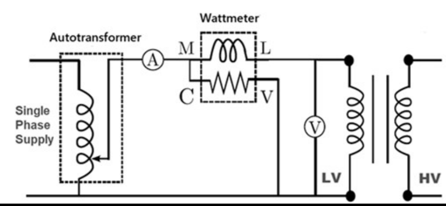
Expt. 4: Tests on 1Φ Transformer

- **Open Circuit Test on Transformer**
- The connection diagram for **open circuit test on transformer** is shown in the figure.
- A voltmeter, wattmeter, and an ammeter are connected in LV side of the transformer as shown.
- The voltage at rated frequency is applied to that LV side with the help of a variac of variable ratio auto transformer.



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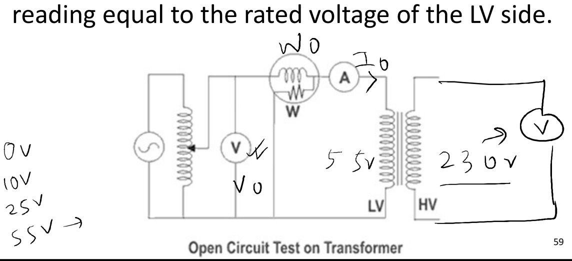
Expt. 4: Tests on 1Φ Transformer

- **Open Circuit Test on Transformer**
- With the help of variac, applied voltage gets slowly increased in different steps and the voltage (V_o) current (I_o) and power (W_o) until the voltmeter gives reading equal to the rated voltage of the LV side.



Open Circuit Test on Transformer

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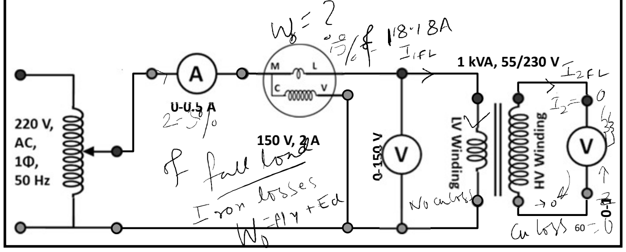
Expt. 4: Tests on 1Φ Transformer

CIRCUIT CONNECTION

- **Open Circuit Test: HV Winding is kept Open Circuited.**
- Take the transformer and keep the HV side open.
- Connect primary winding with the output from a variac.
- Connect Ammeter, Voltmeter and Wattmeter as shown.



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Expt. 4: Tests on 1Φ Transformer

OCT Test Procedure: Step by Step

- 1) Connect the circuit as shown in circuit diagram.
- 2) Switch on the supply after checking connection by concerned teacher.
- 3) Increases the input voltage the to the transformer winding up to **rated value (230V) slowly using dimmer stat**.
- 4) Measure the primary voltage, primary current, primary circuit power and secondary voltage of transformer.
- 5) Reduce the voltage slowly using Variac.
- 6) Switch off the supply and remove connections.

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Expt. 4: Tests on 1Φ Transformer

- **OCT: Important Observations**
- Ammeter gives the reading of the no load current (I_o).
- Transformer no load current is always very small, 2 to 5 % of its full load current.
- $I_1 = I_o$ is very low hence copper losses on primary are also very low.
- As secondary (HV winding) is open, ie, $I_2 = 0$, hence secondary copper losses are zero.
- Thus the total copper losses in O.C. test are negligibly small, hence neglected (**No Copper Loss in OCT**).
- **Therefore the wattmeter reading in O.C. test gives iron losses (which remain constant for all the loads).**

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Expt. 4: Tests on 1Φ Transformer

- **OCT Equivalent Circuit: No-Load Condition**
- Equivalent Circuit:

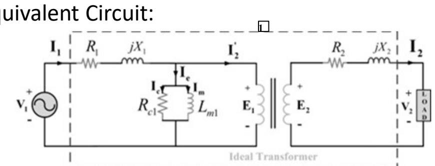

Fig. 1

- Equivalent Circuit (Referred to primary):

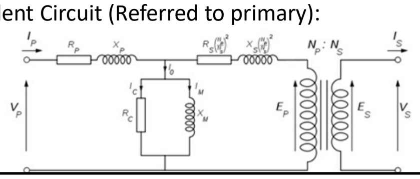

Fig. 2

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Expt. 4: Tests on 1Φ Transformer

- **OCT Equivalent Circuit: No-Load Condition**
- No-Load current is 2-5% of the full load current
- As no load current I_0 is quite small compared to rated current of the transformer, the voltage drops due to this current that can be taken as negligible.

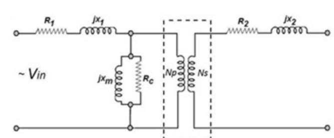

Fig. 1

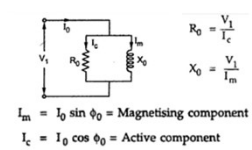

Fig. 2

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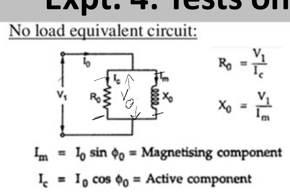
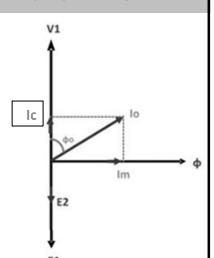
Expt. 4: Tests on 1Φ Transformer





- Now we know W_o, V_o and I_o

$$W_o = V_o I_o \cos\Phi_o \quad \text{Or} \quad \cos\Phi_o = \frac{W_o}{V_o I_o}$$

Now, $I_c = I_o \cos\Phi_o$ and $I_m = I_o \sin\Phi_o$

Thus, $R_c = R_o = \frac{V_o}{I_c}$ and $X_m = X_o = \frac{V_o}{I_m}$

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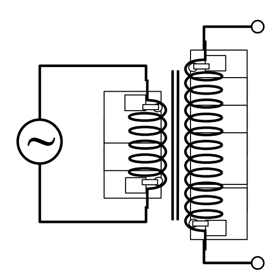
Expt. 4: Tests on 1Φ Transformer

Transformer: Open and Short Circuit

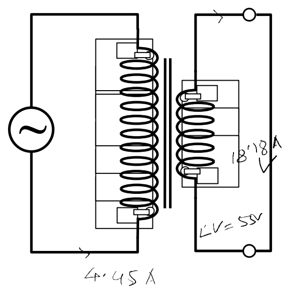
- **Transformer: Open circuit condition**
  - **Power will applied at the primary side.**
  - **No load will be connected.**
  - **No power will be taken from the secondary.**
  - **Input power = Losses of the transformer (Iron Losses).**



Expt. 4: Tests on 1Φ Transformer

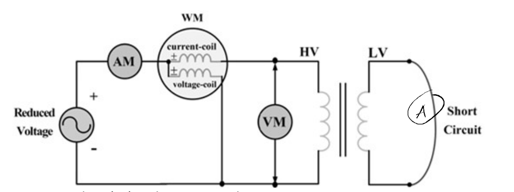
Transformer: Open and Short Circuit

- **Transformer: Short circuit condition**
  - **Power will applied at the primary side.**
  - **No load will be connected.**
  - **But the secondary terminal will be shorted.**
  - **No power will be taken from the secondary.**
  - **Input power = Losses of the transformer (Copper Losses).**



Expt. 4: Tests on 1Φ Transformer

- **Short Circuit Test on Transformer**
- The main purpose of this test is
  - to find full load copper loss
  - winding parameters (R_{eq} & X_{eq})



- In this test, secondary (LV) is short circuited.
- As secondary is shorted, on rated primary voltage it draws a large amount of current.
- Such large current can cause overheating and burning of the transformer.

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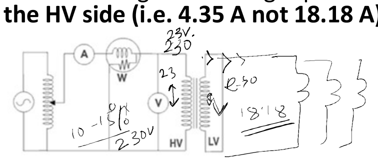
Expt. 4: Tests on 1Φ Transformer

- **SCT on Transformer**
- Power is supplied to the HV side with LV side shorted.
- Voltmeter, ammeter and wattmeter are connected in HV side.
- A low voltage (10-15% of rated voltage) is applied to the HV (primary in this condition) side.
- Now with the help of variac applied voltage is slowly increased until the ammeter gives reading equal to the **rated current of the HV side (i.e. 4.35 A not 18.18 A)**.



Short Circuit Test on Transformer

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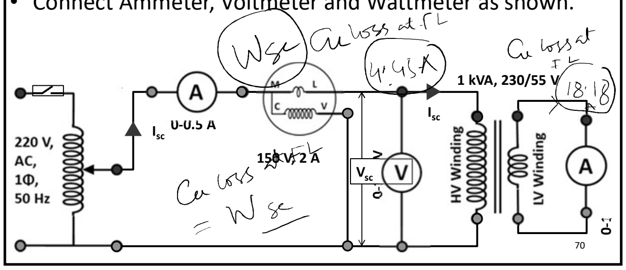
Expt. 4: Tests on 1Φ Transformer

CIRCUIT CONNECTION

- **Short Circuit Test: Low Voltage Winding is Short Circuited**
- Take the transformer and keep the LV side short circuited.
- Connect the variac output to the primary winding (HV) .
- Connect Ammeter, Voltmeter and Wattmeter as shown.



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Expt. 4: Tests on 1Φ Transformer

- **SCT on Transformer: Procedures**
- **Procedure: S.C. test:**
- 1) Connect the circuit as shown in circuit diagram.
- 2) Switch on the supply after checking connection by concerned teacher.
- 3) **Increases the input voltage very carefully and slowly using dimmer stat so that the current in secondary winding reaches rated value.**
- 4) The readings of the Voltmeter (V_{sc}), Ammeter (I_{sc}) and Watt-meter (W_{sc}) are noted.
- 5) Reduce the voltage slowly using dimmer stat.
- 6) Switch off the supply and remove connections.

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Expt. 4: Tests on 1Φ Transformer

- **SCT on Transformer: Observations**
- To limit this short circuit current, primary is supplied with low/reduced voltage (10 – 15 % of the rated voltage) which is just enough to cause rated current to flow through primary which can be observed on an ammeter.
- **As the applied voltage is low the iron loss will be low and neglected.**
- **Since the currents flowing through the windings are rated currents hence the wattmeter reading is the power loss which is equal to full load copper losses.**

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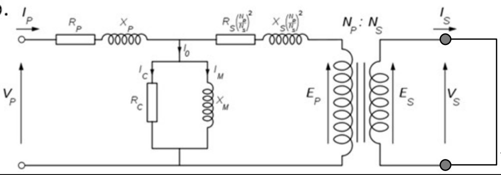
Expt. 4: Tests on 1Φ Transformer

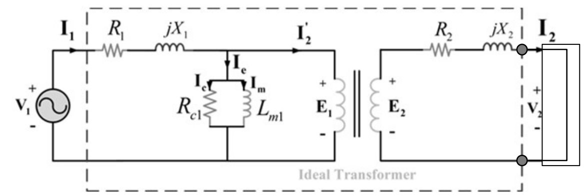
SCT on Transformer: Equivalent Circuit

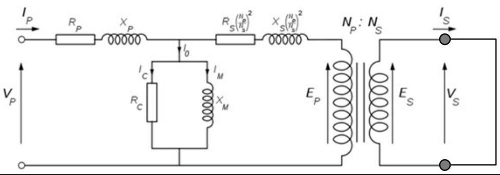
- SCT data is also used to obtain the parameters to approximate the equivalent circuit of a transformer.
- These values are referred to the HV side of the transformer as the test is conducted on the HV side of the transformer.
- These values could easily be converted to the LV side by dividing these values with the square of transformation ratio.



Expt. 4: Tests on 1Φ Transformer

SCT on Transformer: Equivalent Circuit





Expt. 4: Tests on 1Φ Transformer

SCT on Transformer: Equivalent Circuit

- As the core loss is negligible in the SCT, the equivalent circuit reduces to:

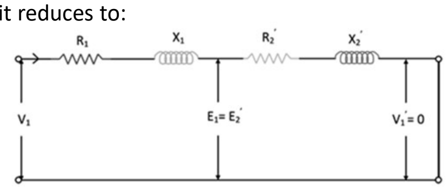
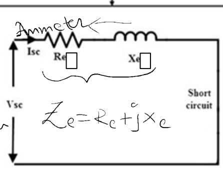


Fig. 1



I_{sc} Z_e

V_{sc}

$V_s = I_{sc} Z_e$

VoH meter

$Z_e = R_e + jX_e$

$Z_e = \sqrt{R_e^2 + X_e^2}$

Fig. 2

$V_{sc} = I_{sc} Z_e$

$Z_e = \frac{V_{sc}}{I_{sc}}$

Expt. 4: Tests on 1Φ Transformer

SCT on Transformer: Calculations

- In SCT, the wattmeter reading can be taken as equal to copper losses in the transformer. Let us consider wattmeter reading is W_{sc}.

$$W_{sc} = R_e I_{sc}^2$$

- Where, R_e is equivalent resistance of transformer.
- If, Z_e is equivalent impedance of transformer.

$$Z_e = \frac{V_{sc}}{I_{sc}}$$

- Therefore, if equivalent reactance of transformer is X_e.

$$X_e = \sqrt{Z_e^2 - R_e^2}$$

Expt. 4: Tests on 1Φ Transformer

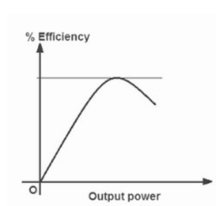
- **Calculation of Efficiency**

What is the Efficiency of Transformer?

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{\text{output power}}{\text{output power + losses}}$$

$$\eta = \frac{\text{output power}}{\text{output power + iron losses + copper losses}}$$

$$\eta = \frac{V_2 I_2 \cos\varphi_2}{V_2 I_2 \cos\varphi_2 + P_i + P_c}$$



Output power versus efficiency

$$\text{\% efficiency} = \frac{kVA\ rating \times 10^3 \times p.f.}{kVA\ rating \times 10^3 \times p.f. + W_{cu+W_i}} \times 100$$

Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation**
- The **voltage regulation** of the **transformer** is the percentage change in the output **voltage** from no-load to full-load.
- **Voltage regulation is represented as a fraction of either no-load or full load voltage**.
- Since power factor is a determining factor in the secondary **voltage**, power factor influences **voltage regulation**.

$$VR = \frac{\text{No-Load Voltage - Full Load Voltage}}{\text{No-Load Voltage}} \times 100\% \quad \text{Or,} \quad \boxed{VR = \frac{E_2 - V_2}{E_2} \times 100\%} \quad \text{VR-Down}$$

$$VR = \frac{\text{No-Load Voltage - Full Load Voltage}}{\text{Full-Load Voltage}} \times 100\% \quad \text{Or,} \quad VR = \frac{E_2 - V_2}{V_2} \times 100\% \quad \text{VR-Up}$$

Expt. 4: Tests on 1Φ Transformer

EXPERIMENTAL RESULTS:

Table-I: **For O.C. test:**

Sl. No	Primary Voltage (V_1)	No-load current (I_0)	Secondary voltage (V_2)	Wattmeter reading (W_{sc})
1.				
2.				
3.				
4.				
5.				

Table-II: **For S.C. test:**

Sl. No	Primary Voltage (V_{sc})	Primary current (I_{sc})	Wattmeter reading (W_{sc})
1.			
2.			
3.			
4.			
5.			

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Expt. 4: Tests on 1Φ Transformer

APPARATUS USED:

SL. No	Equipment	Specification	Makers	Quantity
1.	Auto Transformer			
2.	Ammeter			
3.	Volt Meter			
4.	Watt Meter			
5.				
6.				
7.				

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Expt. 4: Tests on 1Φ Transformer

- **Report:**
- Calculate the equivalent circuit parameters and draw that circuit.
- Calculate efficiency of the transformer.
- **Precautions:**
- On short circuit test the supply voltage should be applied through an autotransformer and increased very slowly from its zero value, so that rated current flows through the circuit.
- Current should not exceed rated value otherwise damage may occur.
- The short circuiting copper wire should be of a larger cross section then that used in transformer winding and all connections must be clean and tight.

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Expt. 4: Tests on 1Φ Transformer

- **Questions:**
- State the losses occurring in a transformer at no-load and on what these depend.
- If a transformer rated for 50 c/s is worked on 60 c/s will the losses increase or decrease for the same applied voltage.
- What materials are used for construction of core?
- What are the different types of core sections used for transformer construction?
- Why the core is laminated in a transformer?
- A transformer is rated 3 KVA, 230/110-V, 50 HZ. What will be the effect on its magnetizing current, if it is now connected to 230-V, 25 HZ supply voltage?
- What is the purpose of short-circuit test on a transformer/
- Why it is necessary to apply low voltage to one side of the transformer when performed short-circuit test?
- Why iron- losses are not considered in short- circuit calculation?

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Expt. 4: Tests on 1Φ Transformer

ısformer Components?

sformers are static electrical ıines which are used to transfer ılternating electrical power from circuit to an another circuit with ıuired change in the voltage and ent levels keeping the power frequency unchanged.

Cooling, Monitoring, Safety
- **Oil**
- **Radiator**
- **Conservator tank**
- **Breather**
- **Bukholz Relay**

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Expt. 4: Tests on 1Φ Transformer

Annexure I

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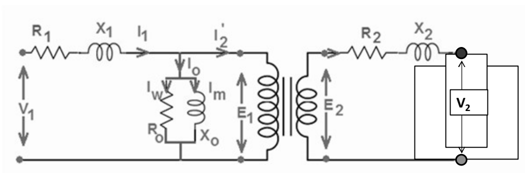
Expt. 4: Tests on 1Φ Transformer

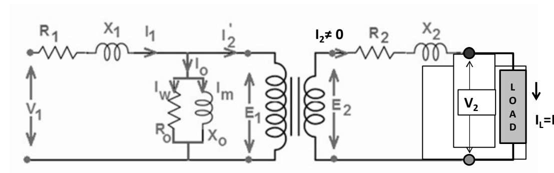
- **Why Voltage Regulation is Important?**
- **Equivalent Circuit at No-Load**
- As there is no current through secondary ($I_2 = 0$), there will be no drop across R_2 and X_2.
- At no-load condition the output voltage V_2 is equal to E_2.



Equivalent circuit of transformer

Expt. 4: Tests on 1Φ Transformer

- **Why Voltage Regulation is Important?**
- **Equivalent Circuit at Load**
- As soon as the load is connected across the secondary, I_L starts flowing through the load which is equal to I_2.
- Due to I_2, R_2 and X_2 will develop certain amount of voltage drops across them.
- At load conditions, the output voltage V_2 is less than E_2.
- With the increase in load, V_2 will decrease.



Equivalent circuit of transformer

Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation Calculation**
- Therefore, the voltage will be varied at the output with load and other conditions.
- Thus, the concept of voltage regulation came.
- The **voltage regulation** formula can be derived from the equivalent circuit and the associated phasor diagram:

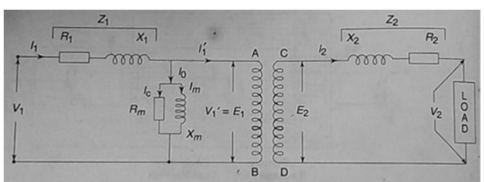


Fig. 3.24 Equivalent circuit of a transformer

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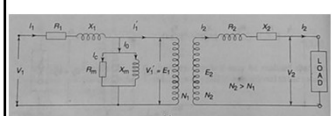
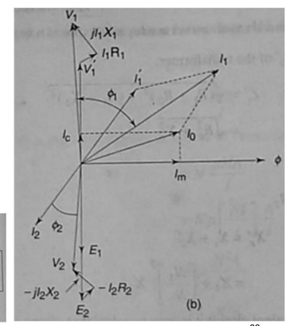
Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation Calculation**
- The phasor diagram of the transformer on load is:
- $N_2 > N_1$
- $E_2 > E_1$
- $V_2 > V_1$
- $I_2 < I_1$
- $V'_1 = E_1$
- $V_2 = E_2 - I_2(R_2 + jX_2)$





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Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation Calculation**
- As the no-load current is very low the equivalent circuit can be approximated as:

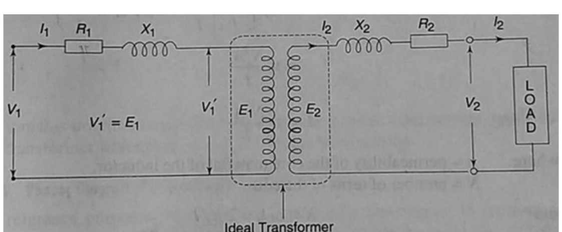

Fig. 3.25 Approximate equivalent circuit of a transformer

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Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation Calculation**
- Approximated equivalent circuit referred to the primary side is as follows:

$$Z'_e = R'_e + X'_e$$

$$R'_e = R_1 + R'_2$$

$$X'_e = X_1 + X'_2$$

$$X'_2 = \left(\frac{N_1}{N_2}\right)^2 X_2$$

$$R'_2 = \left(\frac{N_1}{N_2}\right)^2 R_2$$

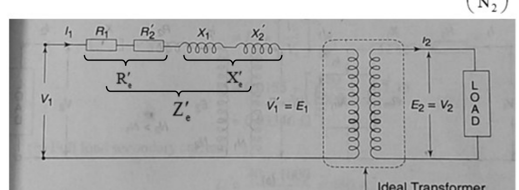

Fig. 3.26 Approximate equivalent circuit of a transformer with secondary quantities referred to the primary side

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Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation Calculation**
- Approximated equivalent circuit referred to primary side:

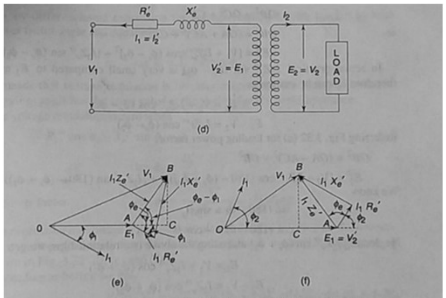

Fig. 3.32 (d) approximate equivalent circuit referred to primary side (e) corresponding phasor diagram for lagging power factor (f) corresponding phasor diagram for leading power factor

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Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation Calculation**
- Approximated equivalent circuit referred to secondary side:

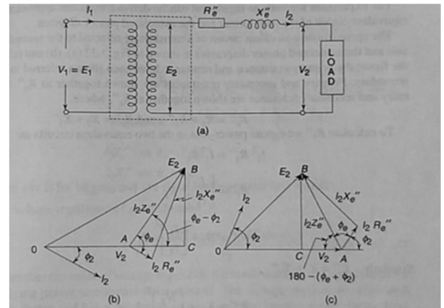

Fig. 3.32 (a) Approximate equivalent circuit referred to secondary side (b) phasor diagram for lagging power factor (c) corresponding phasor diagram for leading power factor

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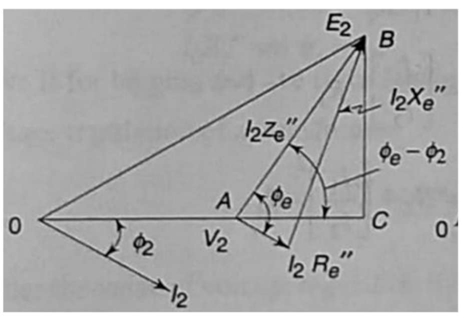
Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation Calculation**
- Phasor diagram for lagging power factor



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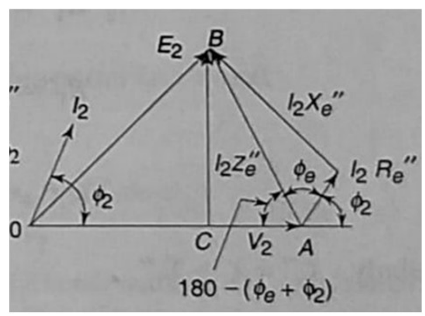
Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation Calculation**
- Phasor diagram for leading power factor



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Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation Calculation**
- Now, from the equivalent circuit we can get,

$$Z''_e = R''_e + X''_e \qquad R''_e = R_2 + R''_1 \qquad R''_1 = \left(\frac{N_2}{N_1}\right)^2 R_1$$

$$X''_e = X_2 + X''_1 \qquad X''_1 = \left(\frac{N_2}{N_1}\right)^2 X_1$$

- Now, from the phasor diagram we can get,

$$\boxed{\text{Regulation} = \frac{E_2 - V_2}{E_2} = \frac{I_2 Z''_e \cos(\Phi_e \mp \Phi_2)}{V_2} \times 100\%}$$

$$\boxed{\text{Regulation} = \frac{I_2\left(R''_e \cos\Phi_2 \pm X''_e \sin\Phi_2\right)}{V_2} \times 100\%}$$

- **Note:** + for lagging p.f. and – for leading p.f.

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Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation from SCT Data**
- Now, using the equivalent circuit obtained from SCT, we can write:

$$W_{sc} = (I_{2sc})^2 R''_e \text{ and } E_{2sc} = (I_{2sc}) Z''_e$$

Where, $E_{2sc} = \left(\frac{N_2}{N_1}\right) E_{1sc} = \left(\frac{N_2}{N_1}\right) V_{1sc}$

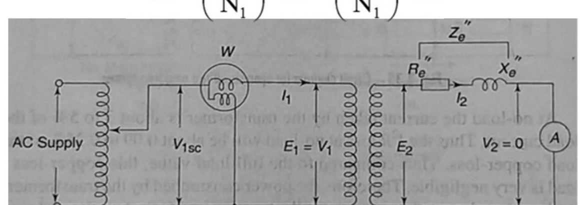

Fig. 3.37 Equivalent circuit of Fig. 3.36 with primary quantities referred to the secondary

Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation from SCT Data**
- Now, using the equivalent circuit we can get from SCT, we can write: $R''_e = \frac{W_{sc}}{(I_{2sc})^2}$ and $Z''_e = \frac{E_{2sc}}{I_{2sc}}$
- Thus, we have: $X''_e = \sqrt{(Z''_e)^2 - (R''_e)^2}$
- Now, from SCT, we can write: $W_{sc} = E_{2sc} I_{2sc} \cos\Phi_e$
- Thus, we have: $\cos\Phi_e = \frac{W_{sc}}{E_{2sc} I_{2sc}}$

$$\Phi_e = \cos^{-1}\left(\frac{W_{sc}}{E_{2sc} I_{2sc}}\right)$$

Expt. 4: Tests on 1Φ Transformer

- **Voltage Regulation from SCT Data**
- Now, if the secondary quantities are referred to the primary, then, from SCT, we can write:

$$W_{sc} = V_{1sc} I_1 \cos\Phi_e$$

- Thus, we have: $\cos\Phi_e = \frac{W_{sc}}{V_{1sc} I_1}$ Or, $\Phi_e = \cos^{-1}\left(\frac{W_{sc}}{V_{1sc} I_1}\right)$

$$\boxed{\text{Regulation} = \frac{E_2 - V_2}{E_2} = \frac{I_2 Z''_e \cos(\Phi_e - \Phi_2)}{V_2} \times 100\%}$$

$$\boxed{\text{Regulation} = \frac{E_2 - V_2}{E_2} = \frac{V_{1sc} \cos(\Phi_e - \Phi_2)}{V'_2} \times 100\%}$$

Expt. 4: Tests on 1Φ Transformer

- **Example 01:**
- A 15 kVA, 2200/220 V, 1Φ transformer gave the following test data: OCT: V_0: 220 V, I_0: 2.72 A, W_0 = 185 Watt

  SCT: V_{sc}: 112 V, I_{sc}: 6.3 A, W_{sc} = 197 Watt
- Calculate the (a) core loss, (b) full load copper loss, (c) full load efficiency at 0.85 lagging power factor, and (d) the voltage regulation at 0.8 lagging and leading power factor.
- **Answer:**
- (a) The core loss is given by: 185 W
- (b) I_2(FL) = I_{HV}(FL) is given by

$$I_{HV}(FL) = I_2(FL) = \frac{kVA}{V_2} = \frac{15000}{2200} A = 6.82\,A$$

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Expt. 4: Tests on 1Φ Transformer

- **Example 01:** SCT: V_{sc}: 112 V, I_{sc}: 6.3 A, W_{sc} = 197 Watt
- Therefore the full load copper loss will be given by:

$$W_{cu}(FL) = W_{sc} \times \left(\frac{I_{HV}(FL)}{I_{sc}}\right)^2 = 197 \times \left(\frac{6.82}{6.3}\right)^2 = 231\,W$$

- (c) The full efficiency at 0.85 lagging pf will be given by:

$$\eta = \frac{15 \times 10^3 \times 0.85}{(15 \times 10^3 \times 0.85) + 185 + 231} \times 100\% = 96.84\%$$

- (d) The equivalent parameters referred to secondary are:

$$Z''_e = \frac{V_{1sc}}{I_{1sc}} = \frac{112}{6.3} = 17.78\,\Omega \text{ and } R''_e = \frac{W_{sc}}{(I_{1sc})^2} = \frac{197}{(6.3)^2} = 4.96\,\Omega$$

- Thus, $X''_e = \sqrt{(17.78)^2 - (7.96)^2} = 17.07\,\Omega$

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Expt. 4: Tests on 1Φ Transformer

- **Example 01:**
- Now, $I_{HV}(FL) = I_2(FL) = I_{2Rated} = \frac{P_{Rated}}{V_2} = \frac{15 \times 10^3}{2200} = 6.82\,A$
- Now,

$$\text{Regulation} = \frac{I_2(FL) \times (R''_e \cos\Phi_2 \pm X''_e \sin\Phi_2)}{V_{2Rated}} \times 100\%$$

$$\text{Regulation} = \frac{6.82 \times ((4.96 \times 0.8) \pm (17.07 \times 0.6))}{2200} \times 100\%$$

$$\text{Regulation} = +4.41\% \text{ for lagging pf}$$

$$\text{Regulation} = -1.94\% \text{ for leading pf}$$

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Thank You

Please contact the concerned teachers for any further doubts.

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