ENERGY CONVERSION TECHNOLOGIES

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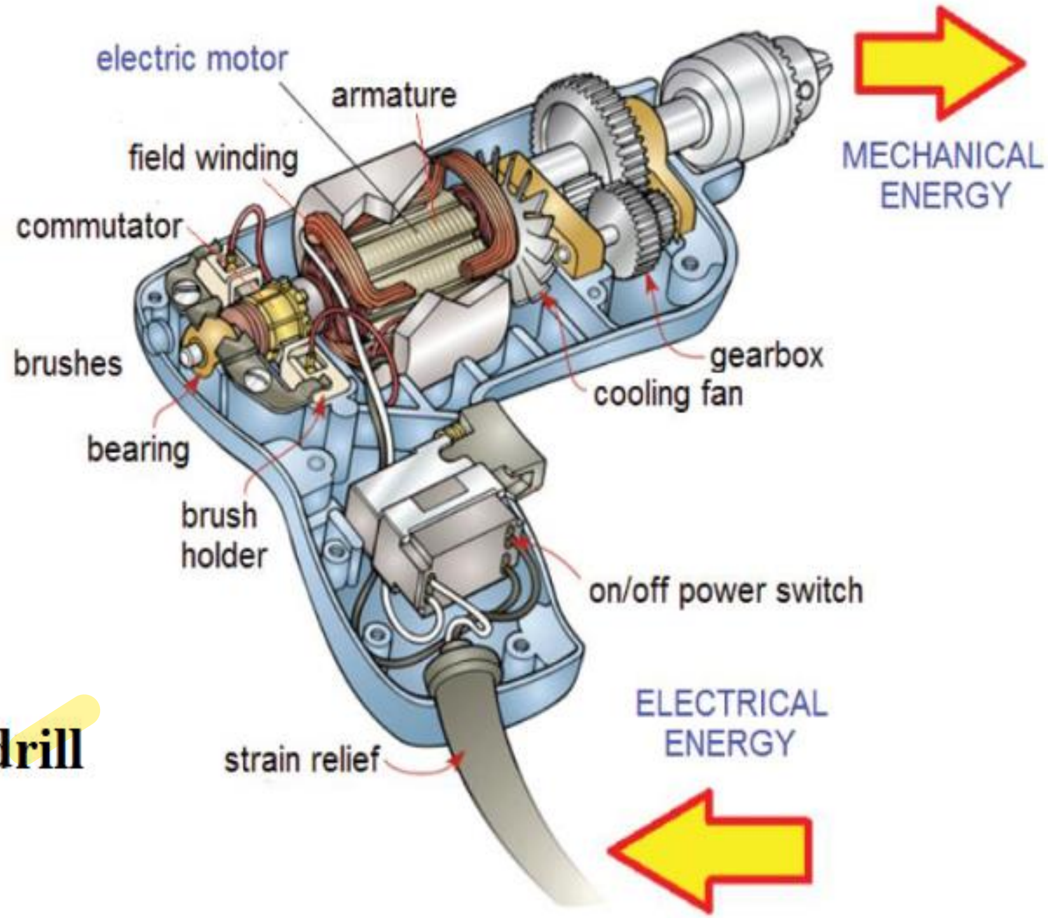
WHAT IS ELECTROMECHANICAL ENERGY CONVERSION?

- Electromechanical energy conversion is a **conversion of mechanical energy into electrical energy** (**generator**) or **vice-versa** (**motor**) with the aid of rotary **motion** (rotary machines) or translatory (linear) motion (linear machines and actuators)
- **Electrical machines** (e.g. motors & generators), solenoid actuators and electromagnets are generally called electromechanical energy conversion devices

Applications

- A television
- Light bulb
- Hair drier
- Transformer
- Single phase Induction motor
- Three phase induction motor
- Synchronous machines:
  - Constant speed, high torque
- Synchronous condenser: An over excited synchronous motor running at no load is called synchronous condenser or capacitor.

APPLICATIONS



Power tools
e.g. electrical drill

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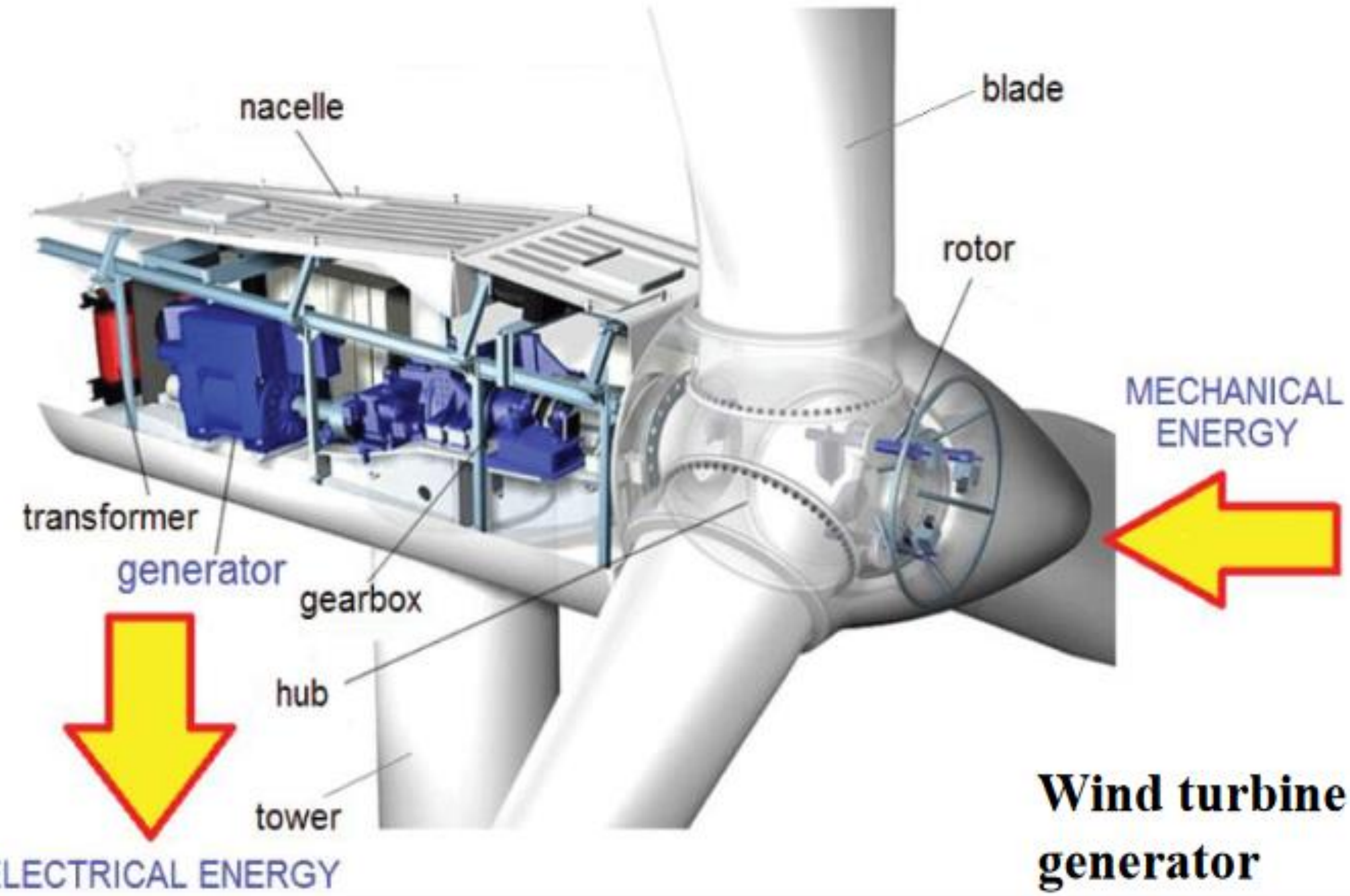
APPLICATIONS



Wind turbine generator

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APPLICATIONS

Generators convert mechanical energy into electrical energy

Turbo generator

Diesel generator

8

APPLICATIONS

Ceiling fan: converts input electrical energy into output mechanical energy

APPLICATIONS

Motors convert electrical energy into mechanical energy

DC motor

Induction (AC) motor

11

APPLICATIONS

Motors convert electrical energy into mechanical energy

BLDC motor (Brushless DC motor)

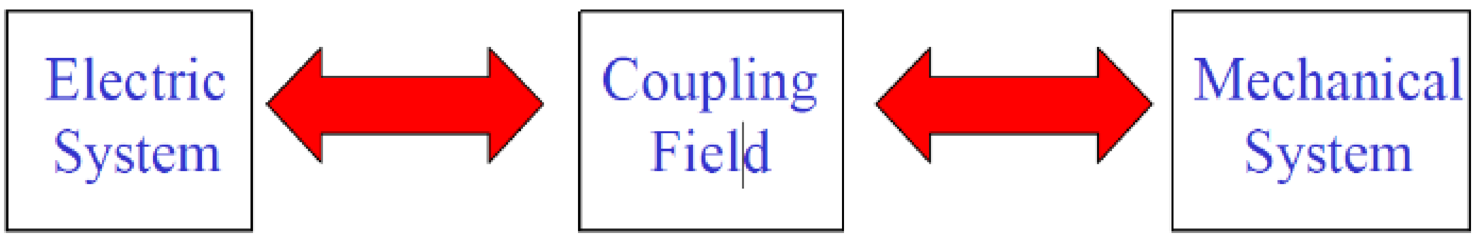
12 V DC motor (Multipurpose Brushed Motor)

Stepper motor

ENERGY CONVERSION PROCESS IN MACHINES

- An electromagnetic machine is one that links an electrical energy system to another (mechanical) energy system by providing a reversible means of energy flow via its magnetic field

- The **magnetic field** is therefore the **coupling** between the two systems and is the **mutual link** for **electro-mechanical energy conversion**



Magnetic field provides handshaking between electrical and mechanical system

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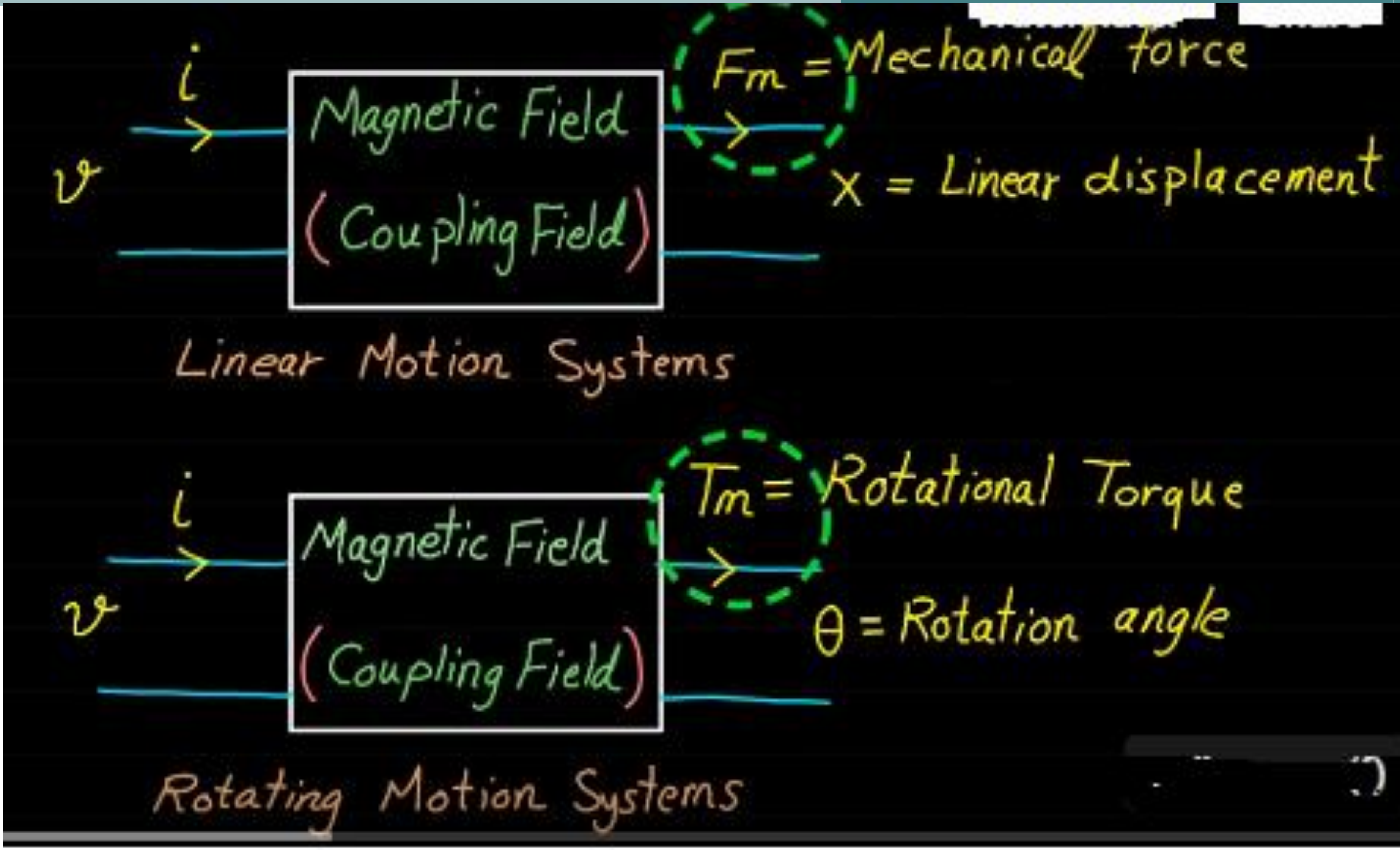
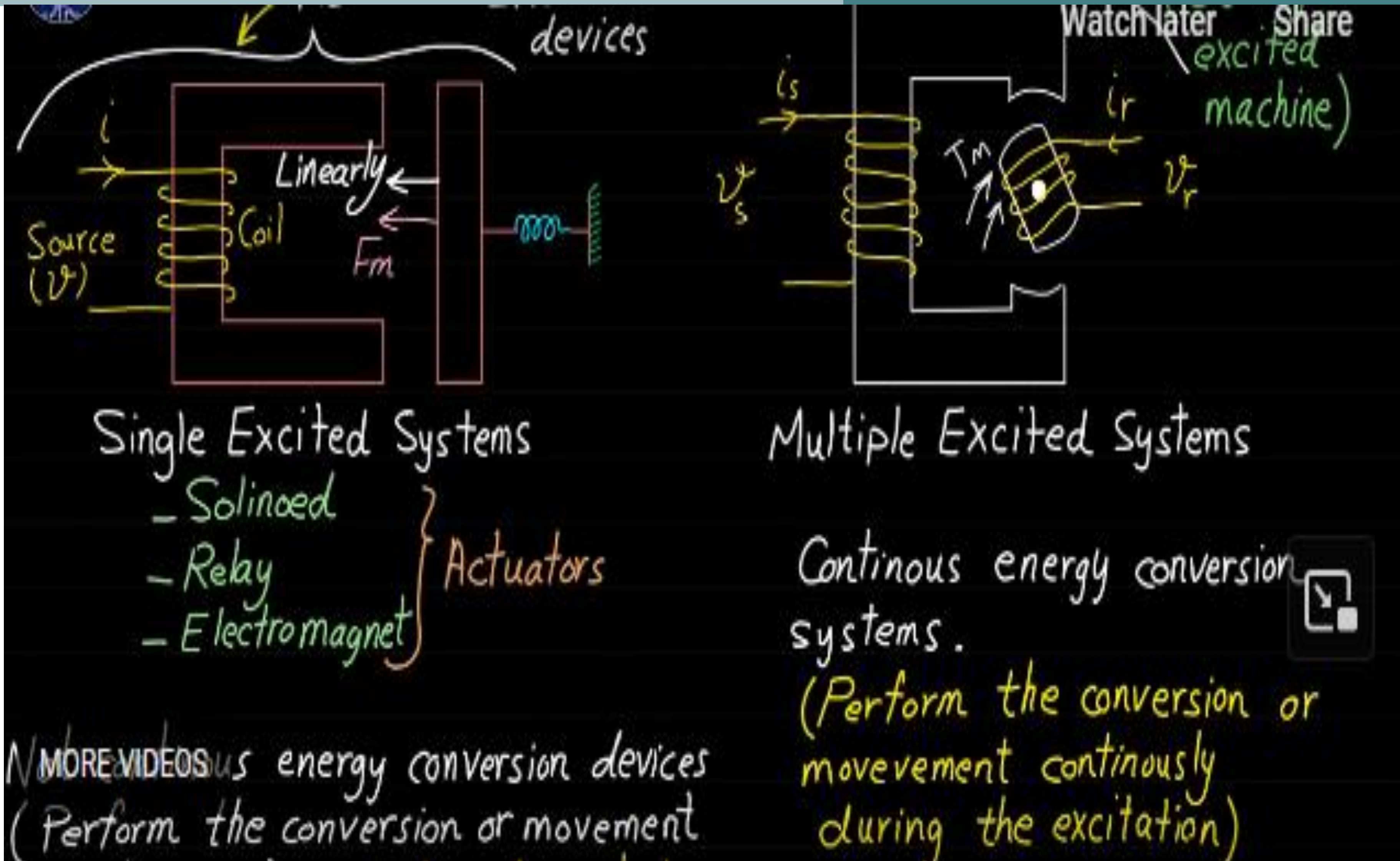
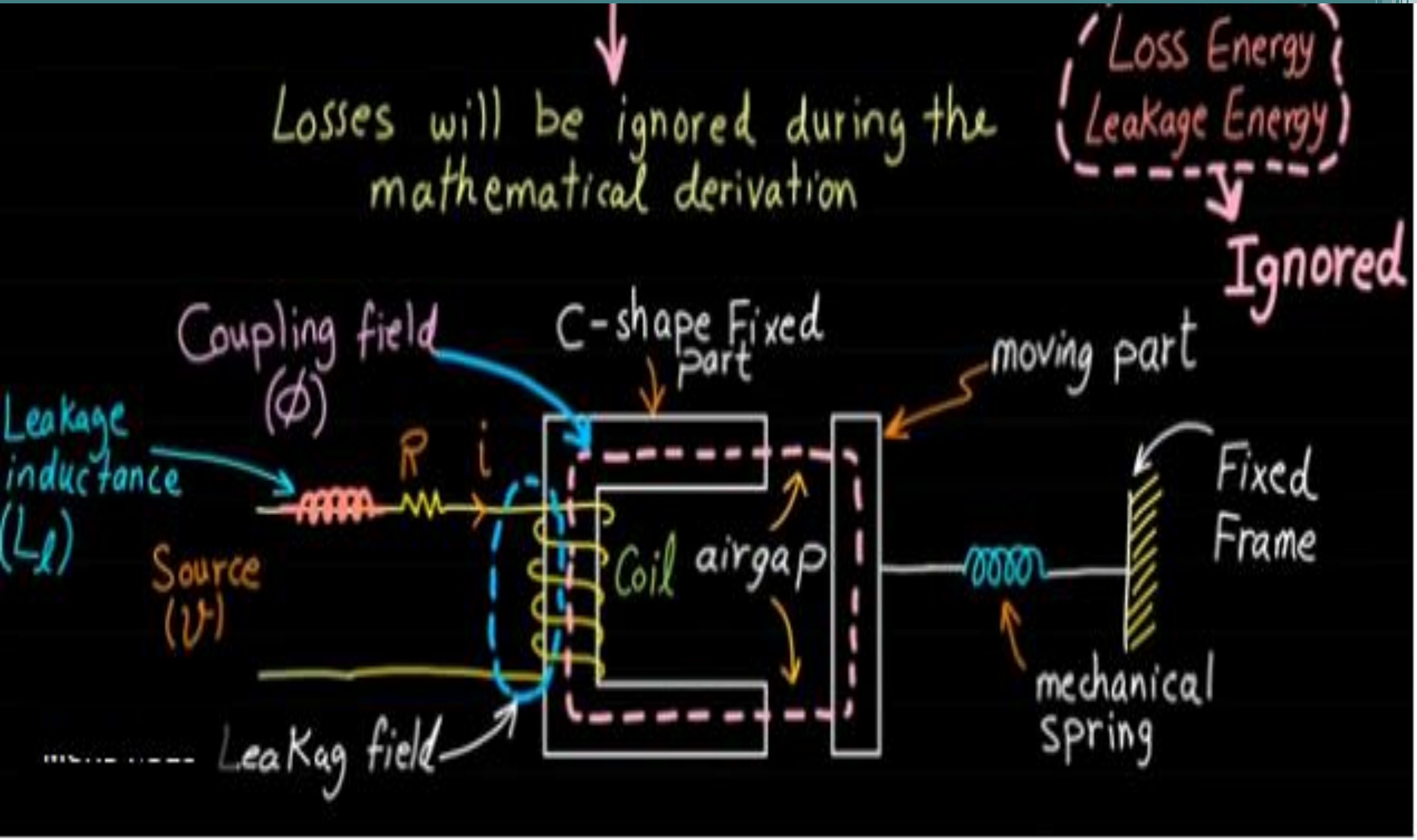


i
v
Magnetic Field
(Coupling Field)
Fm = Mechanical force
x = Linear displacement
Linear Motion Systems
i
v
Magnetic Field
(Coupling Field)
Tm = Rotational Torque
θ = Rotation angle
Rotating Motion Systems


devices
Watch later
Share
excited
machine)
i_s
i_r
i
Linearly
Coil
Source
(v)
Fm
v_s
T_m
v_r
Single Excited Systems
_ Solinoed
_ Relay
_ Electromagnet
Actuators
Multiple Excited Systems
Continous energy conversion
systems.
(Perform the conversion or
movement continously
during the excitation)
MORE VIDEOS
s energy conversion devices
(Perform the conversion or movement


Losses will be ignored during the mathematical derivation
Loss Energy
Leakage Energy
Ignored
Coupling field
(ϕ)
C-shape Fixed part
moving part
Leakage inductance
(L_ℓ)
R
i
Source
(v)
Coil
airgap
Fixed Frame
mechanical spring
Leakag field

Transformers

Transformers: Contents

- Introduction
- Construction:
  - Core type
  - Shell type
- Operating principle
- Types
- Equivalent circuit representation
- Losses and efficiency
- voltage regulation
- Auto-transformer
- Three-phase transformers
- Applications

Transformer

- Electromagnetic energy conversion device
- Windings are not connected electrically, but coupled magnetically.

  Types: Step-up, step-down, isolation transformers
- Step down transformer: Primary winding has more number of turns than secondary, results in higher voltage at primary side than secondary.
- step uo transformer- Same transformer can be used as step –up, where the primary winding becomes secondary and secondary winding becomes the primary winding.
- Weight of transformers:

  For electronics Equipment's: its weight is few tens of grams,

  where as for high voltage power circuits, its weight will be hundreds of tones.
- Efficiency of transformer is higher compared to all electrical machinery because it involves no moving parts.

Transformer

Important tasks performed by the transformer are:

1: For increasing or decreasing voltage or current levels from one circuit to another circuit in both low and high current circuits

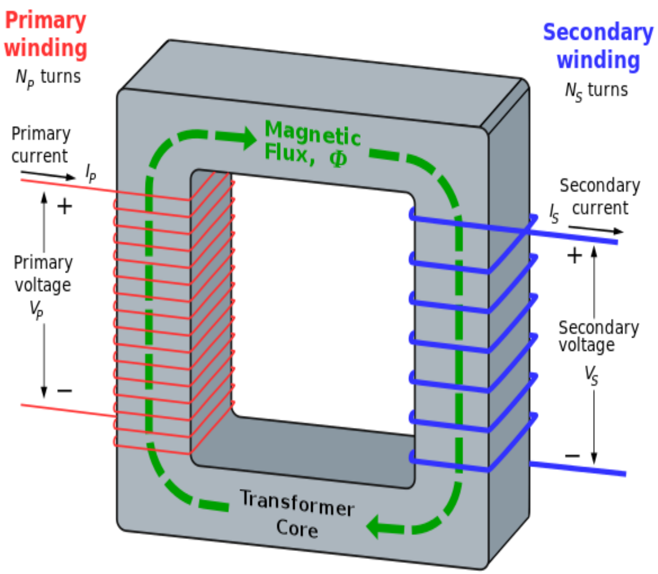
2: For matching the impedance of a source and its load for maximum power in case of electronic and control circuits.

3: Isolating D.C., while permitting only flow of A.C between the circuits

4: Isolating one circuit from another circuit

Introduction

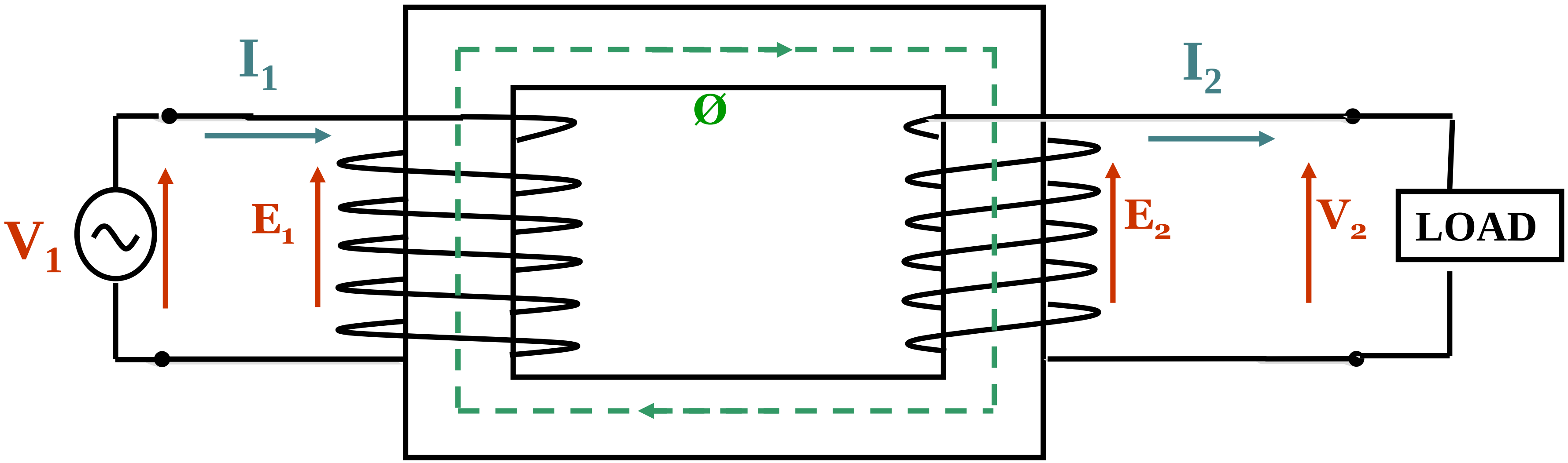
- Static device with AC excitation
- Transfers energy between two or more magnetically coupled circuits without change in frequency.
- Principle of operation: *Electromagnetic Induction*
- Electric circuits are linked by a common ferromagnetic core
- Ferromagnetic core ensures *maximum* magnetic flux linkage
- Applications:
  - Electric power systems
    - Power transmission, distribution networks
  - Electronic circuits
  - Electric traction



- Types

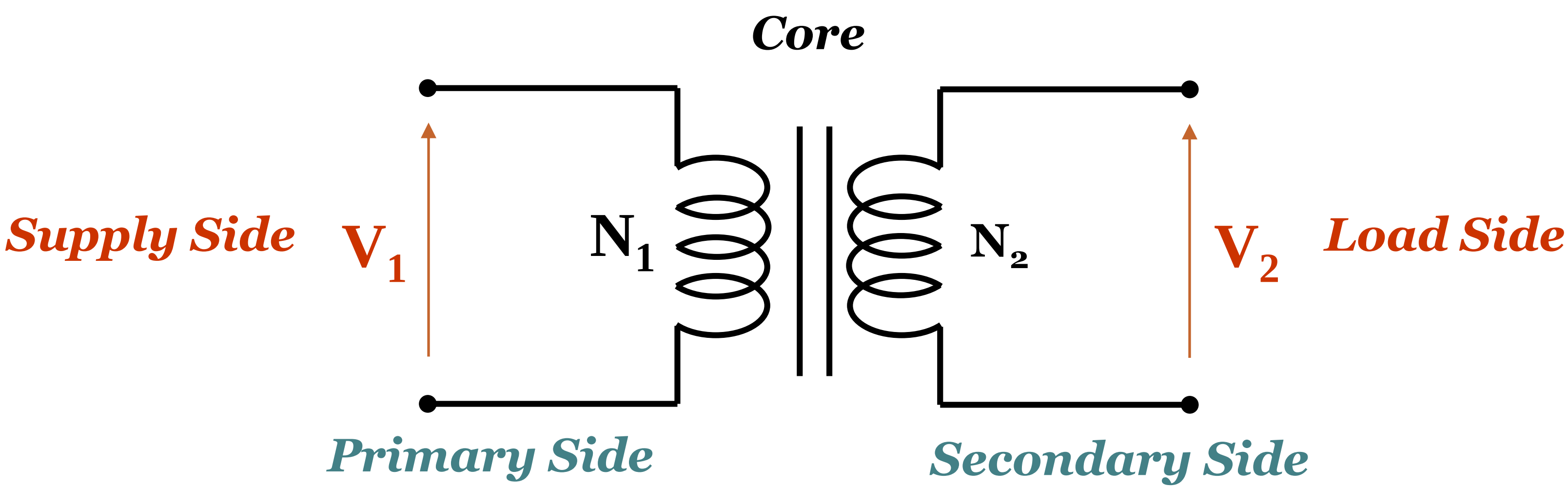
Based on Construction	*Based on Function*	*Based on Windings*
Core Type	Step Up	Single Winding
Shell Type	Step Down	2 or 3 Windings

Operation of Transformer



- Magnetic Core : Flux path
- Flux Linkages : Primary & Secondary
- Induced Emf :
    - Primary – Self Induced Emf
    - Secondary – Mutually Induced Emf

Representation



N_1 = Number of turns on primary
N_2 = Number of turns on secondary

Emf Equation of Transformer

Derive in the class.

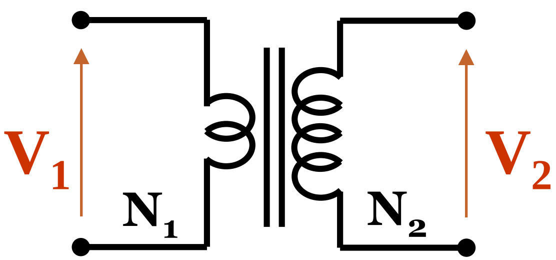
Emf Equation of Ideal Transformer…

$$\frac{V_1}{V_2} \cong \frac{E_1}{E_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2} = a = \textit{Turns Ratio}$$

where, $V_1 \& V_2$ *are the terminal voltages,*

$E_1 \& E_1$ *are the induced RMS voltages,*

$N_2 > N_1$: Step Up

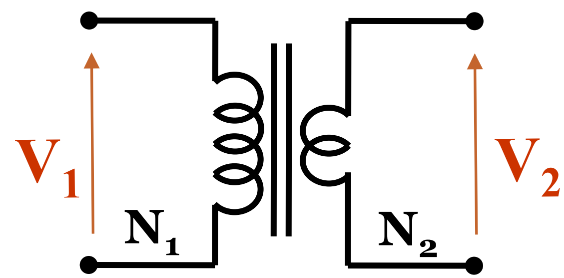


$E_2 > E_1$

$V_2 > V_1$

$I_1 > I_2$

$N_2 < N_1$: Step down



$E_2 < E_1$

$V_2 < V_1$

$I_1 < I_2$

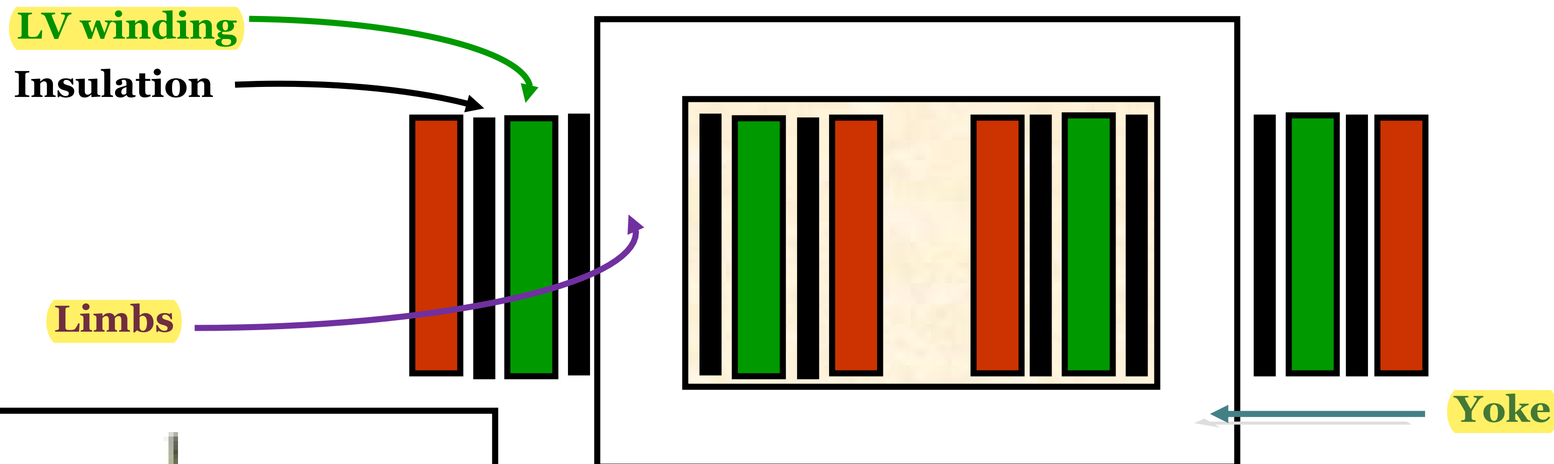
Transformer

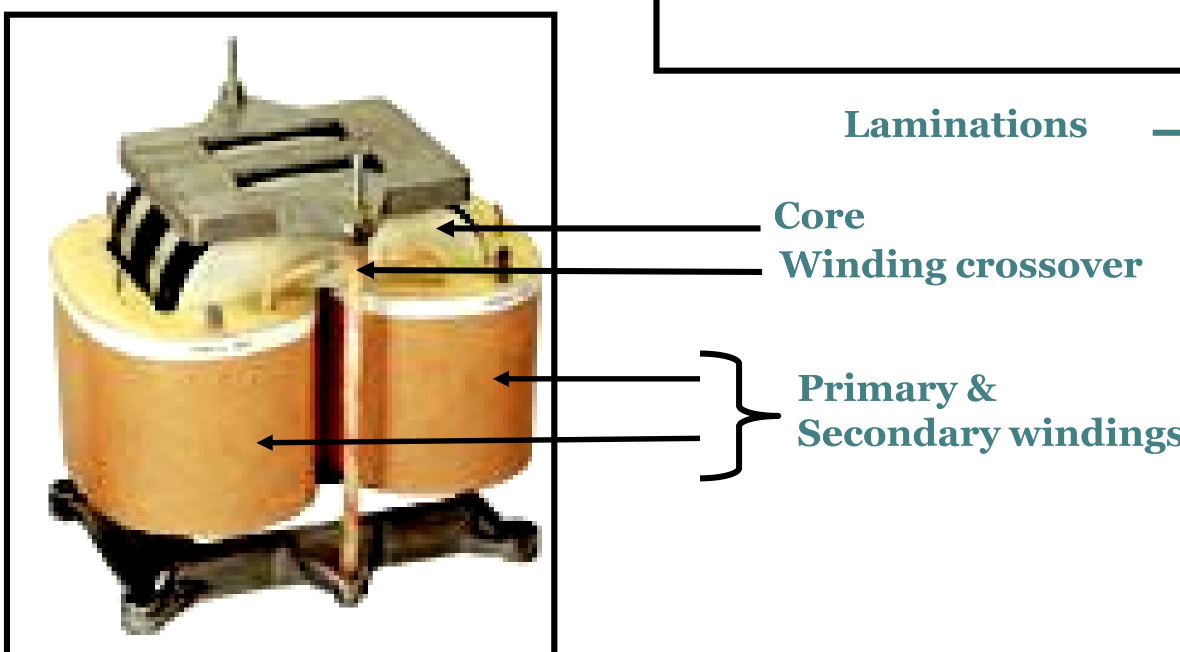
Based on construction:

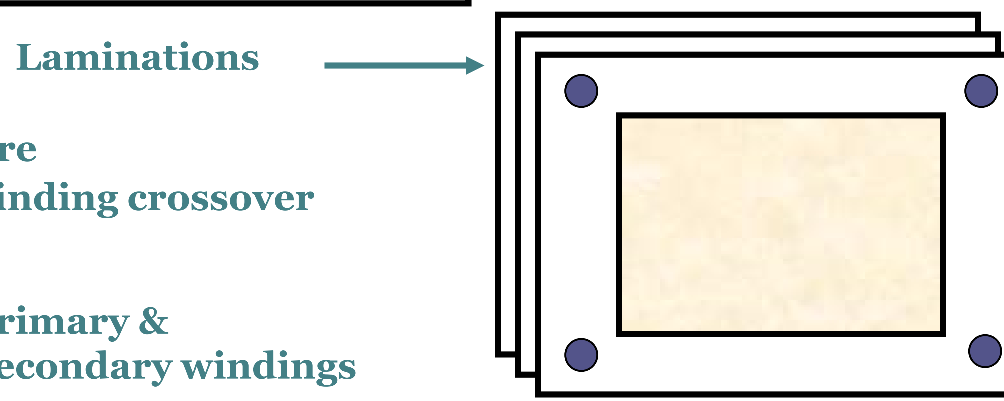
Transformers are classified as core type and shell type.

- The reason for the magnetic core is to confine more flux towards high permeability core.
- Magnetic core is a stack of thin silicon steel laminations of about 0.35 mm thick for 50Hz transformers.
- Vertical portion of the core is called limb and top and bottom portions are called yoke.
- Magnetic core is made of cold rolled grain oriented sheet steel (C.R.G.O.) which has low core loss and high permeability.
- Low power transformers are air cooled, where as high power transformers are immersed in oil for better cooling.

Construction- *Core Type*



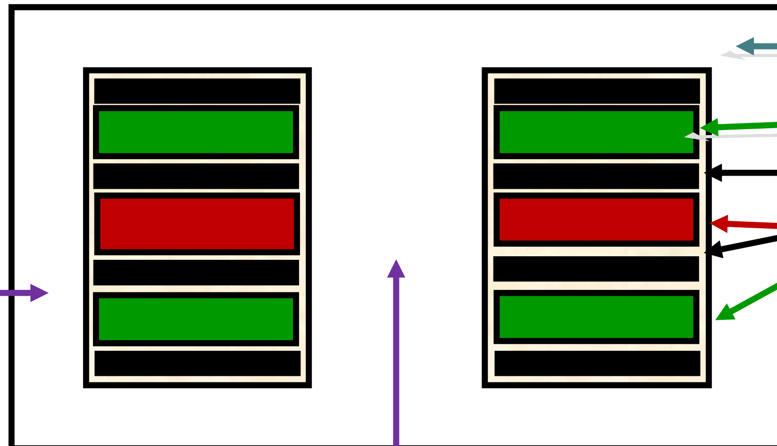


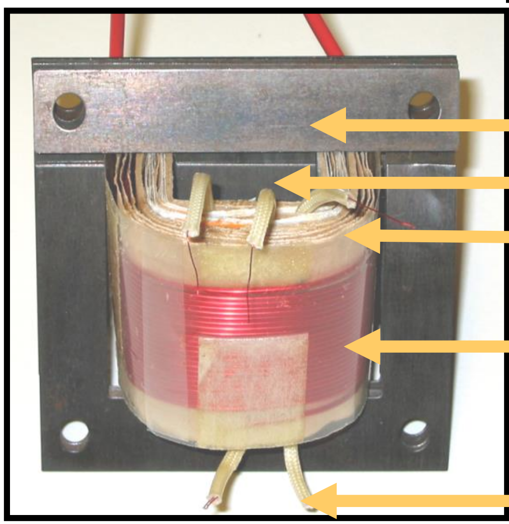


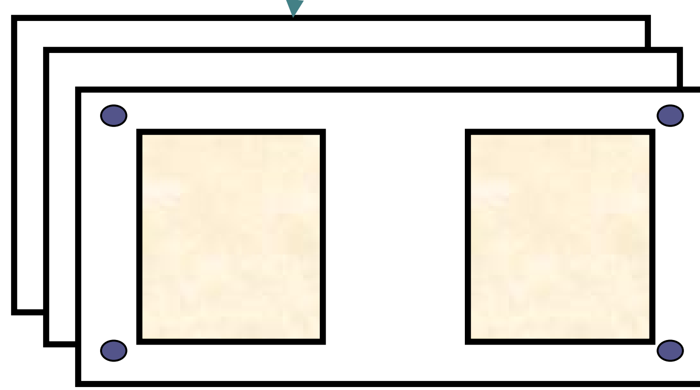
Core type transformer

- 2 legged core.
- Flux has single path
- L.V. windings are placed adjacent to steel core and H.V. windings outside in order to minimize the amount of insulation required.
- Core type transformer requires less iron but more conductor material compared to a shell type transformer.
- Used for high voltage, high power transformers

Construction- *Shell Type*



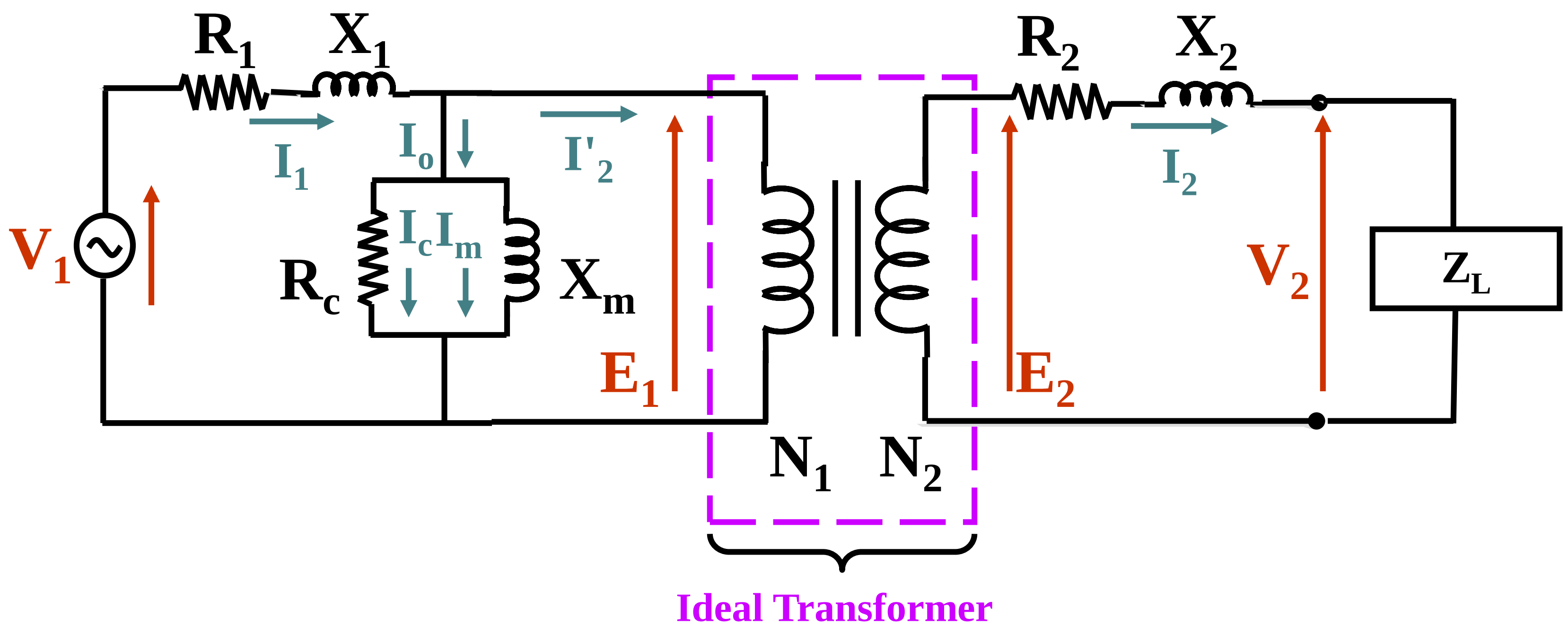




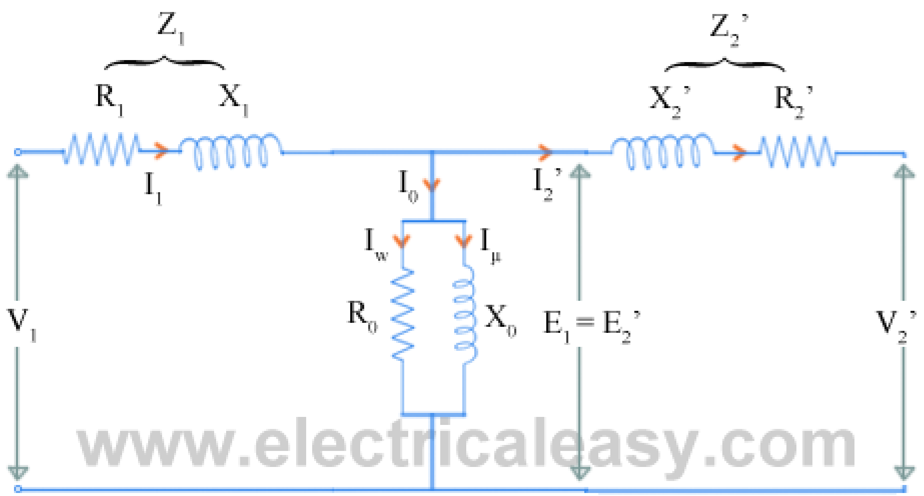
Shell Type transformer

- *Shell Type*
  - 3 legged core.
  - Flux in central limb divides equally and return through outer two legs.
  - L.V and H.V windings wound over central limb are sandwiched.
  - Bottom and top L.V coils are of half the size of other L.V. coils.
  - Used for low voltage

Equivalent circuit of transformer



Equivalent circuit of transformer with secondary parameters referred to the primary



Now, lets refer the parameters of secondary side to primary (complete derivation done in class):

Z_2 can be referred to primary as Z_2'

where, $Z_2' = (N_1/N_2)^2 Z_2 = K^2 Z_2$. ....where $K = N_1/N_2$.

that is, $R_2' + jX_2' = K^2(R_2 + jX_2)$

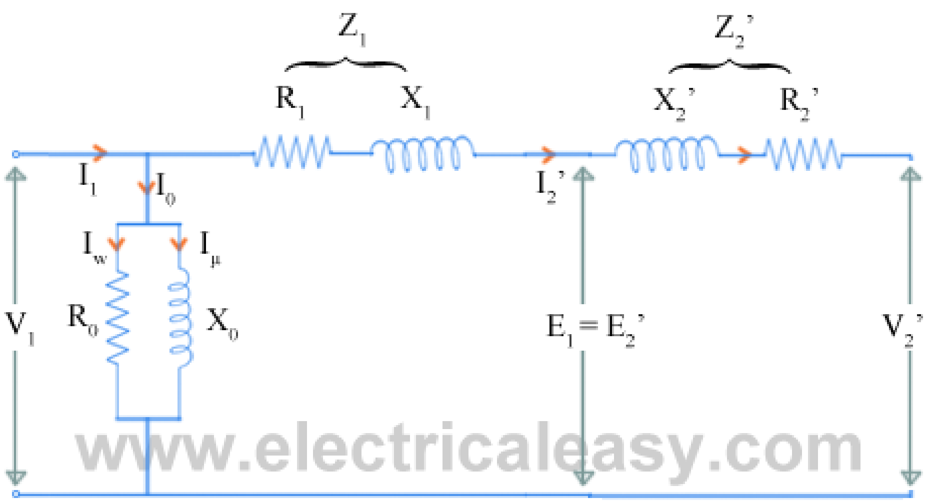
equating real and imaginary parts,

$R_2' = K^2 R_2$ and $X_2' = K^2 X_2$.

And $V_2' = KV_2$

Equivalent circuit of transformer with secondary parameters referred to the primary.

- As the values of winding resistance and leakage reactance are so small that, V_1 and E_1 can be assumed to be equal. Therefore, the exciting current drawn by the parallel combination of R_0 and X_0 would not affect significantly, if we move it to the input terminals as shown in the figure below.



Equivalent circuit of transformer with secondary parameters referred to the primary.

Total equivalent resistance referred to Primary –

$$r_{e_1} = r_1 + r_2' = r_1 + \left(\frac{N_1}{N_2}\right)^2 r_2$$

Total equivalent leakage reactance referred to Primary

$$x_{e_1} = x_1 + x_2' = x_1 + \left(\frac{N_1}{N_2}\right)^2 x_2$$

Total equivalent impedance referred to Primary

$$z_{e_1} = r_{e_1} + j\,x_{e_1}$$

Second

Losses & Efficiency

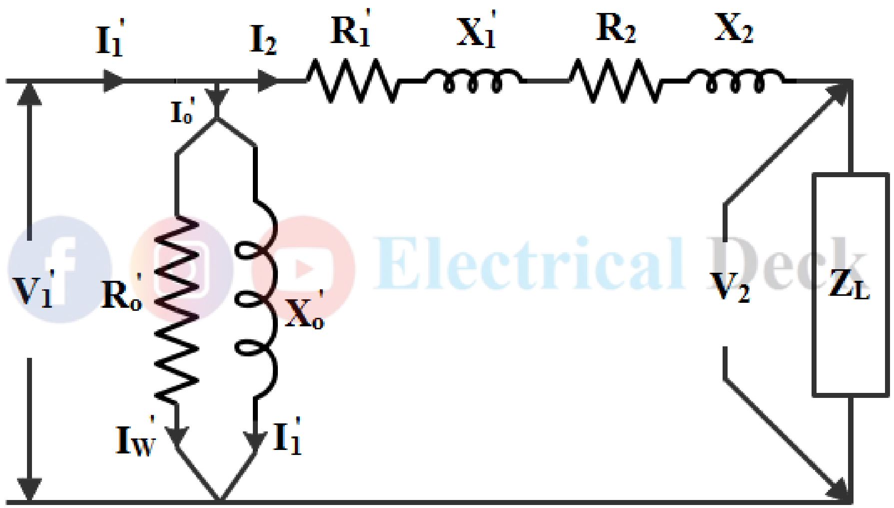
- Core Loss

✓ (i) Hysteresis Loss: Magnetic materials in the core will eventually become magnetically saturated when they are placed in a strong magnetic field, such as the magnetic field generated by an AC current. Hence, hysteresis loss in a transformer occurs due to magnetization saturation in the core of the transformer. It can be minimized using material that has less area of the hysteresis loop. Hence, silica steel or CRGO steel can be used for designing the core within a transformer because it has extremely less area of the hysteresis loop.

(ii) Eddy Current Loss

✓ when a conductor is exposed to a varying magnetic field, resulting in the generation of circulating currents within the conductor. It is also called as iron loss. Hence is due to interaction between conductor and magnetic material. Eddy current losses are directly proportional to area of armature. It can be minimized by increasing the resistance of armature in the path of eddy current by laminating it.

Equivalent circuit of transformer with primary parameters referred to the secondary



Approximate Equivalent Circuit Referred to Secondary

The secondary equivalent of the primary emf,

$$E_1' = E_1 K = E_2$$

The secondary equivalent of primary voltage,

$$V_1' = V_1 K$$

The secondary equivalent of the primary current,

$$I_1' = \frac{I_1}{K}$$

The primary resistance, reactance, and impedance referred to as secondary is given as,

$$\underbrace{R_1' = R_1 K^2, \; X_1' = X_1 K^2}_{}$$

$$Z_1' = Z_1 K^2$$

Losses & Efficiency

- Copper Loss
    - Winding Resistance (in primary and secondary)
  - Current (or Load) dependent, hence variable loss

- Total Loss = Core Loss + Copper Losses

- Efficiency of transformer is Very high 97% to 99% (since it is a static device)

Voltage Regulation

- With a constant voltage applied to the primary winding (i.e., with the source voltage held constant) of a practical transformer, the secondary terminal voltage will change with changes in the load connected to it.

- This is due to the changes in the voltage drops occurring in the primary and secondary windings (due to their internal resistance, R1, R2 and leakage reactances, X1, X2).

- Voltage regulation is the measure of how well a power transformer can maintain constant secondary voltage given a constant primary voltage and wide variance in load current. The lower the percentage (closer to zero), the more stable the secondary voltage and the better the regulation it will provide.

Voltage Regulation

- Voltage regulation is defined as the ratio of the change in the magnitude of the secondary terminal voltage from no-load to full-load given as a percentage of the no-load secondary terminal voltage.

- $\% \boldsymbol{Voltage\ Regulation} = \dfrac{|\boldsymbol{No\ load\ secondary\ terminal\ voltage}| - |\boldsymbol{Full\ load\ secondary\ terminal\ volage}\ |}{|\boldsymbol{No\ load\ secondary\ terminal\ voltage}|} \times 100$

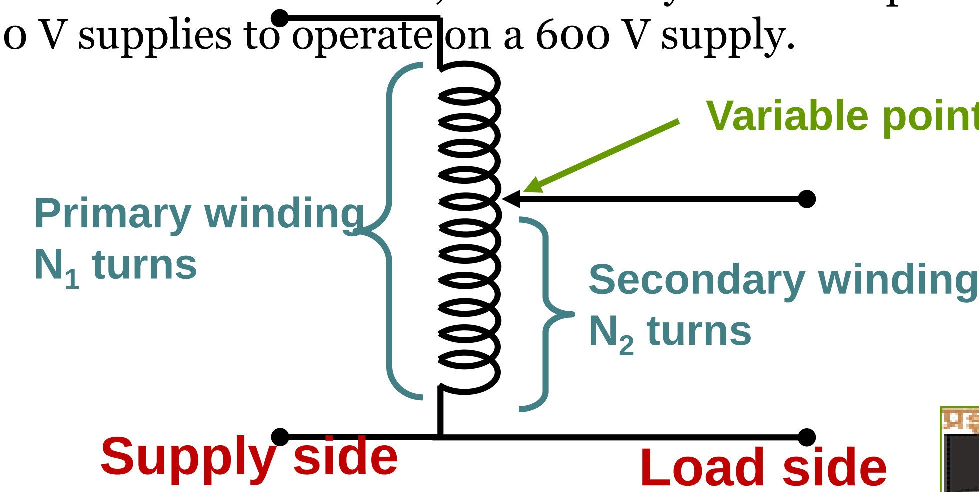
Auto Transformer

- One winding transformer
  - Part of winding common to primary & secondary circuits

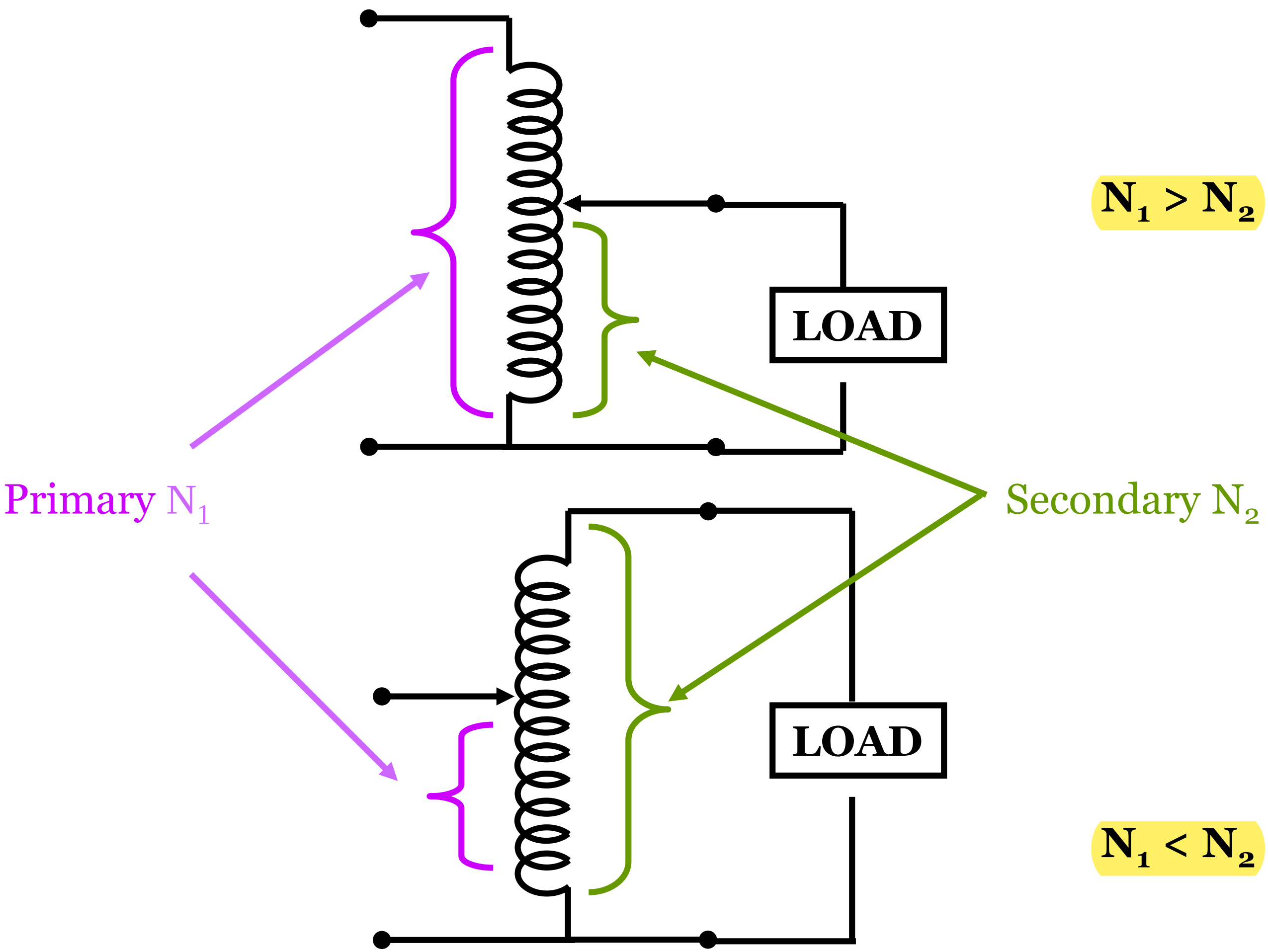
- One winding wound over the entire core

- Secondary winding can be varied using variable point

- Used in power applications to interconnect systems operating at different voltage classes, for example 138 kV to 66 kV for transmission , in industry is to adapt machinery built (for example) for 480 V supplies to operate on a 600 V supply.



Auto Transformer- Types



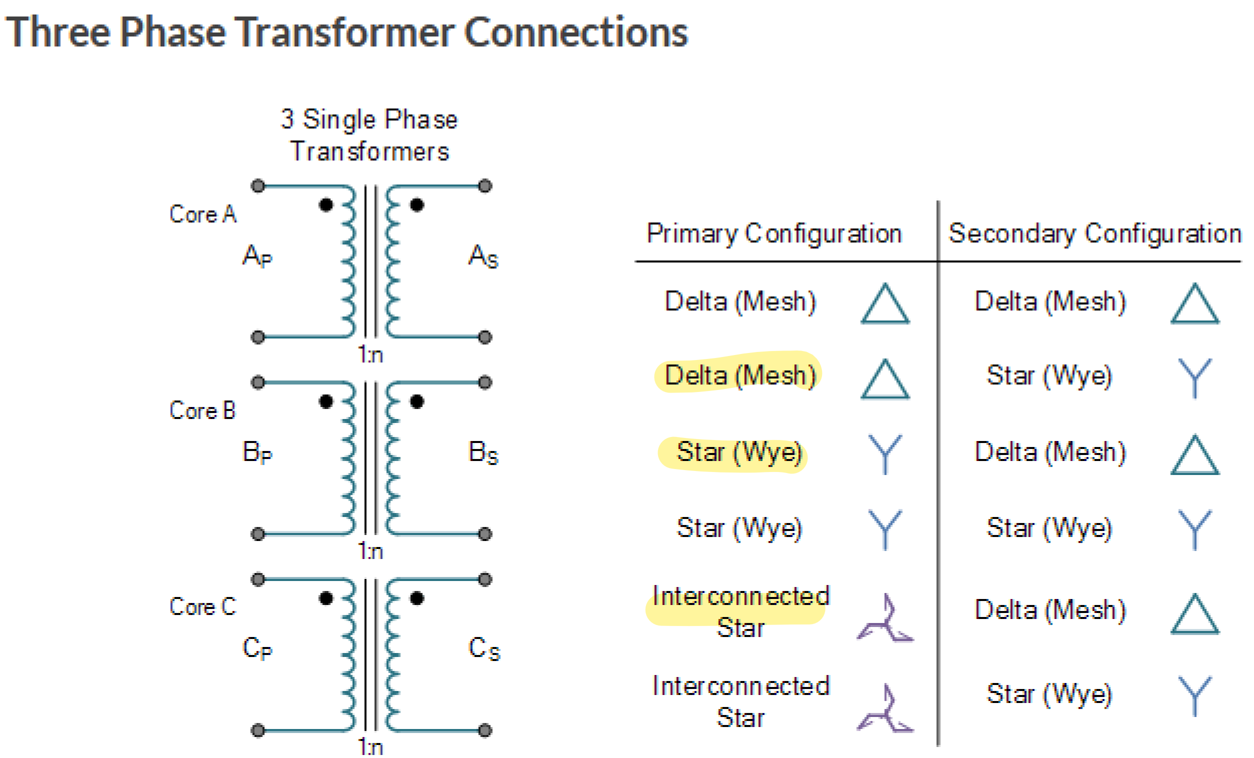
$N_1 > N_2$ **: Step Down type**

$N_1 < N_2$ **: Step Up type**

3 Phase Transformer

- 3 primary coils & 3 secondary coils.
- Possible connections of primary & secondary windings
  - *star/star*
  - *star/delta*
  - *delta/delta*
  - *delta/star*
- 3 single-phase transformers of similar ratings can be connected to form a 3 phase transformer

3 Phase Transformer



Applications

- ***Power Transformer:*** Used in electric transmission network
- ***Distribution Transformer:*** Used in electric distribution networks
- ***Instrument Transformers (PT & CT):*** Used for high voltage & current measurement
- ***Isolation Transformer:*** 1:1 transformers used in circuits to provide electrical isolation.
- ***Constant Voltage Transformer:*** Used as voltage regulators
- ***High frequency Transformer***: Transformers designed for operating with high frequency – ferrite core