MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent institution of MAHE, Manipal)

L26 - Electrical Power system components & Transformers

Basic Electrical Technology

[ELE 1051]

Outline

Power System Components
- Generation
- Transmission, Distribution
- Protection & Control

Types of Loads

Power System Background

Branch of Electrical Sciences dealing with *Generation, Transmission* & *Distribution* of electrical energy.

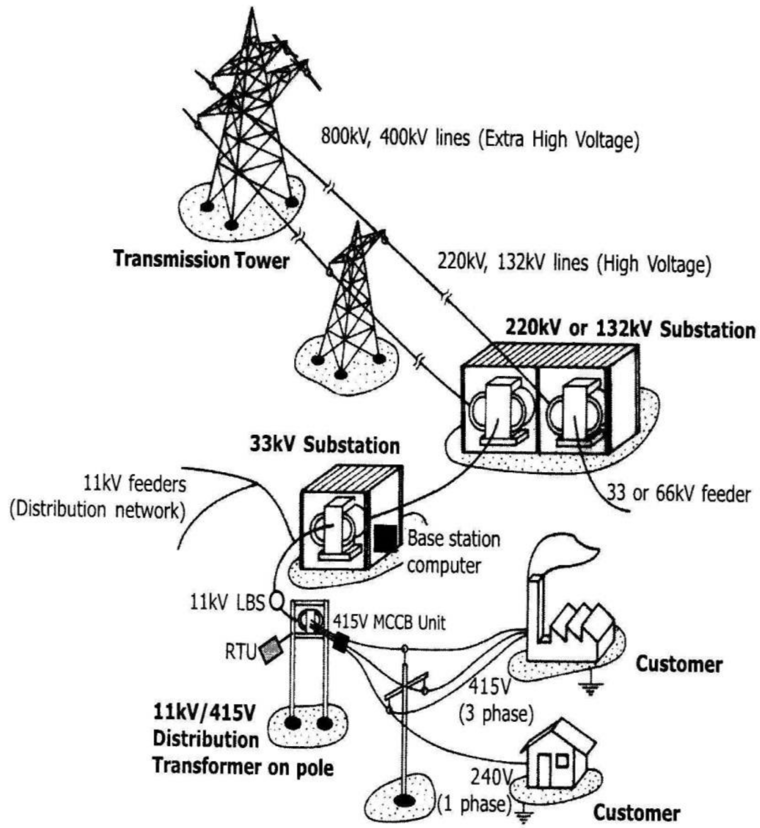
Pearl Street Station in New York City, 1882

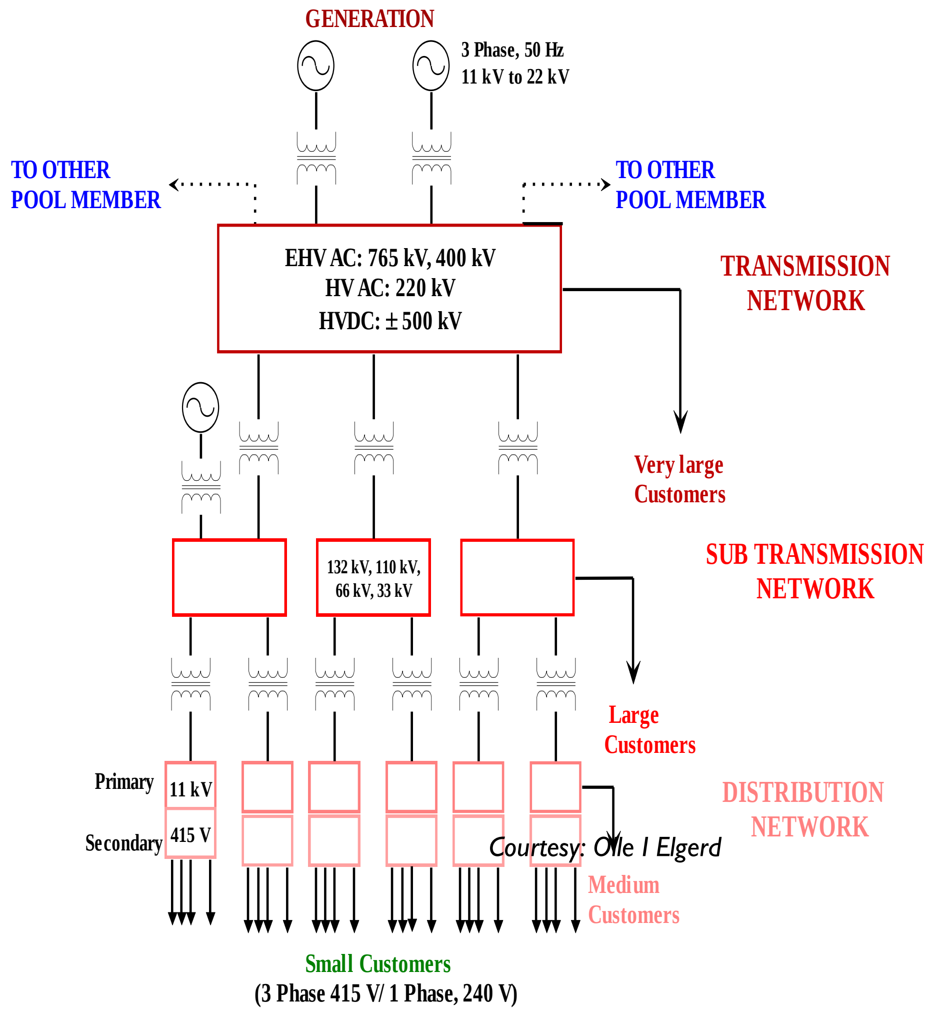
- "Illuminating Companies" by Thomas A Edison
- Concept of DC power generation

Three phase AC power system, 1896

- 2 generators and a transmission line @ 25 Hz.

Power System Structure





Courtesy: Olle I Elgerd

Power System Components

Generation subsystem

Transmission subsystem

Sub-transmission subsystem

Distribution subsystem

Protection and Control subsystem

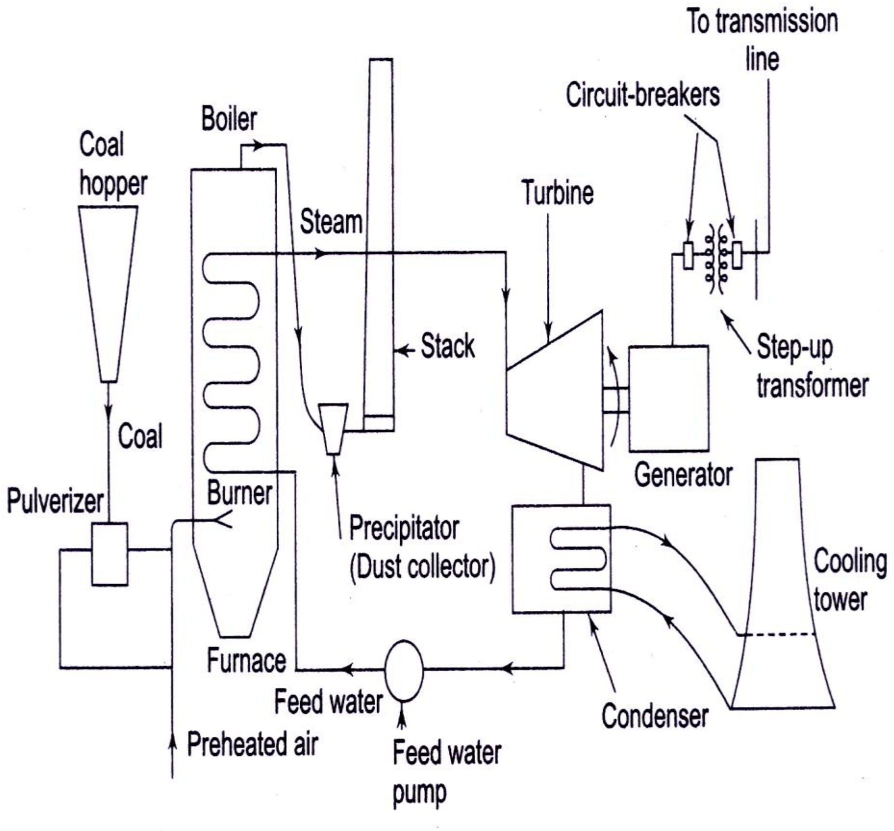
Generation Subsystem

Primary Sources of Energy

- Fossil Fuel
  - Coal, Oil, Natural Gas
- Renewable Energy
  - Water, Solar, Wind, Tidal, Geo-thermal etc.
- Nuclear Energy

Generation Subsystem

Coal Fired Power plant



UPCL, Padubidri, Mangalore

Generation Subsystem

Thermal Power Stations

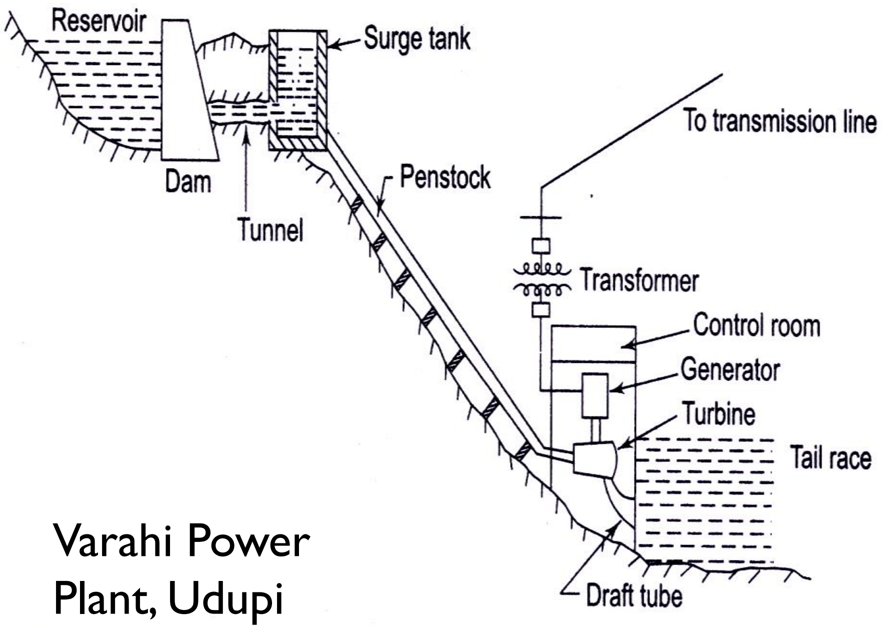
- Coal Fired
  - Turbo alternators driven by steam turbine
- Oil Fired
  - Crude oil or Residual oil
- Gas Fired
  - Combined cycle- First stage: Gas turbine, Second stage: Steam Turbine
- Diesel Fired
  - Internal Combustion engines as prime mover
  - Standby power plants

Generation Subsystem

Hydroelectric Power Station

- Salient Pole alternators driven by turbines.
- Turbines: Impulse Turbine & Reaction Turbine
- Pumped storage plants

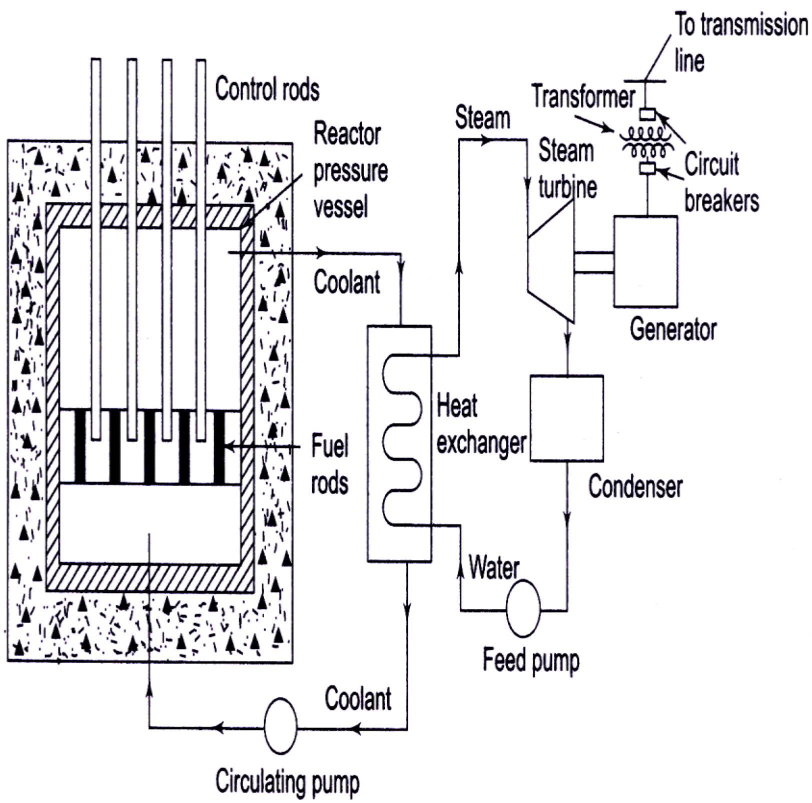
Varahi Power Plant, Udupi Dist.



Generation Subsystem

Nuclear Power Plant

- Fissile Material $^{235}_{92}U,\ ^{239}_{94}Pu$
- Moderator
  - D2O, Graphite
  - Control rods
  - Boron OR Cadmium
- Fast Breeder Reactors
  - Liquid metal (alloy of Na & K) is coolant



$$^{238}_{92}U + \,^{1}_{0}n \rightarrow \,^{239}_{92}U - \beta \rightarrow \,^{239}_{93}Np - \beta \rightarrow \,^{239}_{94}Pu$$

Generation Subsystem

Non-Conventional Power Stations

- Wind Power Stations
- Solar Power Stations
- Micro-Hydel Power Stations
- Bio-Mass Power Stations
- Geothermal Power Stations

Wind Farm in Karnataka

Solar Park, Charanka Village, Gujarat

1MW hydro plant, HP

Bio-mass Plant, Chattisgarh

Transmission, Sub-transmission & Distribution Subsystems

Transmission networks- EHV AC or HVDC

- Operates @765 kV/400 kV/ 220 kV AC or $\pm$ 500 kV DC.

AC Sub-Transmission networks

- Operates @ 132 kV/ 110kV/ 66 kV/ 33 kV

AC Distribution Network

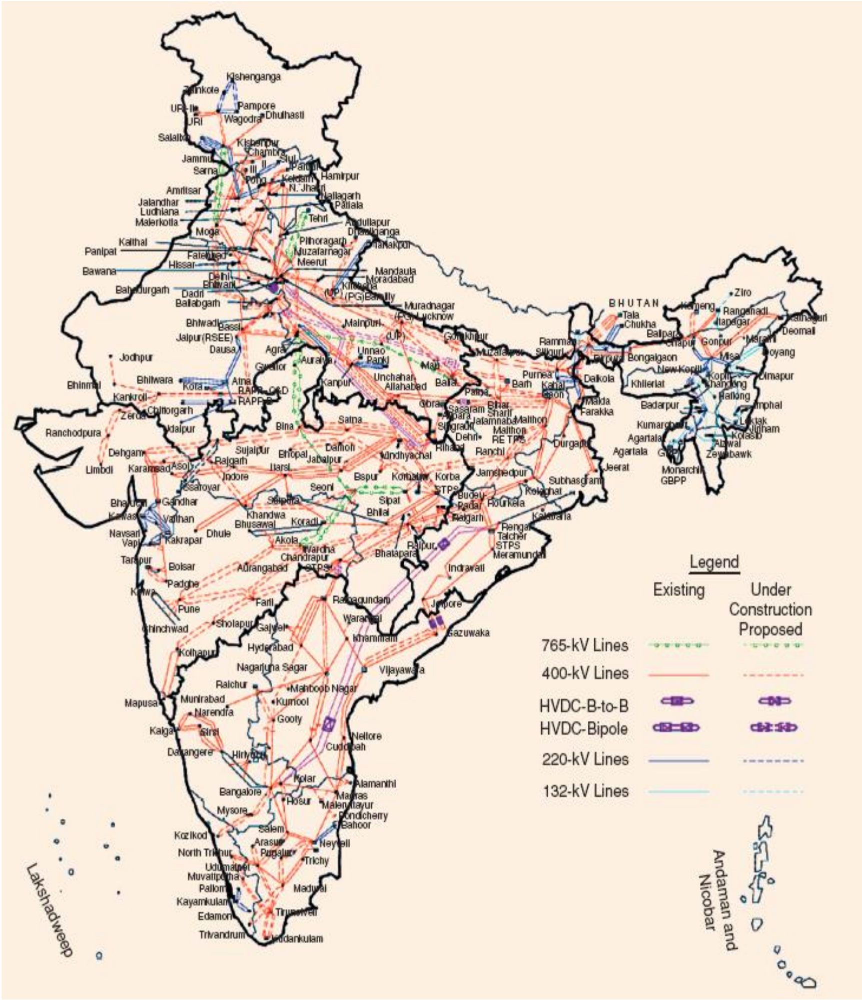
- Primary side: 11 kV
- Secondary side: 415 V, 4 Wire

Share of Renewable resources in India

Resource	Potential (MW)	Upto 9th Plan	Upto 10th Plan	11th Plan Target	Upto 30.09.10	Cumulative Achievement	12th Plan Projection (2017)	13th Plan Projection (2022)
Wind Power	48,500	1,667	5,427	9,000	4,714	12,809	27,300	38,500
Small Hydro Power	15,000	1,438	538	1,400	759	2,823	5,000	6,600
Bio Power	23,700	390	795	1,780	1,079	2,505	5,100	7,300
Solar Power	20-30 MW/sq km	2	1	50	8	18	4,000	20,000 36,910 mw
Total		3,497	6,761	12,230	6,560	18,155	41,400	72,400

Source: Ministry of New & Renewable Energy, Govt. of India

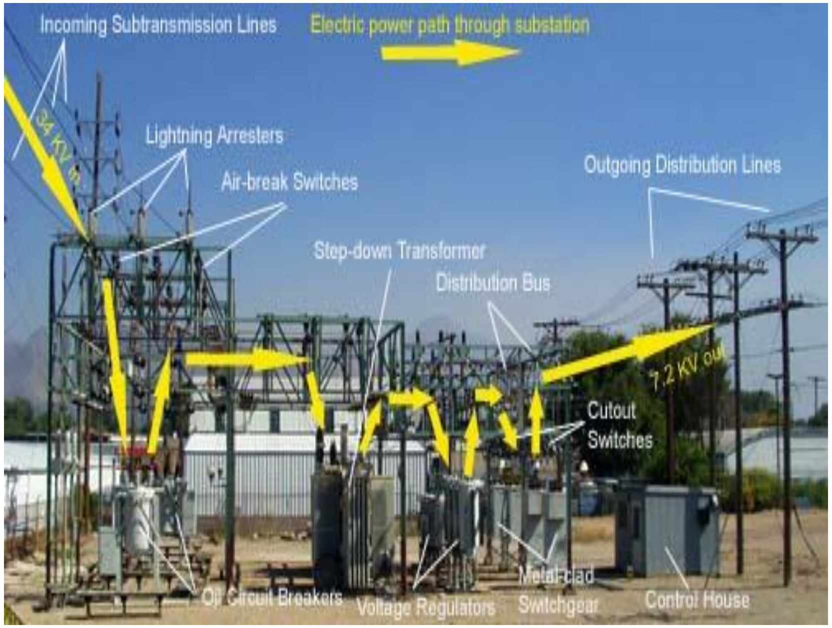
Transmission Network – A Glance



Substation

Substation Components

- Lightning Arrester
- Carrier line communication equipment (Wave Trap)
- Instrument Transformers (CT, PT)
- Circuit Breakers
- Isolators
- Bus Bars
- Power Transformers
- Control Room



Protection & Control Subsystem

Fail free power is *Hypothetical*.

Faults: Open Circuit & Short Circuit

Faults detection : *Relays*.

Fault Isolation: *Circuit Breakers*

Modern Trend: Supervisory Control And Data Acquisition (SCADA) systems.

Types of Loads

Industrial Loads

- 3 Phase
- Complex Tariff Structure

$S = P + jQ$

Domestic Loads/Commercial Loads

- 1 Phase
- Tariff based on energy consumed- kWH

Domestic Loads and Power Ratings

Incandescent lamps - (5 W to 100 W)

Fluorescent lamps - (20 W & 40 W); CFL - (5 W to 25 W)

LED Lamps-(1W to 100W)

Air Conditioner (1.5 T) - 1800 W

Electric Iron - 750 W

Heaters/ Geysers – 2000 W

Ceiling Fan – 60 W

Washing Machine (with heater) – 2.5 kW

Refrigerator – 160 W

PC – 200 W, Laptop – 40 W

Reduce Electricity bill by minimizing the use of heating / environmental conditioning gadgets

Indian Power Sector – A Glance

Sector	MW	Percentage
State	1,03617	27.7
Central	93,927	25.1
Private	1,76,655	47.2
Total	3,74,199	100.0

As on 17/12/2020

Source: Ministry of Power, Govt. of India

Indian Power Sector - A Glance

Fuel	MW	Percentage
Total Thermal	2,31,321	61.8
Coal	1,99,595	53.3
Lignite	6,260	1.7
Gas	24,957	6.7
Oil	510	0.1
Hydro (Renewable)	45699	12.2
Nuclear	6,780	1.8
RES*(MNRE)	90,399	24.2
Total	3,74,199	100

*RES include small hydro, bio-mass, urban and industrial waste power and wind energy

As on 17/12/2020

Source: Ministry of Power, Govt. of India

Summary

Detailed discussion of various power generating sources.

Different levels of voltages at transmission, sub-transmission and distribution stage.

Types of loads.

Indian Power Sector

Basic Electrical Technology

[ELE 1051]

L26 – Transformers

Contents

Introduction

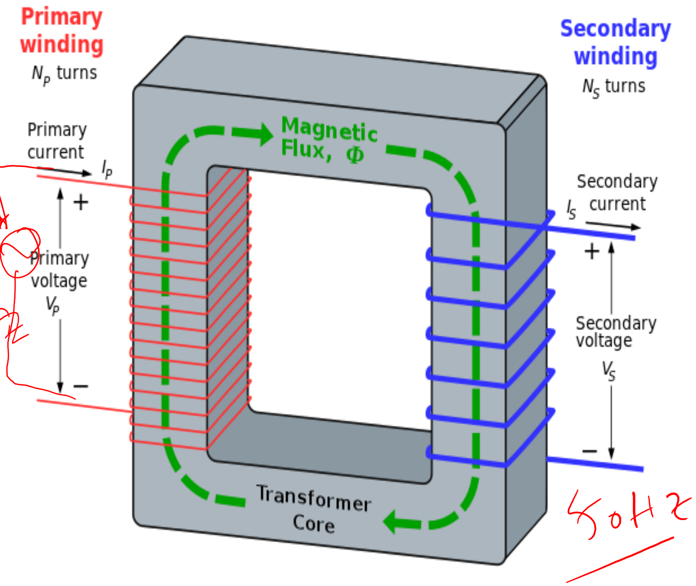
Static device with AC excitation

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



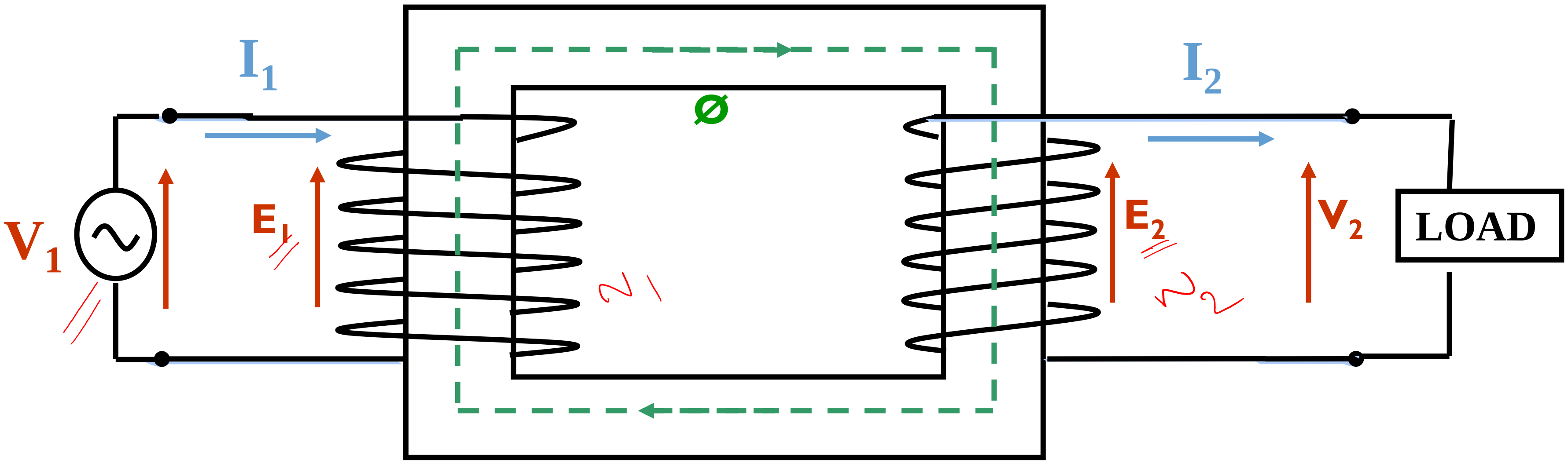
Applications:

- Electric power systems.
- Power transmission, distribution networks.
- Electronic circuits.
- Electric traction.

Types

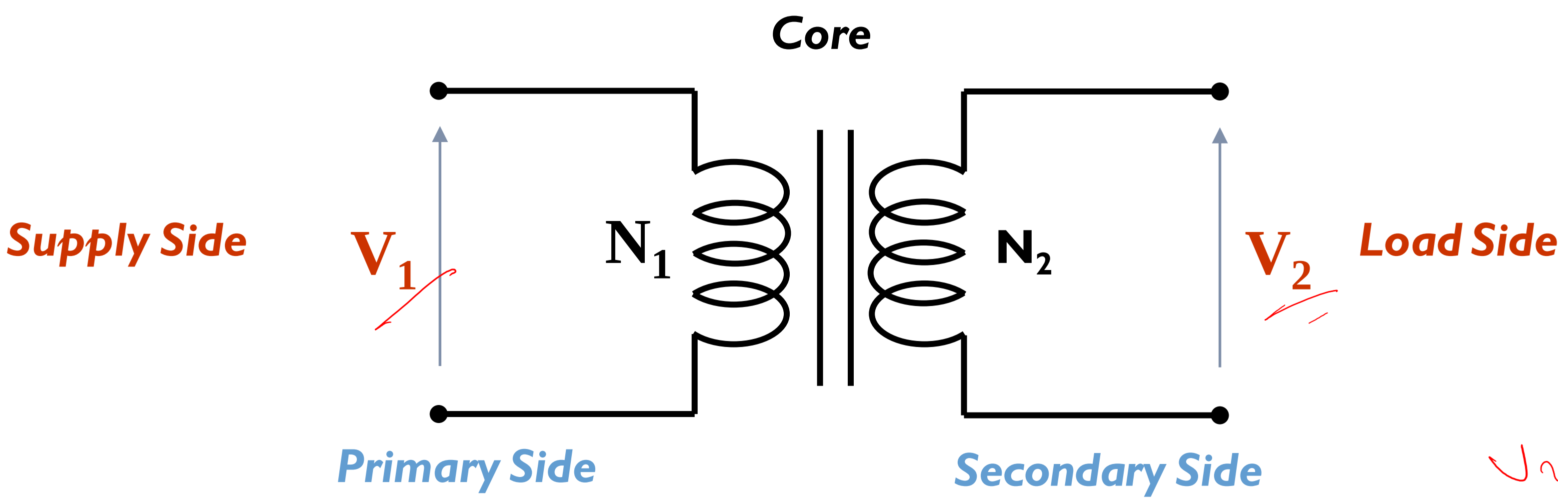
Based on Construction	***Based on Function***	***Based on Windings***
Core Type	Step Up	Single Winding
Shell Type	Step Down	2 or 3 Windings

Operation of Transformer



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

Representation



$V_1/N_1 = V_2/N_2$

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

Emf Equation of Transformer

$v(t) = V_m \sin(\omega t)$

$\omega = 2\pi f$

$\textbf{\textit{Core flux}}, \emptyset = \emptyset_m Sin\omega t$

$$\textbf{\textit{Induced Emf}}, e = -N\frac{d\emptyset}{dt} = N\omega\emptyset_m Sin(\omega t - 90°)$$

$$e = E_m Sin(\omega t - 90°)$$

$$\textbf{\textit{where}}, E_m = N\omega\emptyset_m \rightarrow Maximum\ value\ of\ self\ induced\ emf$$

$$\textbf{\textit{RMS value of self induced emf}}, E = \frac{E_m}{\sqrt{2}} = \frac{N\omega\emptyset_m}{\sqrt{2}} = \frac{2\pi f N\emptyset_m}{\sqrt{2}}$$

$\textbf{\textit{Primary Induced Emf}}, E_1 = 4.44\ N_1 f\emptyset_m$
$\textbf{\textit{Secondary Induced Emf}}, E_2 = 4.44\ N_2 f\emptyset_m$

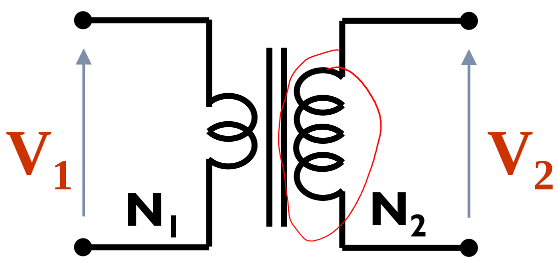
Emf Equation of Ideal Transformer…

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

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

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

$N_2 > N_1$: Step Up



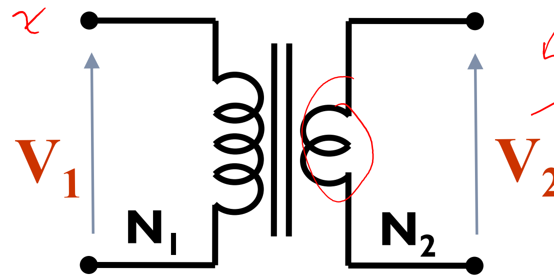
$E_2 > E_1$
$V_2 > V_1$
$I_1 > I_2$

$V_1 I_1 = V_2 I_2$

$N_2 < N_1$: Step down

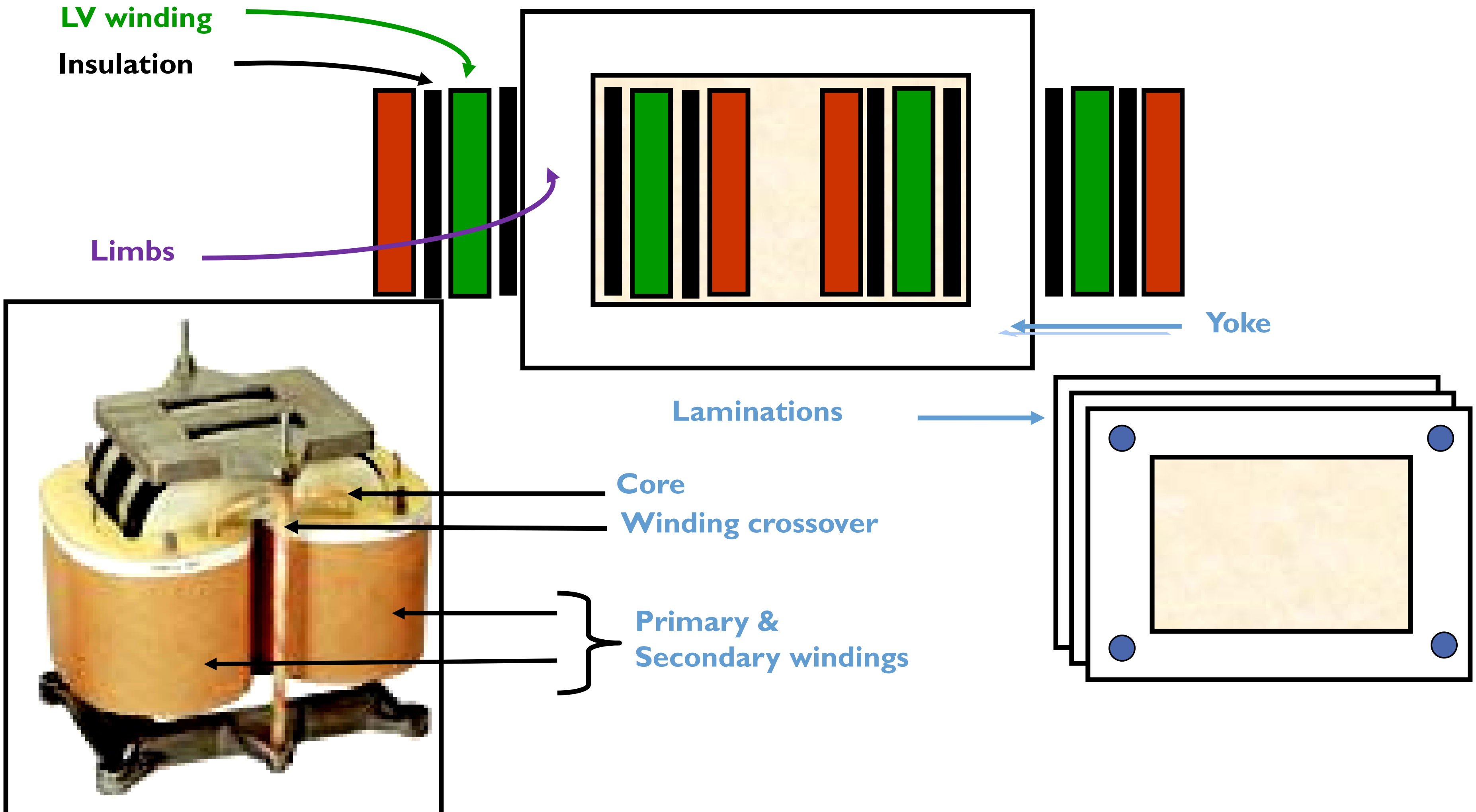
50Hz

50Hz

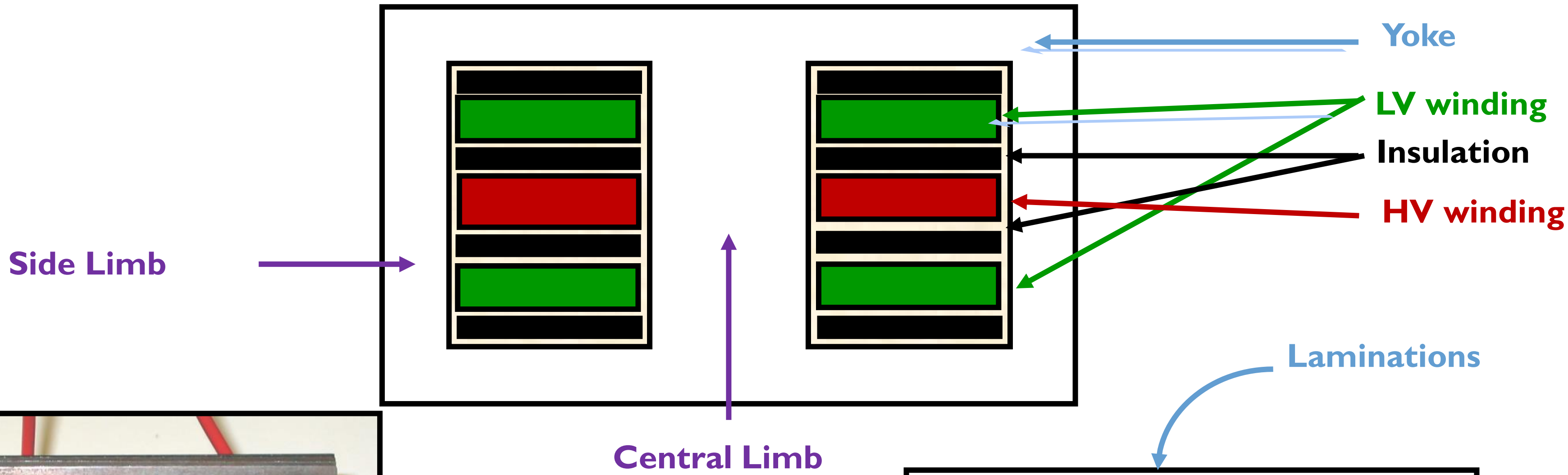


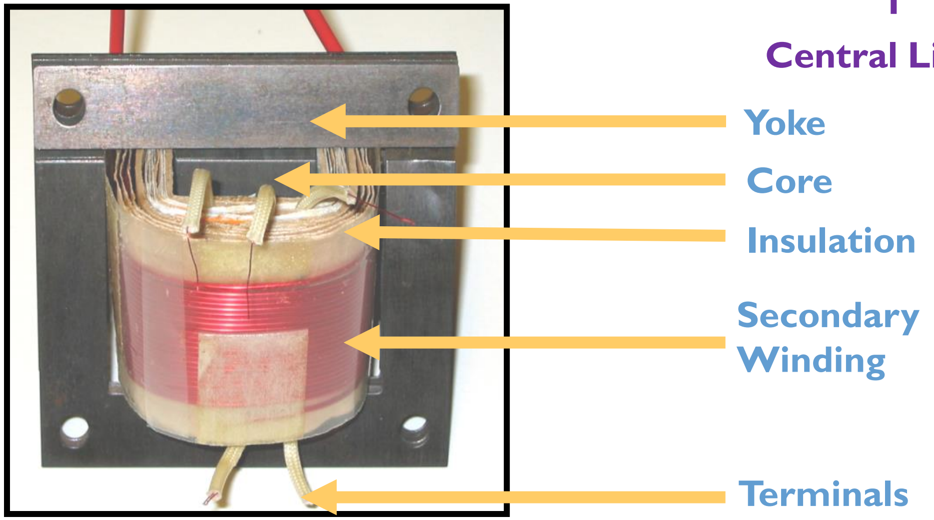
$E_2 < E_1$
$V_2 < V_1$
$I_1 < I_2$

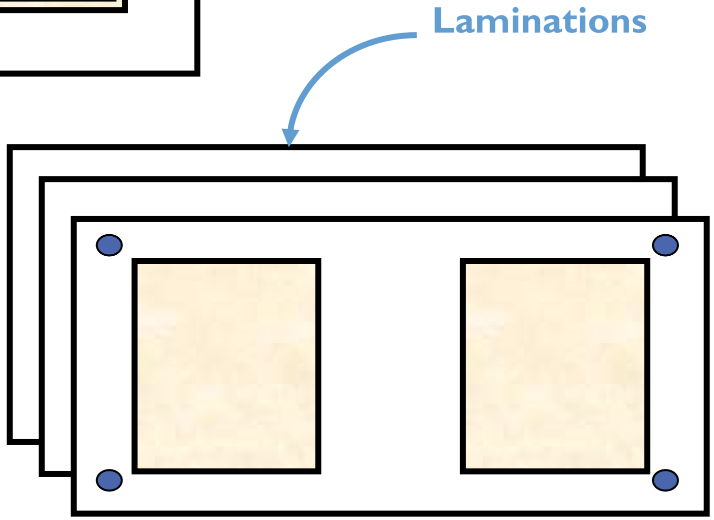
Construction- *Core Type*



Construction- *Shell Type*







Losses & Efficiency

Core Loss

- Hysteresis Loss
- Eddy Current Loss

- Depends on flux which is constant hence the loss is constant

- Minimized using high graded core material and lamination

Copper Loss

- Winding Resistance (in primary and secondary)

- Current (or Load) dependent, hence variable loss

Total Loss = Core Loss + Copper Loss

Efficiency: Very high 97% to 99% (since it is a static device)

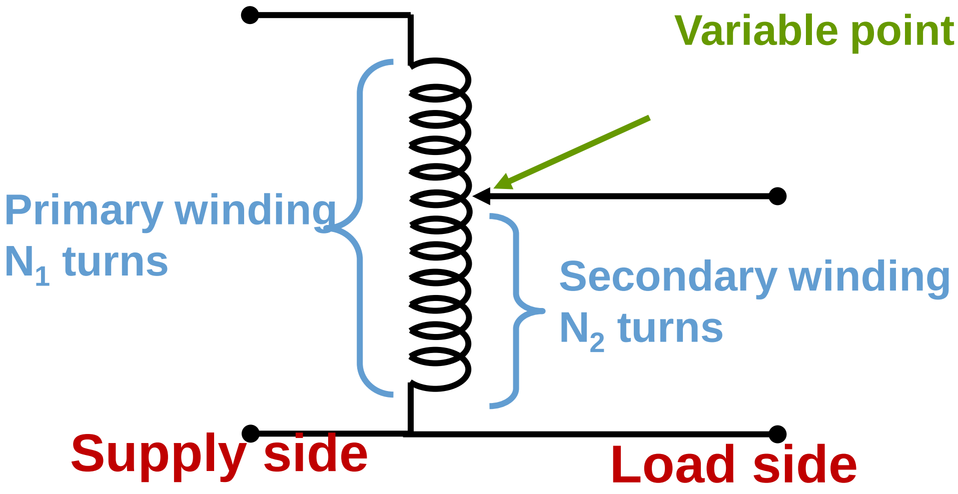
Auto Transformer

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

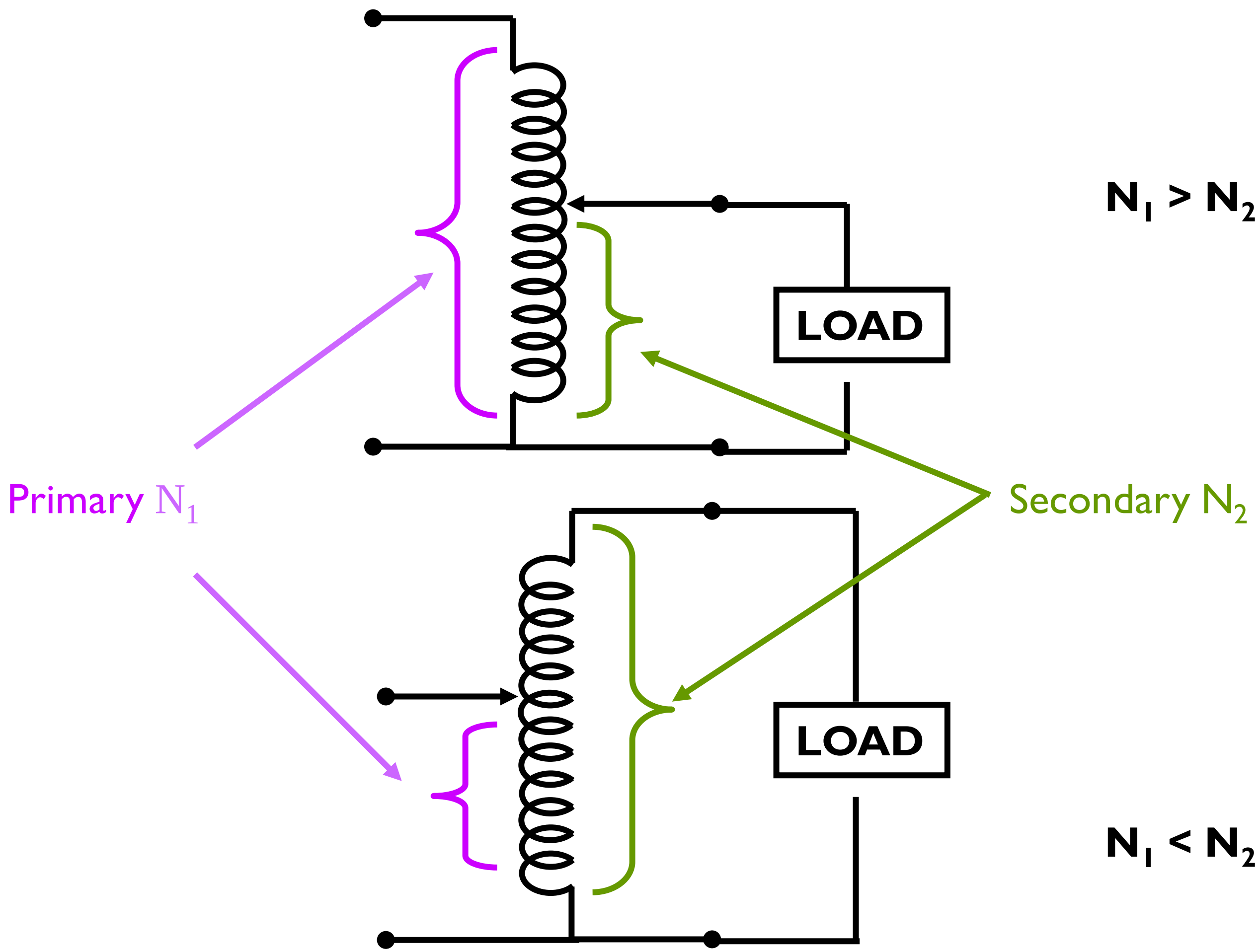
One winding wound over the entire core

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



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

Application

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