Energy conversion I

Lecture 5:

Topic 2: Transformers & its performance (S. Chapman, ch. 2)

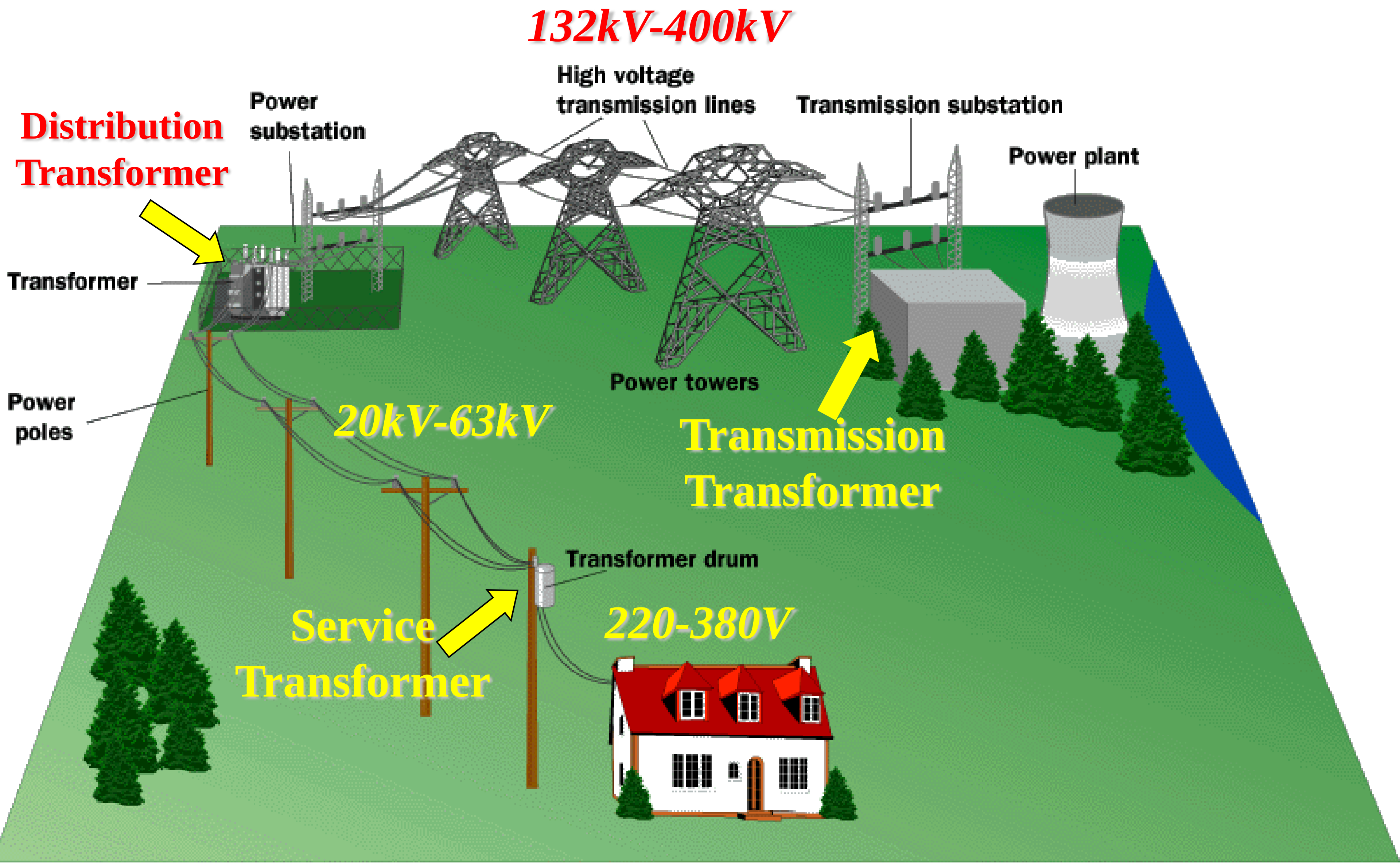
- **Introduction**
- **Types and Construction of Transformers.**
- **Ideal Transformer.**
- Theory of operation of real single-phase transformers.
- The Equivalent Circuit of a Transformer.
- The Per-Unit System of Measurement
- Transformer voltage regulation and efficiency
- Autotransformers
- Three phase transformers

Introduction

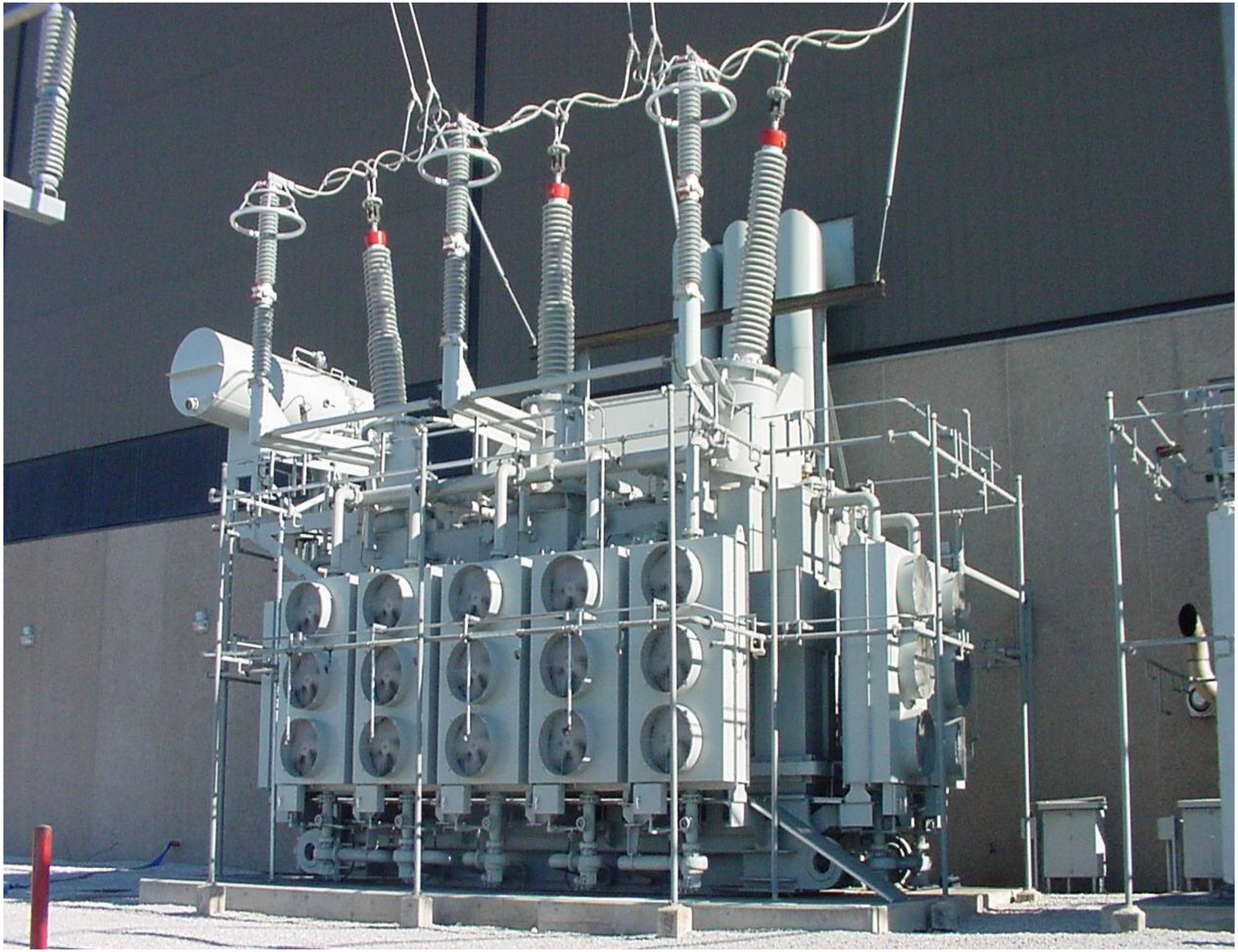
Transformer: a device to **change AC electric power** at **one voltage level** to **AC electric power** at **another voltage level** through the action of a **magnetic field.**

Transformer Applications:

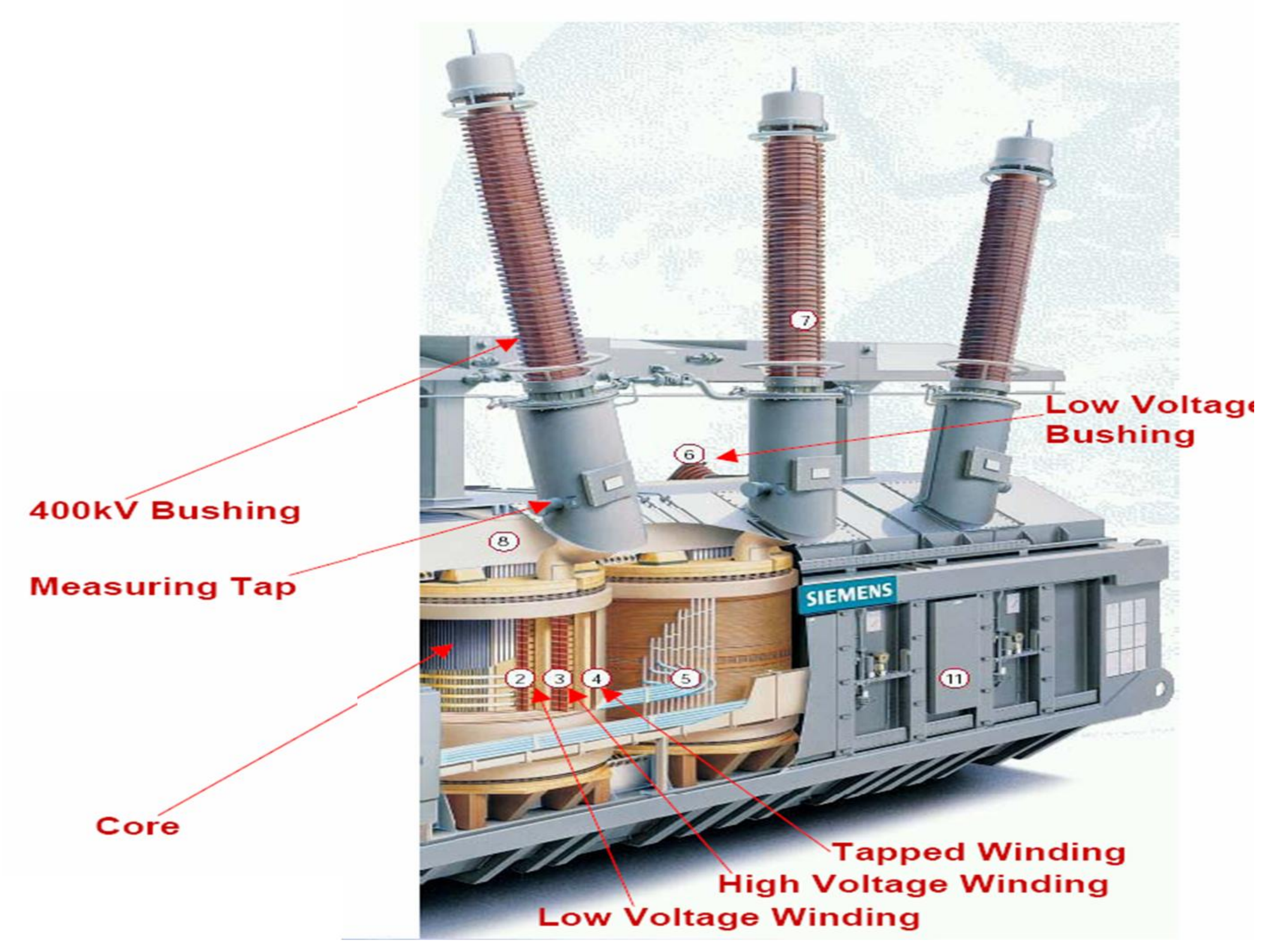
- **Increase voltage of generator's output**
  - Transmit high power at low current
  - Reduce cost of transmission system
- **Adjust voltage to a usable level**
- **Convert voltage or current to measurable levels**
- **Create electrical isolation**
- **Match load impedance**
- **Filters**


132kV-400kV
High voltage transmission lines
Transmission substation
Power substation
Distribution Transformer
Power plant
Transformer
Power poles
Power towers
20kV-63kV
Transmission Transformer
Transformer drum
220-380V
Service Transformer

Transmission Transformer



Transmission Transformer



Distribution Transformer

Distribution Transformer

Dry Type Distribution Transformer

No Explosion

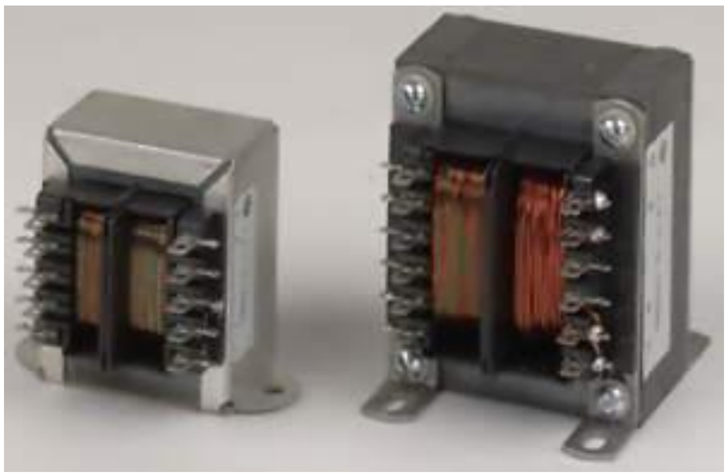
Inflammable

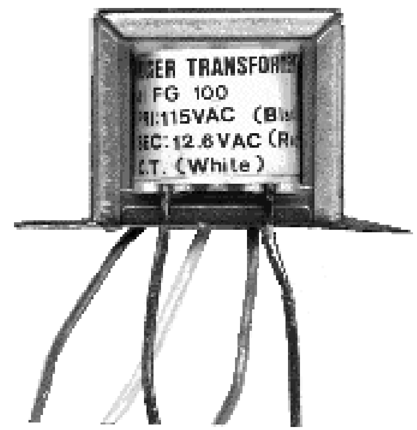
Environment friendly

Non-enclosed indoor

Cast Resin winding

Low Power Transformer





Old electronic apparatus power supply

Measurement Transformer

CT: Current transformer

Converts **High** (/low) currents to more usual currents **XX/5** or **XX/1**.

Usually **primary** is the **main** (hot) line. **Secondary** will be in series with current measuring terminals.

Isolation is required.

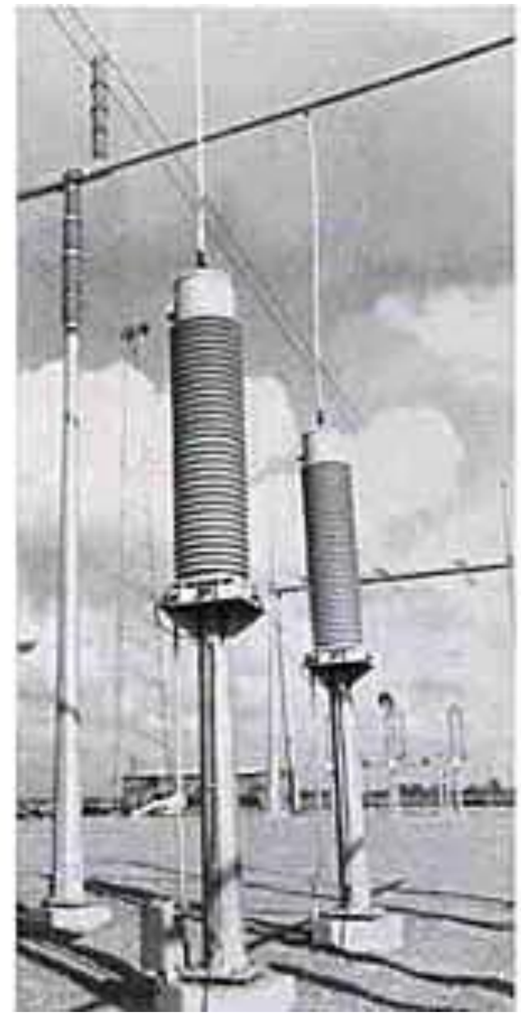
Measurement Transformer

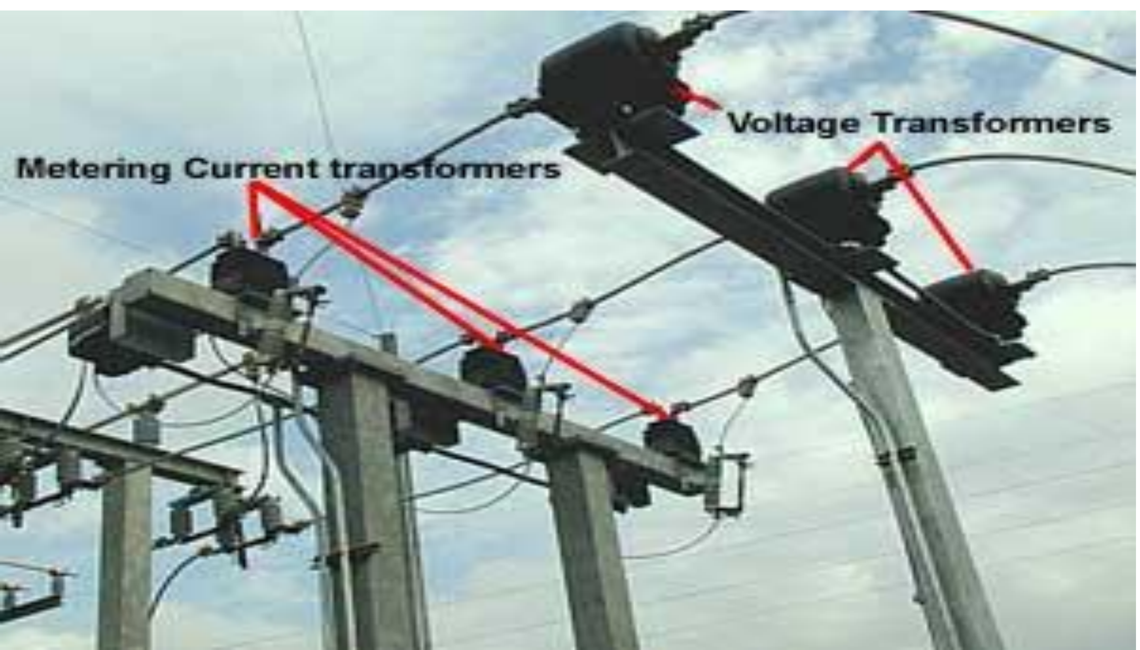
PT: Potential transformer

Converts **High** (/low) voltages to
More **usual voltages XX/110**

Primary is **connected** to the **main**.
Secondary is **connected** to
voltage measuring terminals.

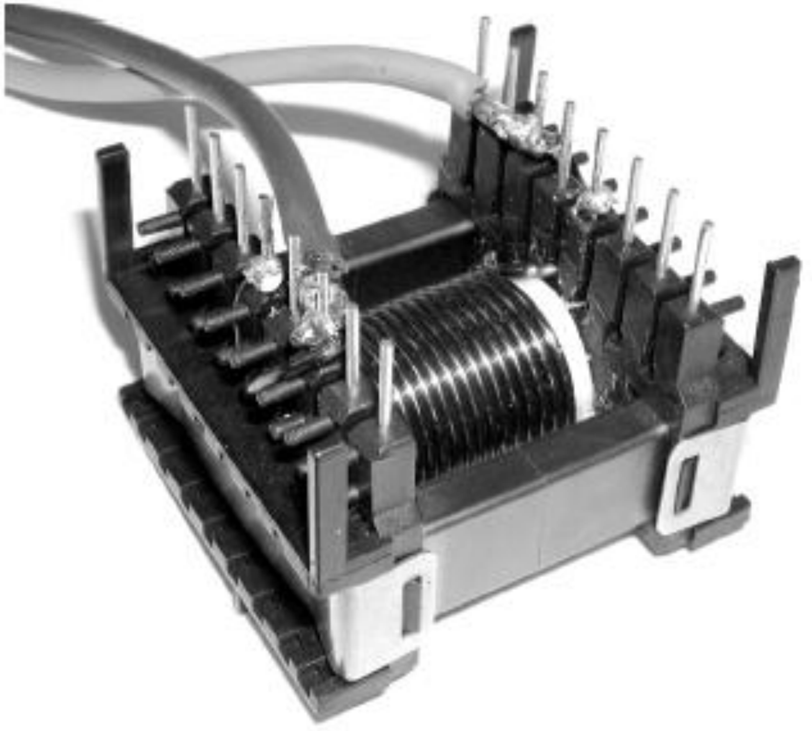
Isolation is required.





High Frequency (Pulse) Transformer

To be used in Electronic, Communication and Power Electronic Switching Circuits.

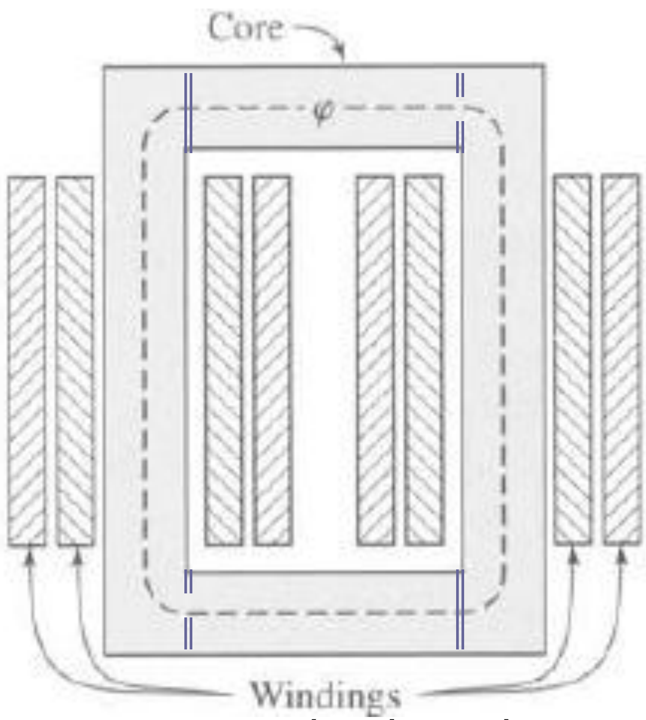


Air, Ferrite or Iron powder cores

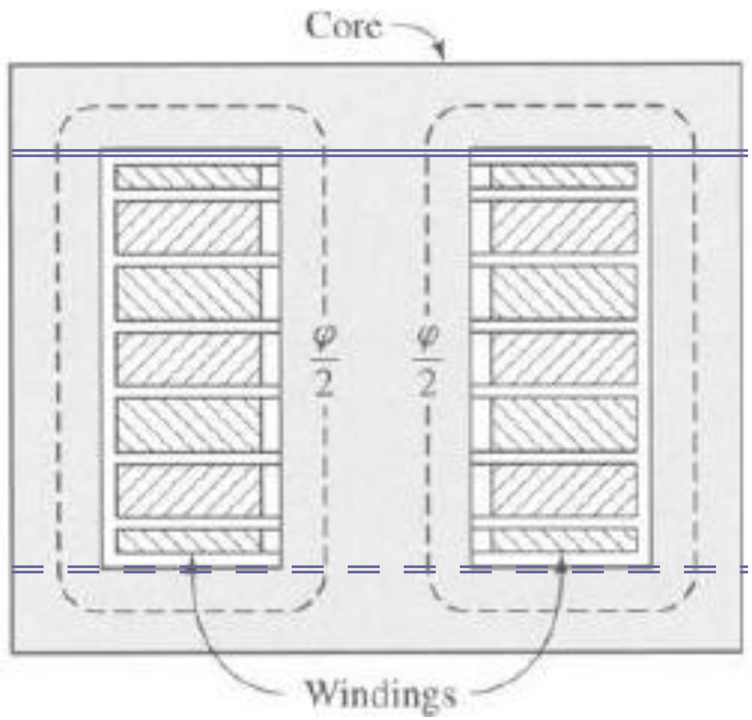
Some kHz up to MHz

Some mW up to some kW

Types of Iron Core Transformers

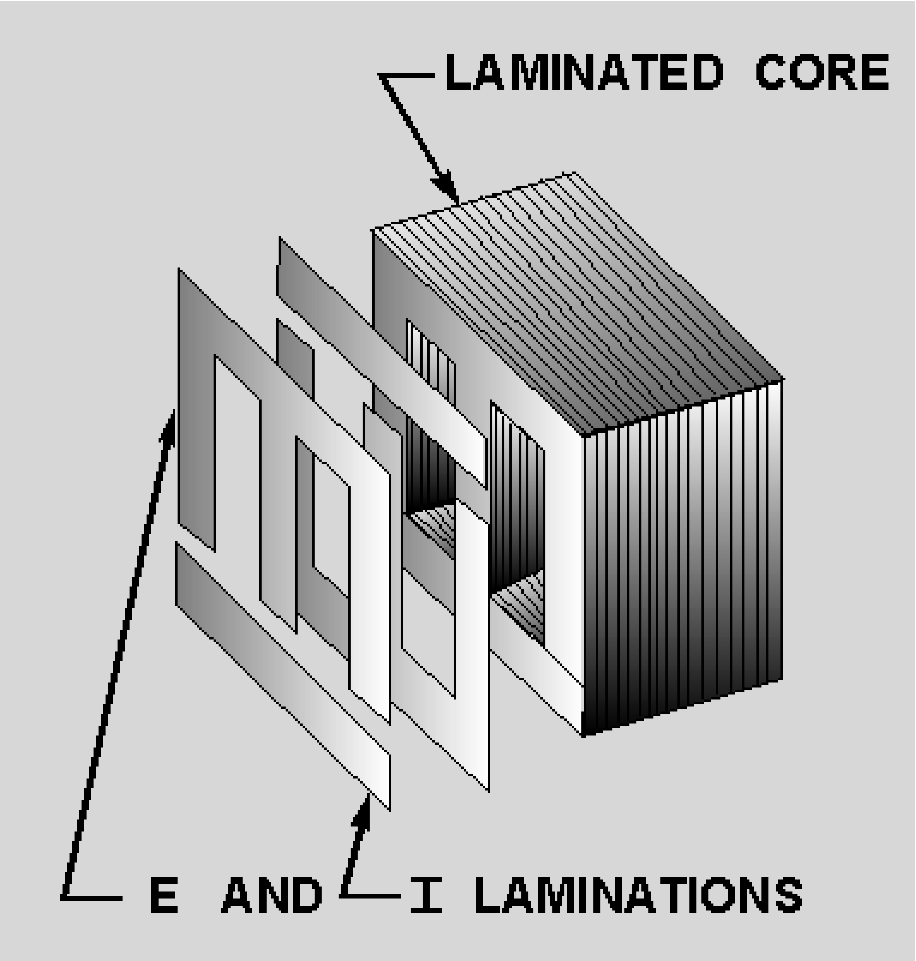


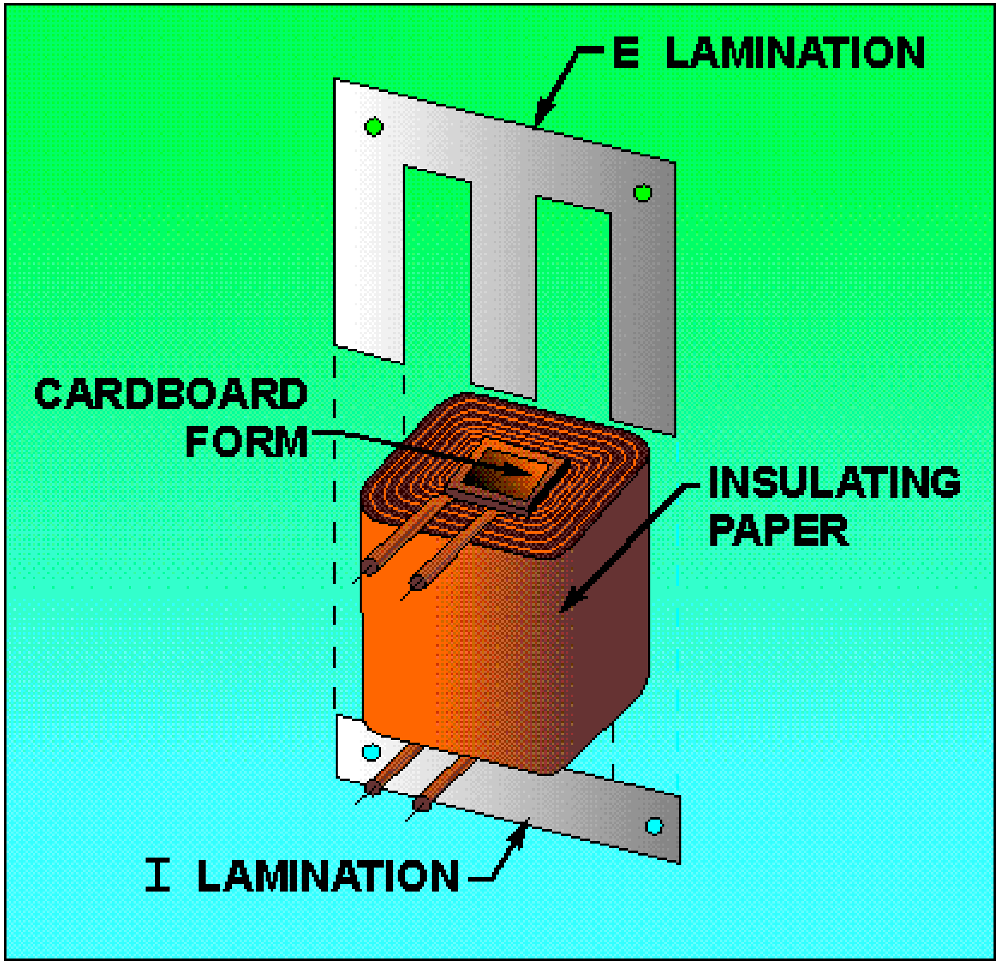
Core type (L Sheets)
Concentric coils



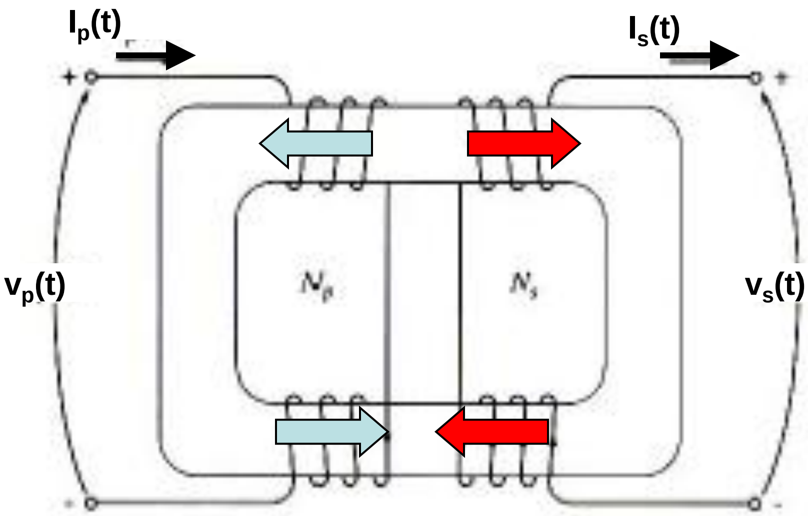
Shell type (EI Sheets)
Concentric/ pancake coils

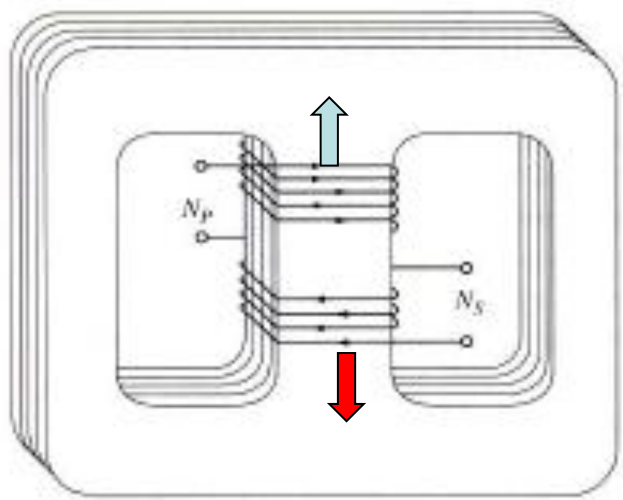
Transformer's Iron Laminated Core

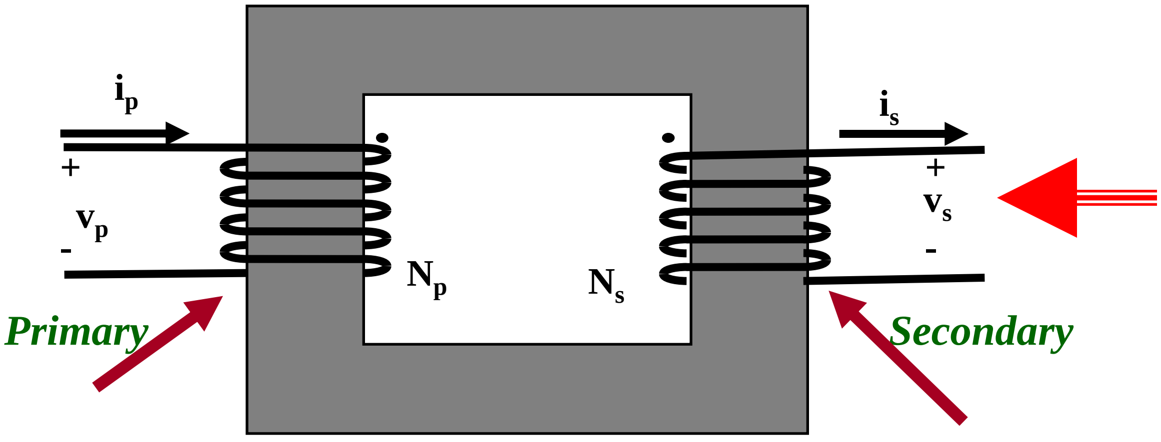




Transformer's Winding schematics



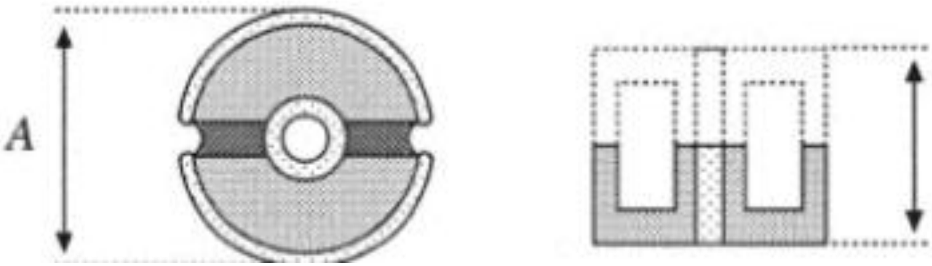




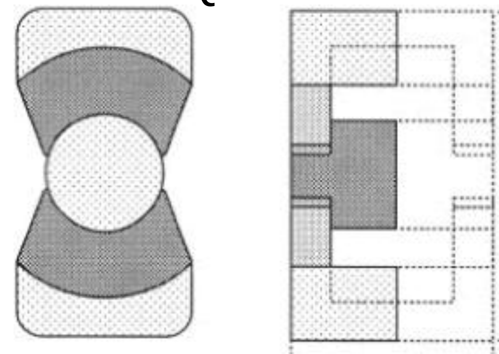
Schematic that will be used to show a transformer

Types of Ferrite Core Transformers

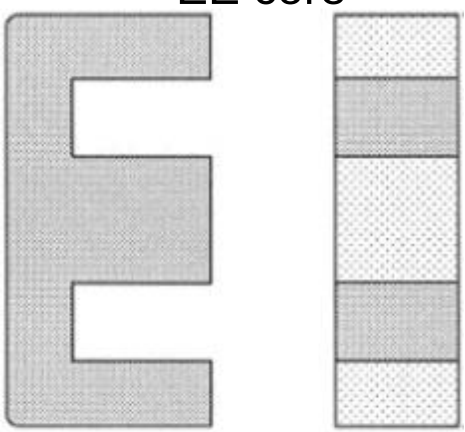
Pot core



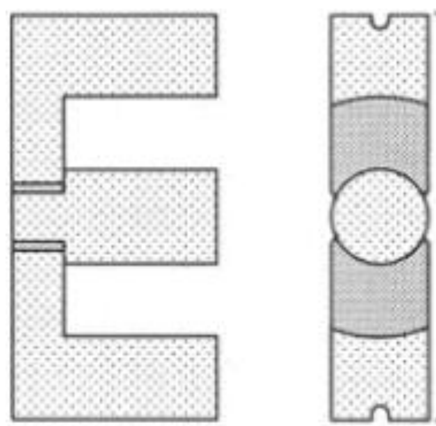
PQ core



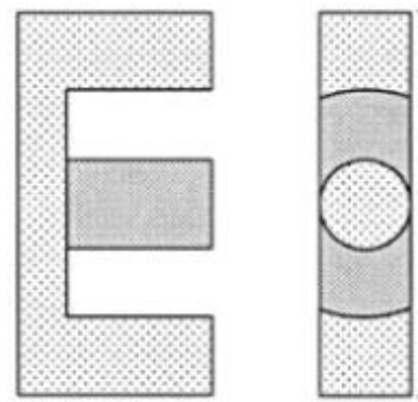
EE core



EC core



ETD core



Ideal Transformer

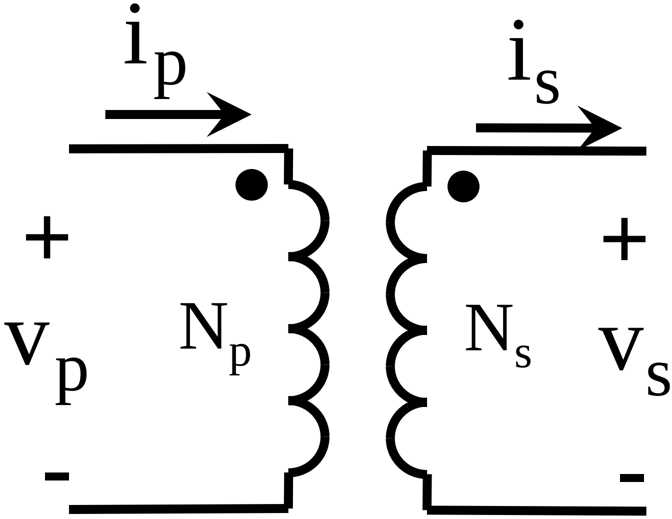
A **lossless** device with an input (**primary**) **winding** and an output (**secondary**) winding (at least).

Windings are electrically **isolated**

Relation between **input** and **output** voltages and currents are:

$$\frac{v_p(t)}{v_s(t)} = \frac{i_s(t)}{i_p(t)} = \frac{N_p}{N_s} = a$$

attention to **dotted terminals**



a : transformer **turn ratio**

Note: $\mathbf{v_p}$ and $\mathbf{v_s}$ are **in phase**
$\mathbf{i_p}$ and $\mathbf{i_s}$ are **in phase**

$$v_p(t) \times i_p(t) = v_s(t) \times i_s(t) \quad \Rightarrow \quad P_{in}(t) = P_o(t)$$

Ideal Transformer

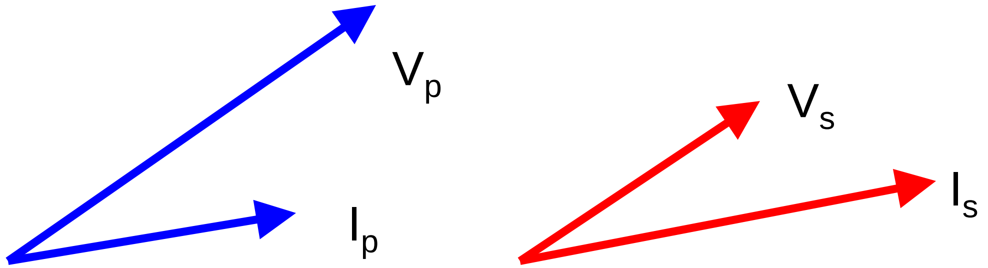
From time domain relations, phasor domain relations are:

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s} = a$$

$$S_{in} = V_p I_p^* = V_s I_s^* = S_{out}$$

$$P_{in} = P_{out}$$

$$Q_{in} = Q_{out}$$

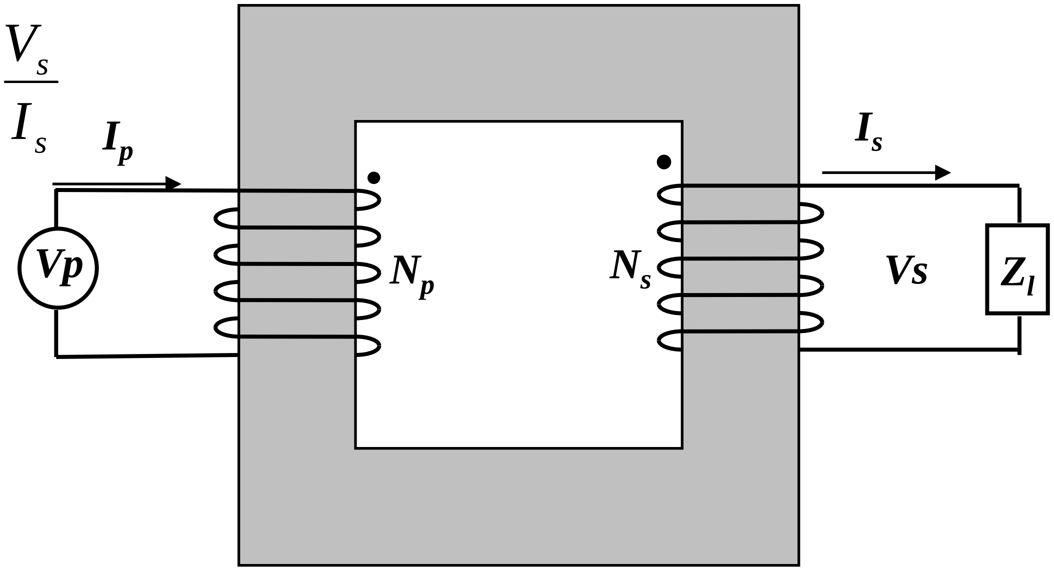


Think about a CT with open circuit in the secondary!

Think about a PT with short circuit in the secondary!

Impedance Transformation through an Ideal Transformer

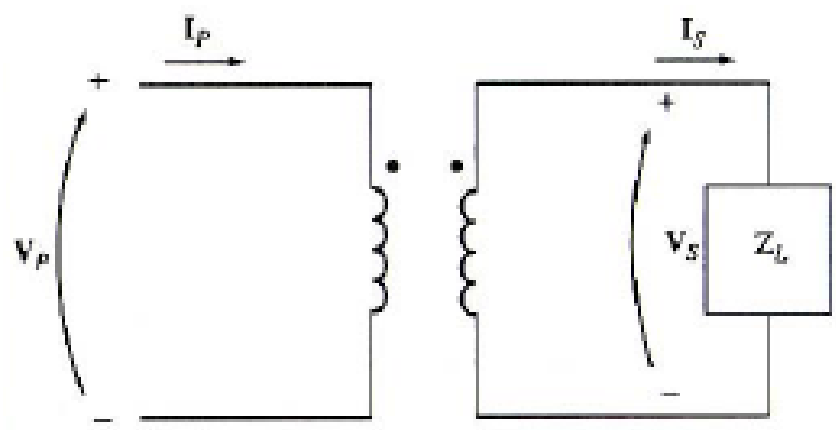
Load Impedance: $Z_l = \frac{V_l}{I_l} = \frac{V_s}{I_s}$

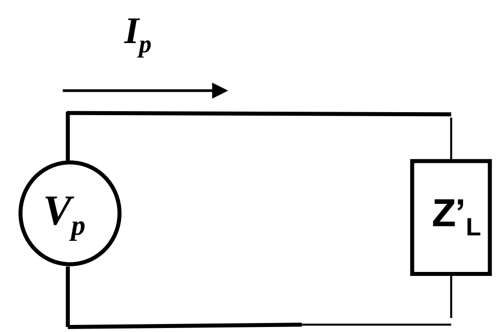


Load Impedance seen from primary winding:

$$Z_L^{'} = \frac{V_p}{I_p} = \frac{aV_s}{I_s / a} = a^2 \frac{V_s}{I_s}$$

$$Z_L^{'} = a^2 Z_L$$

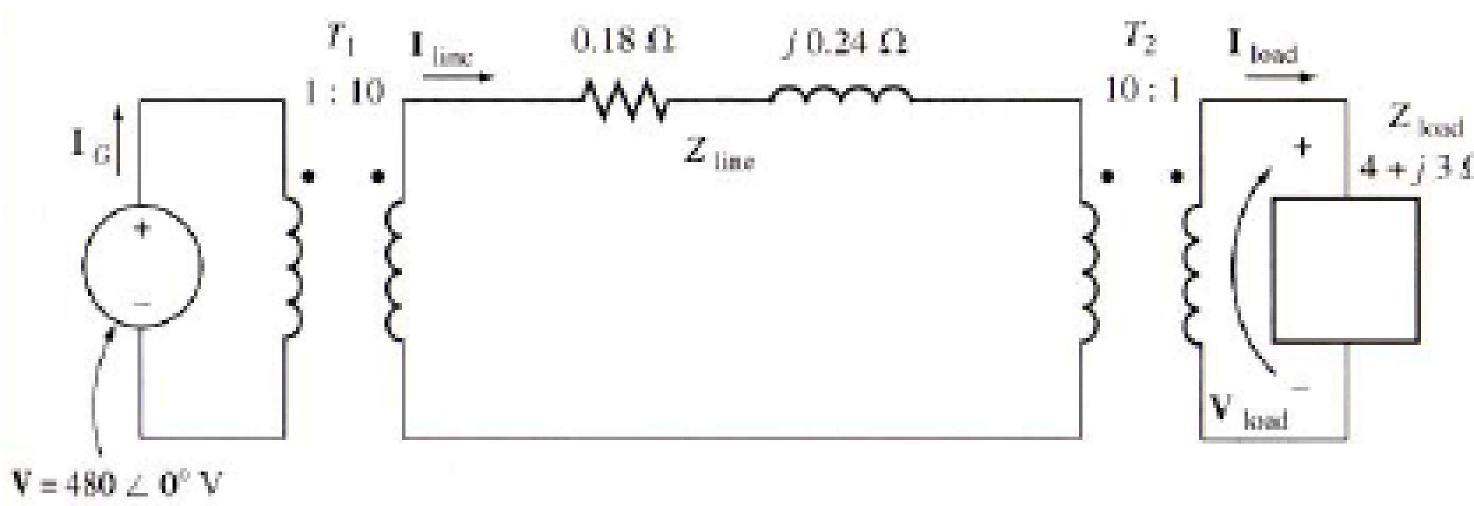




Impedance Transformation through an Ideal Transformer

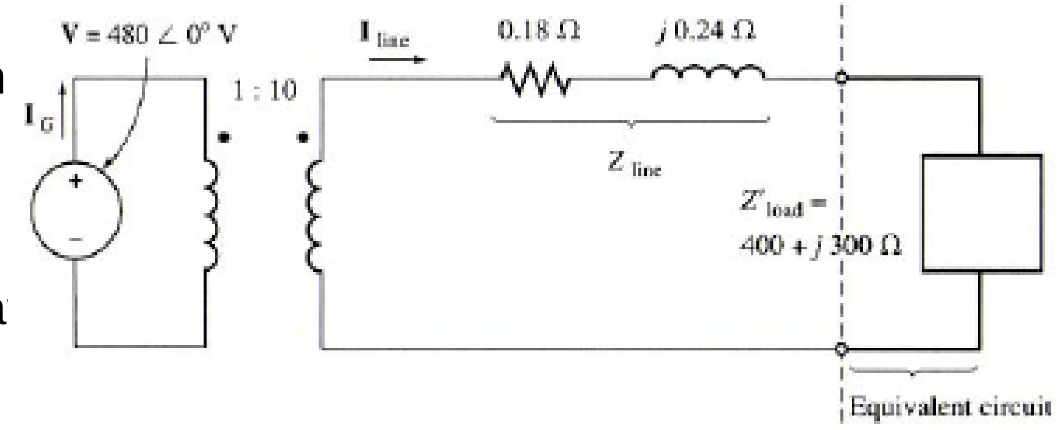
Example: A generator rated at 480V, 60 Hz is connected to a transmission line with an impedance of 0.18+j0.24Ω via a 1:10 step-up transformer. At the end of the transmission line a load of 4+j3Ω is connected through a 10:1 transformer.

What will the load voltage be?
What will the transmission line losses be?



Transfer load impedance: $Z'_{load} = Z_{load}\,(10/1)^2 = 400 + j\,300\ \Omega$

The total Impedance at transmission lin



$Z_{eq} = Z'_{load} + Z_{line} = 400.18+j300.24\Omega$

The total impedance seen from Genera

$Z'_{eq} = Z_{eq}*(1/10)^2 = 4.0018+j3.0024\Omega$

$I_G = V_G/Z'_{eq} = 480/(4.0018+j3.0024) = 95.94\angle-36.88$

Having I_G : $I_{line} = 1/10*IG = 9.594\angle-36.88$

And $I_{load} = 10*\ I_{line} = 95.94\angle-36.88$ and $V_{load} = I_{load}*Z_{load} = 479.7\angle-0.01\,V$

For the transmission Power loss: $P_{loss} = I_{line2}*R_{line} = 9{,}594^2*0.18 = 16.7$ W

Compare with the case no transformer is used