Chapter 4
Transformers

Day 24

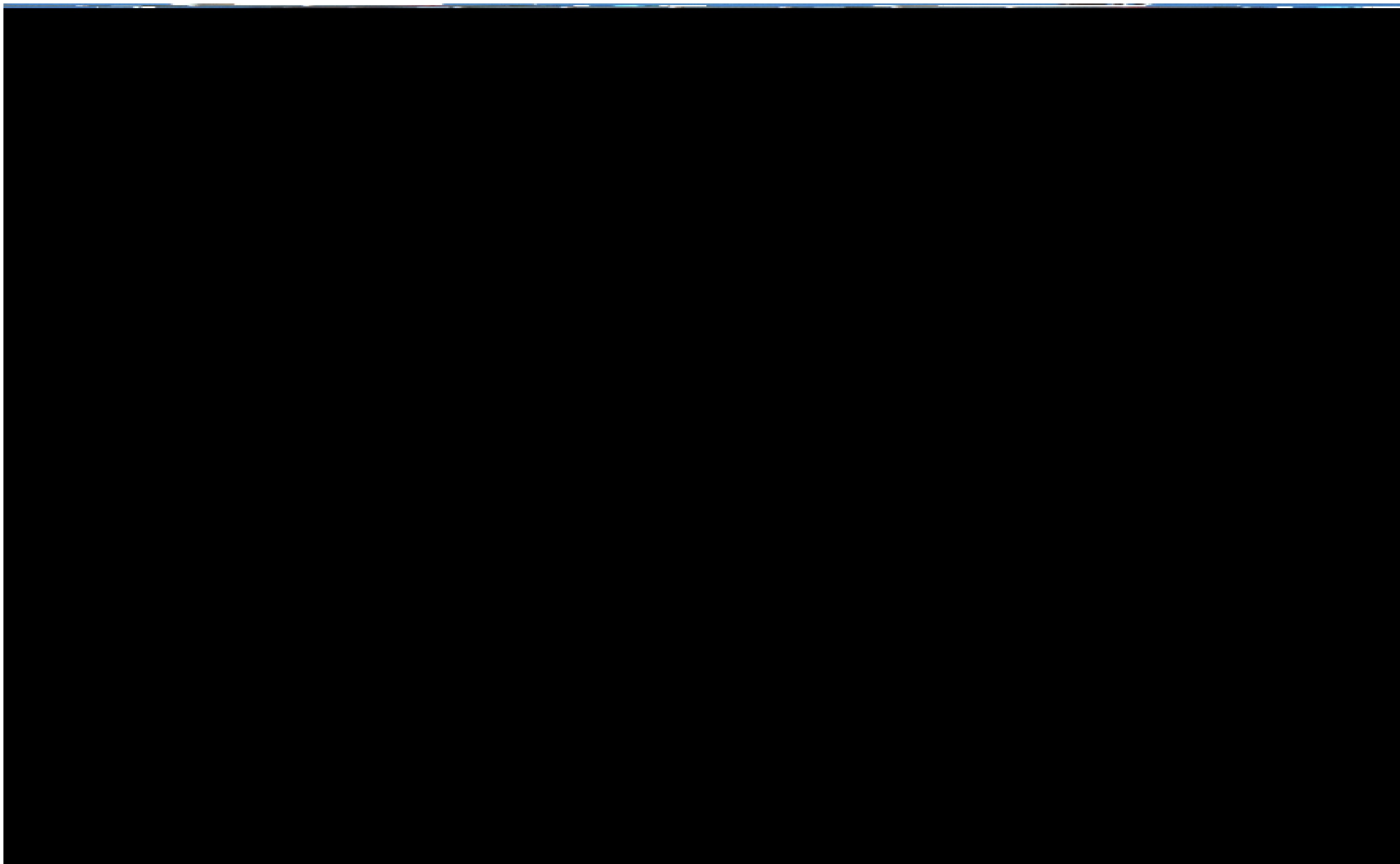
Basics

ILOs – Day 24

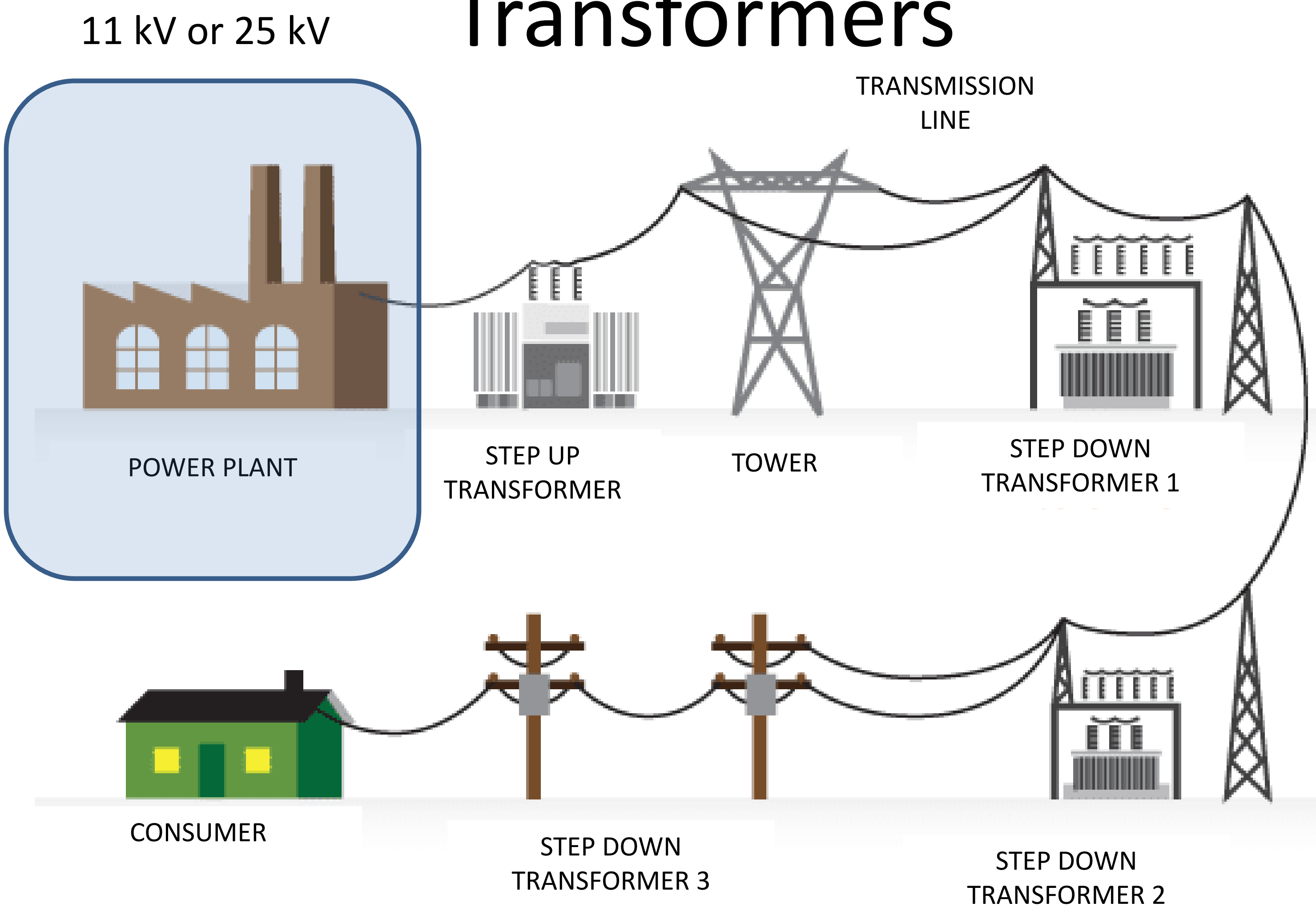
- Realize the use of transformers in real power system
- Understand the basic operating principle of a transformer
- Derive the voltage and current equations in a transformer

Transformers

Transformers

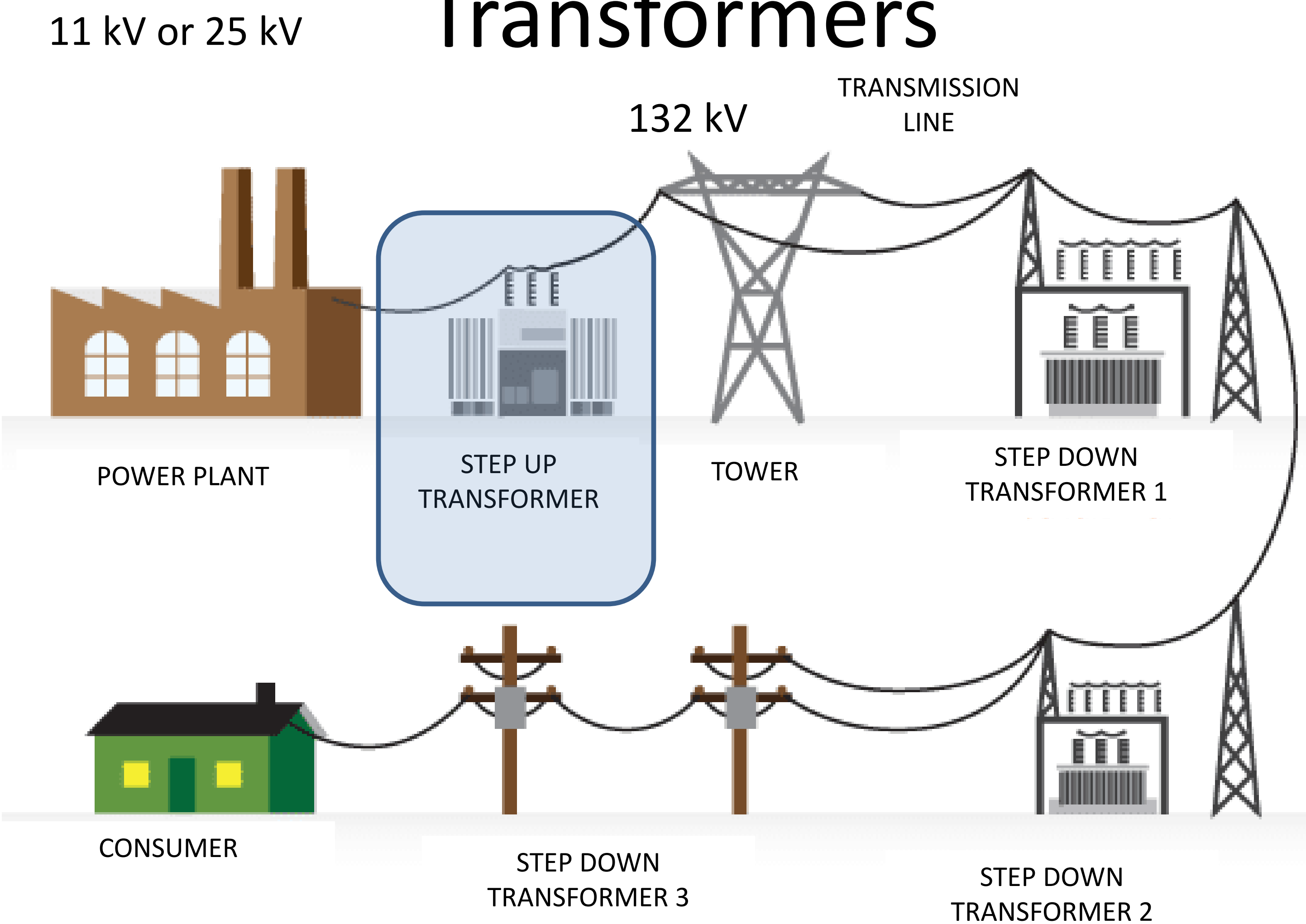


Transformers



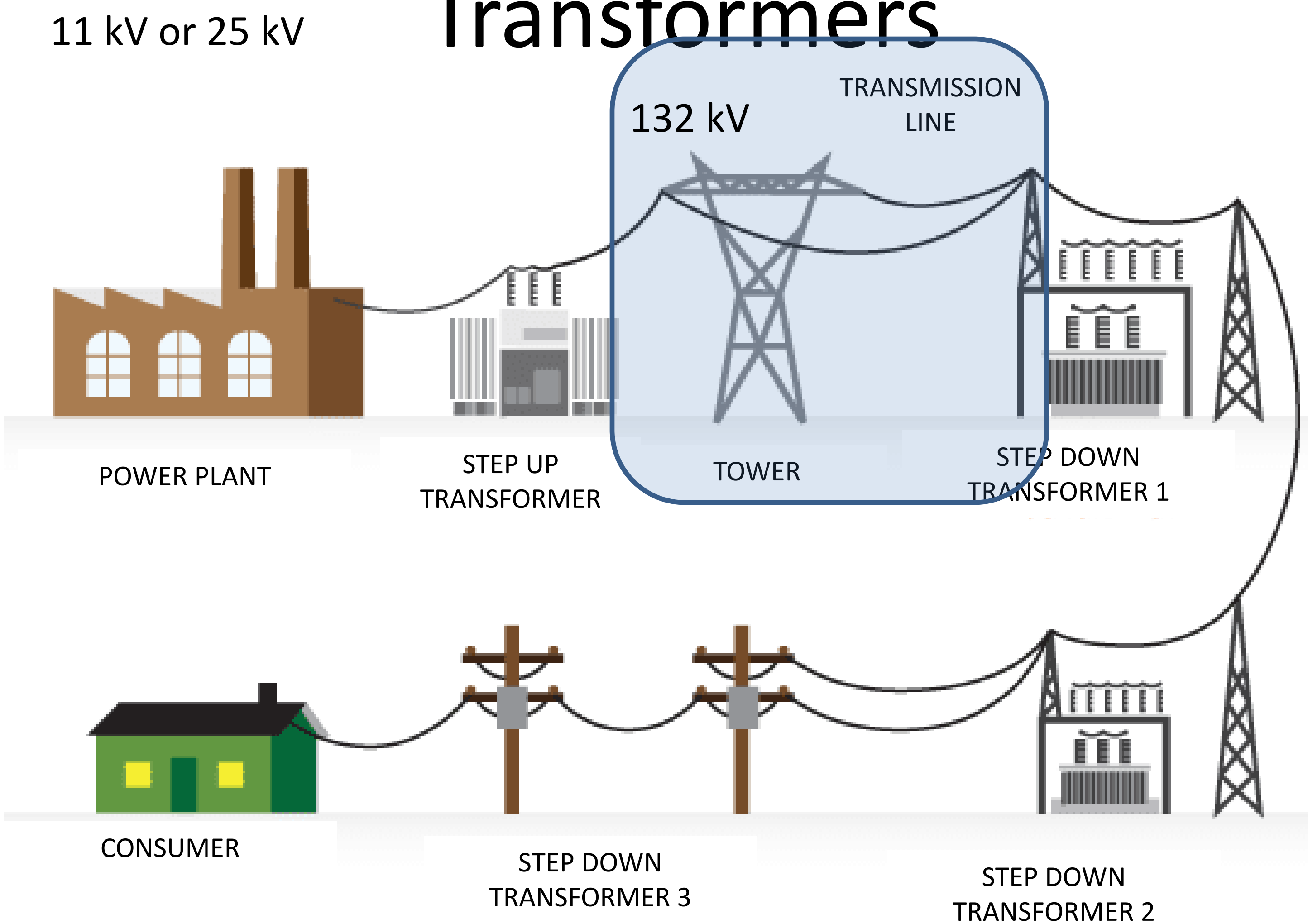
- AC electrical power generated at power stations is generally at 11 kV / 25 kV

Transformers



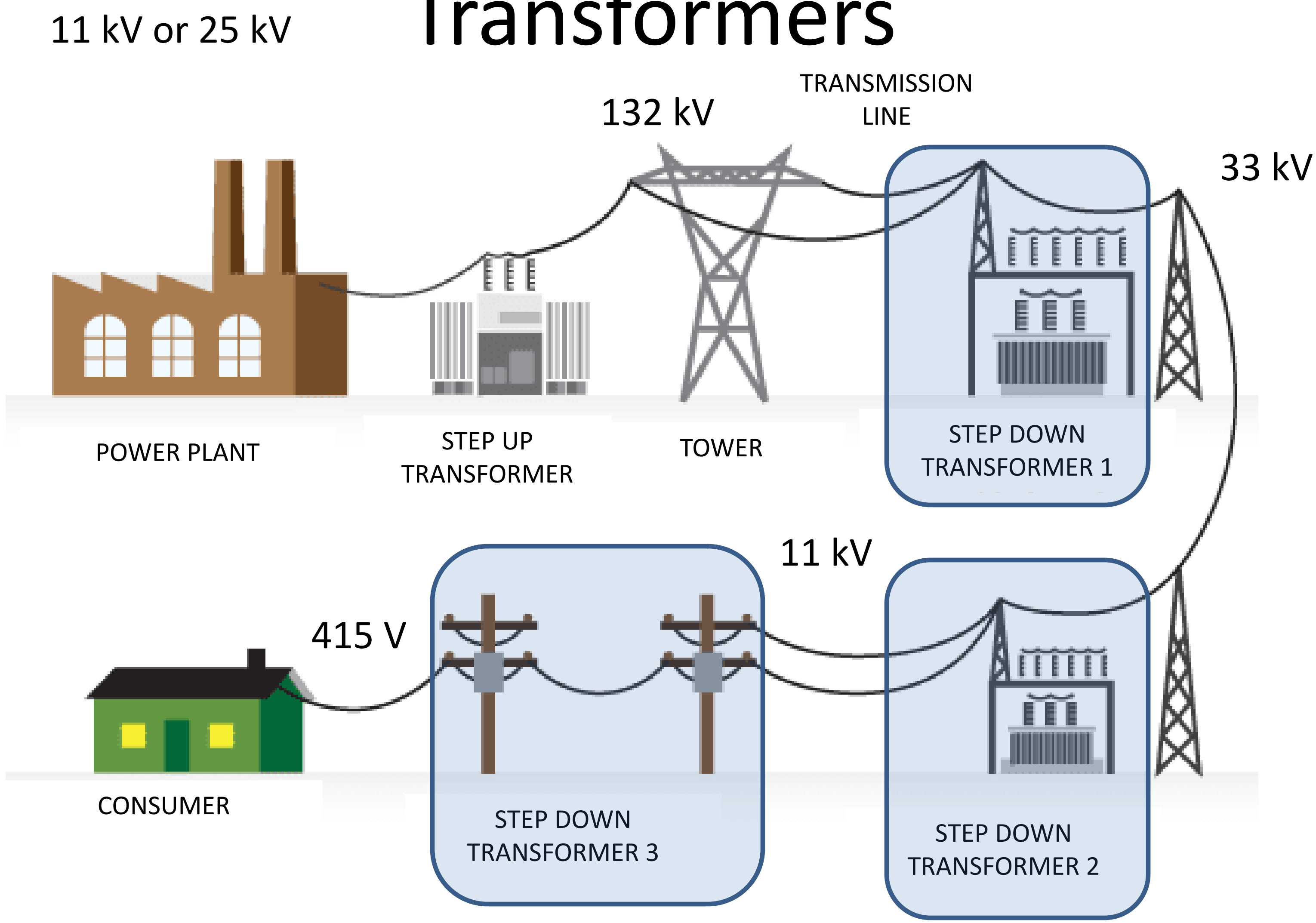
- The voltage is then **increased** to higher voltages to around 132 kV by **step-up transformers**

Transformers



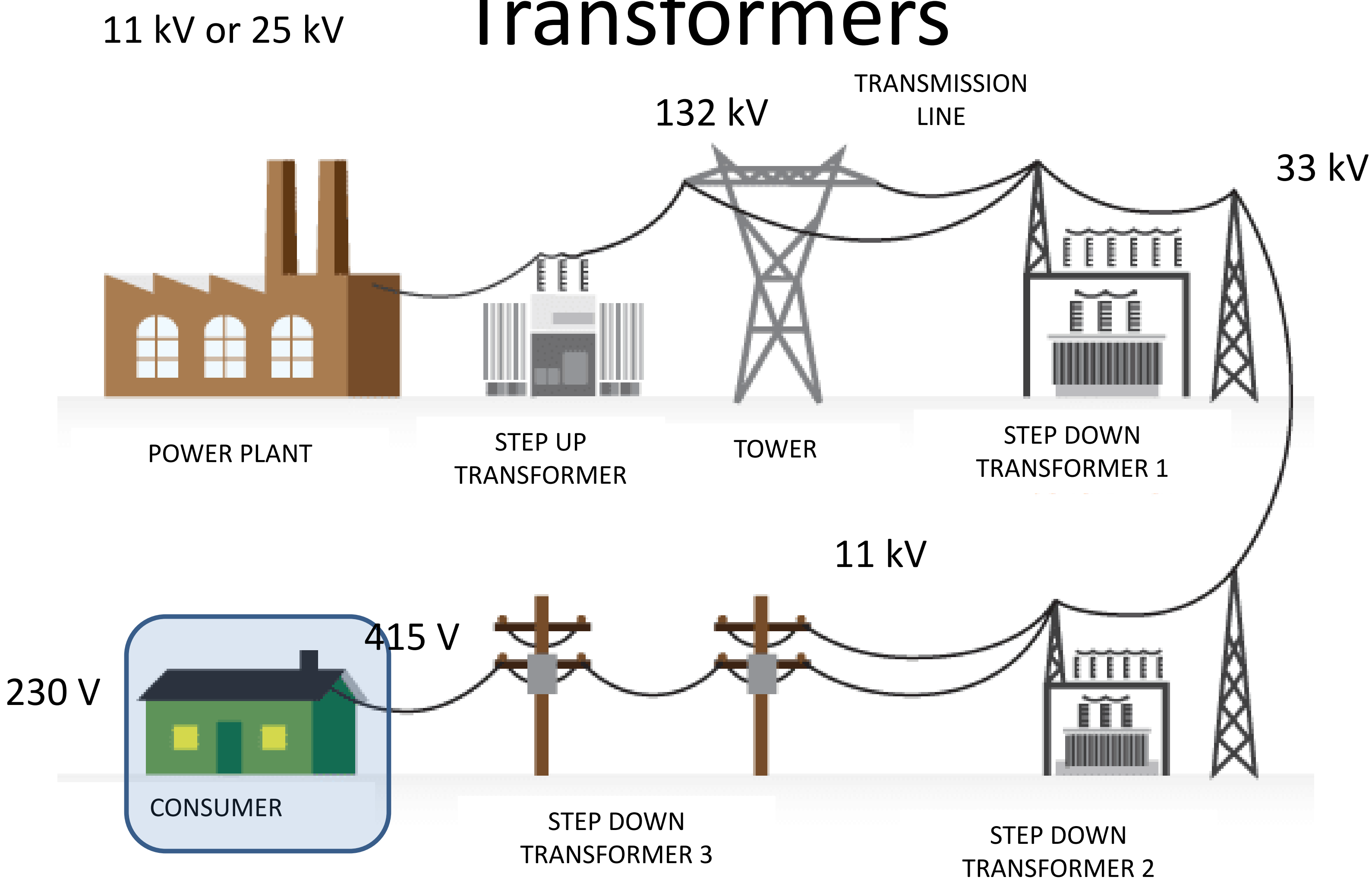
- Power is then transmitted at high voltage over long distances to reach the load centers

Transformers



- At the load centers, **step-down transformers** are used to **reduce** the high voltage to a lower value (33 kV, or 11 kV,or 415 V)

Transformers



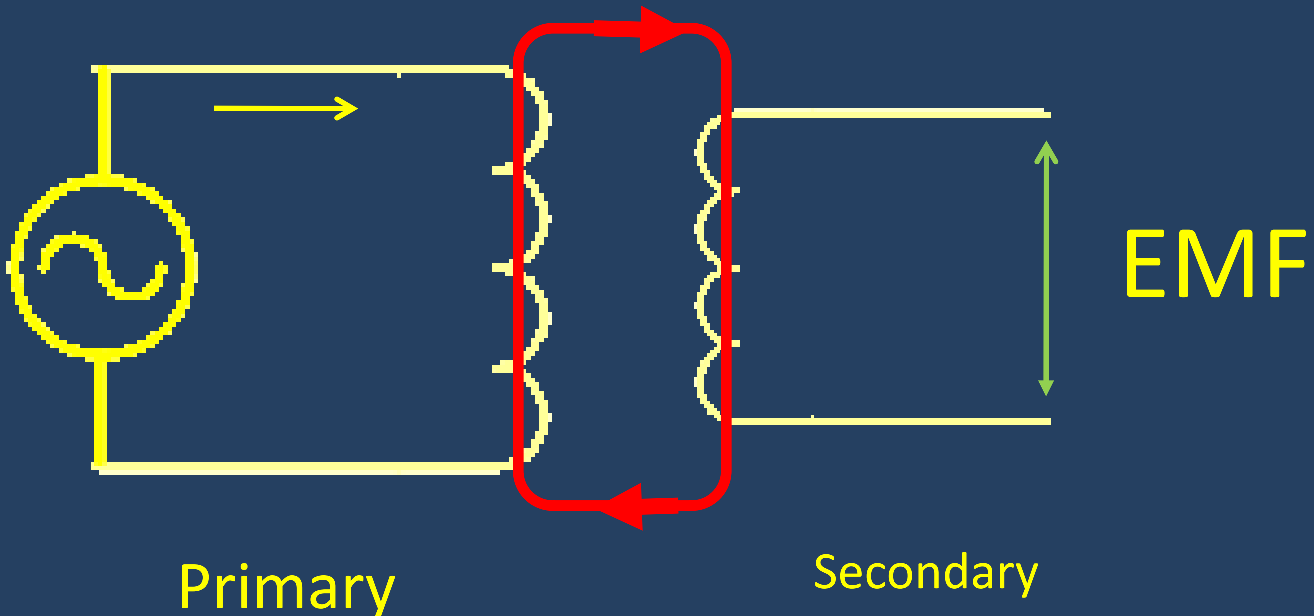
- Suitable for use by the different consumers

Definition

Transformers are **static** electromagnetic devices in which **transformation of voltage and current** occurs **without any change in frequency**, but **no transformation of energy takes place**.

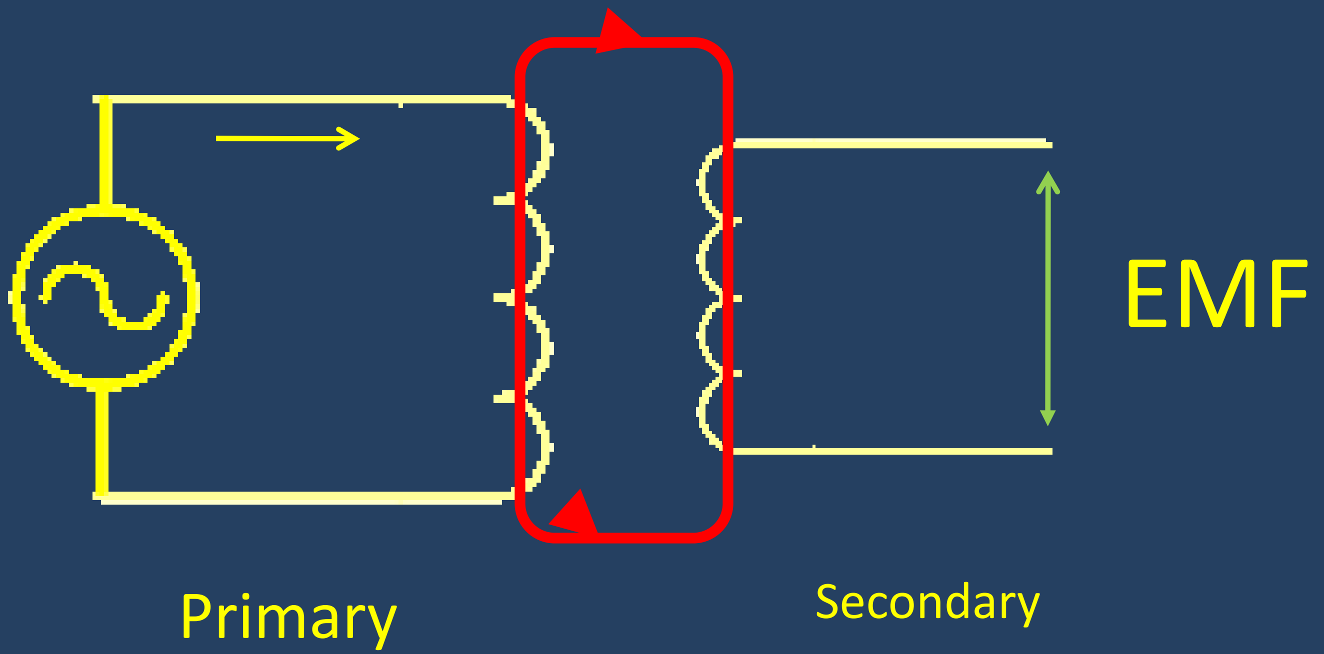
Transformers work on the principle of electromagnetic induction, i.e. **mutual coupling between two coils**.

Electromagnetic induction



- AC supply to primary coil
- AC Current flows through the primary coil
- Primary magnetic flux is created (that is also AC)
- This flux links with secondary coil
- EMF induced in secondary coil (Faraday's law)
- Thus electrical energy is transferred from P to S
- Energy transfer between P and S without electrical connection

Quiz !!



Q: If you want to transfer electrical energy, then why not join P and S directly by a pair of wires?

Induced EMF Expression

- Supply voltage sinusoidal

$$V_1 = V_{\max} \sin \omega t$$

- Supply current sinusoidal (i = v/Z)

$$I_m = I_{\max} \sin \omega t$$

- Flux proportional to current

$$\phi = \frac{N_1 I_m}{S}$$

- So flux is also sinusoidal

$$\phi = \phi_m \sin \omega t$$

Self-Induced EMF in Primary

$$\phi = \phi_m \sin \omega t$$

$$e_1 = -N_1 \frac{d\phi}{dt}$$

$$e_1 = -N_1 \frac{d}{dt}\left(\phi_m \sin \omega t\right)$$

$$e_1 = -N_1 \omega \phi_m \cos \omega t$$

$$e_1 = -N_1 \omega \phi_m \sin\left(90^0 - \omega t\right)$$

$$e_1 = N_1 \omega \phi_m \sin\left(\omega t - 90^0\right)$$

- EMF induced is also sinusoidal
- Same frequency ω as supply voltage
- 90^0 lagging to flux

Self-Induced EMF in Primary

$$e_1 = N_1 \omega \phi_m \sin\left(\omega t - 90^0\right)$$

Peak value

$$E_{m1} = N_1 \omega \phi_m = 2\pi f N_1 \phi_m$$

RMS value

$$E_1 = \frac{E_{m1}}{\sqrt{2}} = \sqrt{2}\pi f N_1 \phi_m = 4.44\, f N_1 \phi_m$$

$$E_1 = 4.44\, f \phi_m N_1$$

Mutually-Induced EMF in Secondary

Same flux links with secondary

$$\phi = \phi_m \sin \omega t$$

$$e_2 = -N_2 \frac{d\phi}{dt} \Rightarrow e_2 = N_2 \omega \phi_m \sin\left(\omega t - 90^0\right)$$

- Secondary EMF induced is also sinusoidal
- Same frequency
- 90^0 lagging to flux

Mutually-Induced EMF in Secondary

$$e_2 = N_2 \omega \phi_m \sin\left(\omega t - 90^0\right)$$

Peak value

$$E_{m2} = N_2 \omega \phi_m = 2\pi f N_2 \phi_m$$

RMS value

$$E_2 = \frac{E_{m2}}{\sqrt{2}} = \sqrt{2}\pi f N_2 \phi_m = 4.44\, f N_2 \phi_m$$

$$E_2 = 4.44\, f \phi_m N_2$$

Voltage ratio

$$E_1 = 4.44\, f\phi_m N_1$$

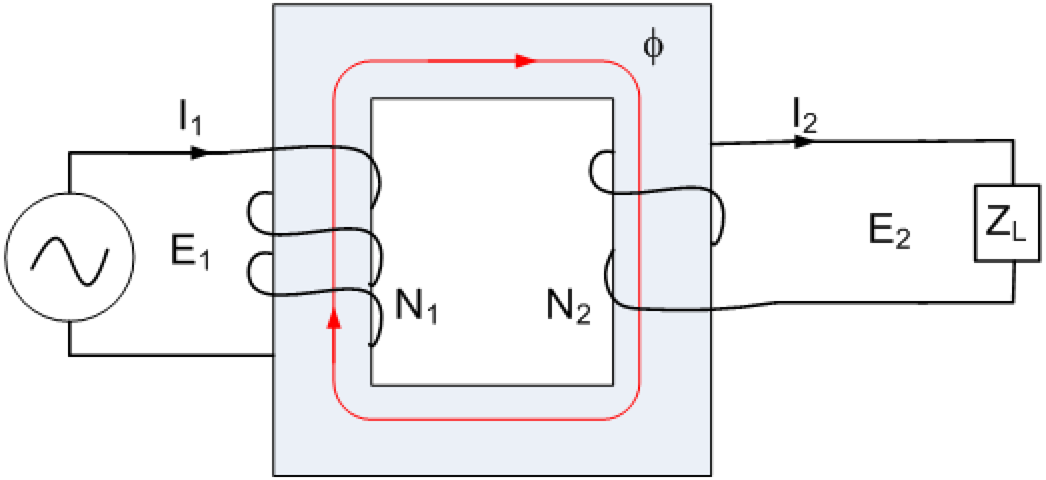
$$E_2 = 4.44\, f\phi_m N_2$$

$$\frac{E_1}{E_2} = \frac{4.44\, fN_1\phi_m}{4.44\, fN_2\phi_m} = \frac{N_1}{N_2} = a$$

Turns ratio

The voltage ratio of a transformer is thus in direct proportion to the turns ratio

Current ratio



Input power = E_1I_1

Output power = E_2I_2

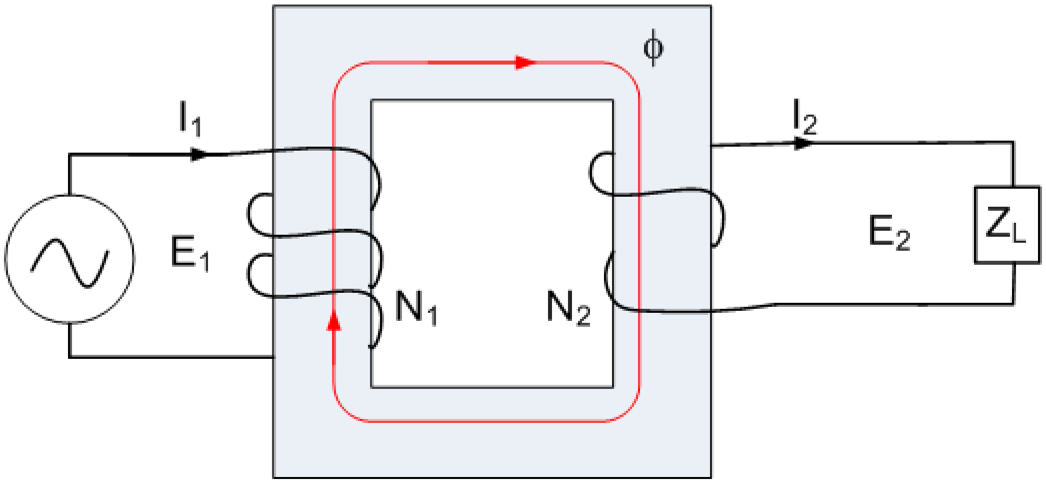
Neglecting power losses, input power = Output power

$$\mathbf{E_1I_1 = E_2I_2}$$

$$\frac{E_1}{E_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2} = a \quad \Rightarrow \quad \frac{I_1}{I_2} = \frac{1}{a}$$

The current ratio of a transformer is thus ***inversely*** *proportional to turns ratio*

Current ratio



Primary MMF = $N_1 I_1$

Secondary MMF = $N_2 I_2$

Neglecting leakage flux, the primary and secondary MMFs must balance (ideally) each other as per Lenz's law

$$\mathbf{N_1 I_1 = N_2 I_2} \quad \Rightarrow \quad \frac{I_1}{I_2} = \frac{N_2}{N_1} = \frac{1}{a}$$

The current ratio of a transformer is thus ***inversely*** *proportional to turns ratio*

- Step up transformer ($E2 > E1$)

  $\rightarrow$($N2 > N1$)

- Step down transformer ($E1 > E2$)

  $\rightarrow$($N1 > N2$)

- Isolation transformer ($E1 = E2$)

  $\rightarrow$($N1 = N2$)

Quiz

- Which winding of a transformer, the high voltage or the low voltage, will have higher current rating?

Quiz

- Can a transformer step up or step down a DC voltage?