ECE 325 – Electric Energy System Components
4- Transformers

Instructor:

Kai Sun

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Content

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- Practical Transformers (Ch. 10)
- Special Transformers (Ch. 11)
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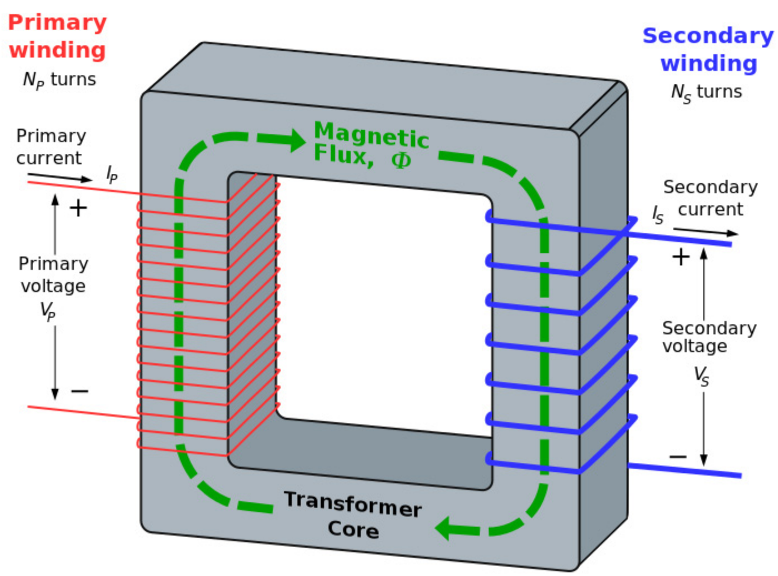
Power Transformer

- Ideal transformers
  - Winding resistance is negligible
  - No leakage flux
  - Permeability of the core is infinite (zero magnetizing current I_p is needed to produce flux)
  - No core loss



- Real transformers:
  - Windings resistance is not negligible
  - Have leakage flux (windings do not link the same flux)
  - Permeability of the core is finite
  - Have core losses (hysteresis losses and eddy current losses due to time varying flux)

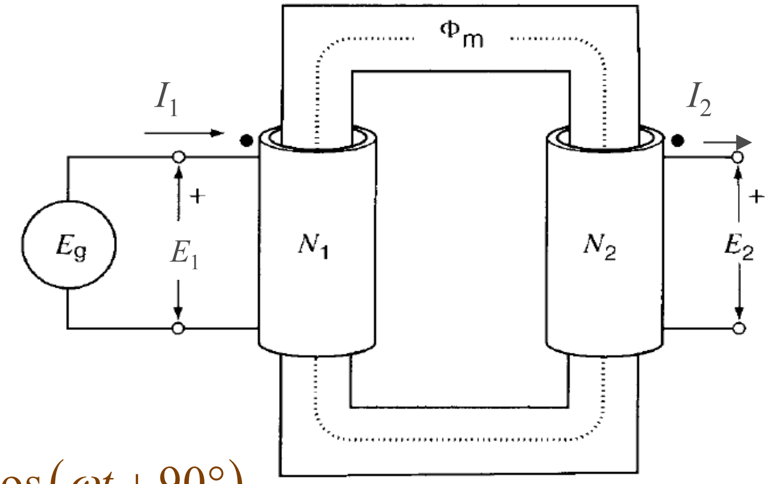
Ideal Transformer

- **Primary winding** (assuming sinusoidal flux):

  Because there is no flux leakage,

  $\phi_1 = \phi_2 = \phi_m$ (mutual flux)

  $$\phi_m = \Phi_{\max} \cos \omega t$$



$$e_g = e_1 = N_1 \frac{d\phi_m}{dt} = \omega N_1 \Phi_{\max} (-\sin \omega t) = 2\pi f N_1 \Phi_{\max} \cos(\omega t + 90°)$$

$$= E_{1\max} \cos(\omega t + 90°)$$ Leading ϕ_m by 90º

$$E_{1\max} = 2\pi f N_1 \Phi_{\max} = \sqrt{2} \times 4.44 f N_1 \Phi_{\max}$$

$$E_g = E_1 = \frac{E_{1\max}}{\sqrt{2}} \angle 90^\circ$$

$$= 4.44 f N_1 \Phi_{\max} \angle 90^\circ$$

- **Secondary winding:**

  Because there is no flux leakage

$$e_2 = N_2 \frac{d\phi_m}{dt} = -\omega N_2 \Phi_{\max} \sin \omega t$$

$$= E_{2\max} \cos(\omega t + 90°)$$

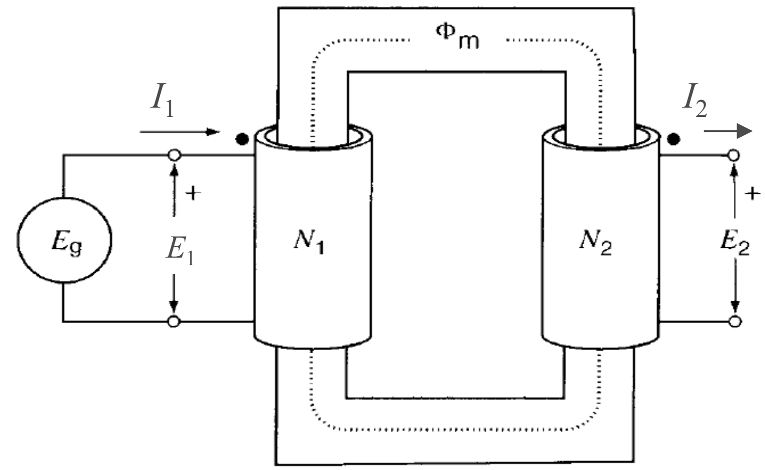
$$E_{2\max} = 2\pi f N_2 \Phi_{\max} = \sqrt{2} \times 4.44 f N_2 \Phi_{\max}$$

$$E_2 = \frac{E_{2\max}}{\sqrt{2}} \angle 90^\circ$$

$$= 4.44 f N_2 \Phi_{\max} \angle 90^\circ$$

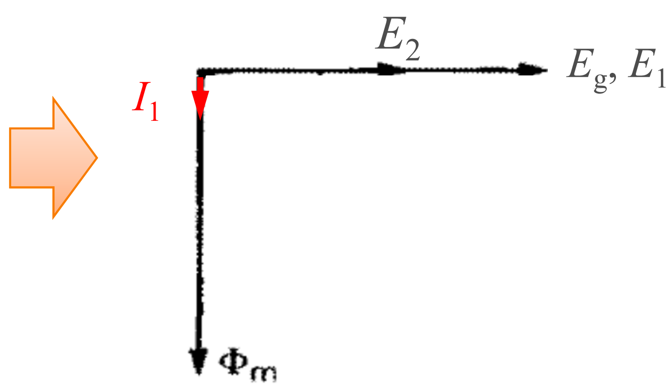
- **Voltage/turns ratio** $a = E_1/E_2 = N_1/N_2$

No-load and Load Conditions



- **Under no-load conditions,** because of infinitely permeable core, no magnetizing current is required to produce flux ϕ_m.

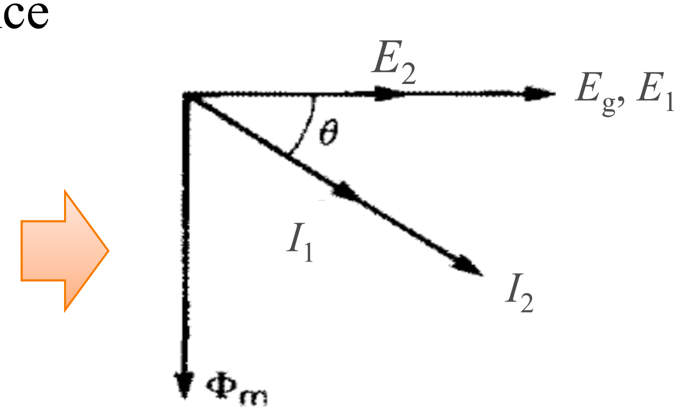
$$I_1 = I_2 = 0$$



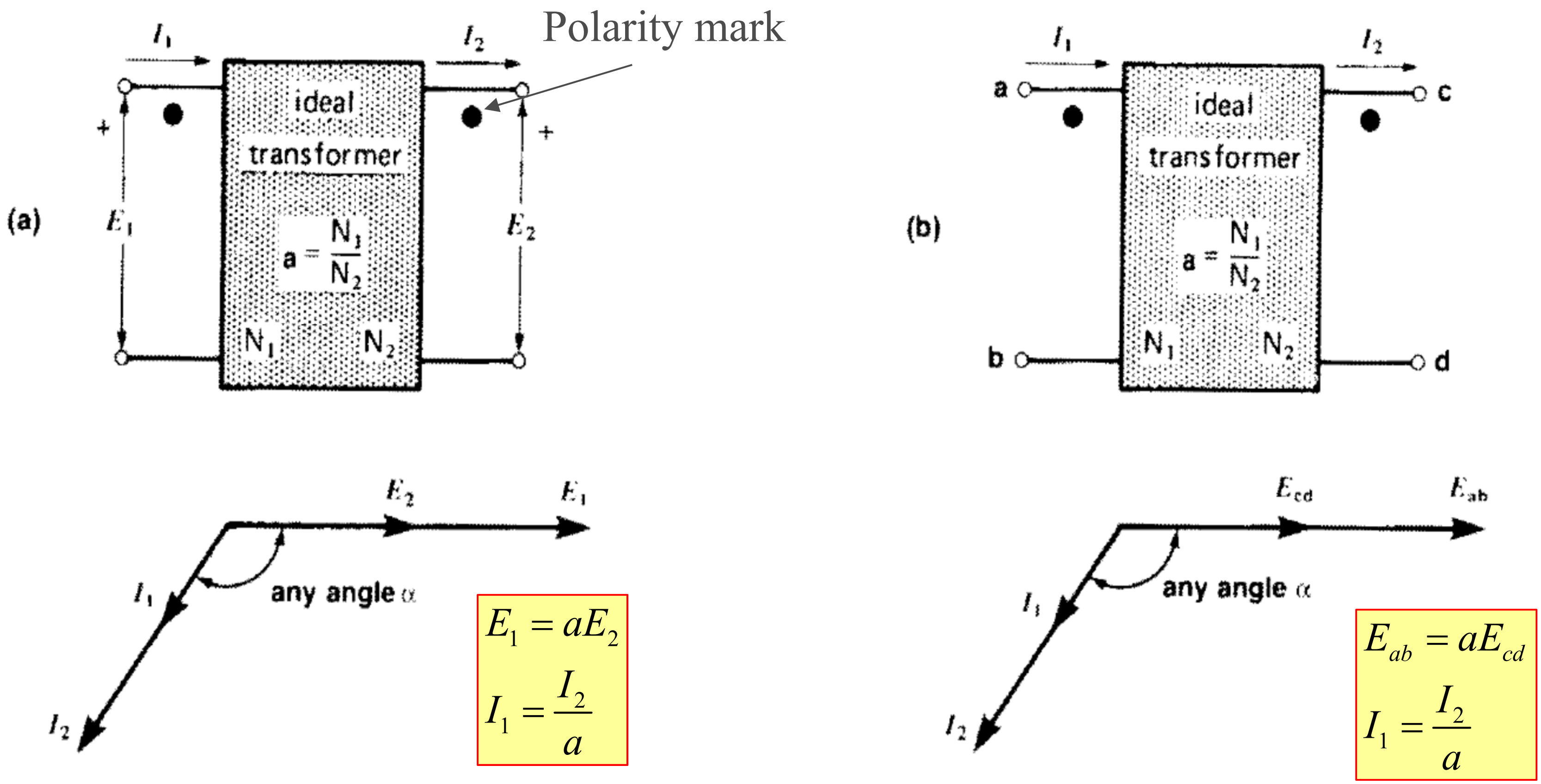
- **Under load conditions** ($I_1 \neq 0$, $I_2 \neq 0$, power factor angle θ) because of the infinitely permeable core, there is an exact mmf balance

$$F_1 = I_1 N_1 = I_2 N_2 = F_2$$

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



Circuit Symbol for an Ideal Transformer



$$E_1 = aE_2$$

$$I_1 = \frac{I_2}{a}$$

$$E_{ab} = aE_{cd}$$

$$I_1 = \frac{I_2}{a}$$

Figure 9.11

a. Symbol for an ideal transformer and phasor diagram using sign notation.

b. Symbol for an ideal transformer and phasor diagram using double-subscript notation.

Impedance Ratio

$$Z = \frac{E_2}{I_2}$$

$$E_1 = aE_2$$
$$I_1 = I_2 / a$$

$$Z_X = \frac{E_1}{I_1} = \frac{aE_2}{I_2 / a} = a^2 Z$$

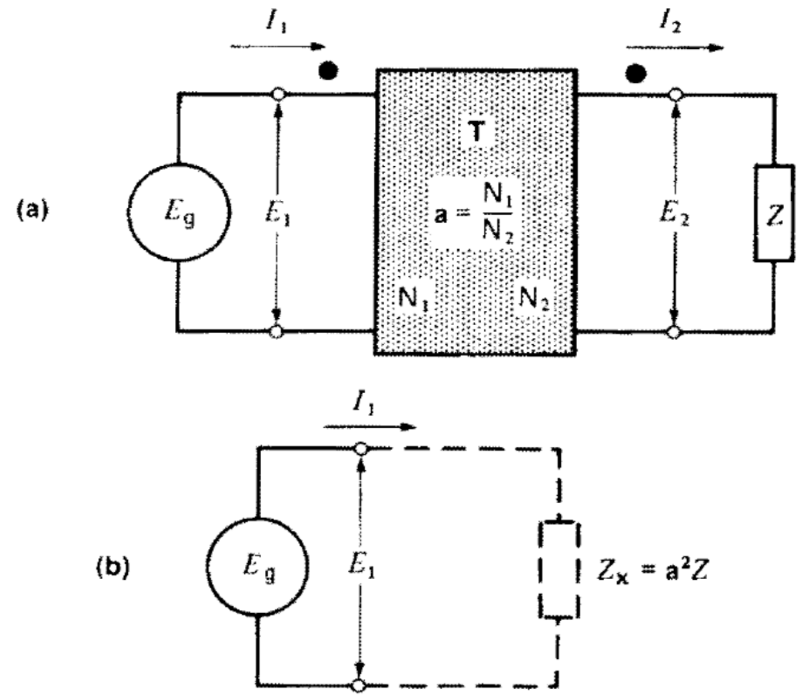
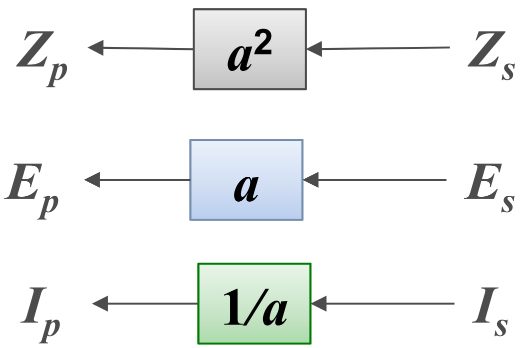
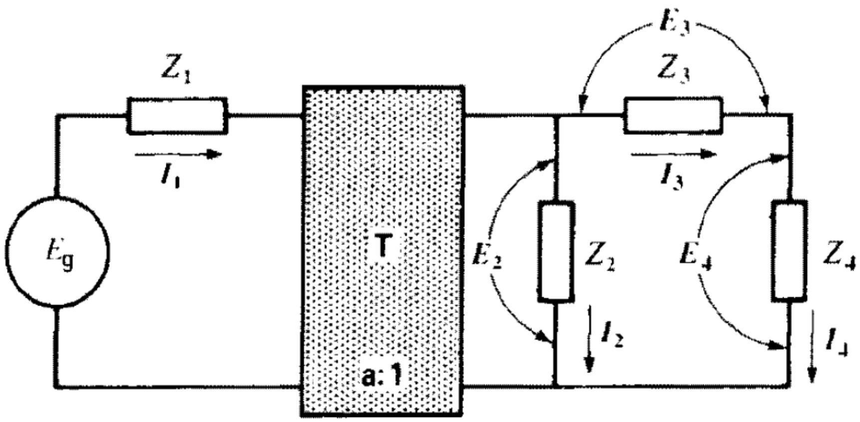


Figure 9.12
a. Impedance transformation using a transformer.
b. The impedance seen by the source differs from Z.

- **Impedance transformation**
  - The impedance seen by the source (primary side) is a^2 times the real impedance (secondary side)
  - Thus, an ideal transformer has the amazing ability to increase or decrease the value of an impedance

Shifting Impedances (P←S)





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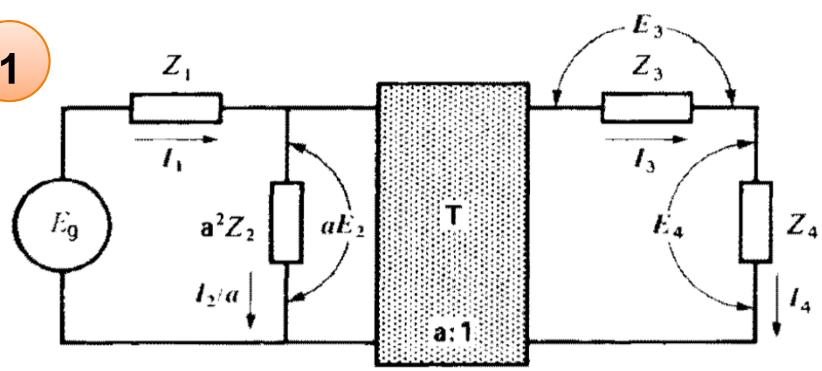

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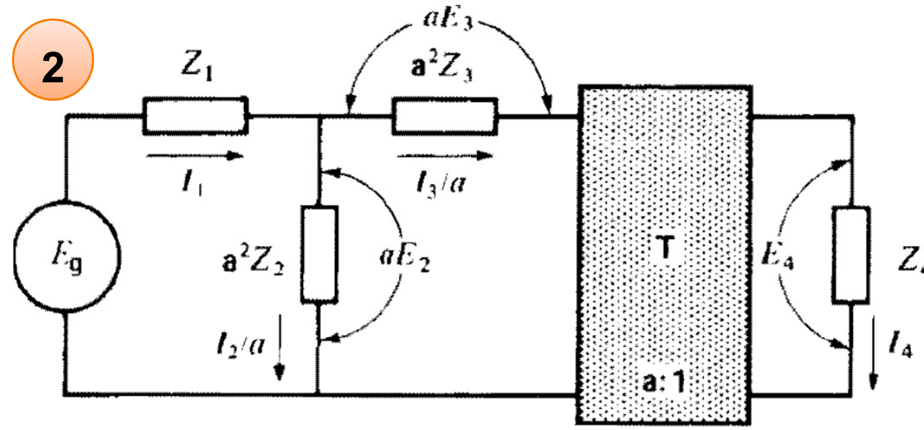

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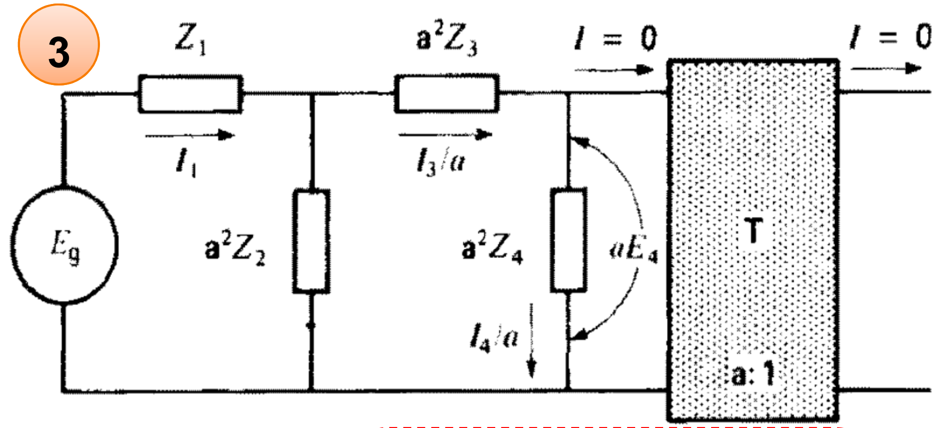

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