First Course on Power Systems

Module 5: Transformers in Power Systems

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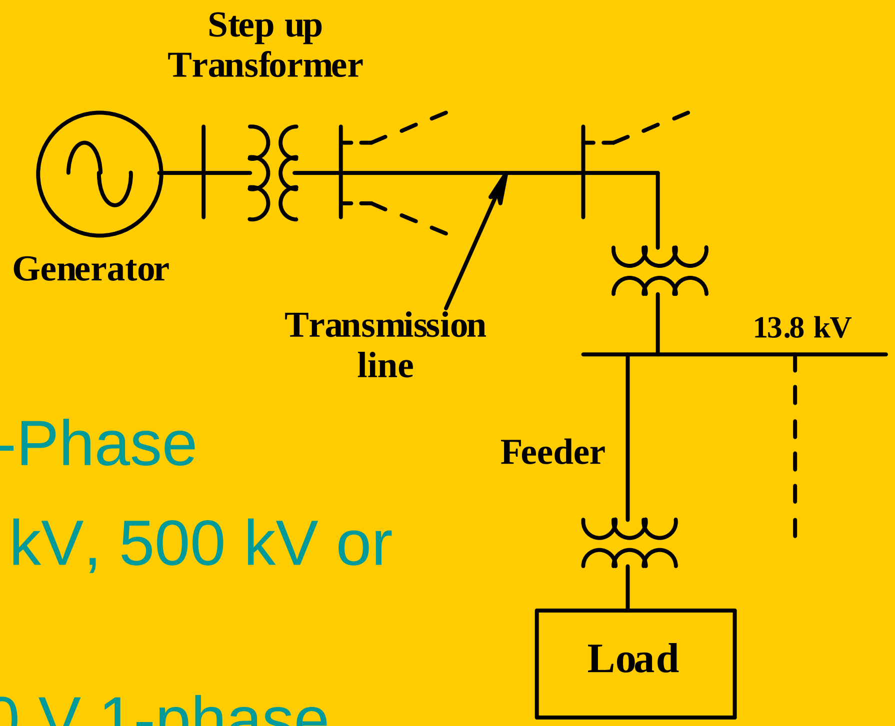
Reference Textbook:
First Course on Power Systems by Ned Mohan, www.mnpere.com

Module 5: Transformers in Power Systems

Need for transformers?



- Generation at 20-kV Level, 3-Phase
- Transmission at 230 kV, 345 kV, 500 kV or 765 kV
- Residential Usage at 120/240 V 1-phase
- Typically, voltage gets transformed 5 times
- Electrical Isolation for safety

Transformer Principle: Generation of Flux

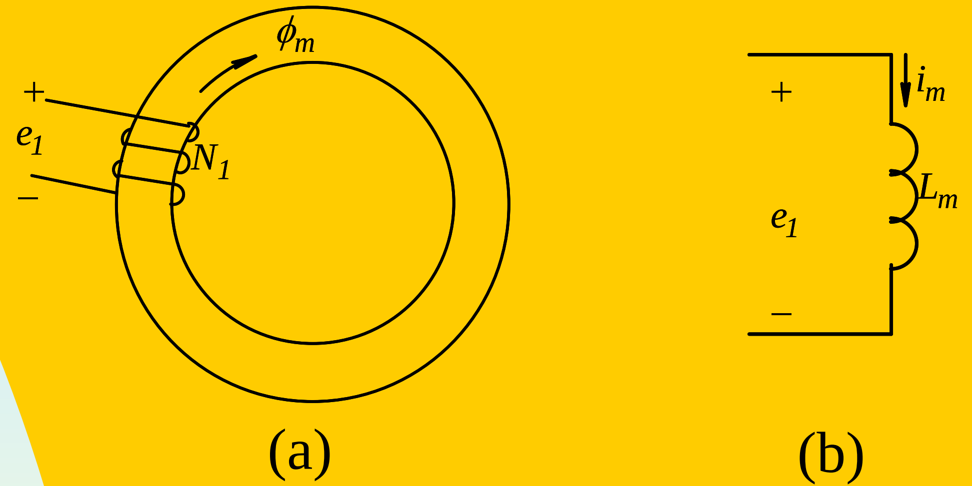
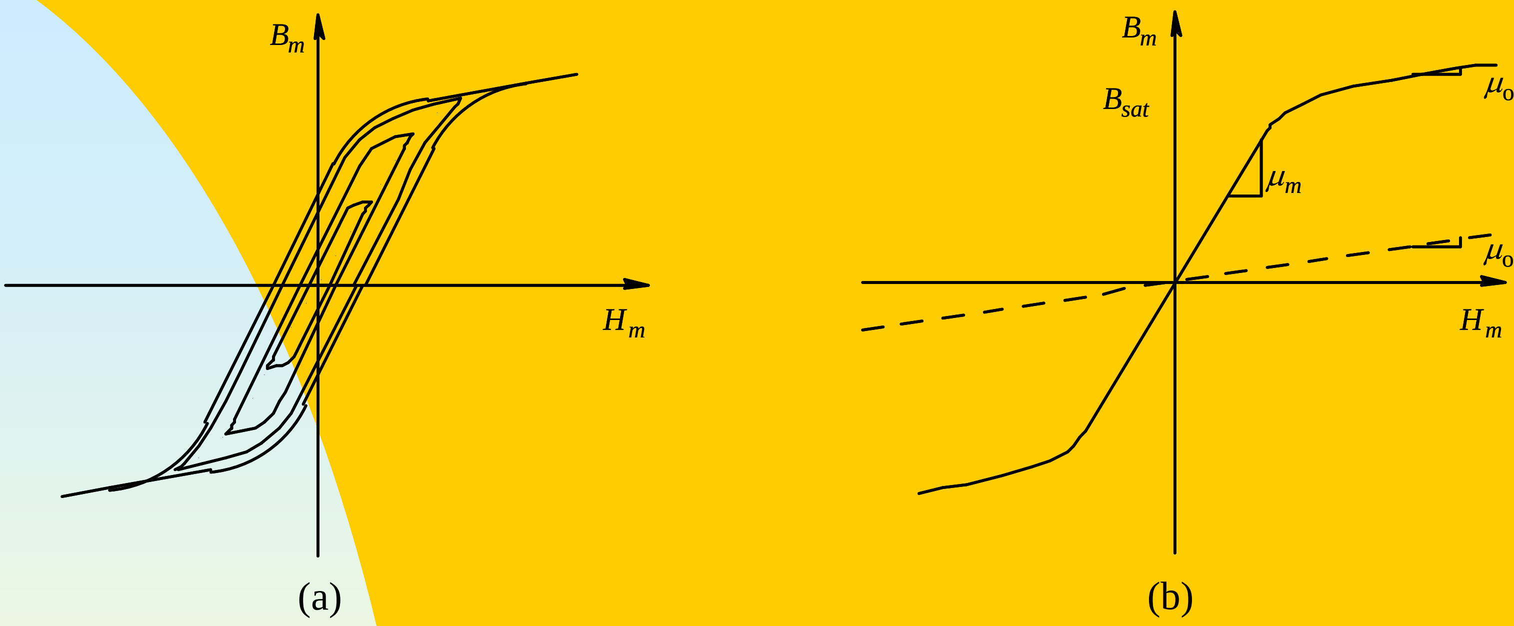


Fig. 6-1 Principle of transformers, beginning with just one coil.

$$e_1(t) = N_1 \frac{d\phi_m}{dt}$$

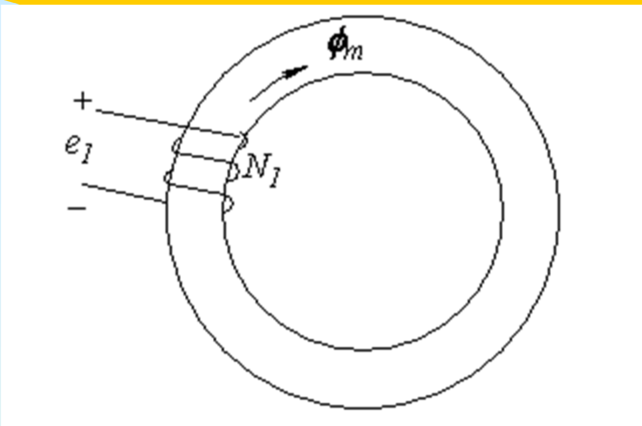
$$\phi_m(t) = \frac{1}{N_1} \int_0^t e_1(\tau) \cdot d\tau$$

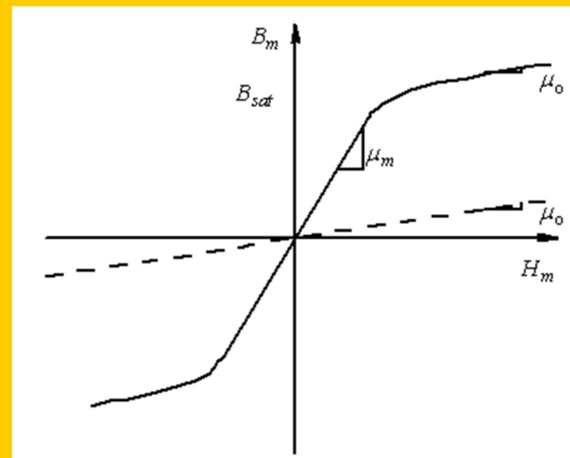
Transformer Exciting Current:



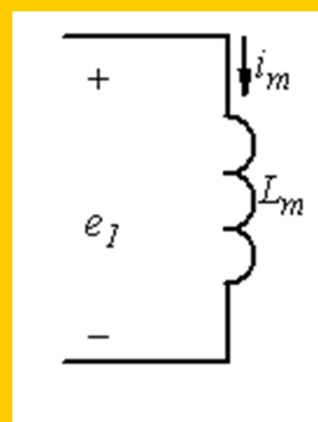
- Core of Ferromagnetic Material such as Silicone Steel
- Hysteresis Loss
- Saturation beyond the “knee”; incremental permeability of air
- Operated at 1.6 T to 1.8 T

Magnetizing Current:





$$L_m = \frac{\lambda_m}{i_m}$$



Magnetizing Flux

$$e_1 = \sqrt{2}E_1(rms)\cos\omega t$$

$$\phi_m(t) = \frac{1}{N_1}\int_0^t e_1(\tau)\cdot d\tau$$

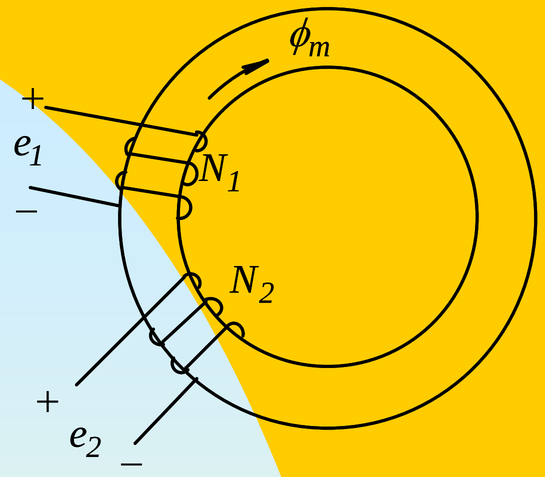
$$\phi_m = \hat{\phi}_m \sin\omega t$$

$$\sqrt{2}E_1(rms) = \left(2\pi f\right)N_1\hat{\phi}_m$$

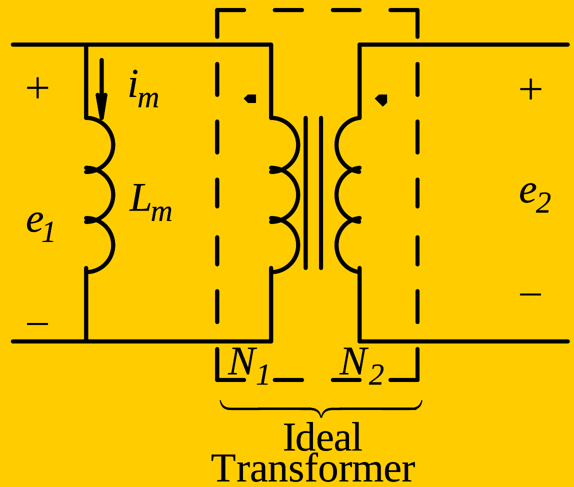
$$\hat{\phi}_m \simeq \frac{E_1(rms)}{4.44N_1 f}$$

- Exceeding the rated voltage causes saturation
- Modern Power Transformer: Magnetizing Current < 0.2% rated

Voltage Transformation



(a)

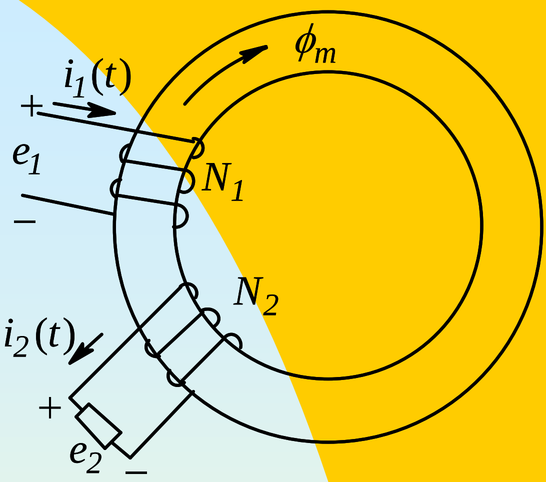


(b)

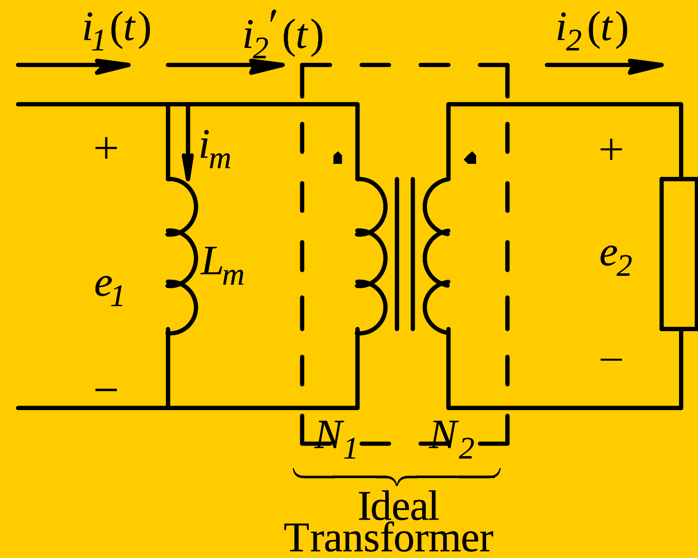
$$e_1(t) = N_1 \frac{d\phi_m}{dt} \qquad e_2(t) = N_2 \frac{d\phi_m}{dt}$$

$$\frac{e_1(t)}{N_1} = \frac{e_2(t)}{N_2} \qquad \frac{e_1(t)}{e_2(t)} = \frac{N_1}{N_2} \qquad \frac{\bar{E}_1}{\bar{E}_2} = \frac{N_1}{N_2}$$

Transformer with Load Connected to the Secondary



(a)



(b)

$$N_1 i_2' = N_2 i_2$$

$$\frac{i_2'(t)}{i_2(t)} = \frac{N_2}{N_1} \qquad \frac{\bar{I}_2'}{\bar{I}_2} = \frac{N_2}{N_1}$$

$$i_1(t) = i_m(t) + i_2'(t) \qquad \bar{I}_1 = \bar{I}_m + \bar{I}_2'$$

Transformer Equivalent Circuit: