Unit 3.3: Transformer Magnetizing Inrush

The transformer has a magnetic core which links the primary and secondary (and possibly tertiary) windings. This core has nonlinear characteristics which can cause large inrush current magnitudes when a transformer is energized. To see how this occurs we need to review a few fundamentals of magnetic circuits. Fig. 3.5 shows a schematic of a simple transformer. The primary side has N_1 turns while the secondary side has N_2 turns.

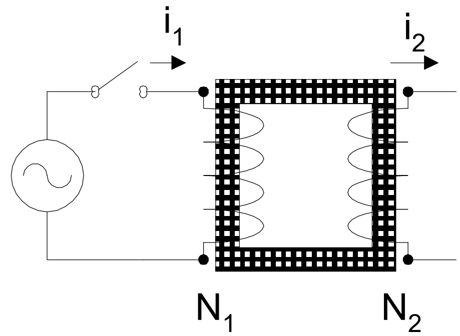

Fig. 3.5 Two-Winding Transformer

The relationship between the magnetic field intensity H, the length, l that the magnetic flux takes through the core, and the primary and secondary current is given by

$$N_1 i_1 - N_2 i_2 = Hl \qquad (3.18)$$

This is based on the assumption that the magnetic field intensity is uniformly distributed.

The magnetic flux density, B is related to the magnetic field intensity by the core permability, μ. The relationship between B and H is nonlinear, as illustrated below.

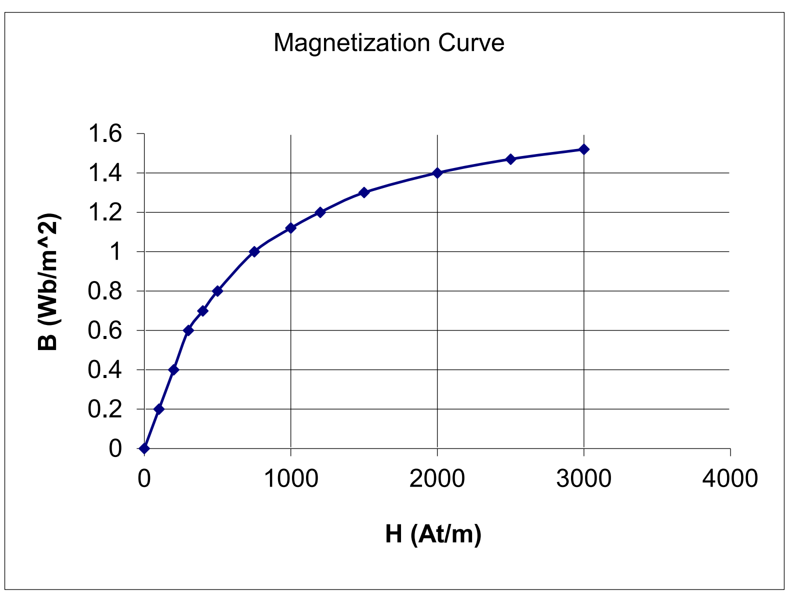

Fig. 3.6 Magnetization Curve

The magnetic flux, φ is related to the magnetic flux density by the cross-sectional area, A of the core path. For a uniform flux density

$$\varphi = BA \tag{3.18}$$

The final relationship that we will need is that between the coil voltage and the magnetic flux flowing through it. This relationship is given by Faraday's law where

$$e(t) = N_1 \frac{d\varphi}{dt} \tag{3.19}$$

Suppose that we have a voltage source connected at t=0 with

$$v_s(t) = \sqrt{2}V_m \sin(\omega t + \theta) \tag{3.20}$$

When the switch is closed, the internal flux and the voltage will be related by

$$\varphi(t) = \frac{1}{N_1}\int_0^t \sqrt{2}V_m \sin(\omega t + \theta)\,dt + \varphi_R \tag{3.21}$$

where φ_R represents residual flux that existed in the core due to the last energization of the transformer.

Evaluating (3.21)

$$\varphi(t) = \frac{\sqrt{2}V_m}{\omega N_1}\left(-\cos(\omega t + \theta) + \cos(\theta)\right) + \varphi_R \tag{3.22}$$

Note that in steady-state, the steady-state flux after the transients have died out would be given by

$$\varphi_{ss}(t) = \frac{-\sqrt{2}V_m}{\omega N_1}\cos(\omega t + \theta) = -\varphi_m \cos(\omega t + \theta) \tag{3.23}$$

For the case where $\theta = 0^o$, then one-half cycle after the transformer is energized, the peak flux reaches

$$\varphi_{peak} = \frac{\sqrt{2}V_m}{\omega N_1}(2) + \varphi_R = 2\varphi_m + \varphi_R \tag{3.24}$$

This large value of flux corresponds with a large magnetic flux density.

Note from the magnetization curve that as B increases, then the material saturates, resulting in much higher values of magnetic field intensity, H. Since the magnetic field intensity, H is directly proportional to the current, then this saturation will cause a large current inrush magnitude. This current inrush can accidently cause relays to operate or fuses to blow.