Topics for Today:

• Announcements
  • Software: Matlab? Will begin using as early as next week.
  • Office hrs: 2pm, M,W,F (will try this, can adjust if needed)
  • Office: EERC 614. Phone: 906.487.2857
  • Ch.2 Solutions posted on web page, go thru them for review.
  • XFMR exercises will be posted, due earliest Sep 11th

• Chapter 2 - Review: Transformers and circuits w/transformers
  • Single phase transformers
  • Basic structure: winding R and Leakage, Core losses and saturation
  • 3-phase transformer banks and phase shifts (ANSI/IEEE vs. IEC)
  • Standard 30°shift transformers, non-standard connections
  • Pos/neg sequence phase shifts
  • Autotransformers
  • Load Tap Changing (LTC) transformers

• Comments on sequence networks

1. Core (no-load) losses minimized by utilizing laser-scribed, super-grain-oriented steel.
2. Lamination width customized to achieve a near perfect-circle core cross section, resulting in the efficient use of materials plus a lighter, more compact, high performance transformer.
3. Coil assembly rigidly braced in a high-strength frame that distributes clamping forces around the full circumference of the windings.
4. Submerged-arc welding process produces deep penetration welds, virtually eliminating leakage from welded tank joints.
5. Inside tank surfaces are painted white to facilitate internal inspection.
6. Transformer exterior coated to a minimum thickness of 3 mils; this coating has superior endurance characteristics and meets the ANSI C57.12.28 standard.
7. Galvanized radiators provide excellent corrosion resistance and require minimal maintenance (fan guards and blades also galvanized).
8. Material-stabilized coils are pressure-fit within the core frame.
9. Patented DETC (De-Energized Tap Changer) features simple and compact in-line contact arrangement (Patent Number: 5,744,764)
10. Waukesha® Type UZD Load Tap Changer designed to withstand up to a half-million operations without the need for contact replacement.
11. Worldbox® Control Enclosure features IEC standard components and is easy to maintain and service in the field.
Transformers -

\[ P_{\text{loss}} \propto i^2 R_{\text{line}} \]

\[
\frac{n^2}{1} = \frac{50}{300} = \frac{1}{6}
\]

\[ n^2 = \frac{1}{6} \Rightarrow n = \frac{1}{\sqrt{6}} \]
\[ S_1 = S_2 \]
\[ (\text{in}) \quad (\text{out}) \]
\[ \tilde{V}_1 \tilde{I}_1 = \tilde{V}_2 \tilde{I}_2 \]
IDEAL!

Non-Ideal
- Flux Leakage
- Winding Resistance
- Magnetic Saturation
- Core Losses, Eddy Currents
- Hysteresis
\[ R = \frac{1}{\mu Ai} \]

**Laminations**

\[ P_E = \frac{1}{2} \]

\[ 4\pi \times 10^7 \]

\[ \mu = \mu_r \mu_0 \]
Lenz’s Law

- Induced voltage causes a current, if coil is shorted, that produces a flux which cancels the $\frac{d\Phi}{dt}$ that induced the voltage in first place.
\[ e_{\text{ind}} = N \frac{d\phi}{dt} = -\frac{dI}{dt} \]

Faraday

Lenz
Mutual Inductance

\[ L_{21} = \frac{N_2 \Phi_{21}}{i_2} = \frac{N_2 N_1}{R} \]

Self-Inductance

\[ L_{11} = \frac{N_1 \Phi_{11}}{i_1} = \frac{N_1^2}{R} \]

Fundamental definition of inductance: \[ L = \frac{\Phi}{i} = \frac{N_2}{i_2} \]

Mutual Inductance

\[ L_{22} = \frac{N_2 \Phi_{22}}{i_2} = \frac{N_2 N_2}{R} \]

Section 4.4 in text, pp. 73-77. See also handout on Basic Magnetic Circuits.


Also of note:

\[
\begin{bmatrix}
I_1 \\
I_2
\end{bmatrix}
\begin{bmatrix}
|l_{m1}\| & |l_{m2}\| \\
|l_{m2}\| & |l_{m1}\|
\end{bmatrix}
= 
\begin{bmatrix}
\phi \frac{V_2}{\omega} \\
\phi \frac{V_2}{\omega}
\end{bmatrix}
\]

In phasor domain:

\[
\begin{bmatrix}
\frac{\partial P_T}{\partial I_1} \\
\frac{\partial P_T}{\partial I_2}
\end{bmatrix}
\begin{bmatrix}
l_{m1} & l_{m2} \\
l_{m2} & l_{m1}
\end{bmatrix}
= 
\begin{bmatrix}
\frac{V_2}{\omega} \\
\frac{V_2}{\omega}
\end{bmatrix}
\]

In time domain:

Note: Reference of voltage at (+) side into terminals is current direction of two-port device:

How to use the concept of mutual inductance
Shell-form

core form.
Next: Ampere's Law
Next: Ampere's Law

\[ NI = \Phi R \]

Electrical \quad Magnetic

\[ \text{MMF} \]
Ampere's Law

\[ NI = \Phi R \]

\[ \vec{H} = \frac{I_{\text{encl}}}{2\pi r} \]

\[ I_{\text{encl}} = \oint \vec{H} \cdot d\ell \]

Clamp-on ammeter or current probe.