Goals for Lecture 1:

1. Review some basic material to help transition from Joe's style to Andy's.
2. Transition to more of a system block diagram; connecting physical significance to individual components of the diagram.
3. Transformer voltage: develop a block diagram and simulink representation of an inductor and discuss concepts below. Evaluate step changes to the input.
4. Transformer voltage: develop a block diagram and simulink representation of a two-winding transformer. Look at step changes in the input and output.
5. Transformer voltage: Look at self and mutual inductances. Show that the transformer goes to an ideal model if leakage is ignored.
6. Saturation: Saturation impacts some gain block but not others
7. Introduce saturation model Se.

Concepts for Lecture 1:

1. Flux linkages do not change instantly
2. Voltages drive flux linkages and currents develop to support flux linkages
3. Inductance: Self versus mutual
4. Saturation impacts on inductances
5. Time constant is inverse of loop gain (in first order system)

Review from Andy's perspective
Start with Ampère's Law: \[ \oint \mathbf{H} \cdot d\mathbf{e} = \int \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} \cdot d\mathbf{s} \]

\[ \text{Current Density} \quad (\text{Am}^{-2}) \]
\[ \text{Displacement current} \]

\[ \times \] assumption: We can ignore displacement current

\[ \oint \mathbf{H} \cdot d\mathbf{e} = \int \mathbf{J} \cdot d\mathbf{s} \]

Integrate in core of inductor

\[ H_L = N_i \]

effective length through core

\[ \text{Inductor} \]

\[ N \text{ turns} \]
\[ B = \mu H \quad \text{or} \quad H = \frac{B}{\mu} \]

* Permeability \((V/m)\) * is a property of the material
* Sometimes \(\mu = \mu_r \mu_0\)

* \(\mu_r\) is about 4000 for transformer iron

\[ \phi = AB \quad \therefore B = \frac{\phi}{A} \]

* Cross sectional area of core

Substitute \(\phi/A\) for \(B\) in \(H = \frac{B}{\mu}\)

\[ H = \frac{\phi}{\mu A} \]

Substitute for \(H\) in equation \(HL = NI\)

\[ \frac{\phi L}{\mu A} = NI \]

Let \(\sigma R = \frac{L}{MU} \quad \text{or} \quad \Phi = \frac{1}{R} = \frac{\mu A}{L} \]

\[ \Phi \quad \frac{\phi}{\sigma} = NI \]

\[ \therefore \phi = N\Phi I \]

* As material saturates \(\mu \downarrow \frac{1}{3} \quad \sigma \downarrow \frac{1}{3} \quad \Phi \downarrow \)
Inductor Continued

Introduce flux linkage \( \Psi \)
\[ \Psi = N \phi \]
Substitute \( N \phi \) for \( \phi \) yields
\[ \Psi = N^2 \phi i \]

Define Inductance
Let \( L = N^2 \phi \) or \( L = \frac{\Psi}{i} \). \( \therefore i = \frac{\Psi}{L} \)

Faraday's Law
\[ e = \frac{d\Psi}{dt} = -\Psi \]

Circuit equation

\[ V = iR + e = iR + \Psi \]

\( \therefore \Psi = V - iR \)

Use the following equations to build a block diagram
\[ e = \Psi = V - iR \]
\[ i = \frac{\Psi}{L} \]

Figure 3.10 in Kundur has wrong direction on \( \phi \).
Inductor Continued

\[ i_R = \frac{\psi}{L} \]

\[ i = \frac{\psi}{L} \]

\[ e = \dot{\psi} + v - i_R R \]

\[ v \rightarrow \frac{\dot{\psi}}{C} \rightarrow \psi \rightarrow \frac{\psi}{L} \rightarrow i = \frac{\psi}{L} \]

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**Note:** \( \psi \) cannot change instantly w/ finite \( \dot{\psi} \).

\( v \) drives the value of \( \psi \).

\( i \) is determined by \( \psi \).

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**Initial conditions in steady state (SS)**

\[ \dot{\psi}_0 = 0 \]

\[ \therefore \quad \frac{\dot{\psi}}{C} - i_0 R = 0 \]

\[ \therefore \quad \frac{\dot{\psi}}{C} = i_0 R \quad \{ \text{Kirchhoff will be relieved} \} \]

\[ \frac{\dot{\psi}}{C} = i_0 \]

\[ i_0 = \frac{\psi}{L} \]

\[ \frac{\psi}{L} = \frac{\psi L}{R} \]

\[ \therefore \quad \psi_{ss} = \frac{\psi L}{R} \]

Also **Note:**

Loop gain \( = \frac{R}{L} \) \quad \therefore \quad \text{Time Constant} \quad \tau = \frac{L}{R}

Multiply by special form of \( 1 \):

\[ \tau = \frac{\dot{x}_0}{x_0} \cdot \frac{1}{R} \]

\[ \tau = \frac{\dot{x}_0}{x_0} \cdot \frac{1}{R} \]

\[ \frac{\dot{E}_0}{E_0} = \frac{1}{R} L \]

\( E_0 = \frac{1}{2} i_0^2 L \quad \therefore \quad E_0 = \frac{1}{2} \psi L \]

\( V_0 = i_0 R_0 \)

\( E_0 = \frac{1}{2} i_0^2 L \quad \therefore \quad R_0 = V_0 \)

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