ECE 525: Lecture 8

- For C-class current transformers, the CT is rated such that the error in the secondary current will be less than 10% if the 20 times rated current flows through a standard burden.
- This should be adjusted to account for the effect of the decaying offset.
- So the equation to never saturate is:

$$R_{totalburden\_pu} \cdot I_{f\_pu} \cdot \left(1 + \frac{X_{system}}{R_{system}}\right) < 20$$

Assuming that the inductance in the CT secondary windings, lead wire and relay can be neglected, the voltage across the CT equivalent circuit magnetizing branch is:

$$v_m(t) = i_{secondary}(t) \cdot (R_{ct} + R_b) \qquad \text{where:} \qquad R_b = R_{lead} + R_{relay}$$

We want to get a measure of how long it takes the CT to saturate if it not sized to meet the above equation.

Equation for current with the DC offset:

$$i_{secondary}(t) = I_{fmax\_sec} \cdot \left(e^{\frac{-t}{T_p}} - \cos(\omega \cdot t)\right)$$

- Assumes fault timing for worst DC offset.

The paper: Juergen Holbach, "Modern Solutions to Stabilize Numerical Differential Relays for Current Transformer Saturation during External Faults", *2006 Power Systems Conference: Advanced Metering, Protection, Control, Communication, and Distributed Resources*, gives the following three equations for estimating the time to saturation for a CT:

The notes included several equations that could be used to describe what the author called "V_{knee}".

$$v_{sat1}(t_s) = I_{fmax\_sec} \cdot R_b \cdot \left[(-XoverR) \cdot \left(e^{\frac{-t_s}{T_p}} - 1\right) + 1\right]$$

Saturation free > 12 ms

$$v_{sat2}(t_s) = I_{fmax\_sec} \cdot R_b \cdot \left[(-XoverR) \cdot \left(e^{\frac{-t_s}{T_p}} - 1\right) - \sin(\omega \cdot t_s)\right]$$

Saturation free 7-12 ms

$$v_{sat3}(t_s) = I_{fmax\_sec} \cdot R_b \cdot (1 - \cos(\omega \cdot t_s))$$

Saturation free < 7ms

- They are not exactly a voltage. This is better described as the ***Volt-Time Area***
- If you are working from measured data:

$$VTA(x) = \sum_{j=0}^{x} \left(V_{sec_j} \cdot \Delta t\right)$$

Δt is the sampling rate

- A more general equation is

$$B_s \cdot N \cdot Area \cdot \omega = \omega \cdot I_{fmax\_sec} \cdot R_b \cdot \left(e^{\frac{-t}{T_p}} - \cos(\omega \cdot t)\right)$$

  - So this works out to be the flux as a function of time, multiplied times the frequency
  - Adding the frequency covers the summation of time slices

Example

$R_b := 5ohm$ $\quad CTR := \frac{1200}{5}$ $\quad CTR = 240$

$I_{fmax\_sec} := 18 \cdot 5A$ $\quad I_{fmax\_sec} = 90\,A$

$I_{fP} := CTR \cdot I_{fmax\_sec}$ $\quad I_{fP} = 21.6 \cdot kA$ $\quad$ • Fault current referred to primary

$I_{fmax\_sec} \cdot \left(R_b\right) = 450\,V$ $\quad$ • If no DC offset needs to be included

$XoverR := 12$ $\quad \omega := 2 \cdot \pi \cdot 60Hz$

$T_p := \frac{XoverR}{\omega}$ $\quad T_p = 31.83 \cdot ms$

$I_{fmax\_sec} \cdot \left(R_b\right) \cdot (1 + XoverR) = 5850 \cdot V$ $\quad$ • Expensive custom order

- pu equation: $\frac{I_{fmax\_sec}}{5A} \cdot \left(\frac{R_b}{8ohm}\right) \cdot (1 + XoverR) = 146.25$

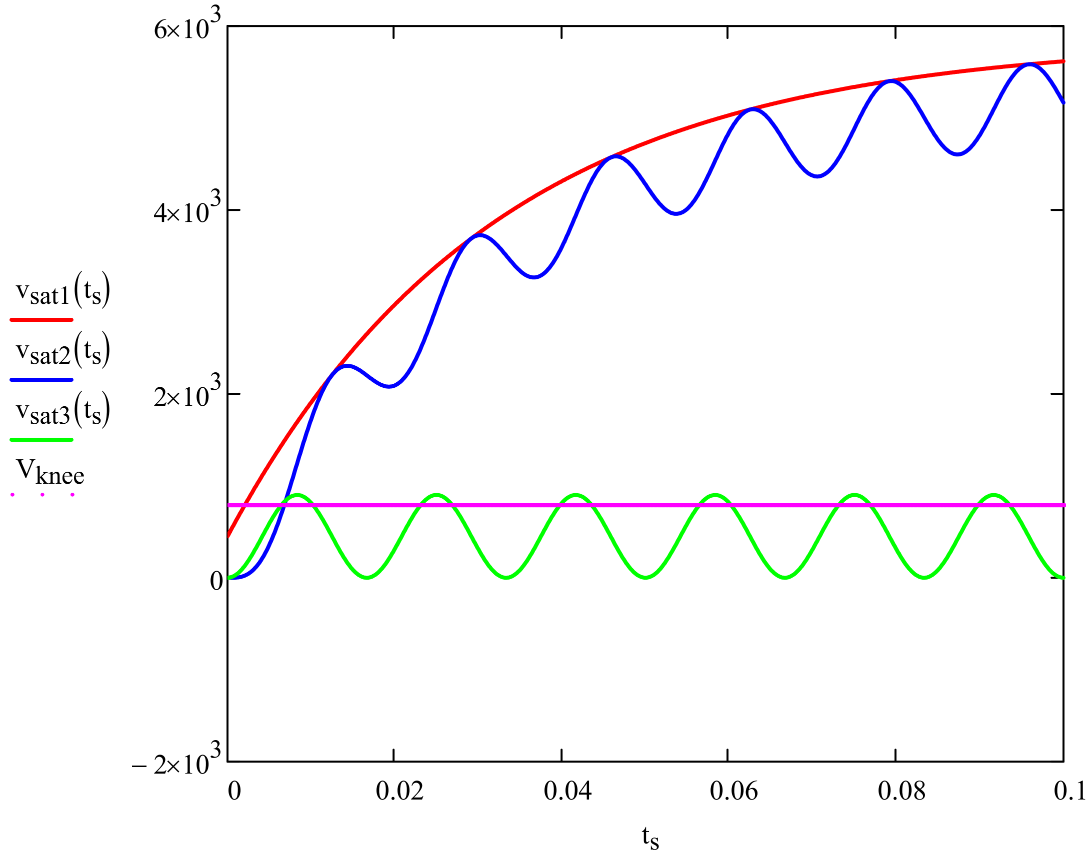
Now lets say we want $V_{knee} := 800V$

$$v_{sat1}(t_s) := I_{fmax\_sec} \cdot R_b \cdot \left[(-XoverR) \cdot \left(e^{\frac{-t_s}{T_p}} - 1 \right) + 1 \right]$$

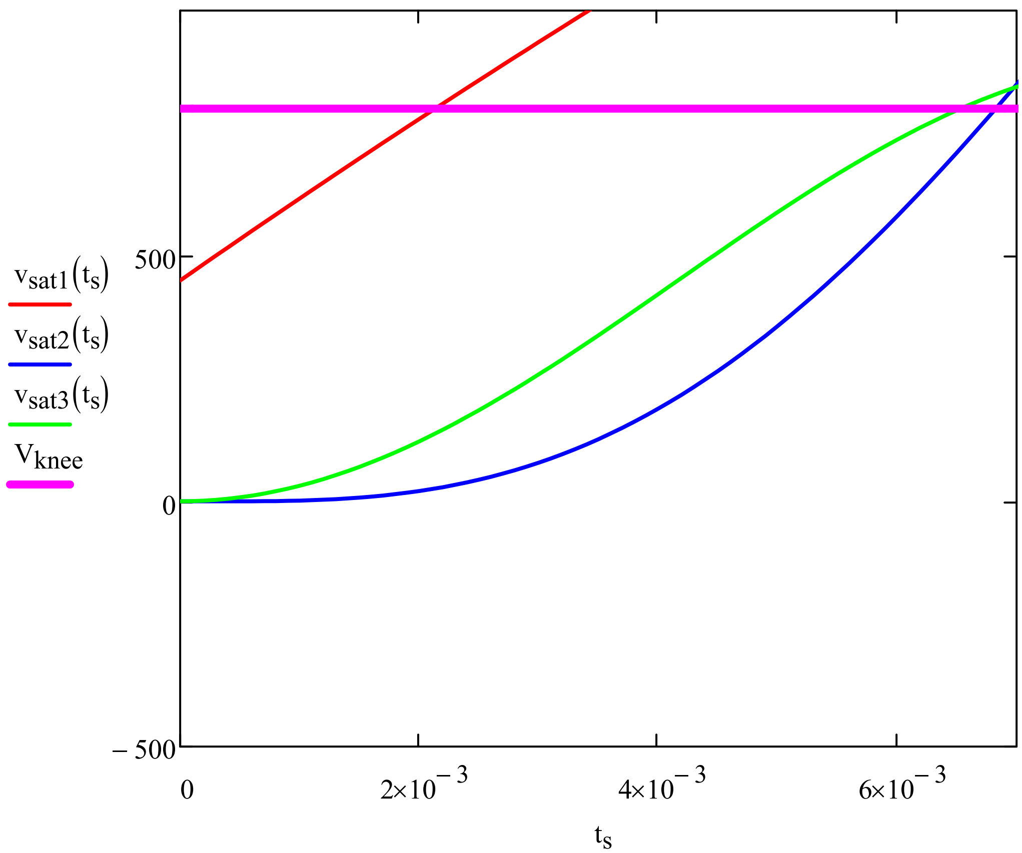
$$v_{sat2}(t_s) := \left[I_{fmax\_sec} \cdot R_b \cdot \left[(-XoverR) \cdot \left(e^{\frac{-t_s}{T_p}} - 1 \right) - \sin(\omega \cdot t_s) \right] \right]$$

$$v_{sat3}(t_s) := I_{fmax\_sec} \cdot R_b \cdot (1 - \cos(\omega \cdot t_s))$$

$$t_s := 0ms, 0.1ms .. 100ms$$



Zoom in to the beginning:



Saturation in 6.6 ms