University of Idaho

# ECE 525

# POWER SYSTEM PROTECTION AND RELAYING

SESSION no. 6

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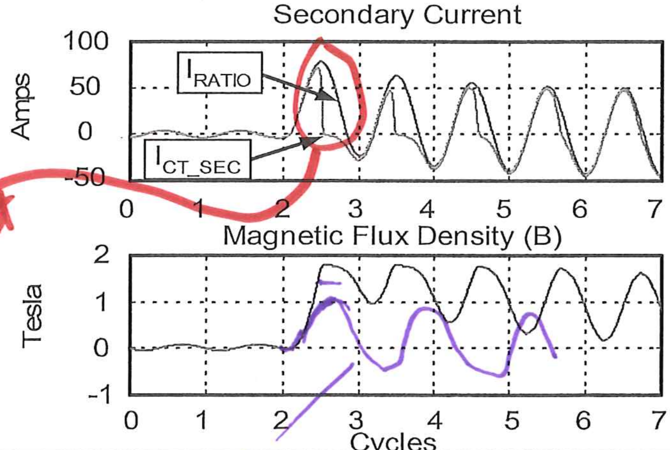
## CT Response During Fault Condition

$i_m$ - magnetizing current

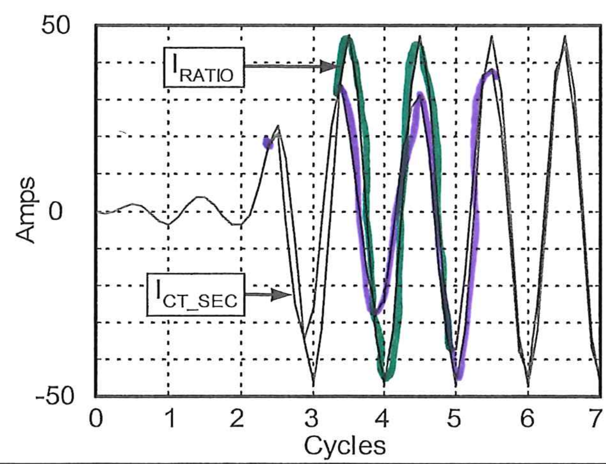


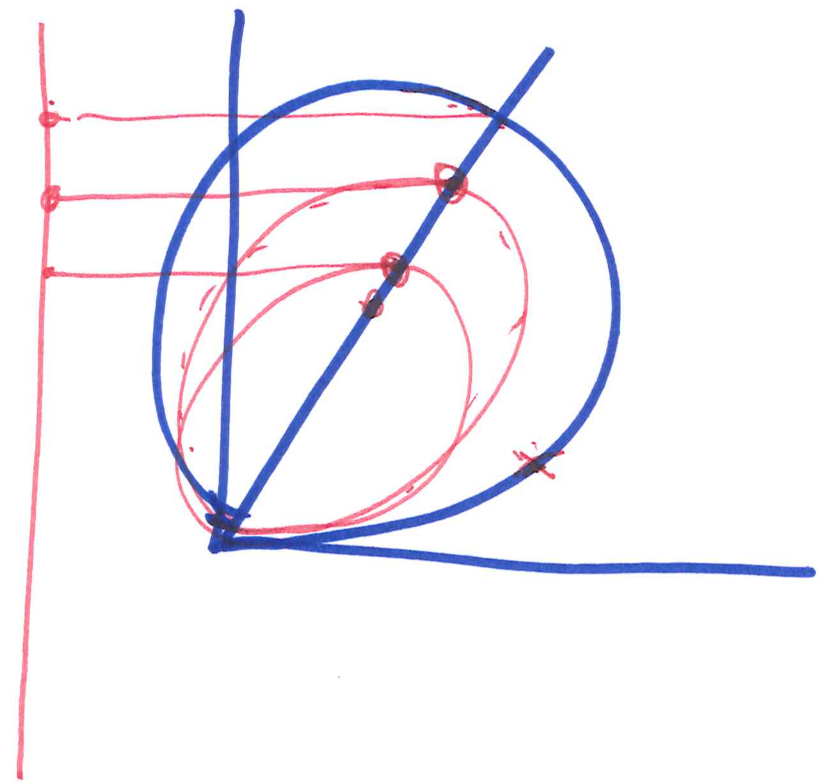



$i_{ratio} = i_{ct\_sec} + i_m$



## Filtered Currents





$$Z_{AG} = \frac{V_{AG}}{I_A + k_0 3I_0}$$

↓

$$m\, Z_{Line} = V$$

$$m = \frac{V_{AG}\, V_{pol}^*}{Z_L (I_A + k_0 3I_0) V_{pol}^*}$$

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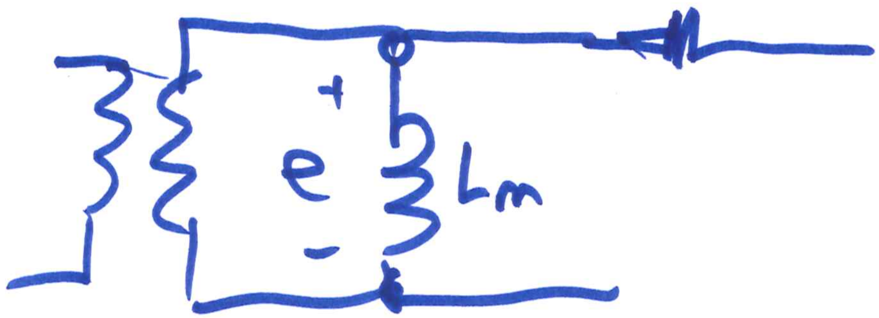


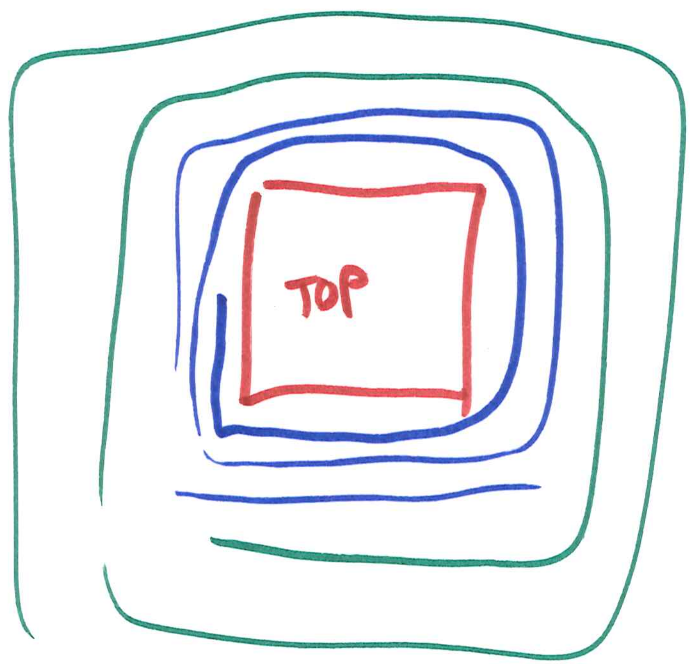

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## Distance Element Response

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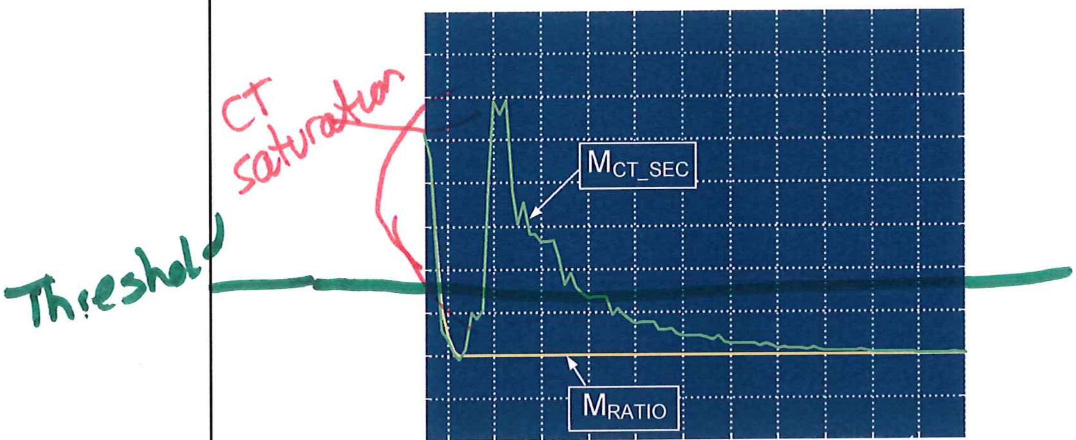




## Effects of CT Saturation

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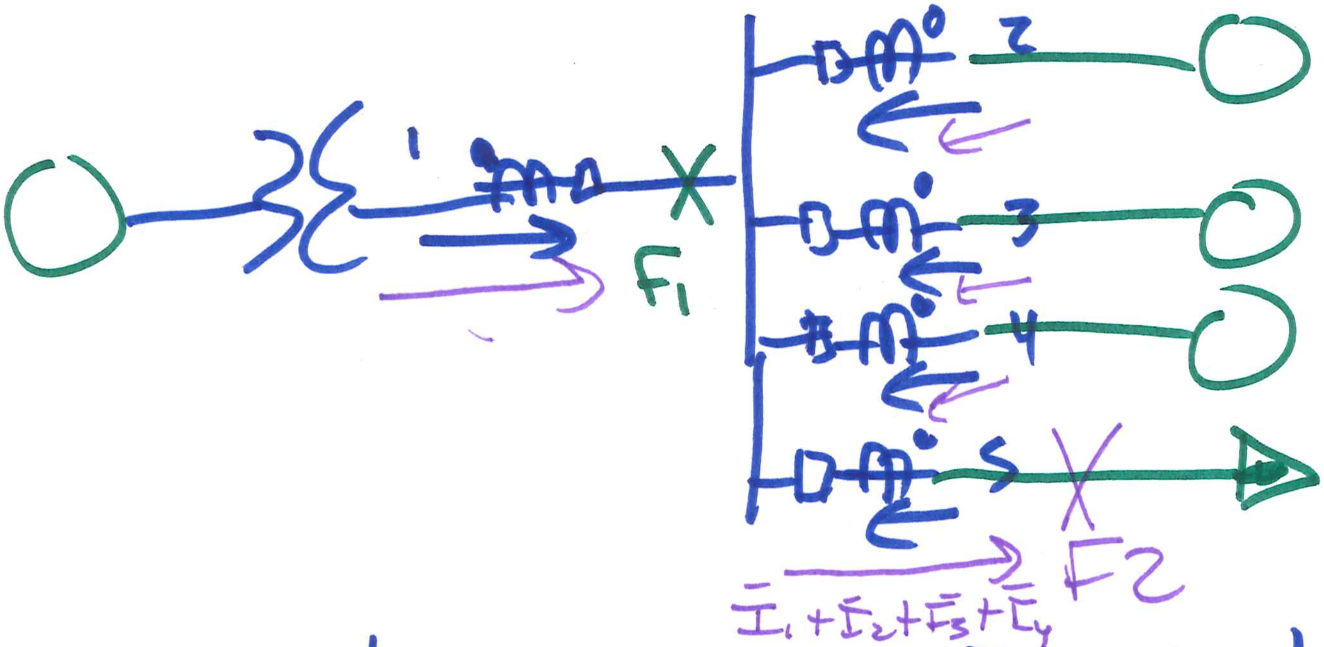
Current signal has reduced magnitude

Current signal has angle error

CT saturation causes distance element underreach

# Differential Protection



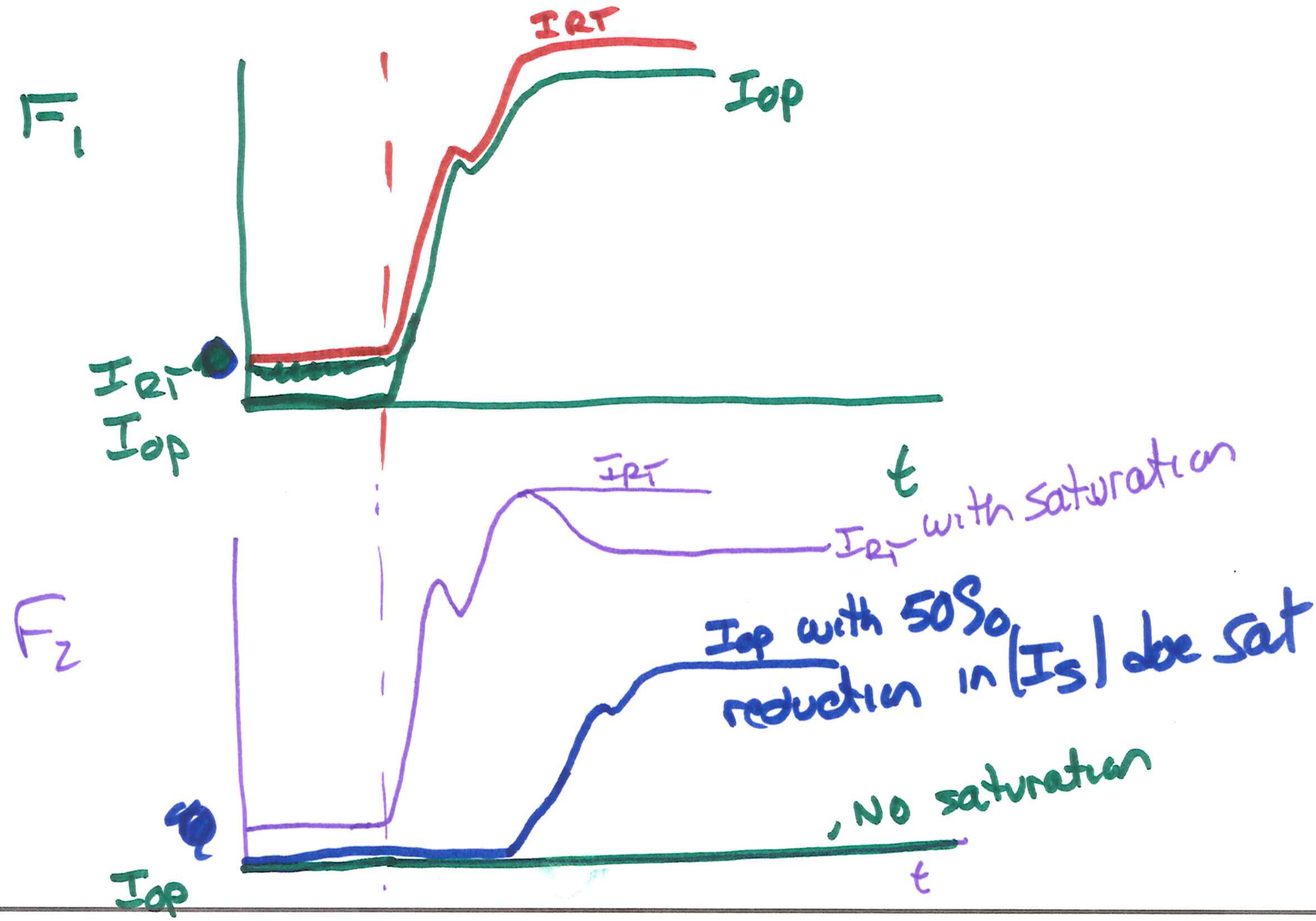

$$I_{op} = |\bar{I}_1 + \bar{I}_2 + \bar{I}_3 + \bar{I}_4 + \bar{I}_5| = 0$$

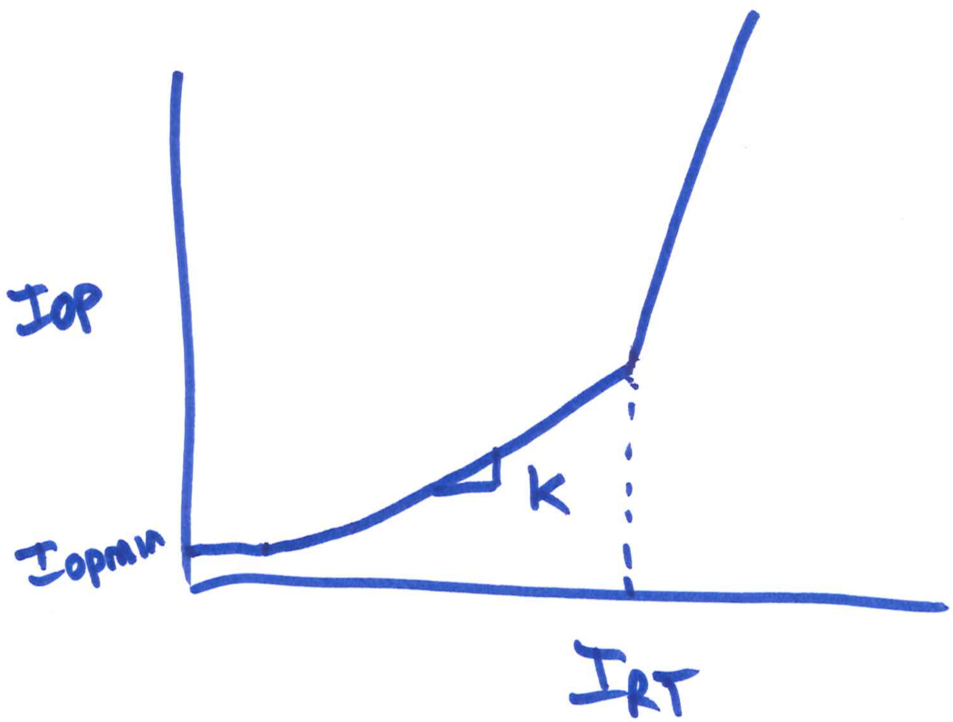
$$I_{RT} = |I_1| + |I_2| + |I_3| + |I_4| + |I_5|$$

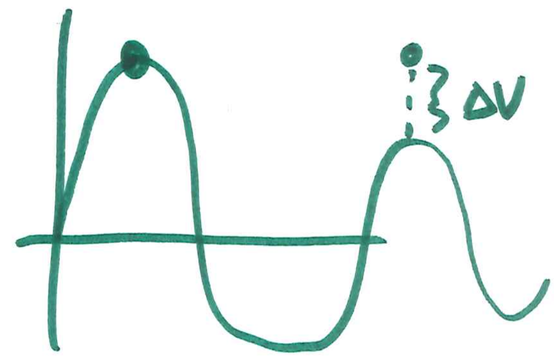
$$I_{op} > k\, I_{RT}$$

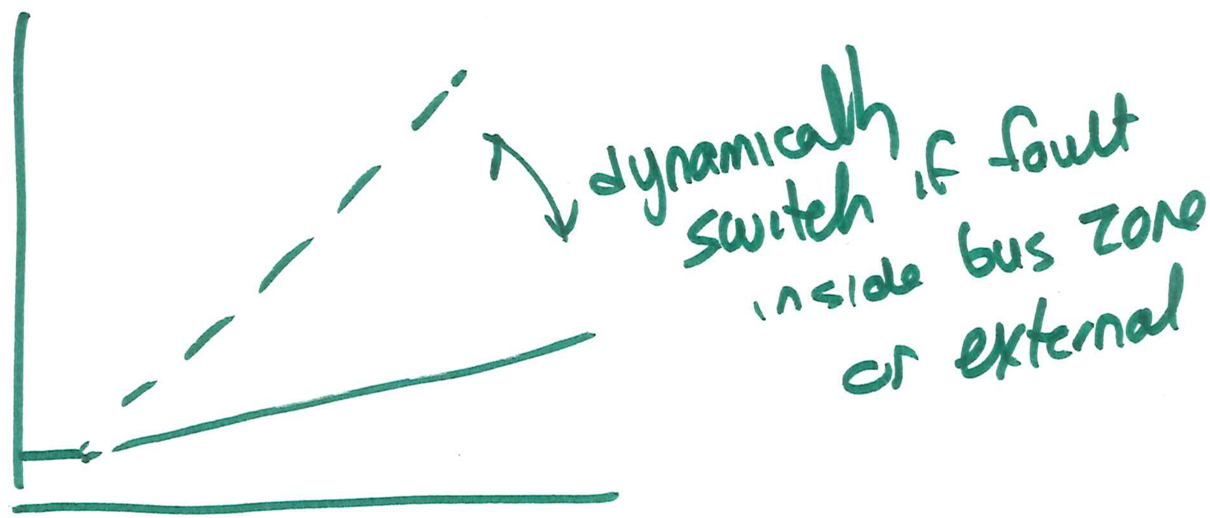
Suppose CT on incomer 5 saturates

$|I_{5_{sec}}| = 0.5\,|I_{5_{ratio}}|$




IOP
IOPMIN
K
IRT


ΔV


dynamically switch if fault inside bus zone or external

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# What Do I Need to Know to Select a Correct CT



- Maximum fault current
- Systems X/R ratio
- CT burden

*at different fault types 3Ø, LL, DLG, SLG*

*impedance on CT secondary*

*dc offset decay rate*



# CT Core Flux



$$i_S := \hat{Is}\cdot[(\sin\varpi t - \frac{\pi}{2}) + e^{-\frac{R}{L}\cdot t}]$$

$$\phi := k\int v\,dt$$

*fund freq*

$$\phi_{ss} := k\int \hat{Is}\cdot\sin(\varpi t - \frac{\pi}{2})\cdot R_B dt$$

$$\phi_{ts} := k\int \hat{Is}\cdot e^{-\frac{R}{L}\cdot t}\cdot R_B dt$$

$$\frac{\phi_{ts}}{\phi_{ss}} := \frac{\varpi L}{R} := \frac{X}{R}$$

*$R_{CT}$ $R_{Lead}$, $R_{relay}$*

*$L_s \approx 0$*

$$\phi_{ss} := \frac{k\cdot R_B\cdot \hat{Is}}{\varpi}$$

$$\phi_{ts} := \frac{k\cdot R_B\cdot \hat{Is}\cdot L}{R}$$

Total core flux:

$$\phi_c := \phi_{ss} + \phi_{ts} := \phi_{ss}\cdot\left[1 + \frac{X}{R}\right]$$

*for worst case dc offset*

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# ANSI Classification of CTs

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At 800 V the CT will go into saturation

Rated burden calculation: $Z_{rated} := \frac{ANSI_{Voltage}}{20 \cdot I_{nom}}$

VA rating of CT calculated from rated burden:

$$VA_{rated} := I_{nom}^{2} \cdot Z_{rated}$$

Percent error of the CT: by definition all C class CTs should not have more than 10% error at 20 x nominal current



# IEC Classification of CTs

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Done by class, Accuracy Limit Factor, and VA

Example: 5P20, 40VA

- 5P = class
- 20 = Accuracy Limit Factor (ALF)
- At rated burden of 40VA, if current through CT is 20 x nominal current, maximum measurement error will be 5%

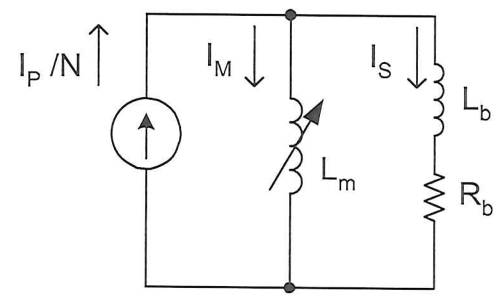
CT saturation voltage at rated burden:

$$V_{sat} := ALF \cdot \frac{VA_{rated}}{I_{nom}}$$

This Mathcad CT simulation is based on the paper "Computer Simulation of Current Transformers and Relays For Performance Analysis" by R.Garrett, W.C. Kotheimer, and S.E. Zocholl, presented before the 14th Annual Western Protective Relay Conference, October 20-23, 1987.

R.W. Folkers
May 7, 2003
Modified by B.K. Johnson

Current Transformer Model




| | |
|---|---|
| $CY := 6$ | Length of simulation in cycles |
| $I_{mag} := 16000$ | RMS magnitude of CT primary current — fault current |
| $X := 38$ | Power system inductive reactance component of X/R |
| $R := 2$ | Power system resistance component of X/R |
| $R_B := 8$ | Resistive burden. Reactive burden set to 20% $R_B$ |
| $X_B := 1$ | Reactive Burden in Ohms |
| $I_{rated} := 5$ | CT rated secondary current |
| $N := 240$ | CT turns ratio ⟶ $CTR = 240 = \frac{240 \cdot 5}{5} = \frac{1200}{5}$ |
| $V_{RAT} := 800$ | CT "C-Rating" |
| $Rem := 0.$ | Per Unit Remnant Flux |

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$f := 60$ Frequency (leave units out so plotting works)

$\omega := 2 \cdot \pi \cdot f$ Angular frequency (leave units out so plotting works)

$L_b := \frac{X_B}{\omega}$ Calculate burden inductance (keep unitless to simplify other calculations later) $L_b = 2.653 \times 10^{-3}$

$V_{RAT} := V_{RAT} \cdot (1 - Rem)$ Include effects of remnant flux

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CT doesnt saturate w/ 20 × Irated ∘ Z_ST < 800 (C800)

Normalized equati

$$\left(1+\frac{X}{R}\right)\cdot\frac{I_{mag}}{I_{rated}N}\cdot\frac{\left|R_B + j\cdot\omega\cdot L_b\right|\cdot 100}{V_{RAT}} = 268.7$$

If this is less than 20, the CT satisfies criterion to avoid saturation entirely

(Ifault; 1/5 · 240)

## Simulation Time and Indexing

$\Delta t := .00001 \quad i := 1 .. \mathrm{ceil}\left(\frac{CY}{f\cdot\Delta t}\right) \qquad t_i := i\cdot\Delta t$

Time step is 10 microseconds

## Primary Current Definition

$\theta := \mathrm{atan}\left(\frac{X}{R}\right) \qquad \tau := \frac{X}{\omega\cdot R} \qquad \tau = 0.05 \qquad \theta = 86.987\cdot\mathrm{deg}$

$\phi := \theta - 90\cdot\mathrm{deg}$

$$I_i := \sqrt{2}\cdot I_{mag}\cdot\left(\sin\left(\omega\cdot t_i + \phi - \theta\right) - e^{\frac{-t_i}{\tau}}\cdot\sin(\phi - \theta)\right)$$

## Magnetic Values

$\mu_0 := 4\cdot\pi\cdot 10^{-7} \qquad \mu_r := 15000 \qquad B_{sat} := 1.8$

## Calculate cross sectional area of CT core

$A := \frac{V_{RAT}}{\omega\cdot N\cdot B_{sat}} \qquad A = 4.912\times 10^{-3}$

## Mean core length

$L := .75$