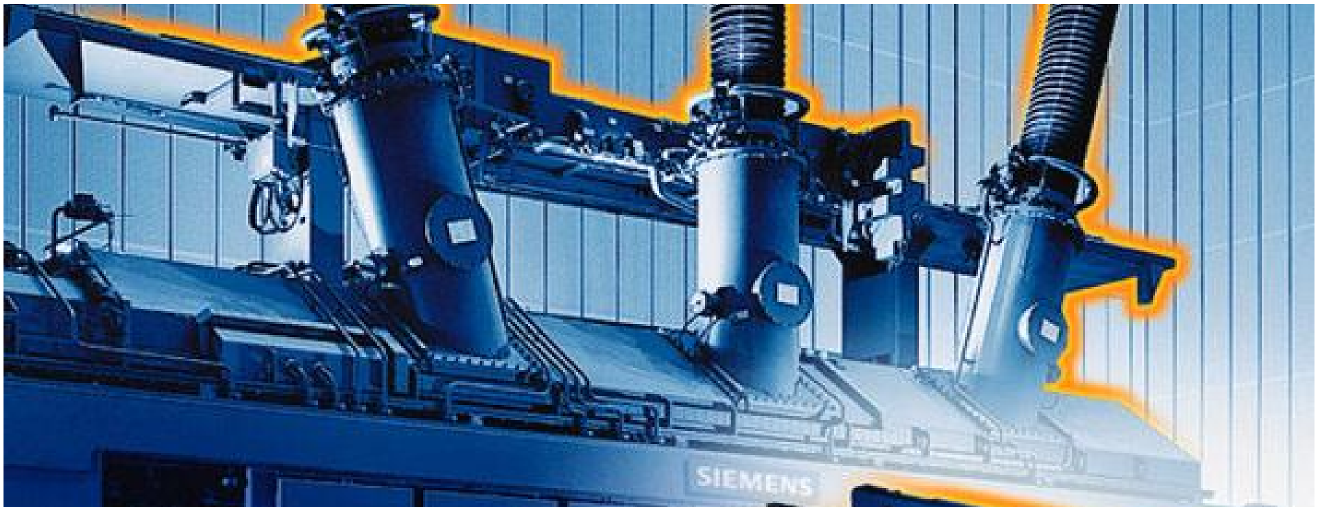

Modern Solutions to Stabilize Numerical Differential Relays for Current Transformer Saturation during External Faults

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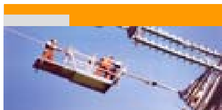
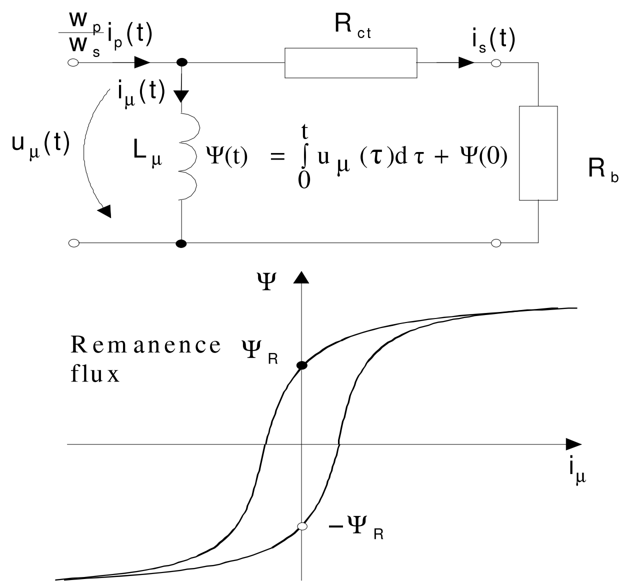


Overview

- Basics on CT saturation
  - DC-offset
  - Remanence
  - saturation free time < 7ms
- Influence of CT saturation on protection
- Stabilization methods for differential protection
- Summery

Current transformer equivalent circuit and magnetising characteristic

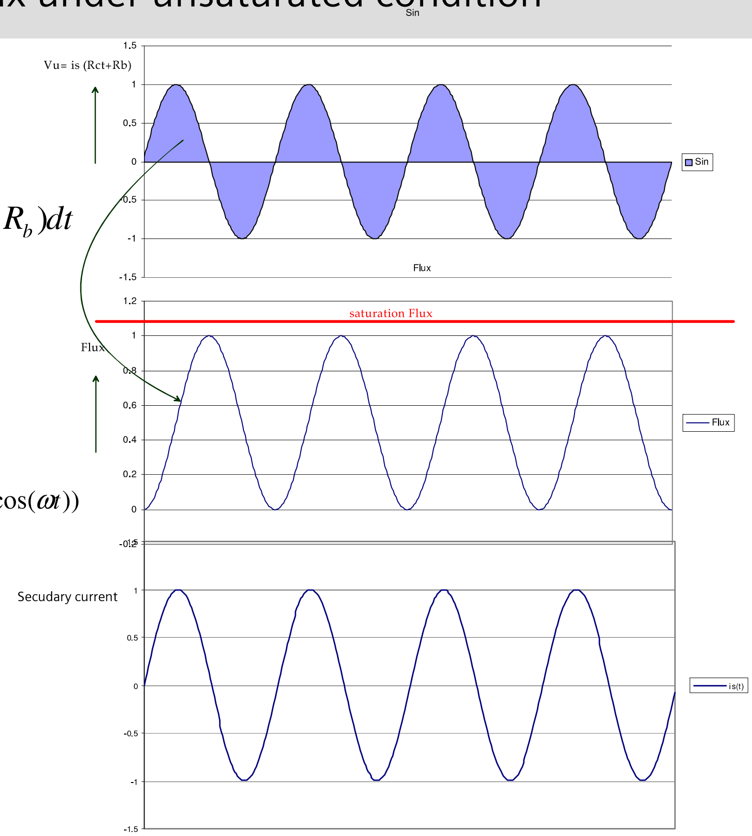


Voltage and flux under unsaturated condition

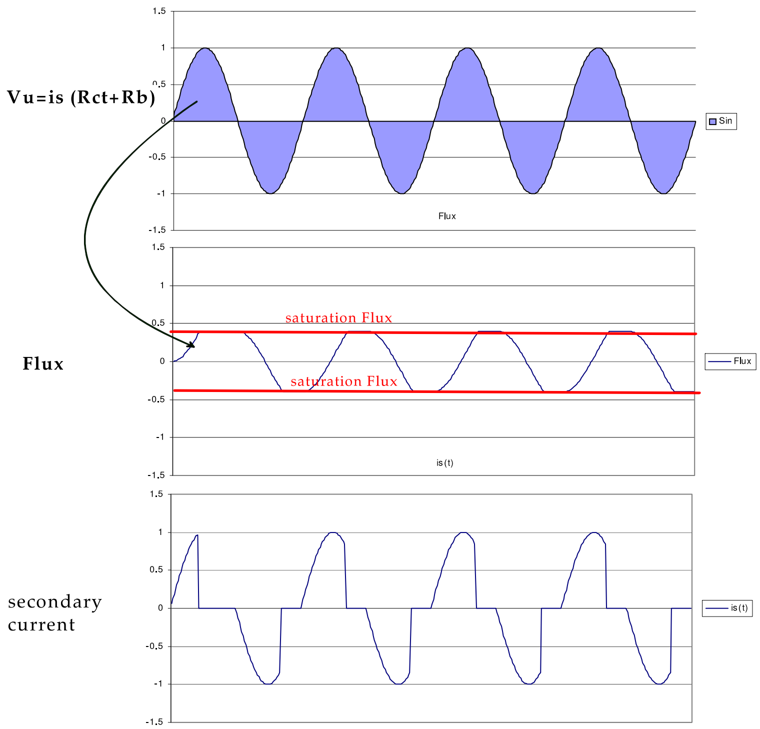
$$Flux = \int v_\mu(t)dt$$
$$= \int i_s(t)\cdot(R_{CT}+R_b)dt$$

$$for \quad i_s(t) = I\sin(\omega t)$$

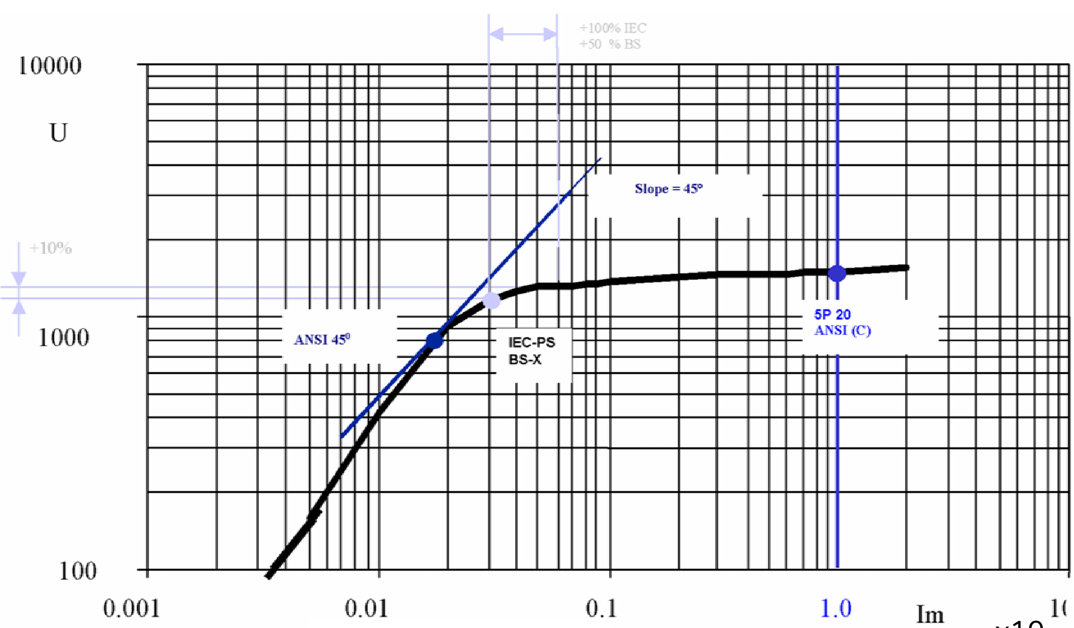
$$Flux = \frac{I\cdot(R_{CT}+R_b)}{\omega}(1-\cos(\omega t))$$



Saturated condition



Specification of saturation flux by Vknee



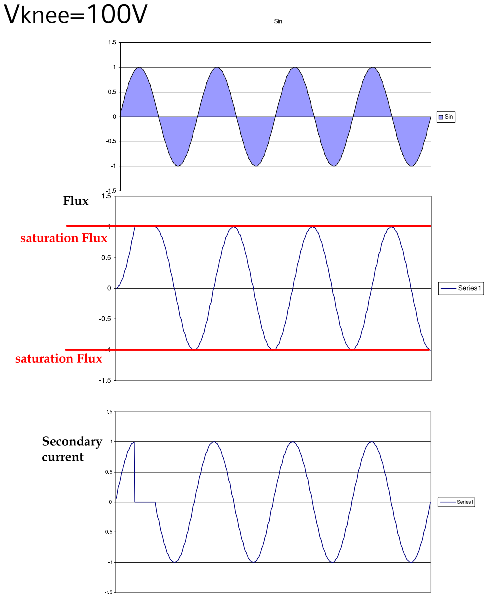
The knee point voltage is the highest exciting voltage generated by a **symmetrical** secondary short circuit current on which the flux in the CT will not reach the saturation flux.

Dimensioned for the maximum symmetrical short circuit current

Example: Isc=20000A, CT ratio =1000/5, RCT=0.5 Ohm, Rb=0.5 Ohm

Vexciting max=Isc(sec)*(RCT+Rb)=100A*1Ohm=100V

Selected CT has Vknee=100V



To avoid saturation-> $V_{knee} = 2 * I_{sc}(R_{CT} + R_b)$

Prove of overdimension factor of 2

$$Flux = \int v_\mu(t)dt$$
$$= \int i_s(t)\cdot(R_{CT}+R_b)dt$$

$$for \quad i_s(t) = I\sin(\omega t)$$

$$Flux = I\cdot(R_{CT}+R_b)\int \sin(\omega t)dt$$

$$Solution \ for \int \sin(\omega t)dt = -\frac{1}{\omega}\cos(\omega t) + C$$

$$1.\ Flux = 0 \qquad for\ t = 0 \qquad \Rightarrow \qquad C = 1$$
$$2. Flux = \frac{-I\cdot(R_{CT}+R_b)}{\omega} \qquad for\ t = 1\ cycle \qquad \Rightarrow \qquad C = 0$$

$$Flux_{t=0} = \frac{I\cdot(R_{CT}+R_b)}{\omega}(1-\cos(\omega t)) \qquad Flux_{t=1\,cycle} = -\frac{I\cdot(R_{CT}+R_b)}{\omega}\cos(\omega t)$$

$$\max(Flux_{t=0}) = 2\frac{I\cdot(R_{CT}+R_b)}{\omega} \qquad \max(Flux_{t=1cycle}) = \frac{I\cdot(R_{CT}+R_b)}{\omega}$$

$$\text{overdimension factor} = \frac{\max(Flux_{t=0})}{\max(Flux_{t=1cycle})} = 2$$

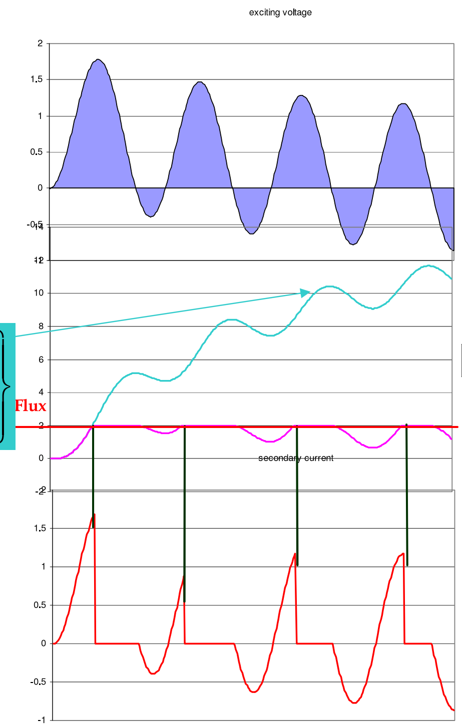
DC-Offset

$$Flux = \int v_{\mu}(t)dt$$

$$= \int i_s(t) \cdot (R_{CT} + R_b)dt$$

$$i_s(t) = I\left(e^{-\frac{t}{T_P}} - \cos(\omega t)\right)$$

$$V_{knee} = I(R_{CT} + R_b)\left\{\left[-\omega T_p\right]\left(e^{-\frac{t}{T_P}} - 1\right) - \sin(\omega t)\right\}$$



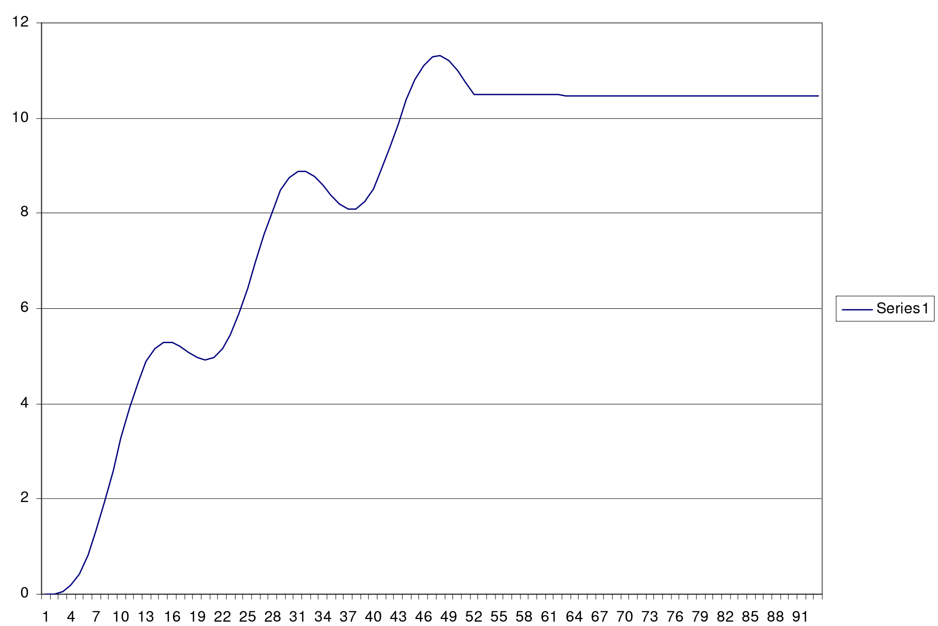
For no saturation at all : Set t=infinitive and -sin(wt)=1

$$V_{knee} = I(R_{CT} + R_b)\left[1 + \omega T_p\right] or$$

$$V_{knee} = I(R_{CT} + R_b)\left[1 + \frac{X}{R}\right]$$

Remanence

The flux inside the CT will not go to zero after the fault current is interrupted!



Considering remanence flux

$$K_{\text{Remanece}} = \frac{100}{100 - \text{Prozent } \mathit{of} \text{ Remanence}}$$

Example: Worst case of remanence (iron closed CT's) = 80%

$$K_{\text{Re}\,manece} = \frac{100}{100-80} = 5$$

CT dimensioning for no saturation under all worst case condition

Example: Isc=20000A, CT ratio =1000/5, RCT=0.5 Ohm, Rb=0.5 Ohm
Tp=60ms, iron closed CT

1. considering DC offset

$$V_{knee} = I(R_{CT} + R_b)\left[1 + \omega T_p\right]$$
$$V_{knee} = 100A \cdot 1Ohm(1 + 22.6) = 2260V$$

2.considering 80% remanence

$$K_{\text{Re}\,manece} = \frac{100}{100-80} = 5 \qquad \Rightarrow \quad V_{knee} = 5 \cdot 2260V = 11300V$$

The dimension of a CT that will not saturate for the maximum short circuit current that has a full DC offset with a long time constant and is at 80% in remanence, will lead to uneconomical and oversized CT's.

With consideration of saturation free time tsat

The requirement that no saturation is allowed will lead to uneconomical and oversized CT's

$$V_{knee} = I(R_{CT} + R_b)\left[1 + \frac{X}{R}\right]$$

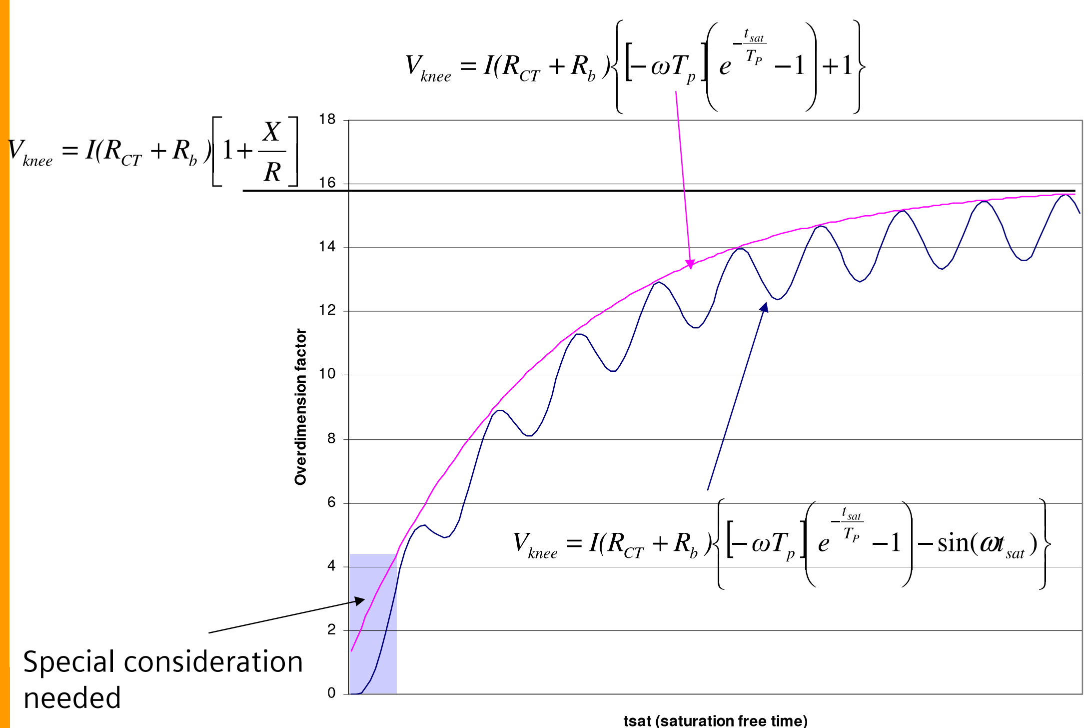
Modern numerical relays only require a certain saturation free time tsat. The following formula takes this into consideration:

$$V_{knee} = I(R_{CT} + R_b)\left\{\left[-\omega T_p\right]\left(e^{-\frac{t_{sat}}{T_P}} - 1\right) - \sin(\omega t_{sat})\right\}$$

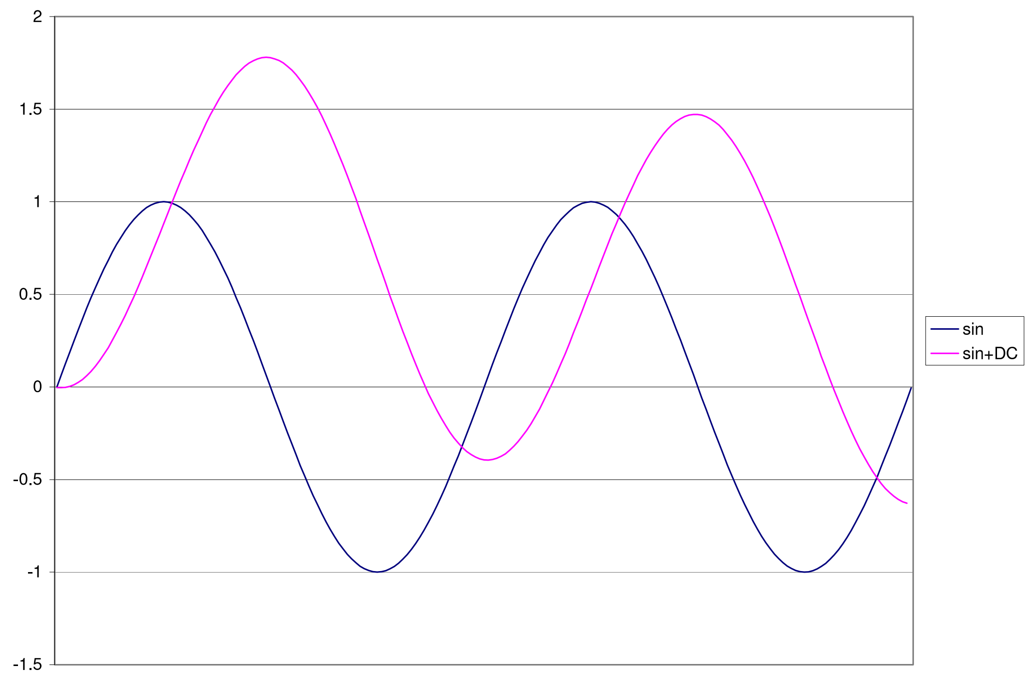
Many times a simplified version where –sin(wt) is replaced by 1 is used

$$V_{knee} = I(R_{CT} + R_b)\left\{\left[-\omega T_p\right]\left(e^{-\frac{t_{sat}}{T_P}} - 1\right) + 1\right\}$$

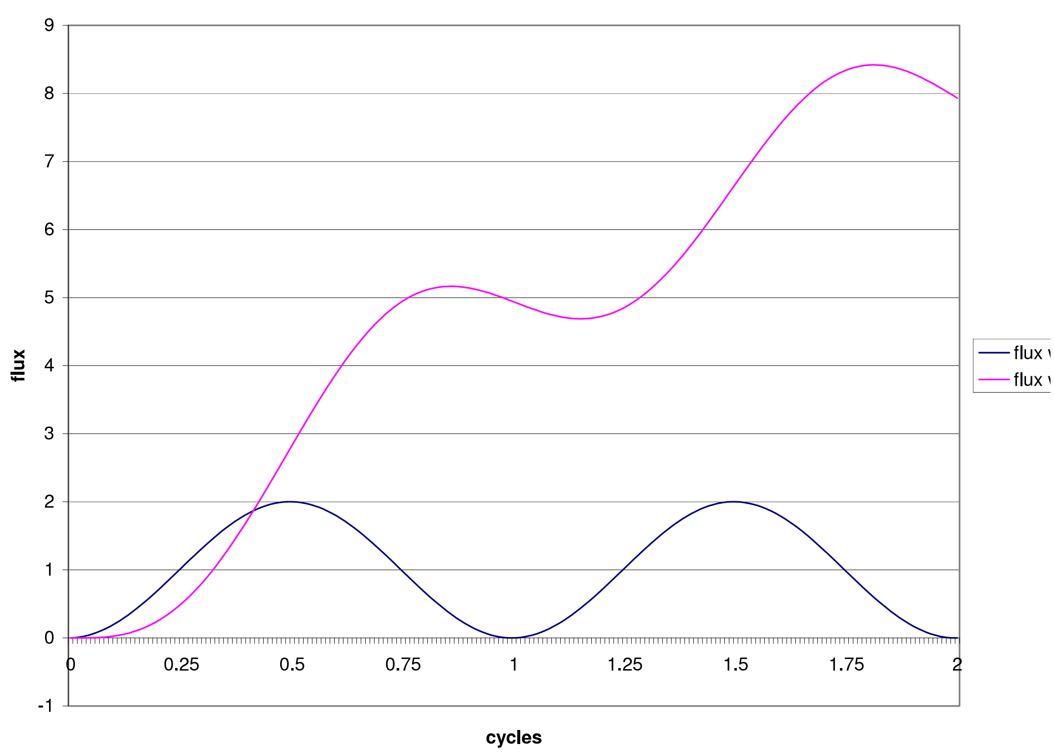
What does the different formulas describe?



Saturation free times < 7ms



Flux for saturation free time <7 ms



Which formula should be applied

No saturation

$$V_{knee} = I(R_{CT} + R_b)\left[1 + \frac{X}{R}\right]$$

Saturation free time > 12ms

$$V_{knee} = I(R_{CT} + R_b)\left\{\left[-\omega T_p\right]\left(e^{-\frac{t_{sat}}{T_P}} - 1\right) + 1\right\}$$

Saturation free time between 7-12 ms

$$V_{knee} = I(R_{CT} + R_b)\left\{\left[-\omega T_p\right]\left(e^{-\frac{t_{sat}}{T_P}} - 1\right) - \sin(\omega t_{sat})\right\}$$

Saturation free time < 7ms

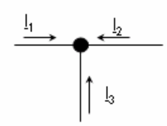
$$V_{knee} = I(R_{CT} + R_b)[1 - \cos(\omega t_{sat})]$$

Influence of CT saturation on protection

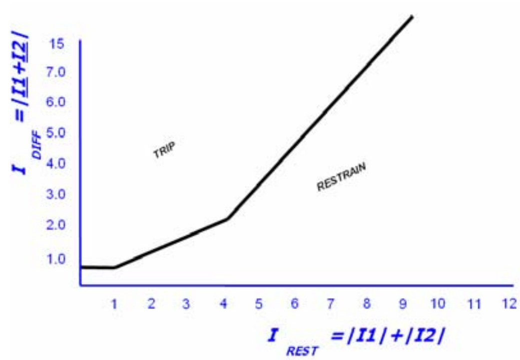
- Distance protection
  - Close in faults
    - Direction has to be correct
    - High speed tripping decision before saturation
  - Zone end fault
    - Accuracy and timing will be effected
- Overcurrent protection
  - based on RMS or fundamental
  - 50 element not influenced if remaining current is above pickup
  - 51 element experienced an additional time delay
- Differential protection
  - Critical for the security of the protection!

Differential protection

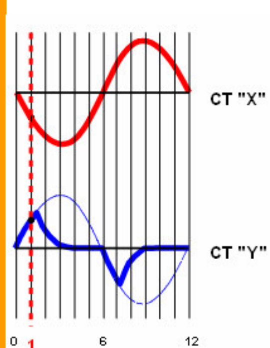
Kirchhoffs Law

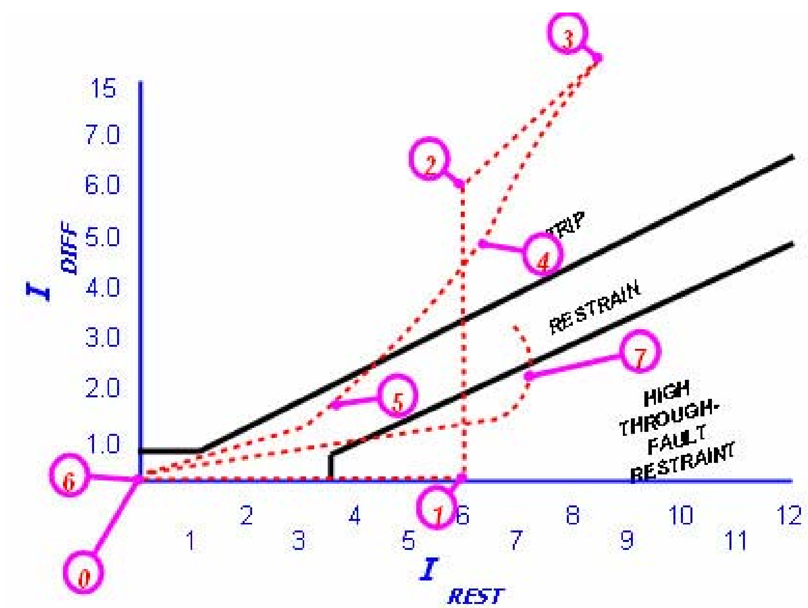


I1+I2+I3=0

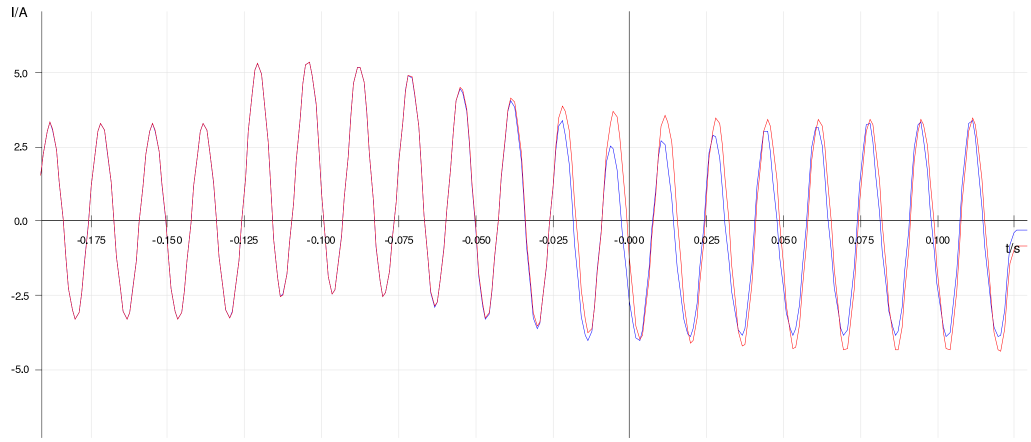


Differential protection with CT saturation

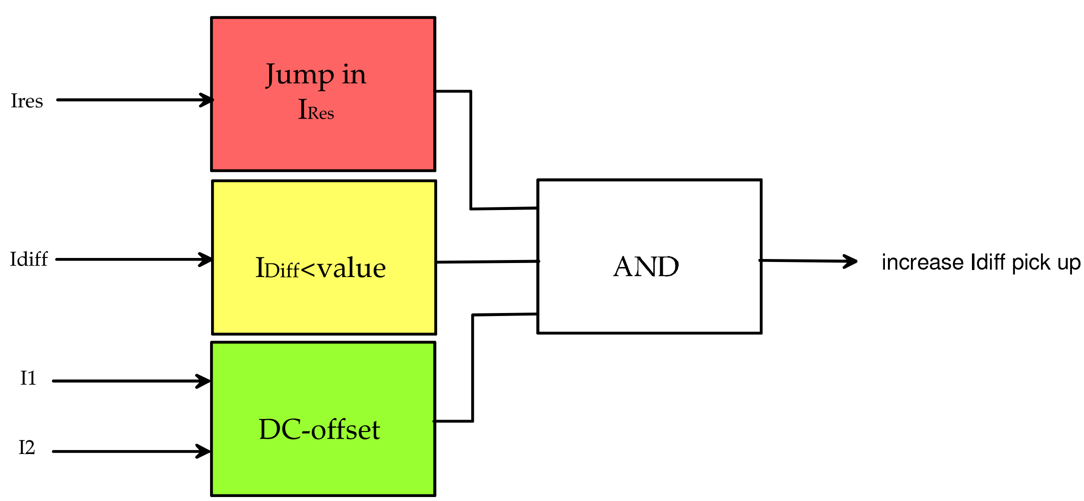




Small currents with long DC time constant



Summary



Summary

- By specifying a CT the following must be considered:
  - Max fault current
  - CT burden
  - DC time constant
  - Remanence
  - Required saturation free time
- Saturation free time must be specified by each relay manufacturer
- Small current with long DC time constant can also cause saturation
- Modern numerical relays using intelligent algorithms can deal with CT saturation much better their electromechanical and analog static predecessors

Questions

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