Evaluating the Impact of Increasing System Fault Currents on Protection

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Outline

- Overview of increasing short circuit fault current levels
- Impacts of increased fault levels on protection relays
- Impact evaluation techniques
- Case studies

Causes of increasing fault current

- Installation of new transmission facilities, transformers and generators
- Additions and changes to existing generators
- Reconfigurations of the bulk electric system (BES) network
- New distribution generation

OEB Maximum Allowable Fault Levels

- Maximum allowable fault levels set out by the Ontario Energy Board

Nominal Voltage (kV)	Maximum 3-Phase Fault (kA)	Maximum SLG fault (kA)
500	80 (usually limited to 63 kA)	80 (usually limited to 63 kA)
230	63	80 (usually limited to 63 kA)
115	50	50
44	20	19 (usually limited to 8 kA)
27.6 (4-wire)	17	12
27.6 (3-wire)	17	0.45
13.8	21	10

Hydro One Data

- Maximum fault currents in some major substations

Nominal Voltage (kV)	Fault Current (up to kA)
500	50.47
230	73
115	32.69

- CB interrupting capacity requirement

Nominal Voltage (kV)	1990s (kA)	Present (kA)
500	40/63	63/80
230	40/50/63	50/63/80
115	40/50	40/50/63

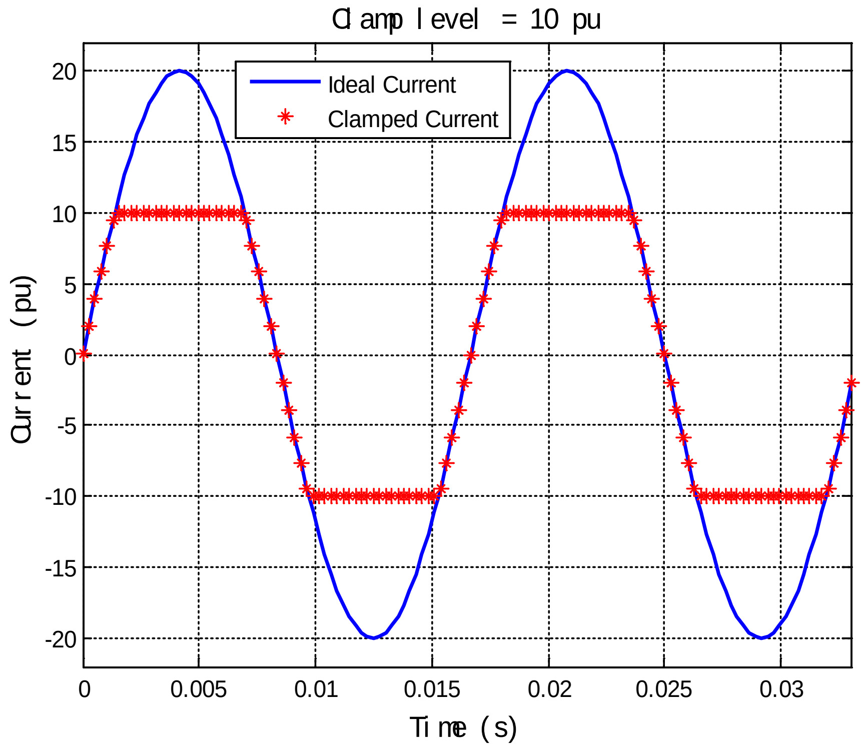
- Increased by 27% in the last twenty years

Questions from Protection Engineers

- What will be the impact of increasing fault current on protection relays?
- Will relays be reliable or not under such situations?
- What are the effects on the dependability and security of a relay?
- How to evaluate a specific application?
- How to upgrade relay or adjust relay settings to increase dependability and security?

Impacts – ADC Range and Clamping

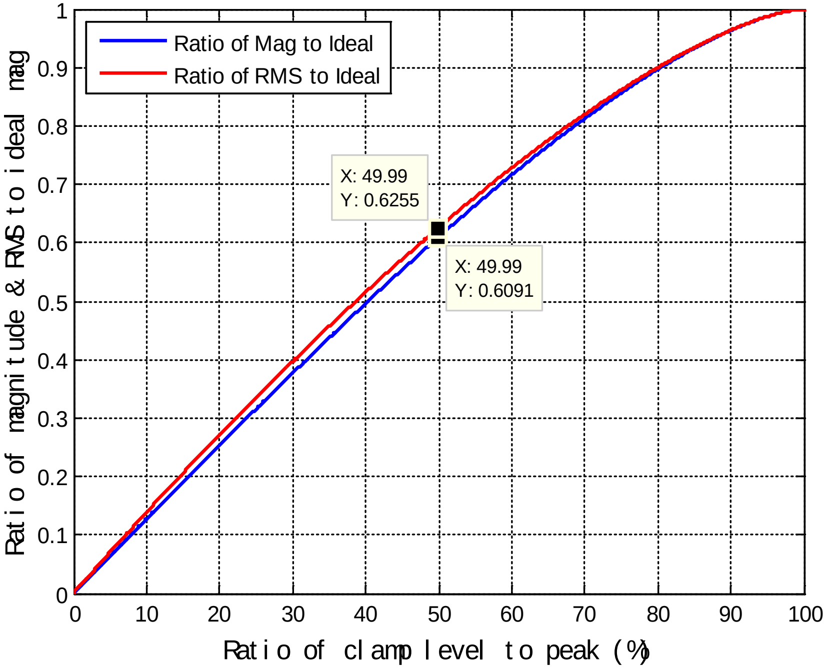
- Due to the conversion range of ADC, digital current samples will be clamped if they exceed the conversion levels.



Ratio of clamped level to true peak determines phasor magnitude error.

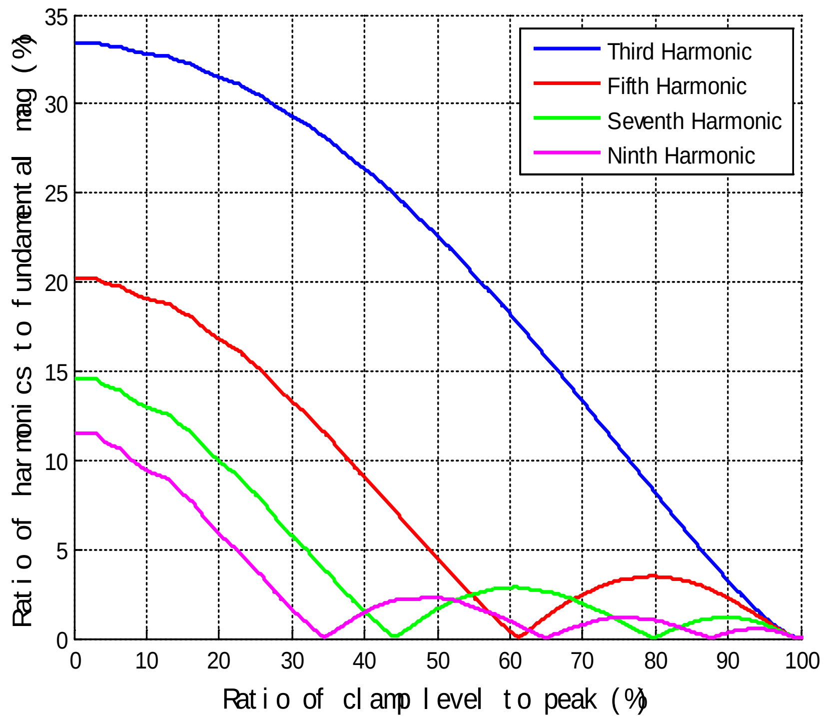
Impacts – ADC Range and Clamping

- The lower clamp level results in the smaller current magnitude and rms values
- Affecting protection functions that are related to the current magnitude or rms values.
- Negligible effect on current phasor angle



Impacts – ADC Range and Clamping

- Erroneous odd harmonics are induced
- For third harmonic, the larger fault current will result in the larger ratio of odd harmonics to fundamental magnitude
- The fifth harmonic ratio may be used to inhibit 87T function during overexcitation
- No even harmonics induced

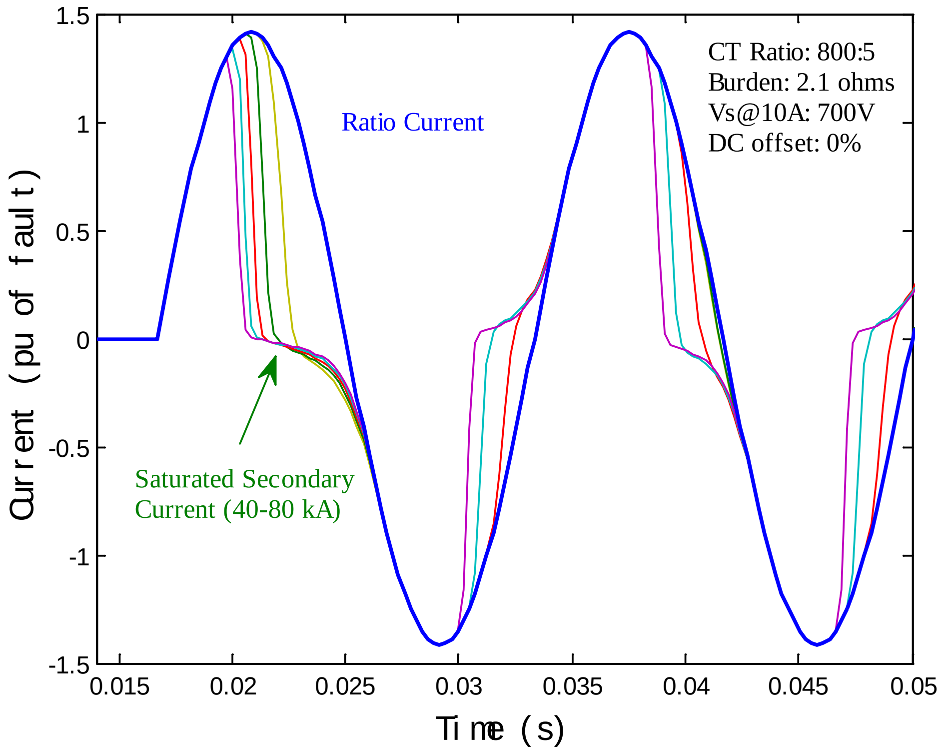


Impacts – CT Saturation

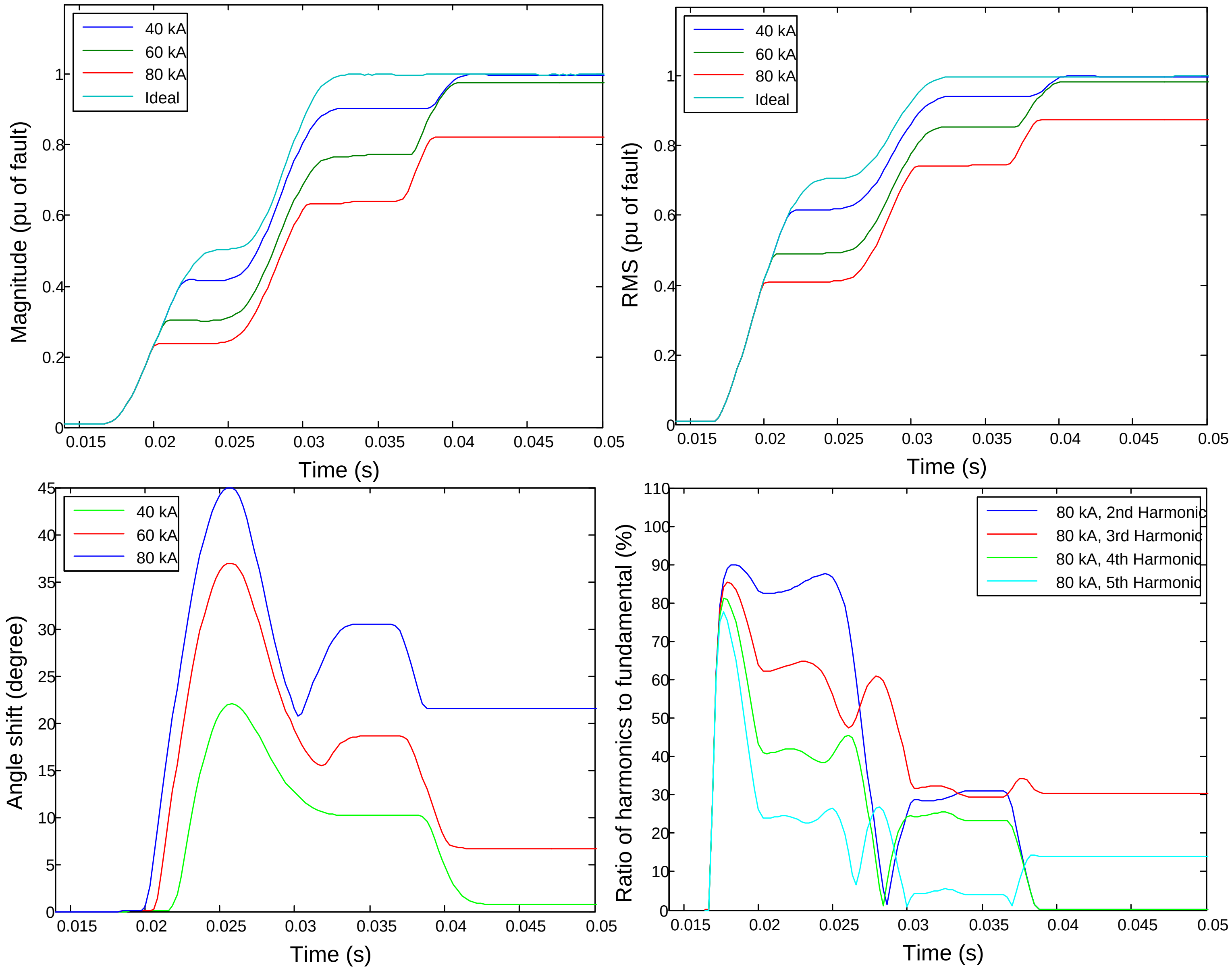
- AC saturation: caused by the symmetrical current with no DC component

To avoid AC saturation

$$V_X > I_S \times Z_S$$



Impacts – CT Saturation (AC)

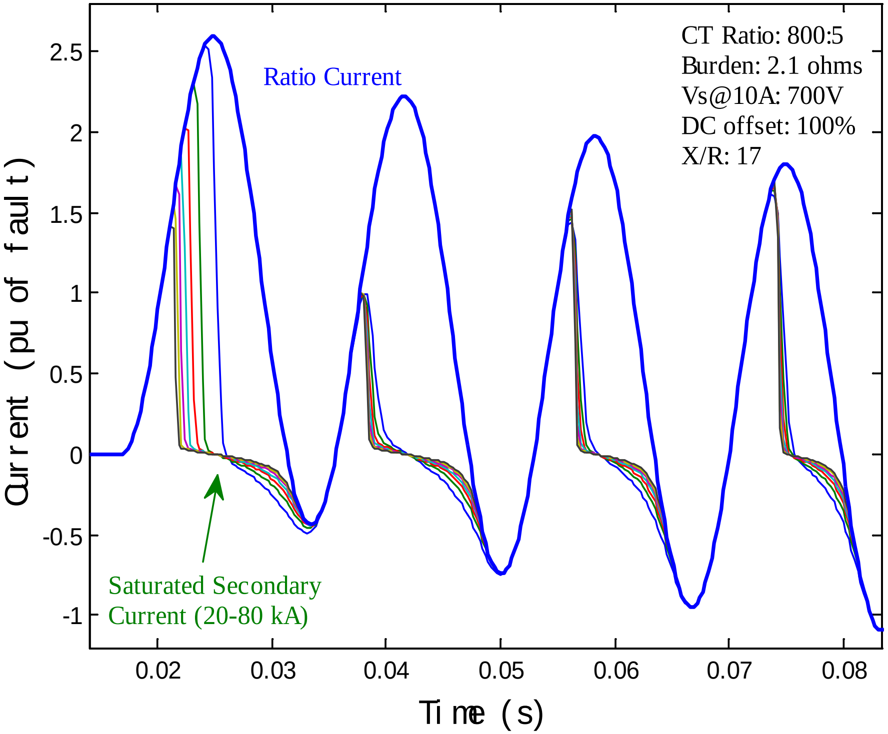


Impacts – CT Saturation

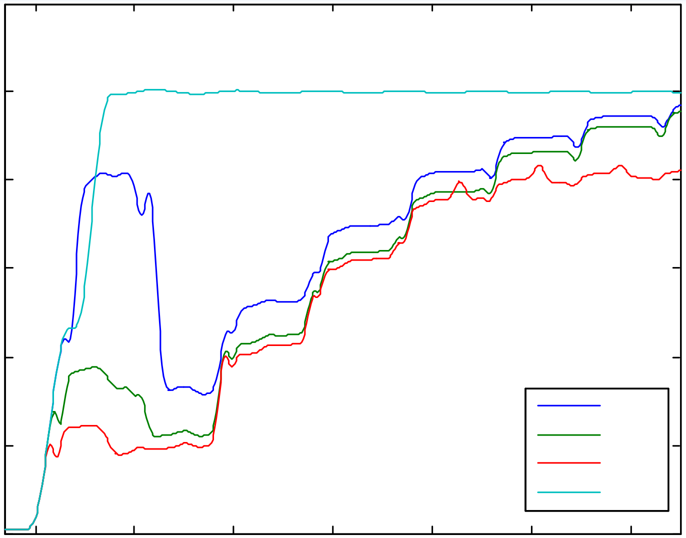
- DC saturation: caused by DC component in the fault current, unipolar half wave current or remnant flux in the CT

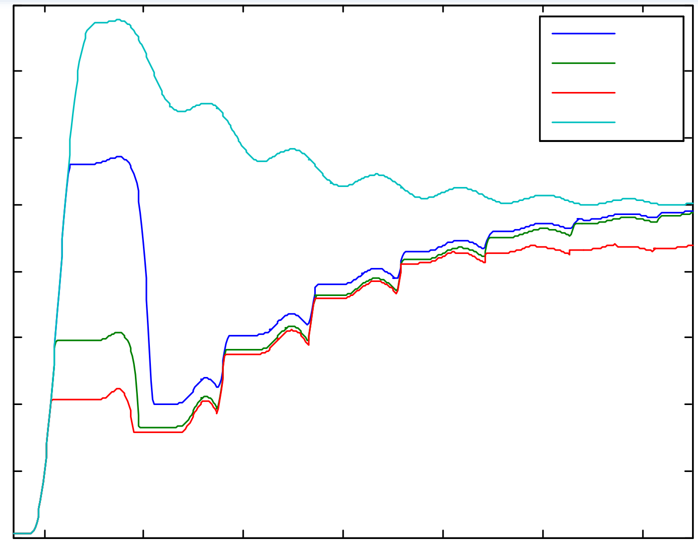
To avoid DC saturation

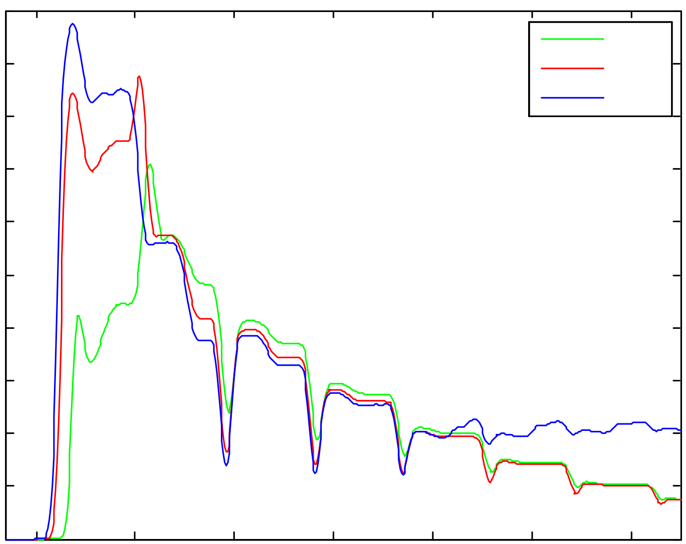
$$V_X > I_S \times Z_S \times (1 + \frac{X}{R})$$

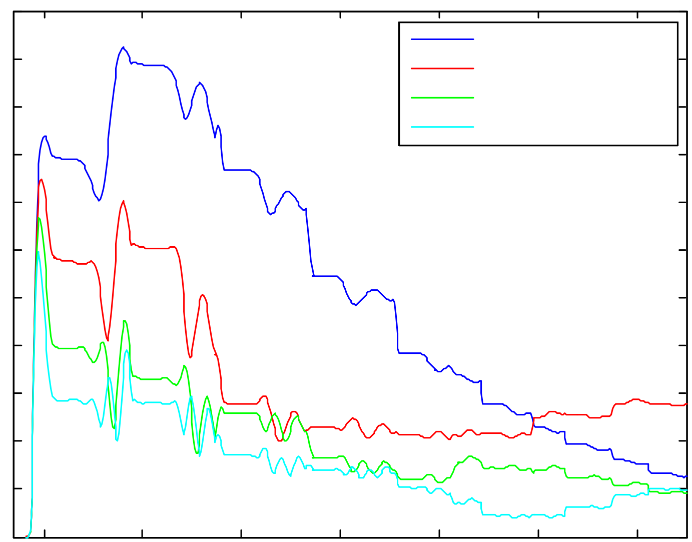


Impacts – CT Saturation (DC)









Impacts – CT Saturation

- Reduced magnitude and rms values, which affect current-based protection functions

- Result in the leading angle, which may affect directional functions.
    - DC saturation will cause more leading angle shift compared to AC saturation

- Increased ratios of harmonics to fundamental

Evaluation Techniques

- Test in a high current laboratory
  - Apply high primary fault current to CT, as the true fault
  - Needs special equipment, costly and rarely available to most users

- Test using a real time power system simulator
  - Model the power system, simulate different system and fault conditions in real time, generate analog signal, which can be applied to a signal amplifier and then injected into input of the relays
  - Capacity of the signal amplifier is a major concern for high level secondary fault currents

Evaluation Techniques

- Simulate in electromagnetic transient analysis software
  - Relay model built-in in the s/w: relay performance can be directly tested by simulating different system and fault conditions
  - Relay model not built-in in the s/w : the specific function in a relay can be modeled but requires algorithm details and skills.
  - Save simulated raw waveforms as COMTRADE files and inject to the relay by using a test set.
  - Program analysis software, such as MATLAB, to load raw waveforms, simulate signal processing, model relay functions, and analyze relay response-very complicated.

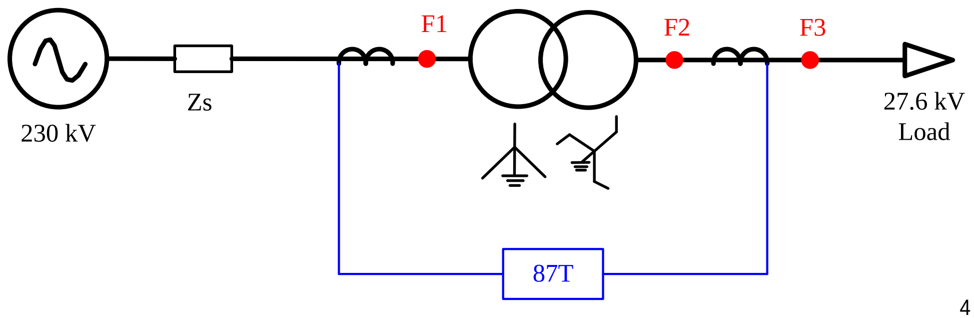
Evaluation Techniques

- Playback recorded waveforms
  - Analyze the relay performance and corrective actions by playing back waveforms recorded from a misoperation event due to a heavy fault

- Program in a simple Excel spreadsheet
  - For example, once the maximum fault level is determined and CT parameters are known, the PSRC CT saturation calculator can generate the secondary current with saturation or without it, and calculate the fundamental magnitude

Case Studies – 1

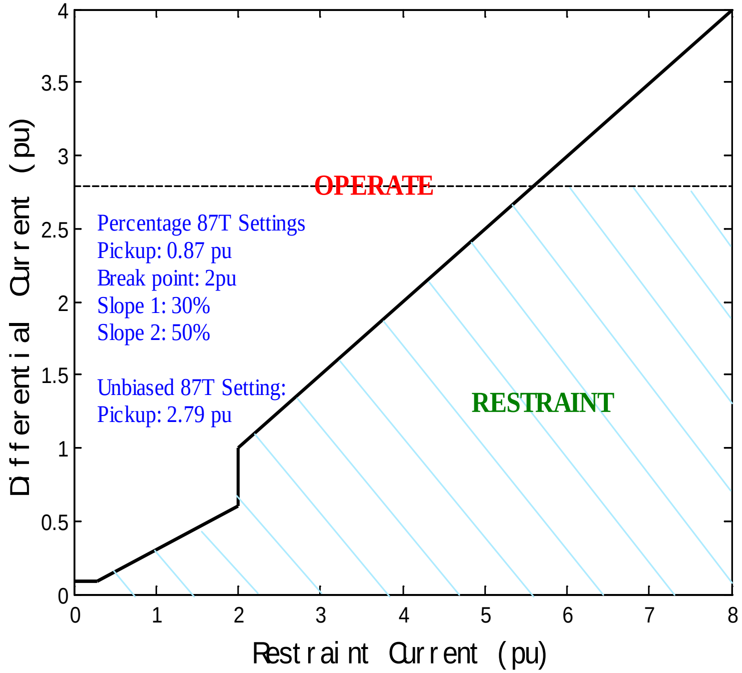
- Transformer differential relay in a 230/27.6kV substation



CT: HV 800/5, burden 1.6 ohms

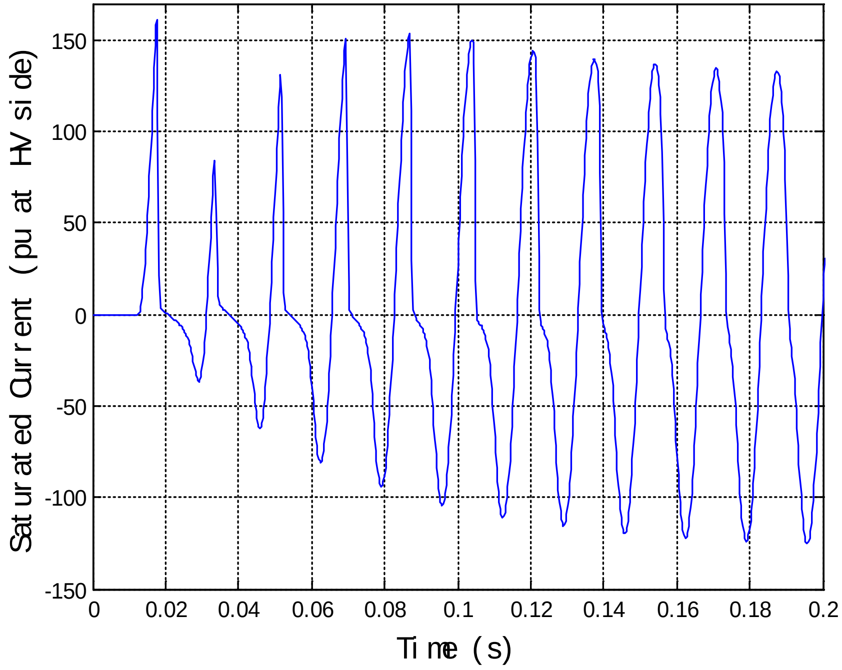
LV 1600/5, burden 1.73 ohmw

- Three fault locations at F1, F2 and F3
- Different fault types
- Two different fault current levels, 60 and 73 kA (F1 point)
- Two fault inception angles, 0 and 90 degree (phase A voltage)



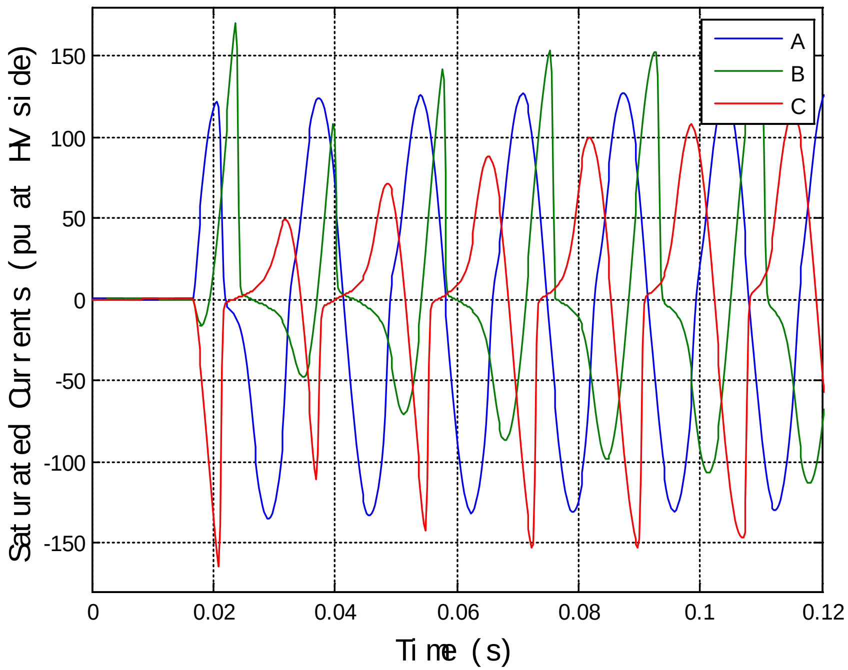
Case Studies – 1

- CT saturation example I – SLG fault at F1



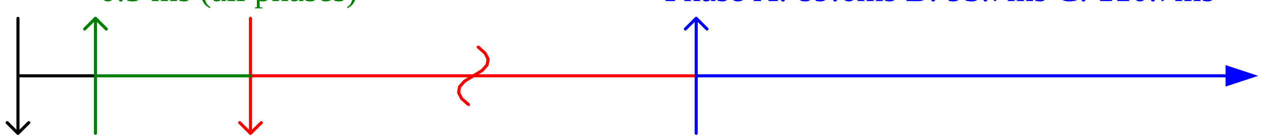
Case Studies – 1

- CT saturation example II – three-phase fault at F1



Percent 87T PKP, but inhibited by 2nd
< 0.5 ms (all phases)

Percent 87T operates, 2nd inhibit unblocked
Phase A: 89.6ms B: 93.7ms C: 110.7ms



0
Fault Inception

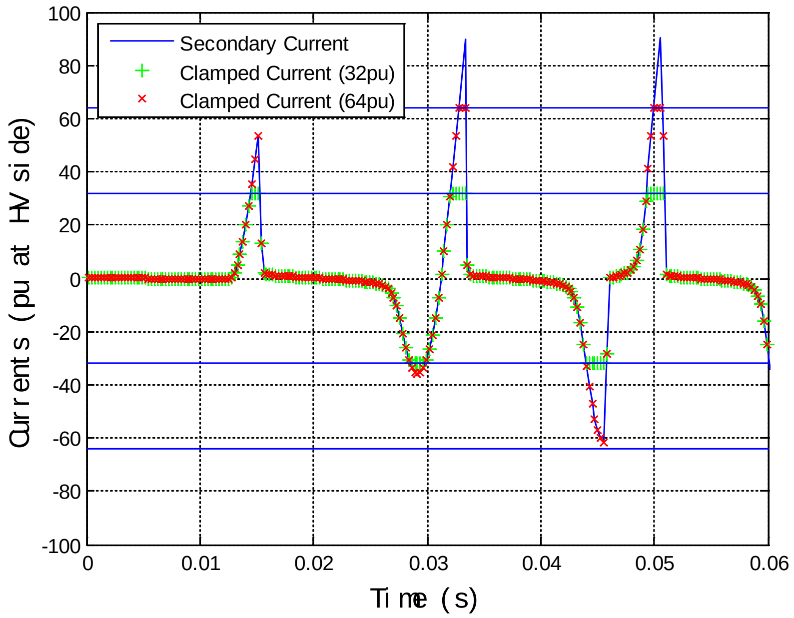
<1 ms (all phases)
Unbiased 87T operates

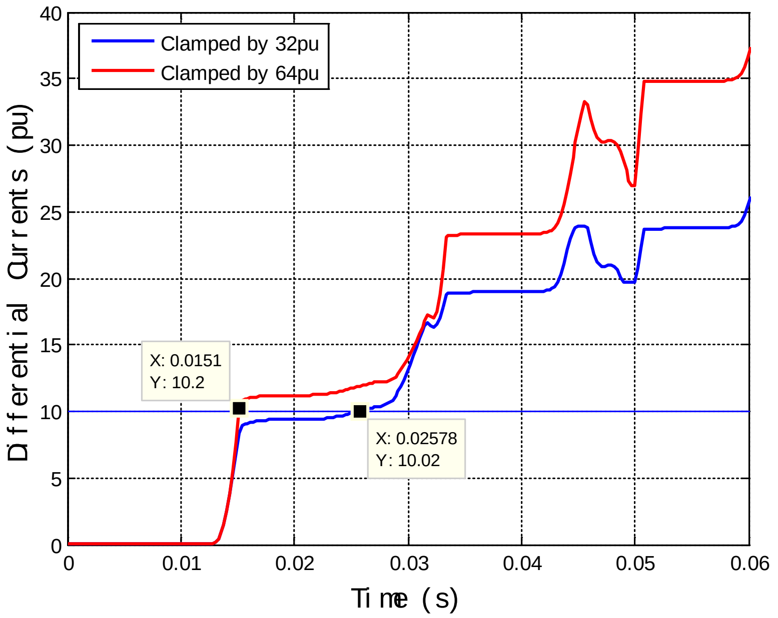
Case Studies – 1

- Effect of CT saturation
  - Percentage differential function does not have failure to operate for internal faults or misoperations for external faults (studied case only)
  - The instantaneous (unbiased) differential protection function should be enabled to avoid a slow operation, if the percentage differential function can be potentially blocked by the second harmonic inhibit

Case Studies – 1

- Effect of clamping levels, with 10pu pickup setting





- Unbiased 87T clamped by 32pu will be slower by 10.68ms

Case Studies – 1

- Results:
  - In the studied substation, the existing CT and relay settings are able to handle the increased fault current level, when both biased and unbiased differential elements are enabled.
  - The increased fault level has effect on the operate time of the biased differential function, but this can be mitigated by proper setting of the unbiased differential function.

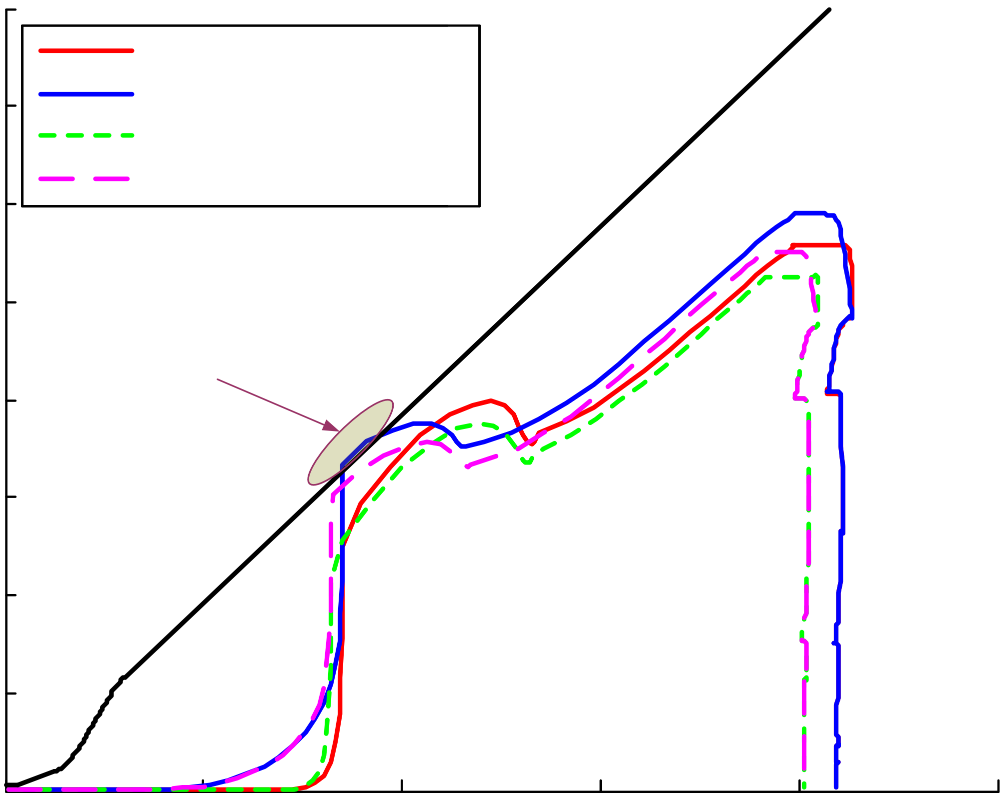
Case Studies – 2

- A 100MVA Yd11 transformer in a 138/19.5kV substation

- Similar fault scenarios
  - Internal and external faults
  - Fault levels: 50 and 65 kA
  - Clamping levels: 32 and 64 pu

Case Studies – 2

- Example: External fault @ low voltage side
- Experience CT saturation



Conclusions

- CT saturation would reduce the magnitude and cause a leading phase angle shift of the current phasor

- Relay internal clamping level limits the measurement range of waveforms, therefore, the calculated magnitudes are decreased potentially endangering differential function and erroneous harmonics are generated

Conclusions

- By analyzing 87T function,
  - Always enable the unbiased differential function to avoid slow operation due to the inrush inhibit of the percentage differential function, thereby improving the relay dependability
  - The security of the percentage differential function may be jeopardized due to the increased fault current and lower clamping level. The security can be ensured by increasing the differential settings or by employing dedicated CT saturation function available in the relay.
  - The 87T function with the larger clamping level is typically able to respond faster.

Thank You

Questions?