ANALYZING THE IMPACT OF SHUNT REACTOR SWITCHING OPERATIONS BASED ON DFR MONITORING SYSTEM

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Presentation Outline

- Advantages of DFR Monitoring System
- Types of Shunt Reactors
- Inrush Phenomenon and its Effects on Reactor Protection
- CT Saturation and its Effects on Reactor Protection
- Avoiding Misoperations
- Conclusions

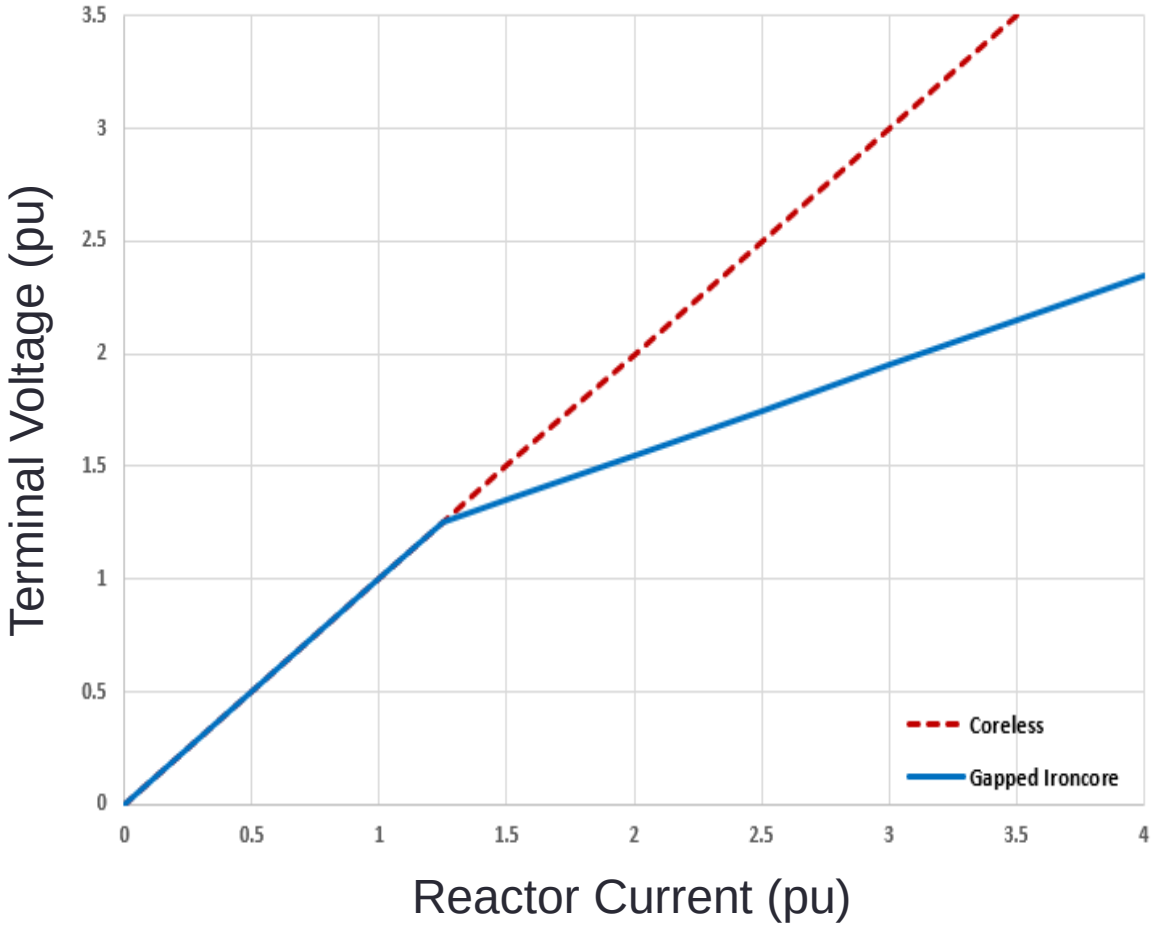
DFR Monitoring System

- Evidence for event analysts
- Analyzing and avoiding misoperations in the real-world system
- Superior sampling rates, extended record lengths and unfiltered recording abilities
- Required for certain BES elements according to NERC PRC-002-2 and PRC-018-1 standards

Types of Shunt Reactors

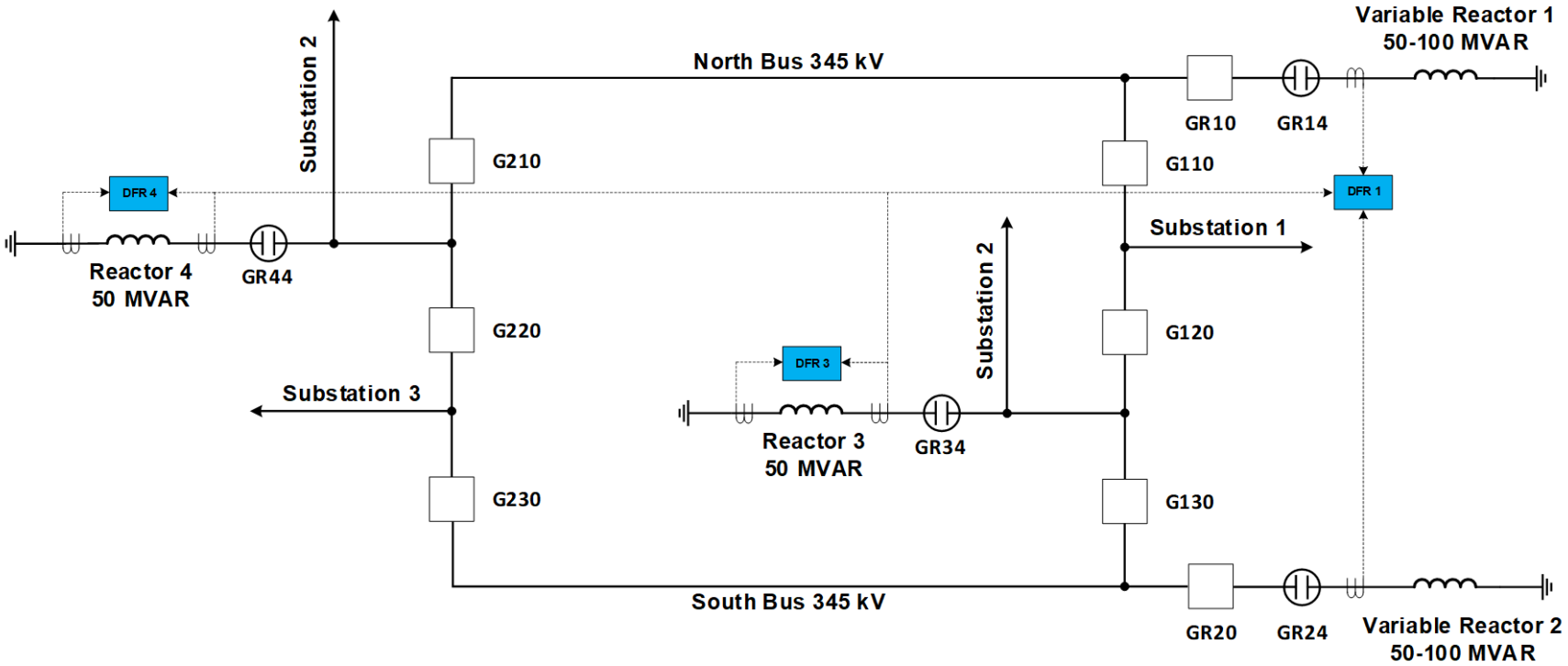
- Shunt reactors based on type of core used:
  - Coreless (Air-core)
  - Gapped Iron-core
- Factors to focus on:
  - Saturation of the equipment
  - Harmonic content in the reactor current
  - Decaying DC offset

Shunt Reactor Magnetic Characteristics



[*CIGRE Working Group B5.37 – Protection, Monitoring and Control of Shunt Reactors*]

System One-Line



Inrush Phenomenon

- What is Inrush Current?

$$V(t) = \sqrt{2}V_{rms}\sin(\omega t + \delta)$$

$$I_{Reactor}(t) = \frac{\sqrt{2}V_{rms}}{|Z|}\sin(\omega t + \delta - \theta) - \frac{\sqrt{2}V_{rms}}{|Z|}\sin(\delta - \theta)\, e^{\frac{-t}{L/R}}$$

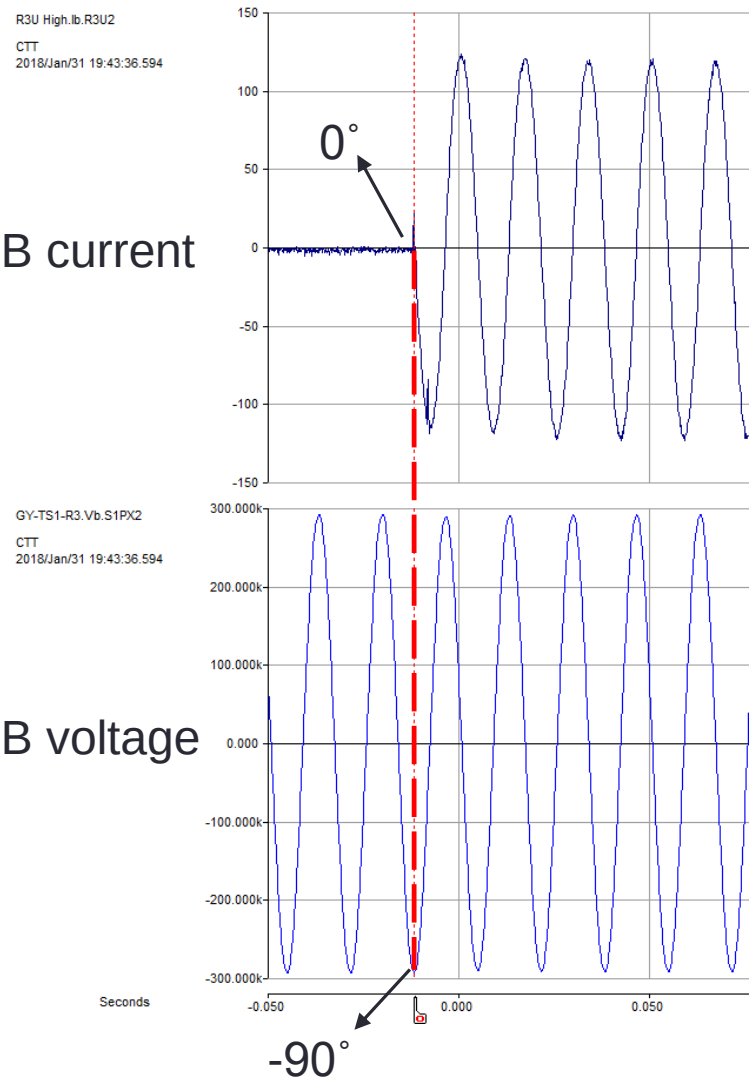
Where,

$$|Z| = \sqrt{R^2 + (\omega L)^2}$$

$$DC\ offset\ time\ constant = \frac{L}{R}$$

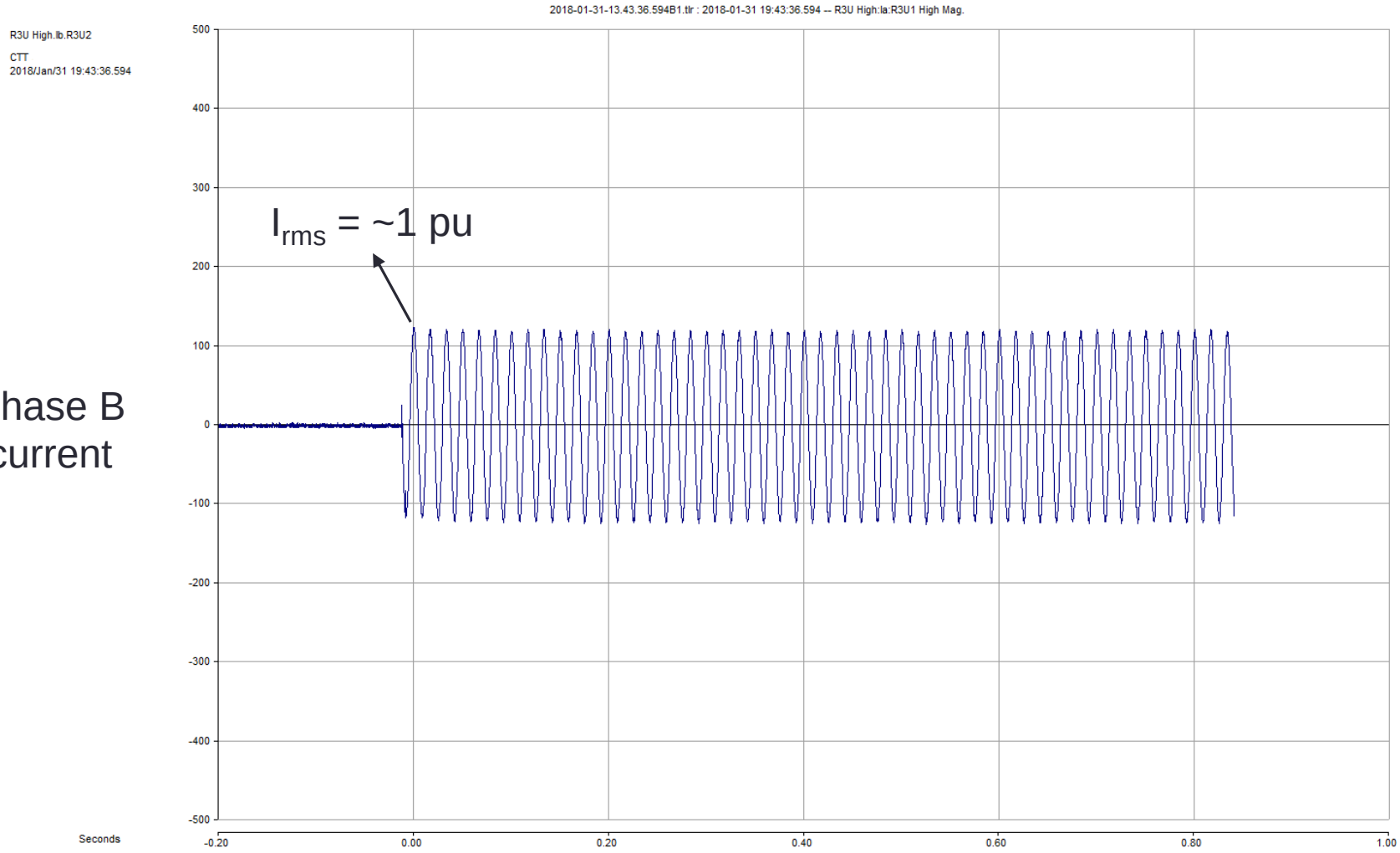
$$\delta = phase\ angle\ of\ voltage;\ \theta = arctan(\frac{\omega L}{R})$$

Scenario 1: Peak Voltage Crossing



Scenario 1: Peak Voltage Crossing

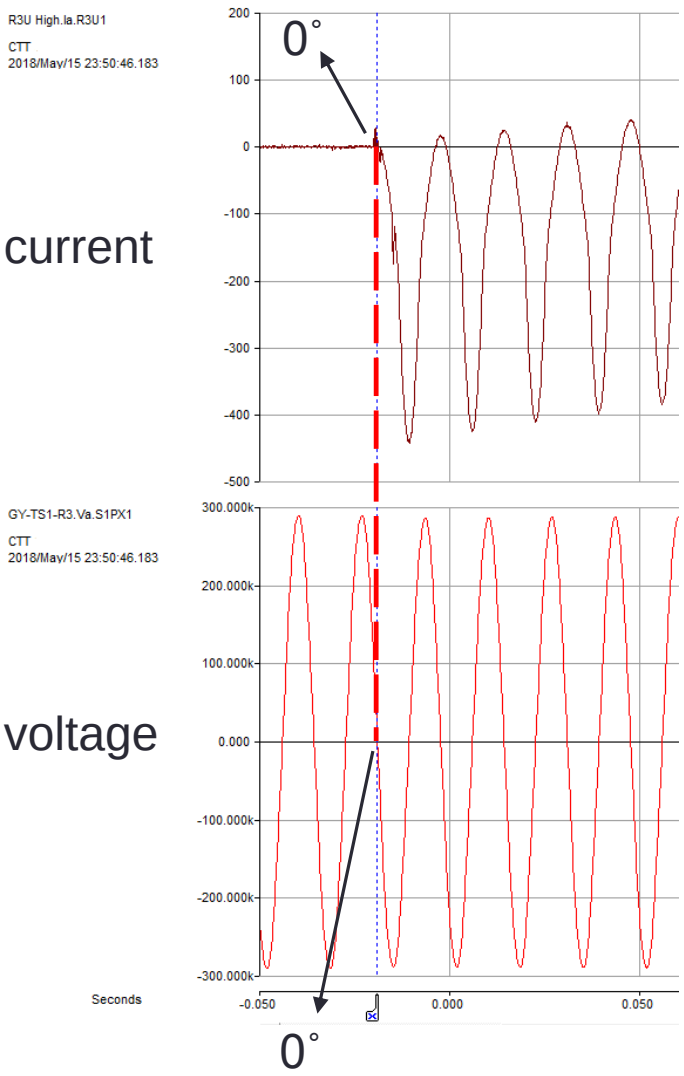
Phase B current



Scenario 2: Zero Voltage Crossing

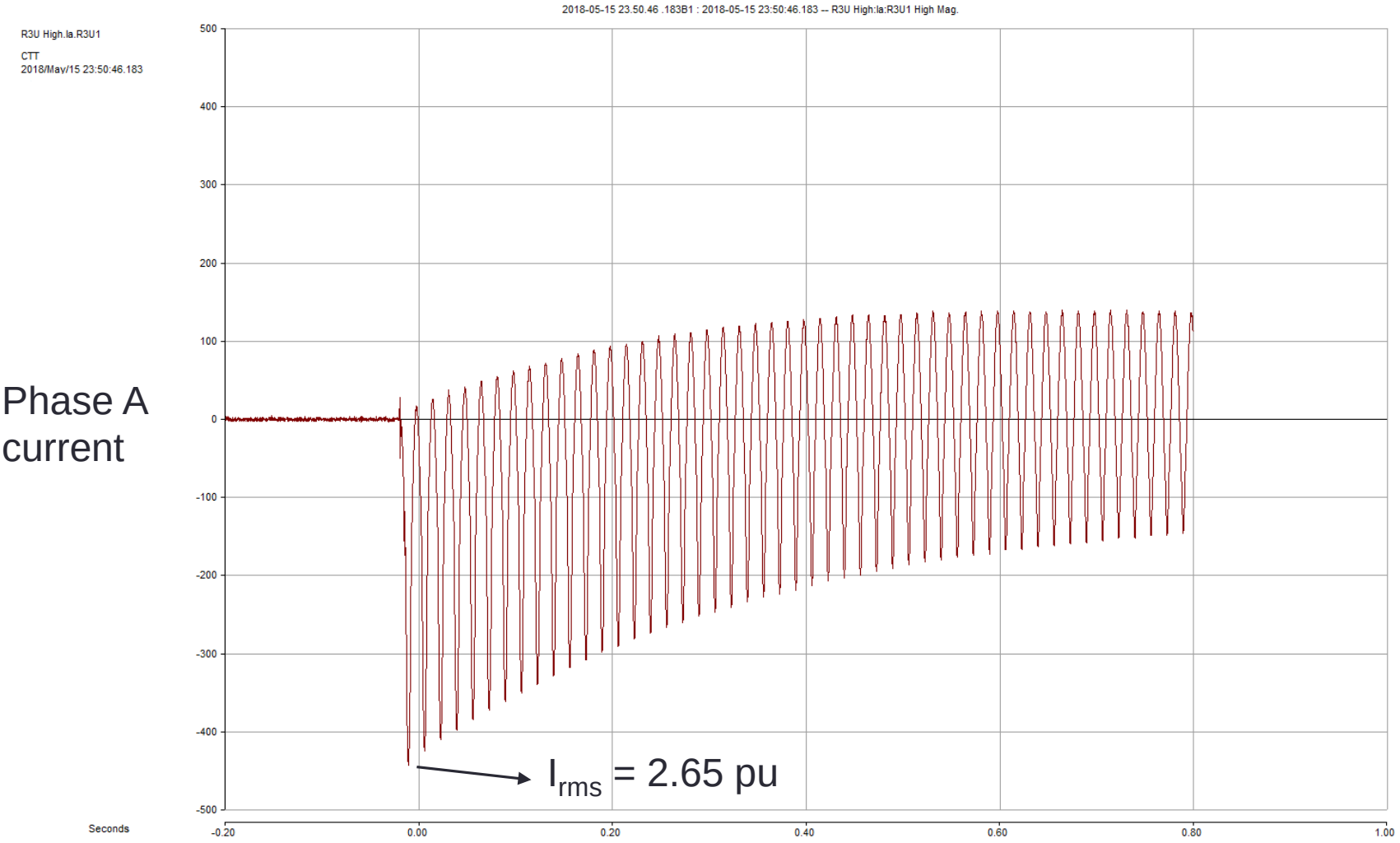
Phase A current

Phase A voltage



Scenario 2: Zero Voltage Crossing

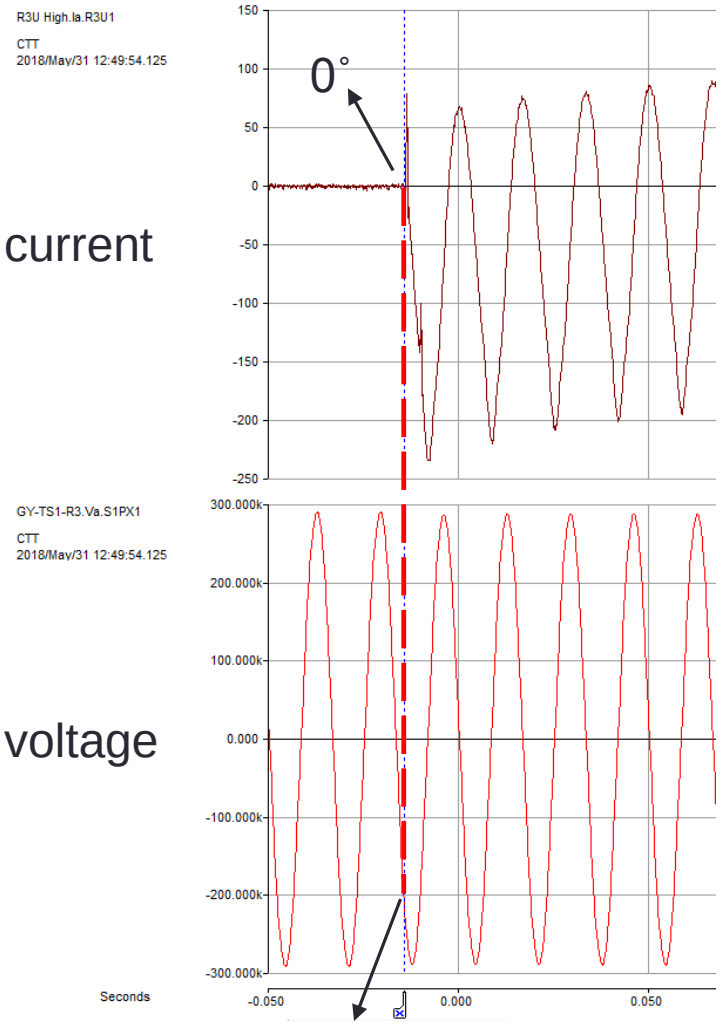
Phase A current



Scenario 3: Intermediate Voltage Crossing

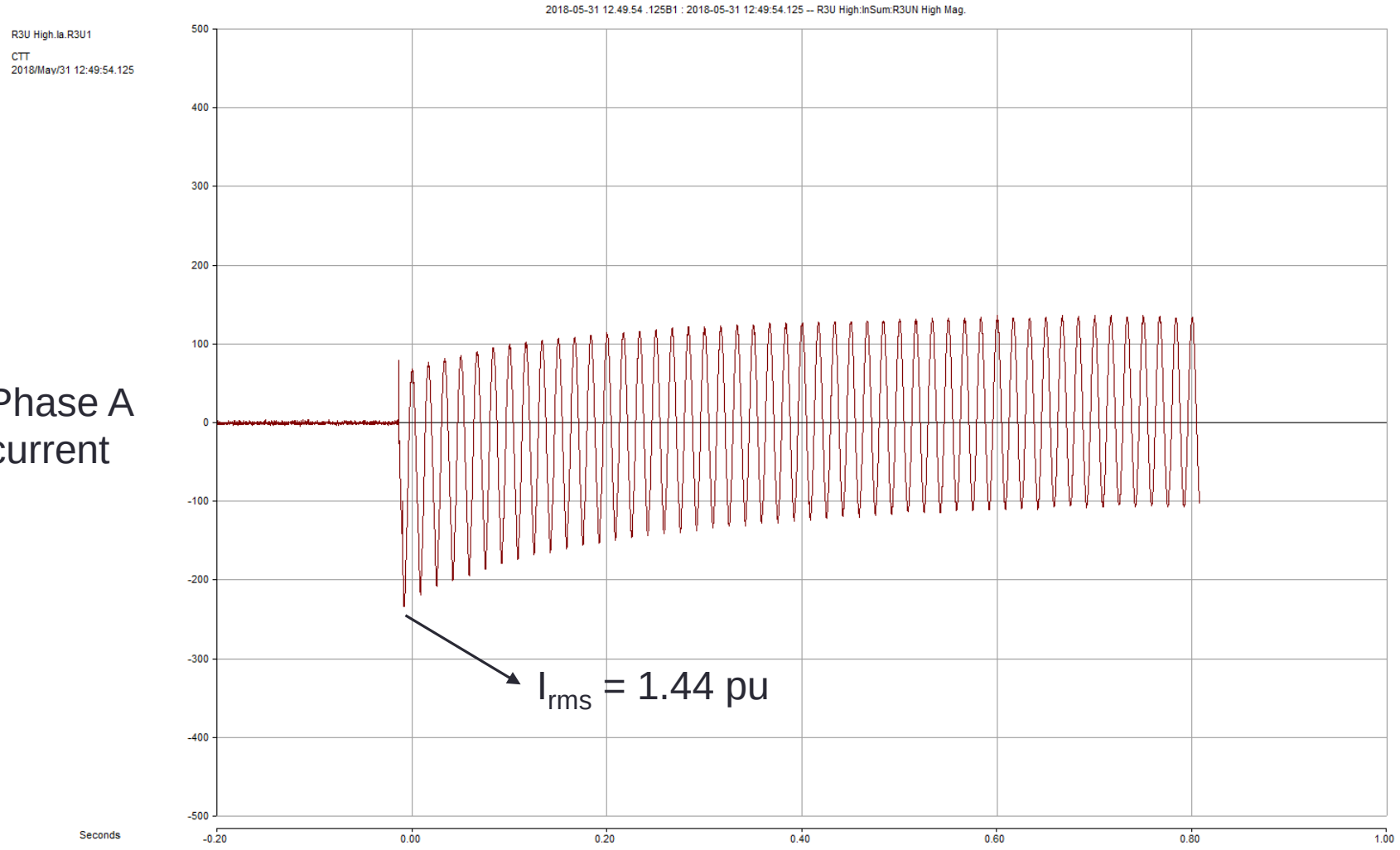
Phase A current

Phase A voltage

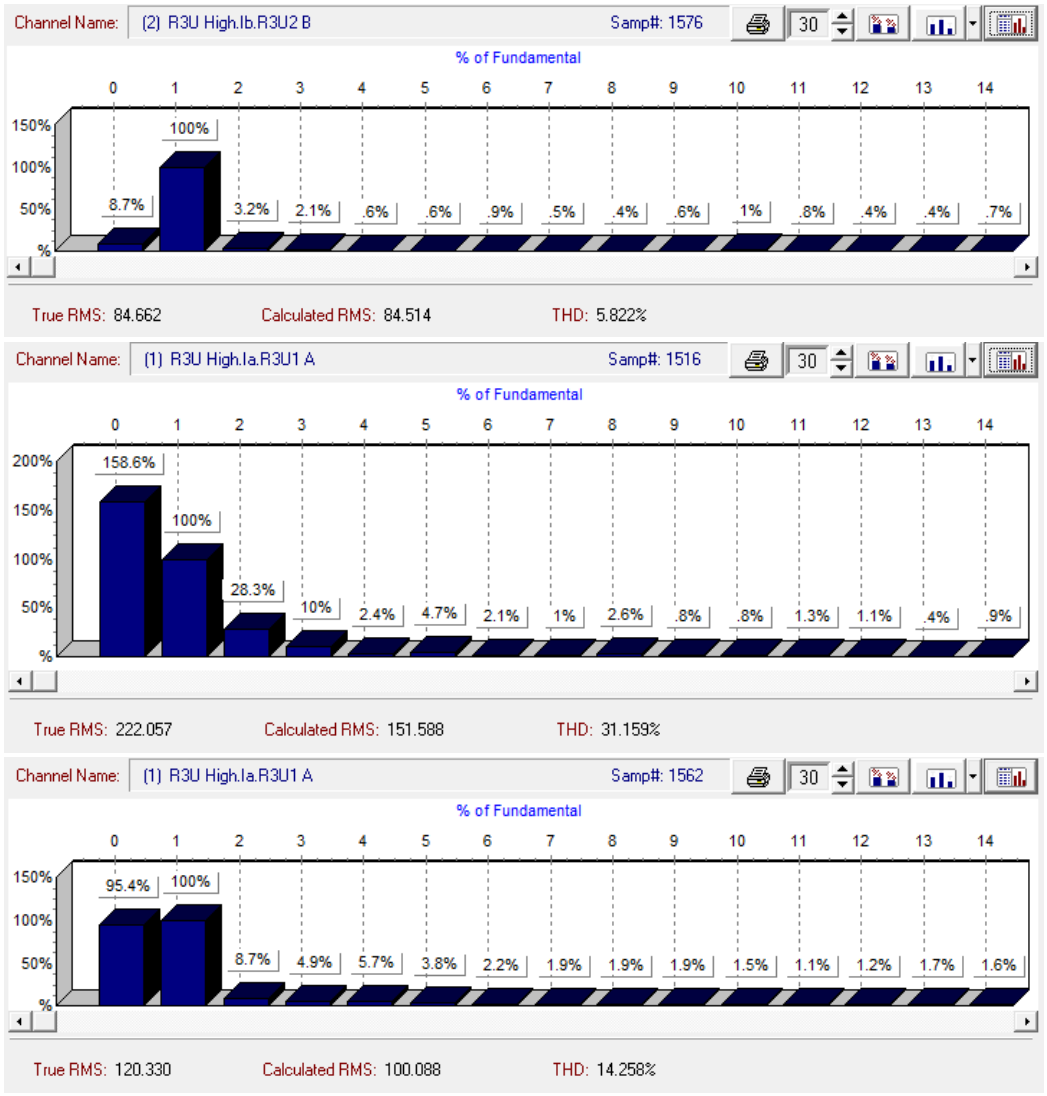


Scenario 3: Intermediate Voltage Crossing

Phase A current



Harmonic Content Comparison



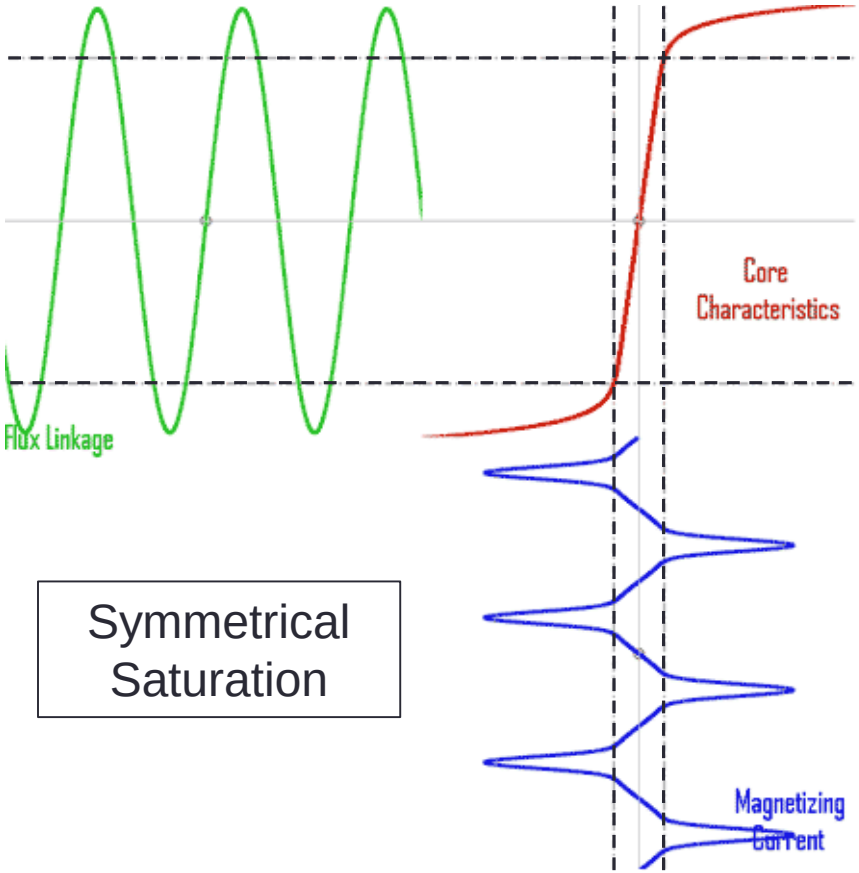
- Peak Voltage Crossing
- Zero Voltage Crossing
- Intermediate Voltage Crossing

Effect of Inrush Current on Reactor Protection

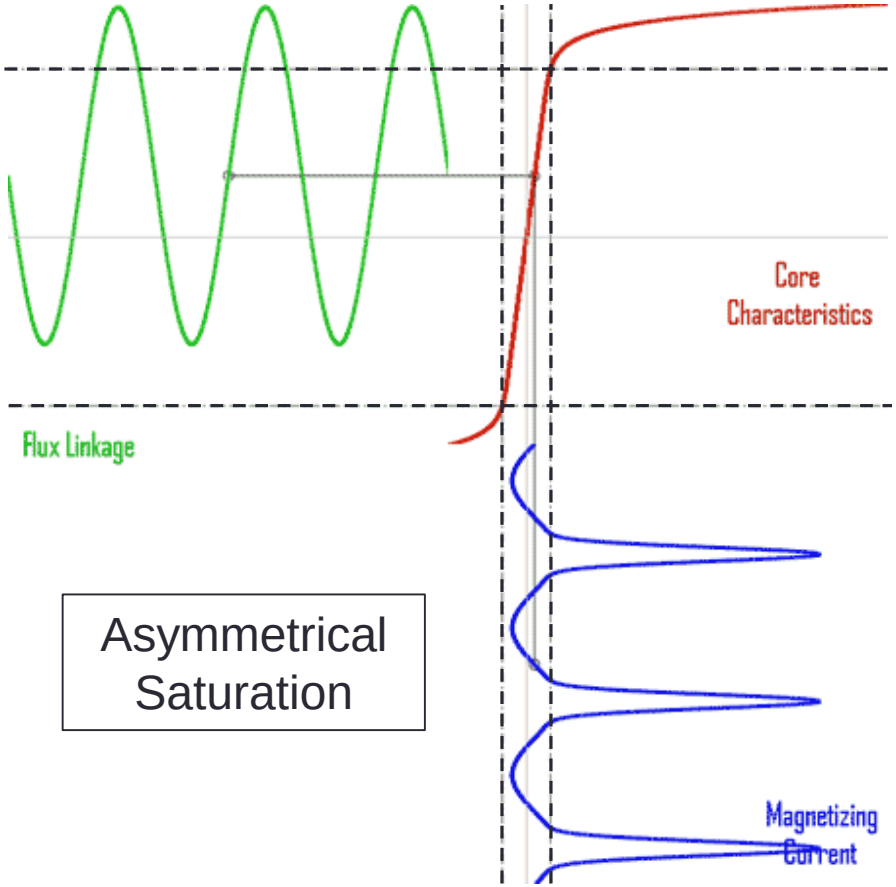
- Instantaneous ground overcurrent element
- CT saturation
  - Unrestrained (Instantaneous) differential element

CT Saturation

- CT operation
- Types of CT saturation:



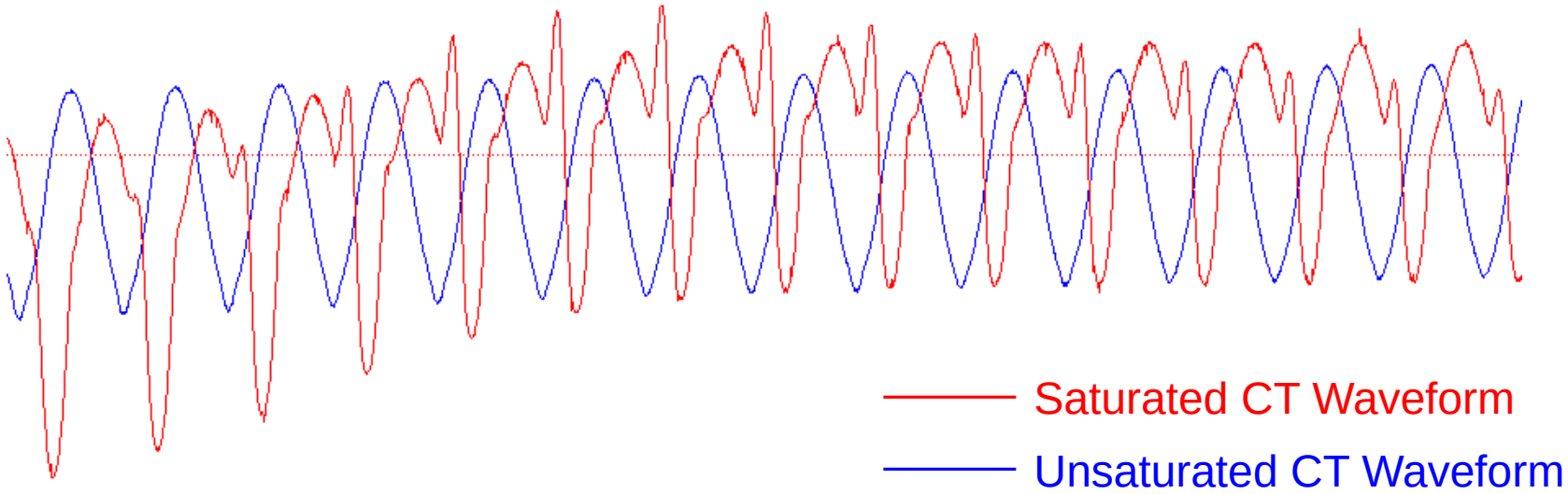
Symmetrical Saturation



Asymmetrical Saturation

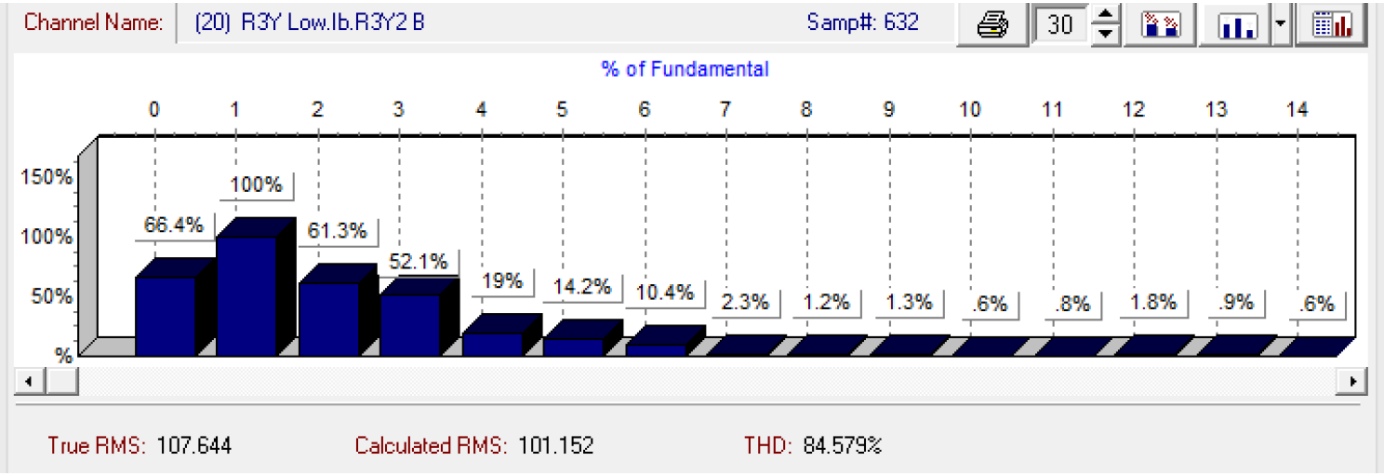
Identifying CT Saturation

- Based on characteristic waveform

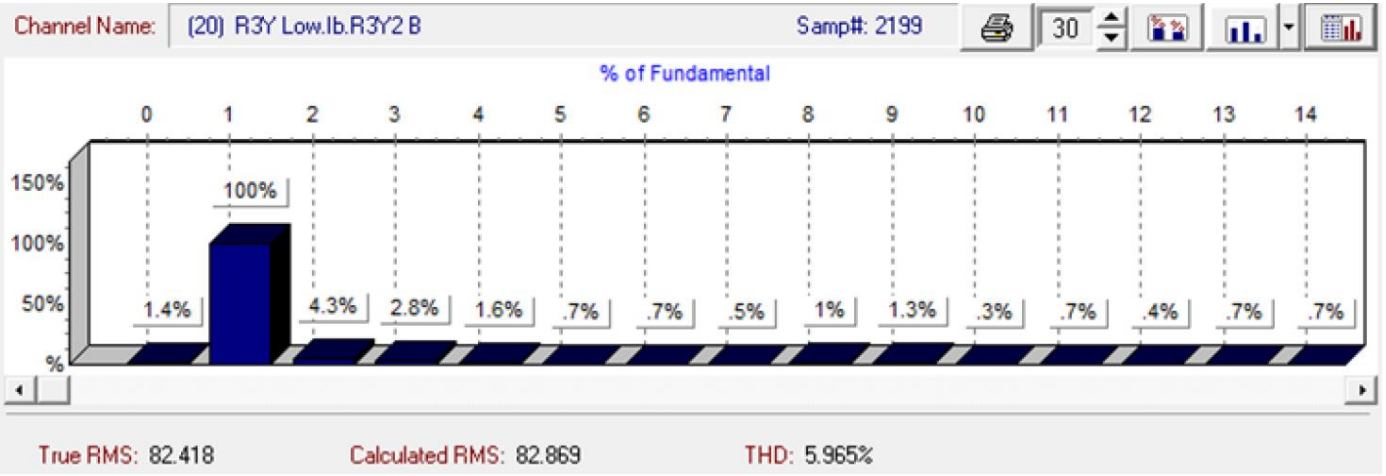


Identifying CT Saturation

- Based on presence of harmonics



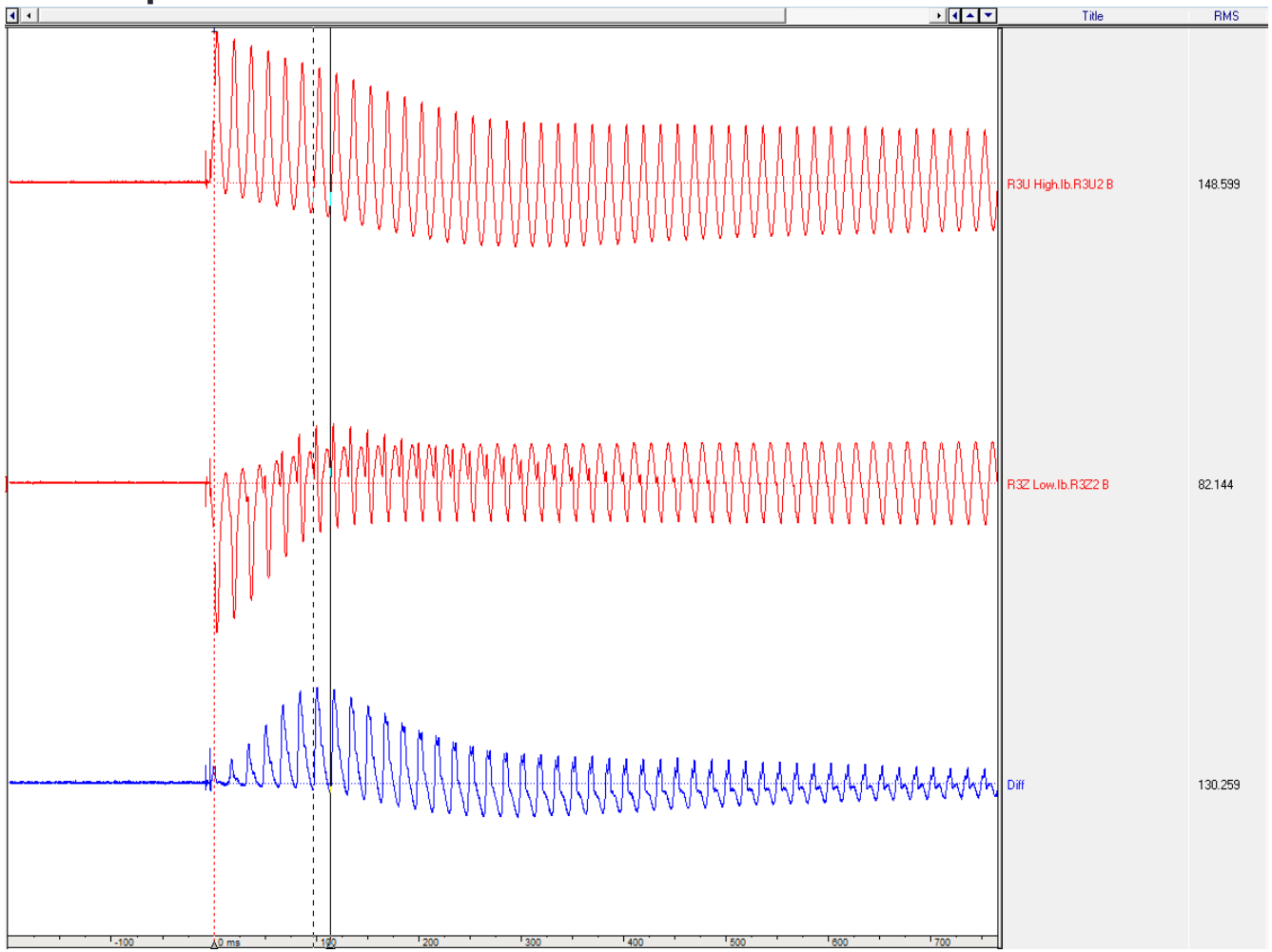
- Saturated CT



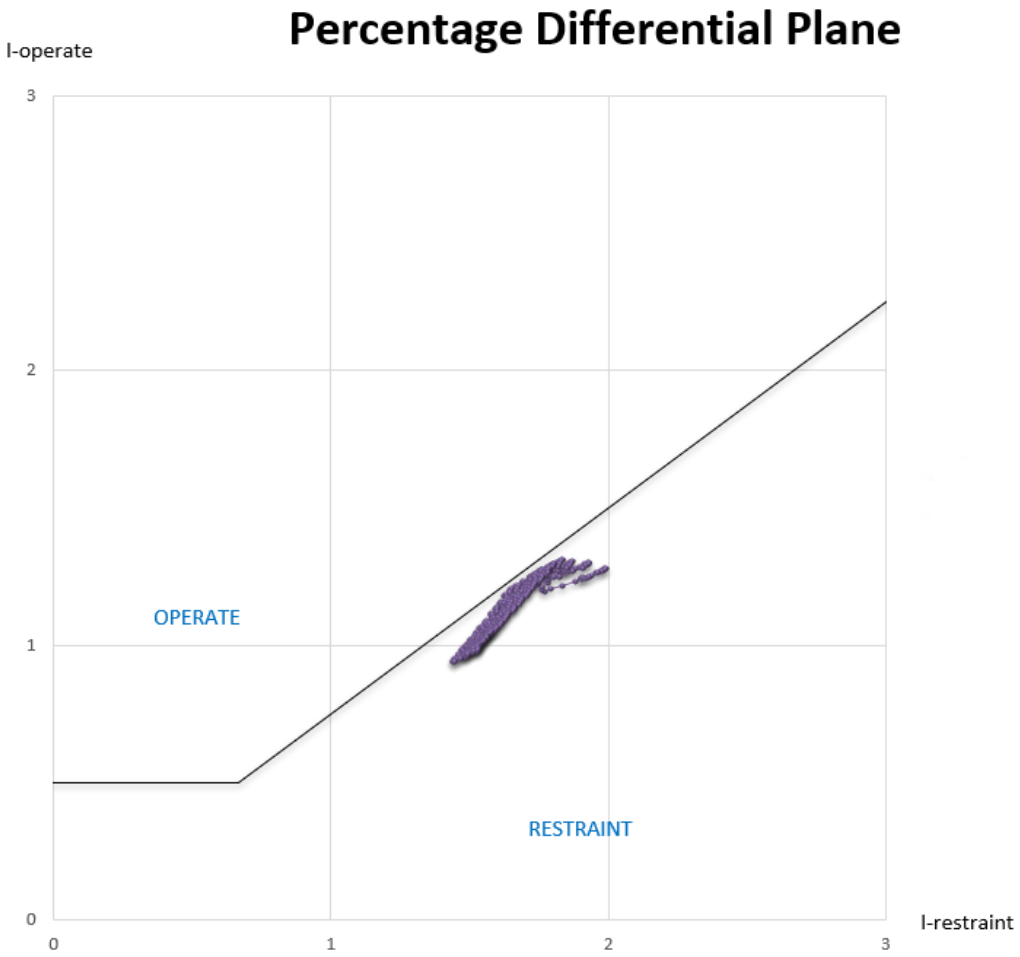
- Unsaturated CT

Identifying CT Saturation

- Based on presence of differential current



Effect of CT Saturation on Reactor Protection



$$IOPB = |IBH + IBL|$$

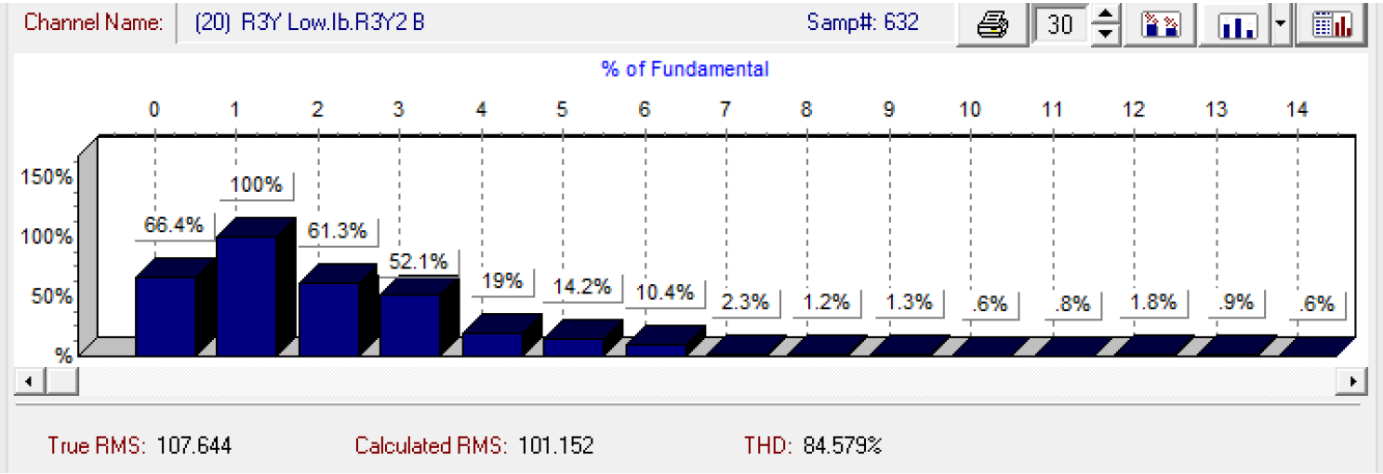
$$IRTB = |IBH| + |IBL|$$

$$IOP > IRT * SLP$$

— Restrain Slope • B phase current plot

Averting Misoperations

- Differential protection
  - Use of Harmonic Blocking and Harmonic Restraint



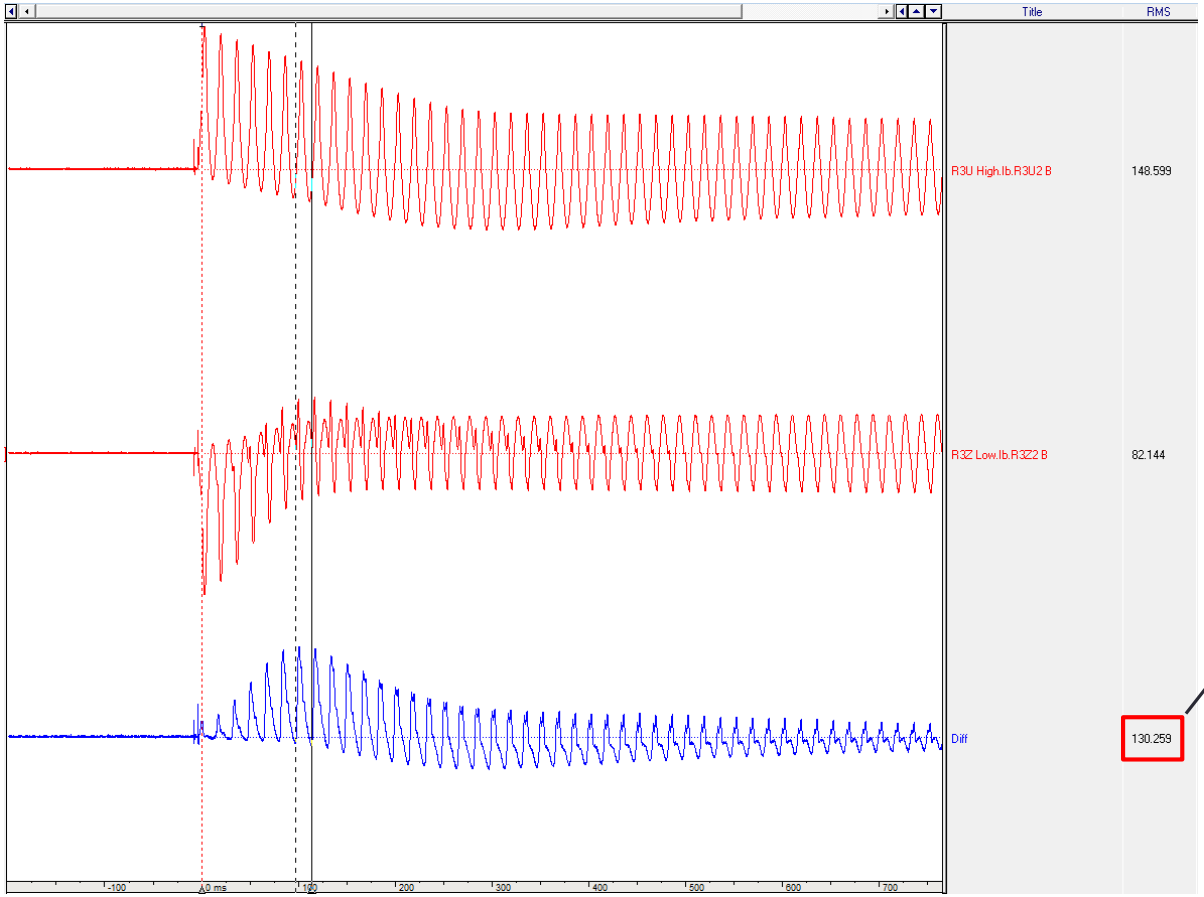
Averting Misoperations

- Differential protection
  - High Instantaneous Differential pickup

High side current

Low side current

Differential current

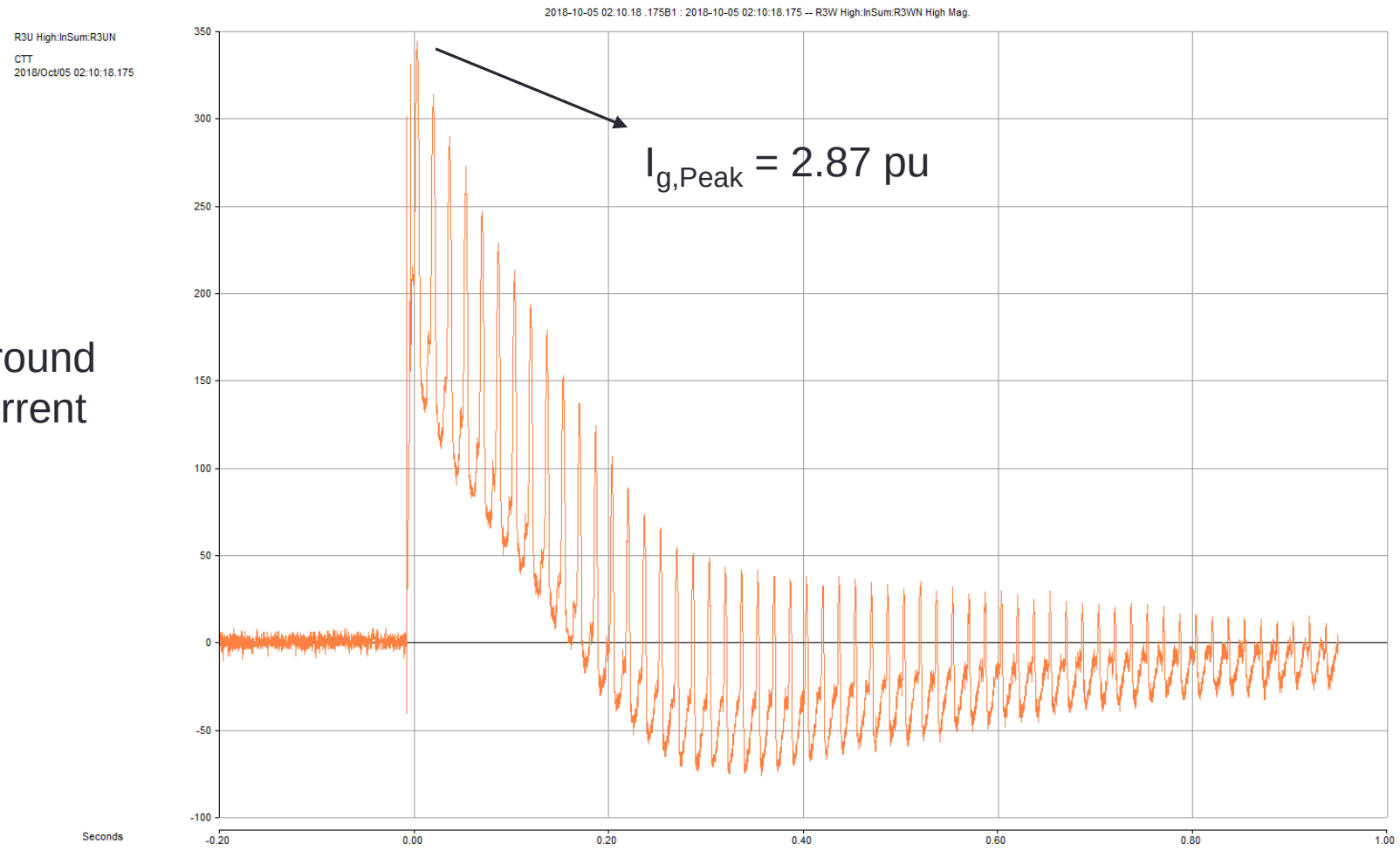


I_{rms} = 1.56 pu

Averting Misoperations

- Instantaneous ground overcurrent protection

Ground current



Conclusions

- Inrush Current experienced by Shunt Reactors:
  - DC offset – Phase angle of Voltage waveform
  - Harmonic content - Linearity of the core magnetic characteristics
  - Can be avoided by using synchronized switching
- Identifying CT saturation using DFR monitoring system
- Protective elements to focus on:
  - Instantaneous Ground overcurrent element
  - Instantaneous Differential element
- Avoiding misoperations

QUESTIONS

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