

Comparative Characterization of Parallel Distribution Sensors Under Field Conditions (Project T-35)



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October 19, 2010

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Industry Sponsors



- Southern Company
- Exelon
- American Electric Power
- Entergy
- PG&E
- National Grid
- ABB
- Bryan Texas Utilities

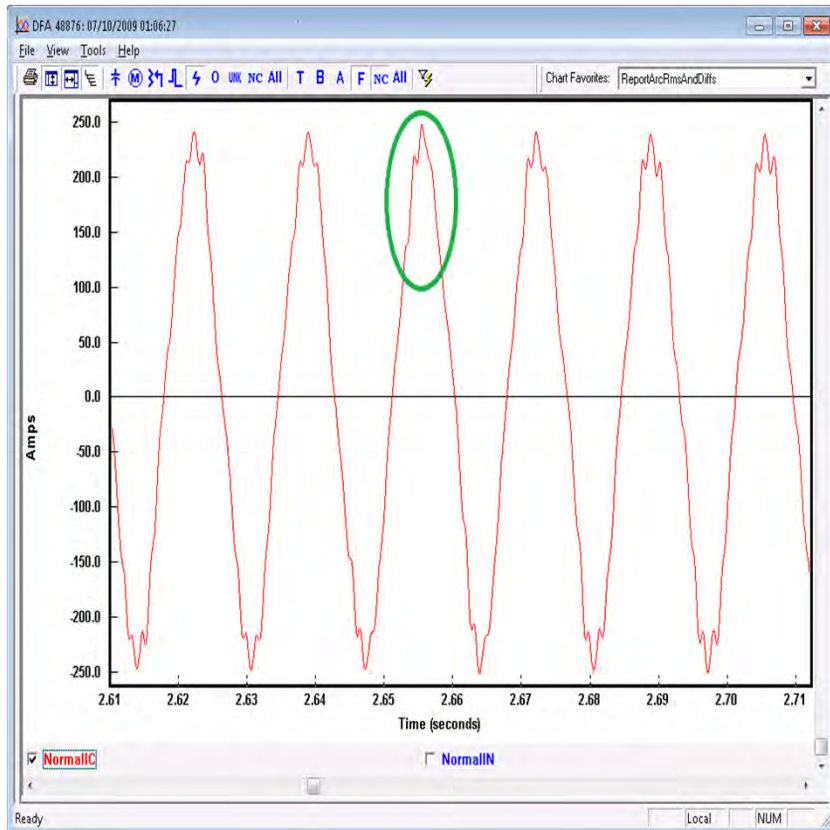
Researchers wish to extend special thanks to Southern Company, which provided all sensors used in the project, and to Bryan Texas Utilities, which hosted the installation site.



Project Purpose

- Emerging technologies for improved management of distribution systems require current and voltage measurements.
- Accuracy and waveform fidelity requirements vary by function. For example:
 - RMS voltage for conservation voltage reduction
 - Broad-bandwidth waveforms for power-quality monitoring or fault anticipation

Example Incipient Failure Waveform



The figure is a screenshot of a web browser window titled "DFA Alerts and Reports - Mozilla Firefox". It displays a web interface for "DFA Alerts and Reports". The interface includes a navigation bar with "Alerts", "Reports", and "Diagnostics" tabs. Below the navigation bar, there is a "Welcome Demo User" message and a "Change Password/Sign Out" link. The main content area shows a table of alerts for Feeder 48876. The table has columns for "Feeder", "Alert Type", "Phases", "Comments", and "Last Occurred". The first two rows of the table are highlighted in yellow.

Feeder	Alert Type	Phases	Comments	Last Occurred
48876	Probable failure of switch or clamp	A	Ratio: 0.25, Type-B (Smooth)	10/31/09 02:32:38
48876	Probable failure of switch or clamp	C	Ratio: 0.26, Type-A (Sharp)	07/10/09 07:26:07

Event Type	Phases	Occurred
Probable failure of switch or clamp	C	07/10/09 07:26:07
Probable failure of switch or clamp	C	07/10/09 07:22:35
Probable failure of switch or clamp	C	07/10/09 07:01:57
Probable failure of switch or clamp	C	07/10/09 06:49:52
Probable failure of switch or clamp	C	07/10/09 06:48:29
Probable failure of switch or clamp	C	07/10/09 01:08:14
Probable failure of switch or clamp	C	07/10/09 01:07:10
Probable failure of switch or clamp	C	07/10/09 01:06:27
Probable failure of switch or clamp	C	07/10/09 00:59:38
Probable failure of switch or clamp	C	07/09/09 21:48:23
Probable failure of switch or clamp	C	07/09/09 21:37:56

Change page: 1 Go Page size: 11 Change Displaying page 1 of 1, items 1 to 11 of 11

- Third peak is subtly different from other cycles. DFA algorithms recognize this as a specific incipient failure mode, but this requires sensors that represent waveform correctly.
- Steady-state harmonic distortion is significant, but common for feeder currents, and does not itself indicate an incipient failure on the feeder.



Project Purpose (cont.)

- Traditional current and potential transformers (CTs and PTs) are the de facto standard for sensing, but cost of acquisition and installation can be barrier to deploying new technologies.
- Alternative sensors offer lower installed costs, but their sensing characteristics (linearity, frequency, transient response) are generally unknown.



Project Purpose (cont.)

- The quality of any measurement or control system is limited by the measurement system and the transfer characteristics of the sensors used to provide inputs to that system.
- While this seems obvious, it would be easy for a utility engineer to simply assume that a particular sensor's output is an accurate representation of reality, without questioning the validity of that assumption.

Project Purpose (cont.)



- The goal of this project has not been to quantify absolute accuracy of sensors, but rather to compare their harmonic and transient response to conventional CTs and PTs.

Sensor Selection Process



- Researchers conducted webcasts and consulted with utility advisors to select candidate sensors for evaluation.
- Consensus quickly formed for two types of alternative sensors.

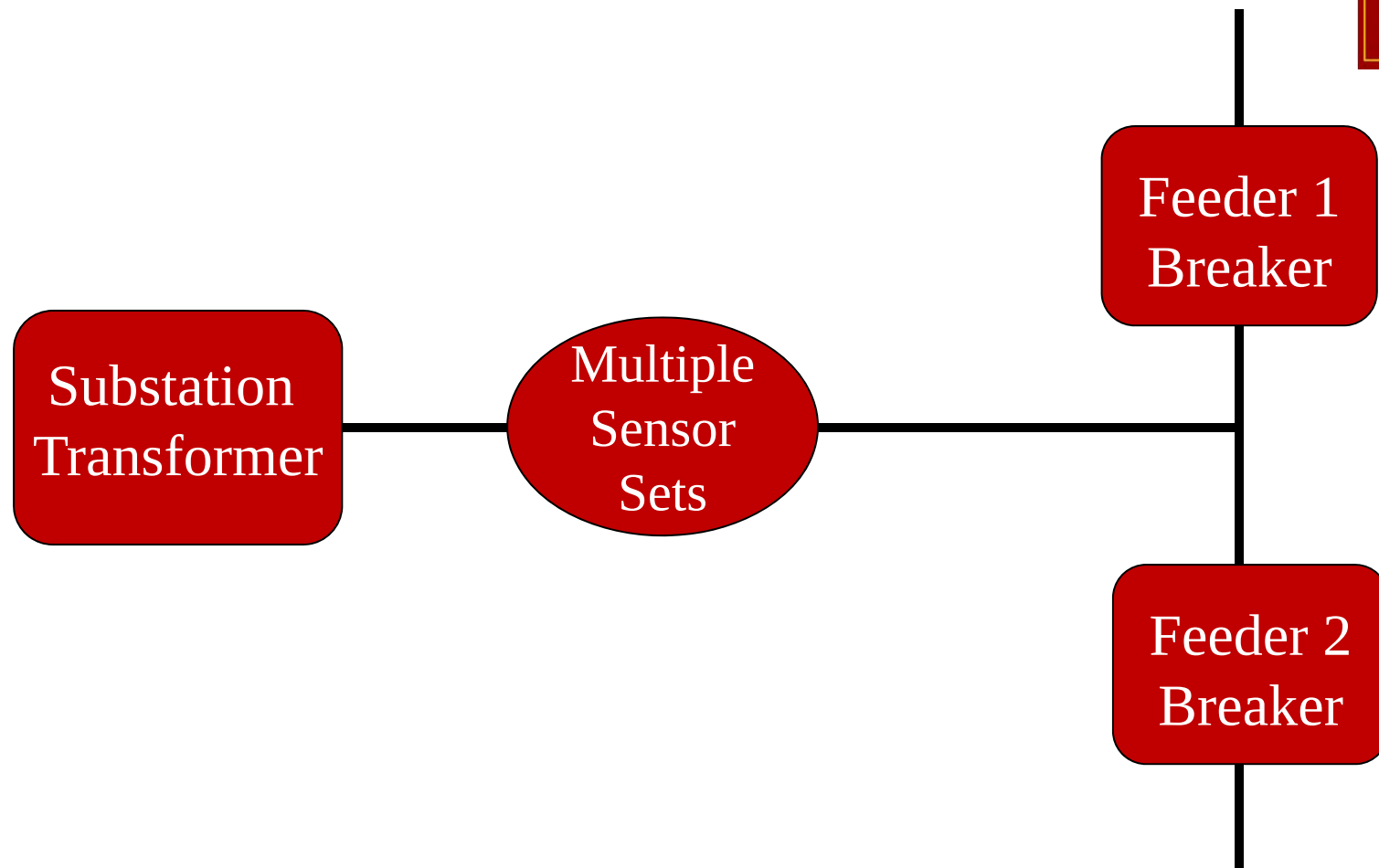


Sensor Selection Process

- There was interest in a third sensor, based on optical phenomena, which entered the market during the evaluation period.
- Researchers received “serial number one” sensors for evaluation, but difficulties with sensor electronics prevented sufficient evaluation.



Sensor Installation

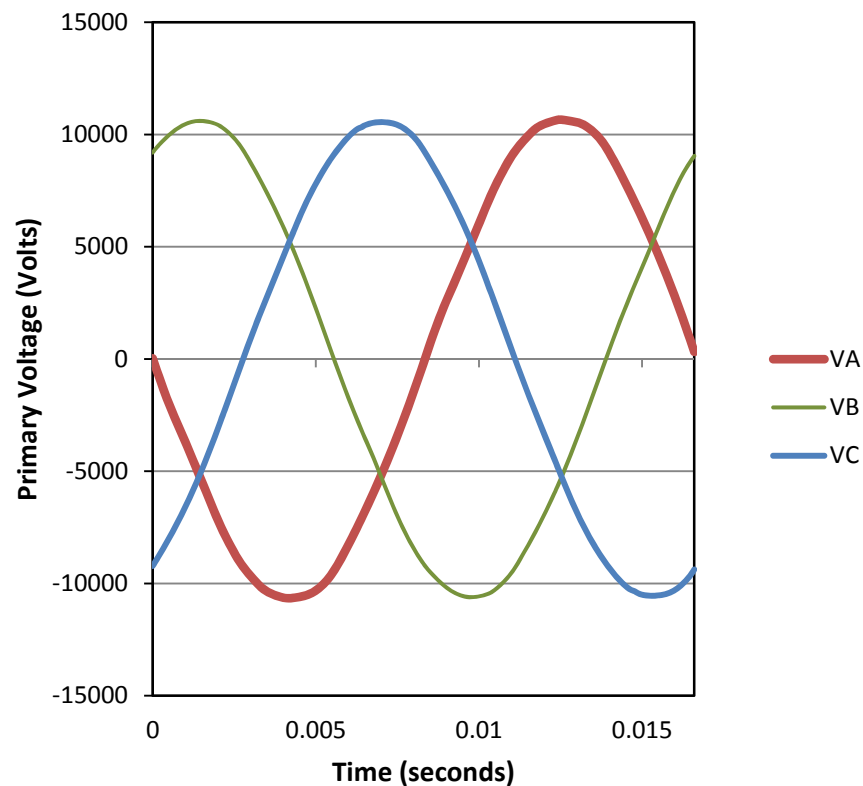


Sensors monitor distribution bus for two 12.47/7.2kV multi-grounded-wye feeders supplying residential, light commercial, and oil-field load with a peak load of approximately 3MW. Maximum calculated fault current for the feeder is $4,617A_{RMS}$.

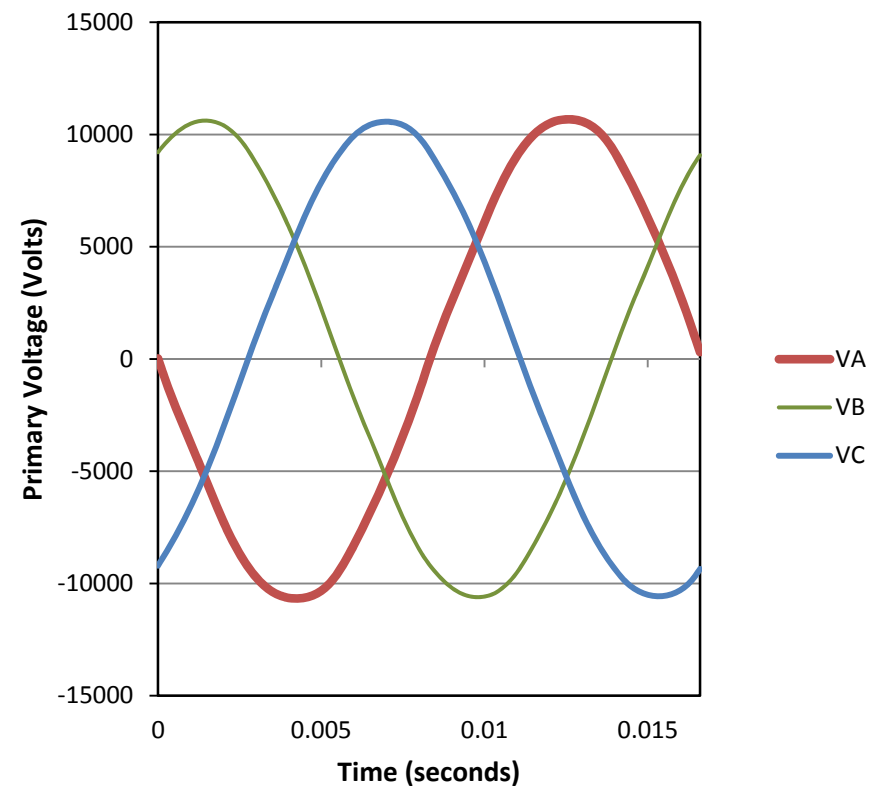


Waveform Comparison: Steady State Voltages

Traditional PT

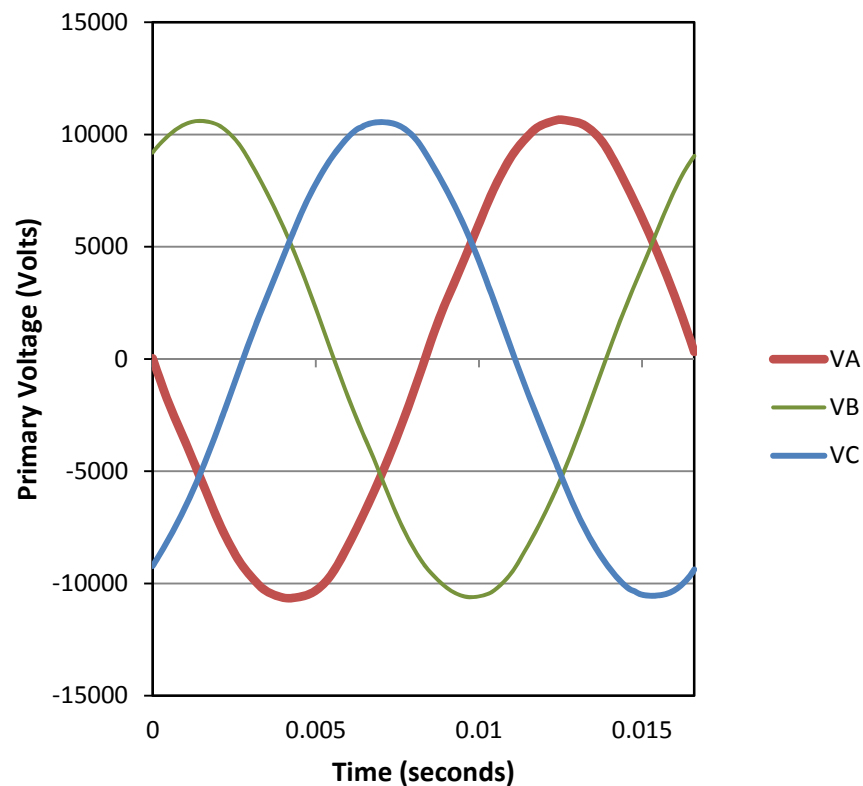


Alternative Sensor 1

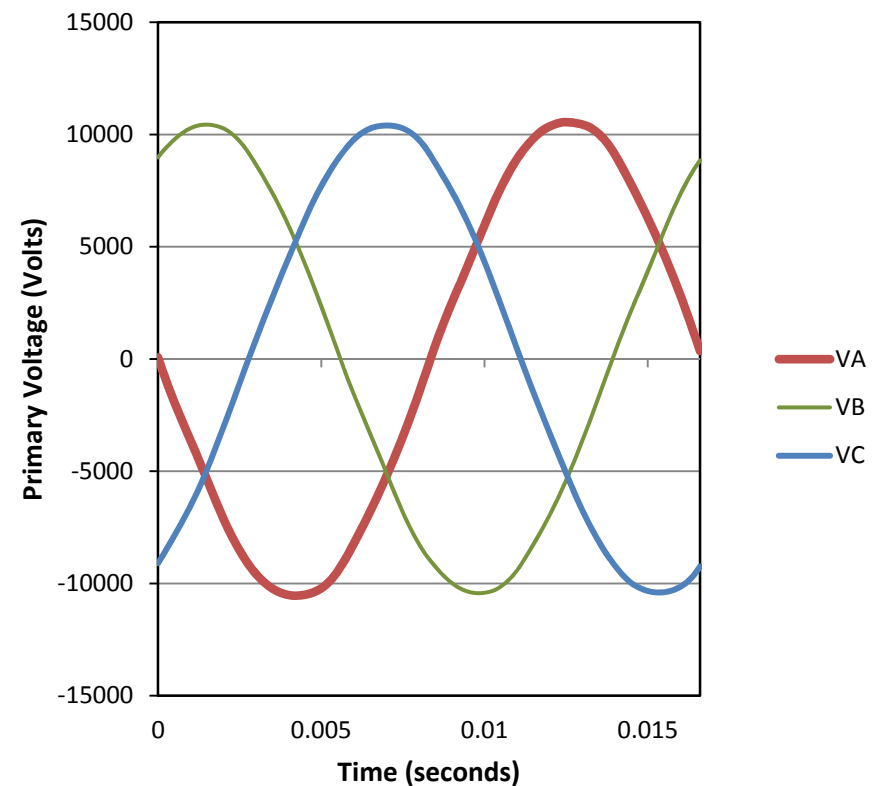


Waveform Comparison: Steady State Voltages

Traditional PT

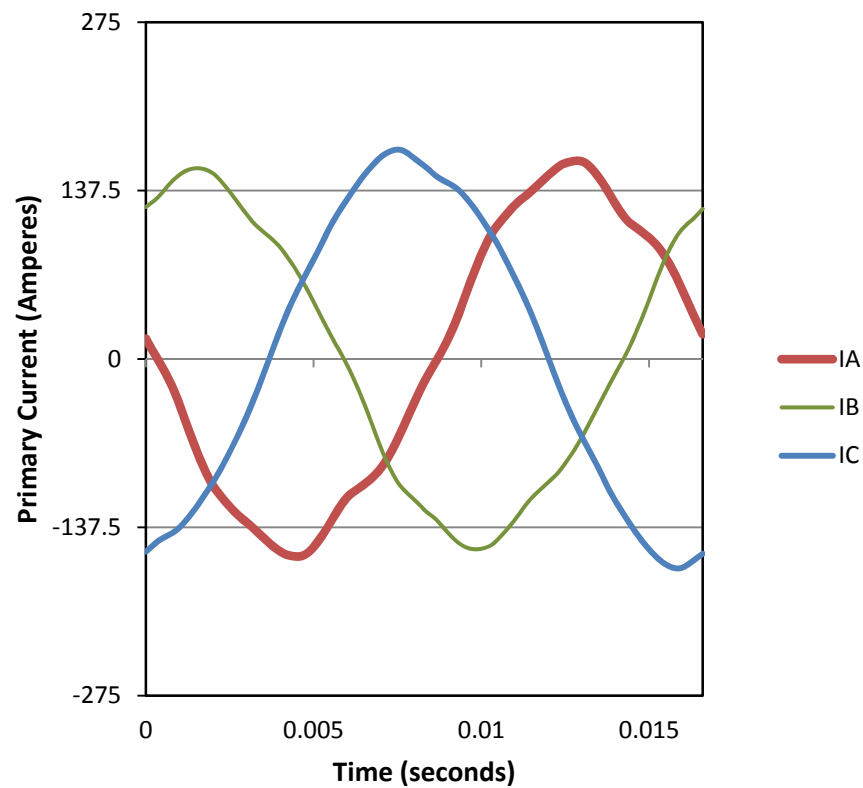


Alternative Sensor 2

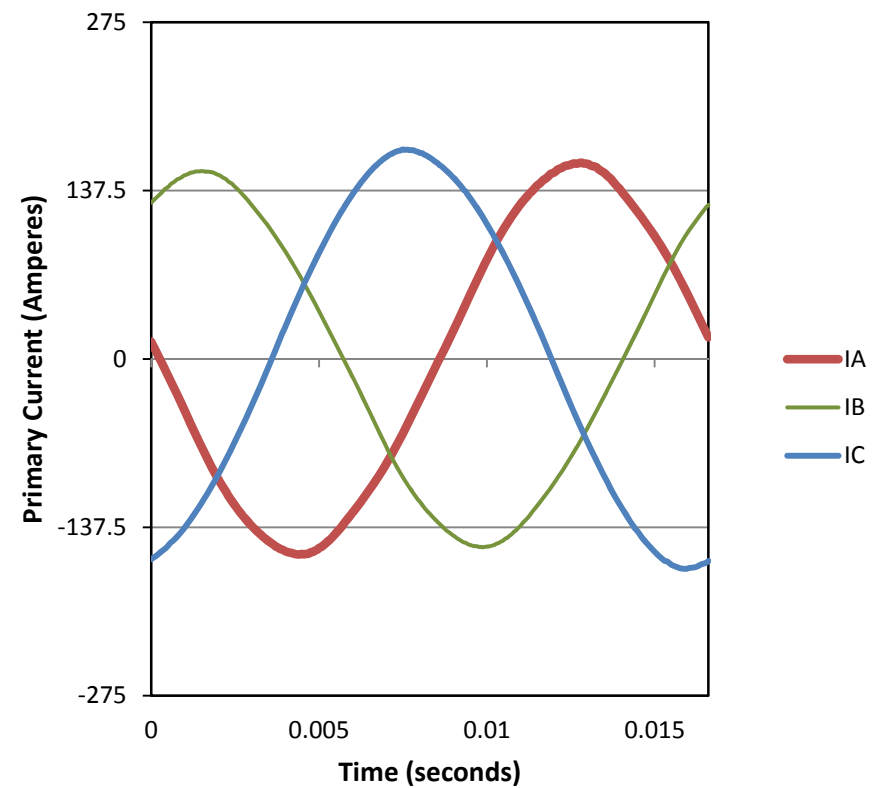


Waveform Comparison: Steady State Currents

Traditional CT

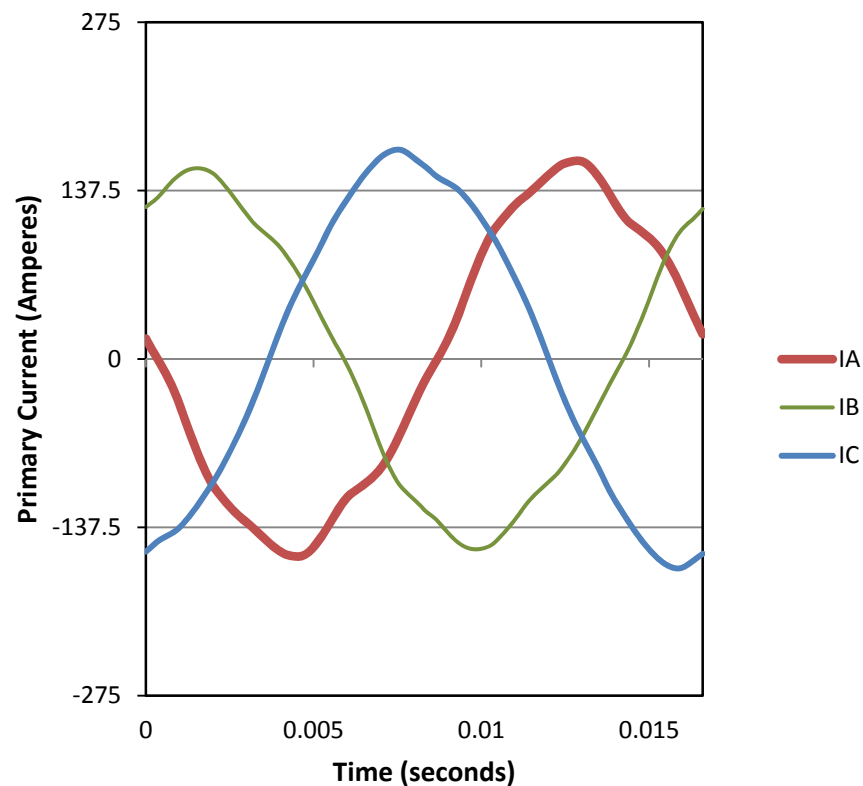


Alternative Sensor 1

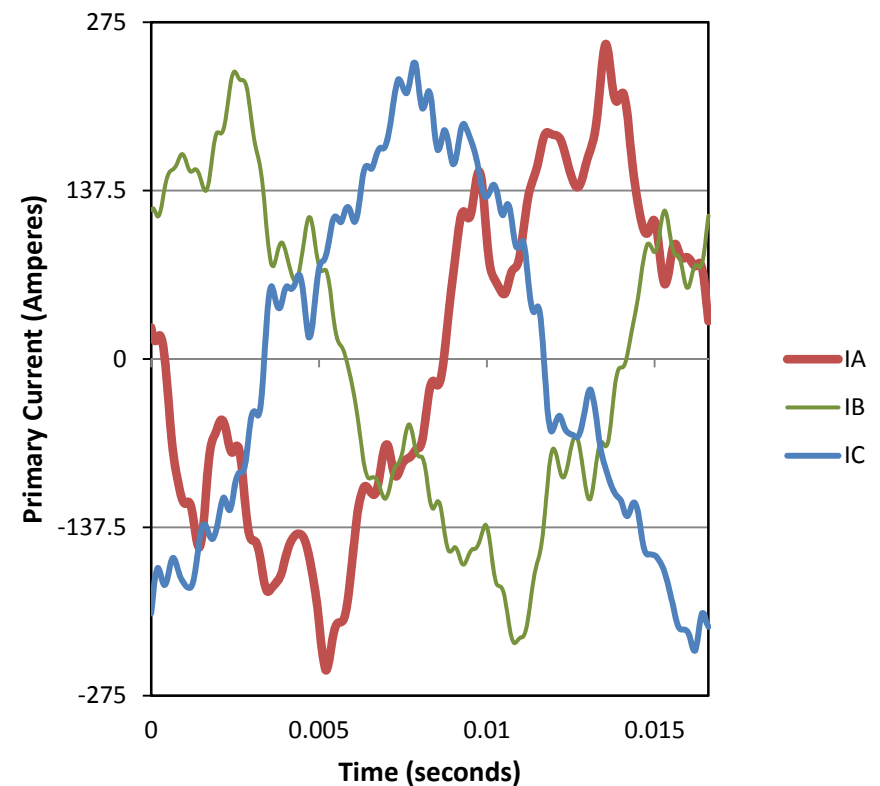


Waveform Comparison: Steady State Currents

Traditional CT



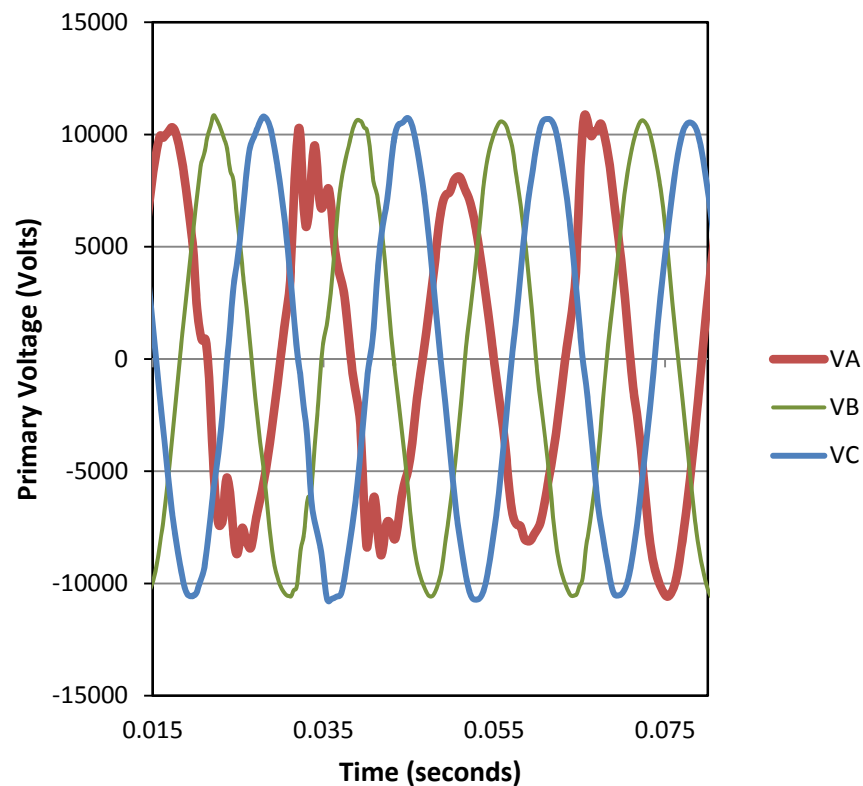
Alternative Sensor 2



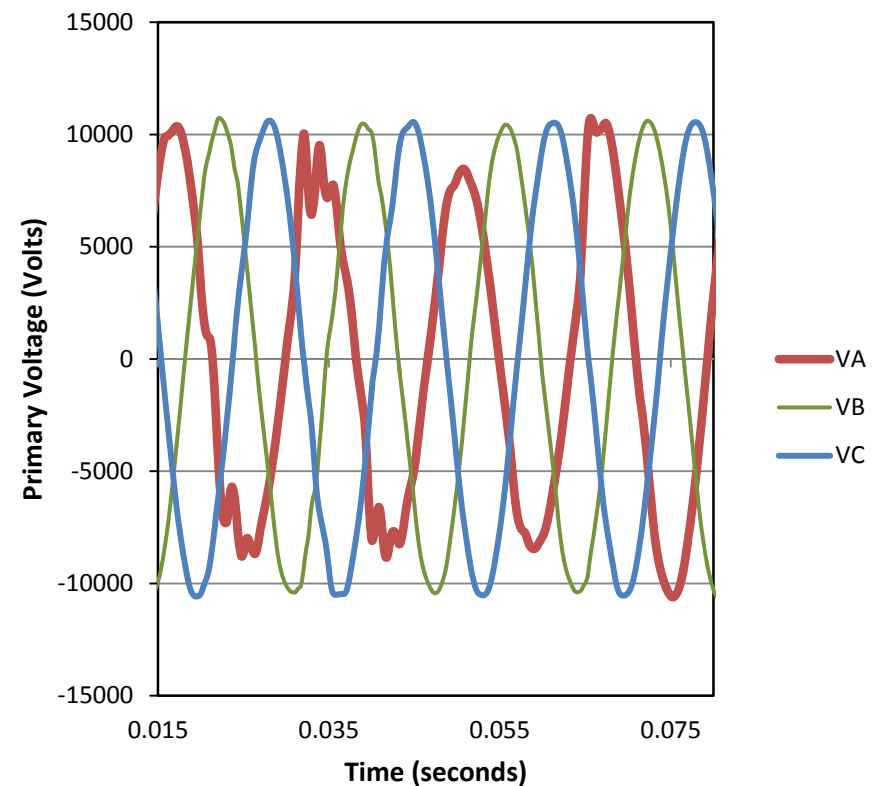


Waveform Comparison: Voltages During Overcurrent Fault #1

Traditional PT



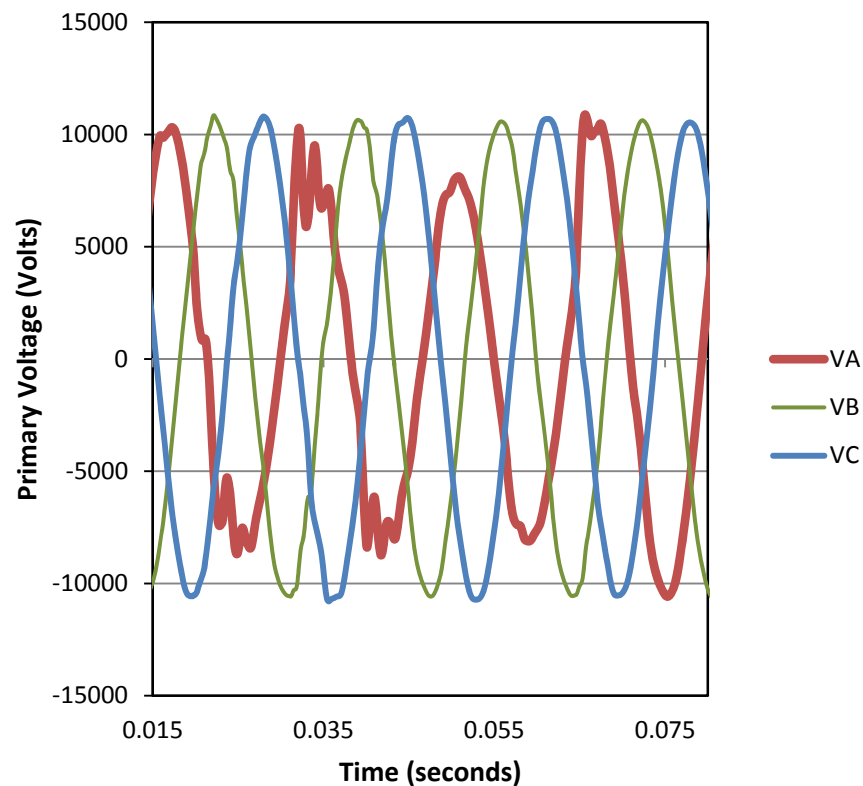
Alternative Sensor 1



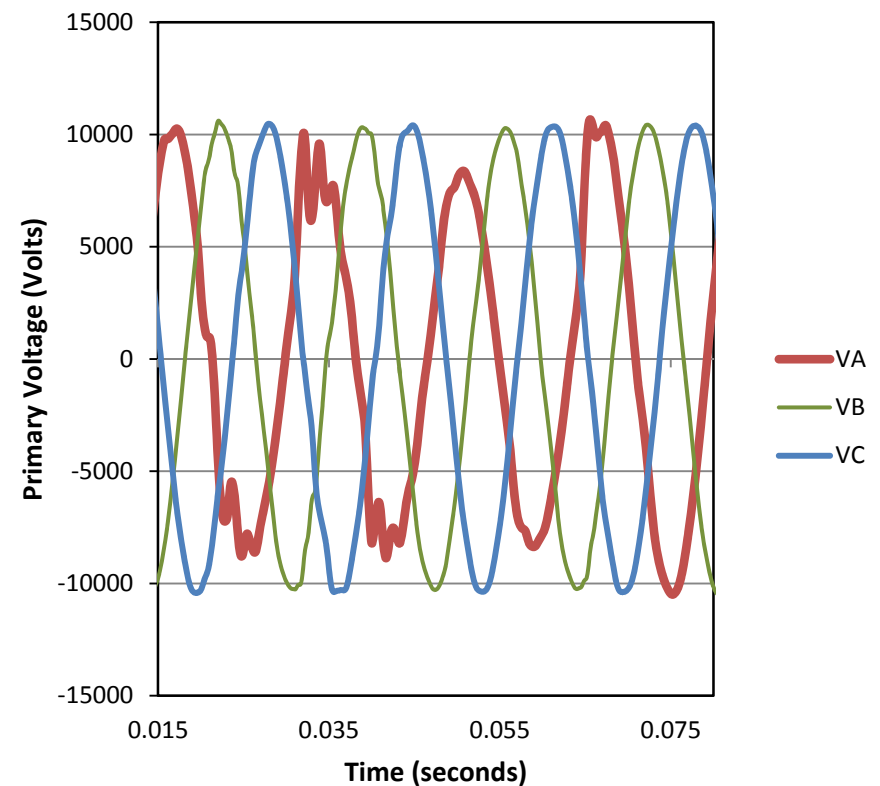


Waveform Comparison: Voltages During Overcurrent Fault #1

Traditional PT

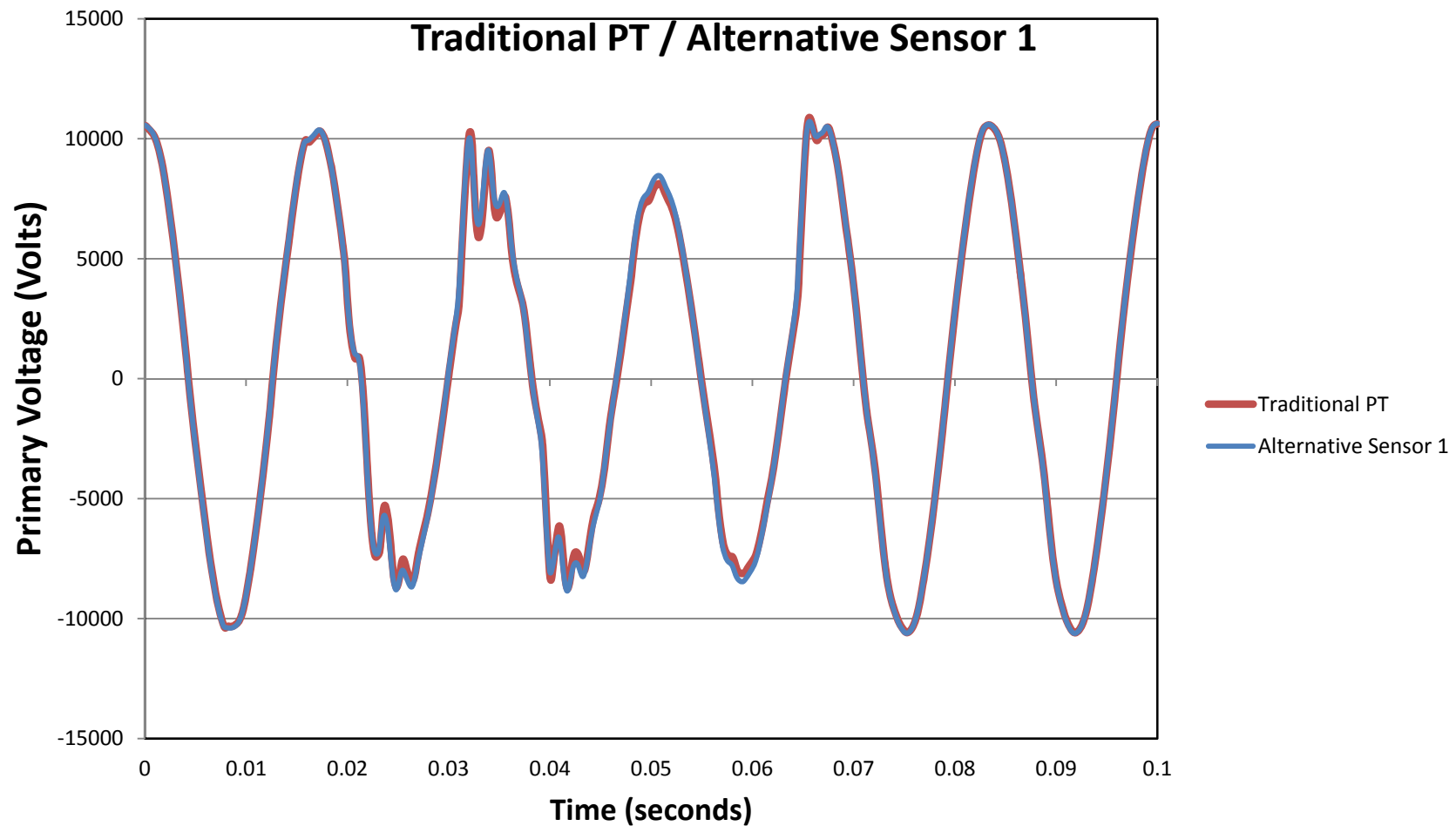


Alternative Sensor 2



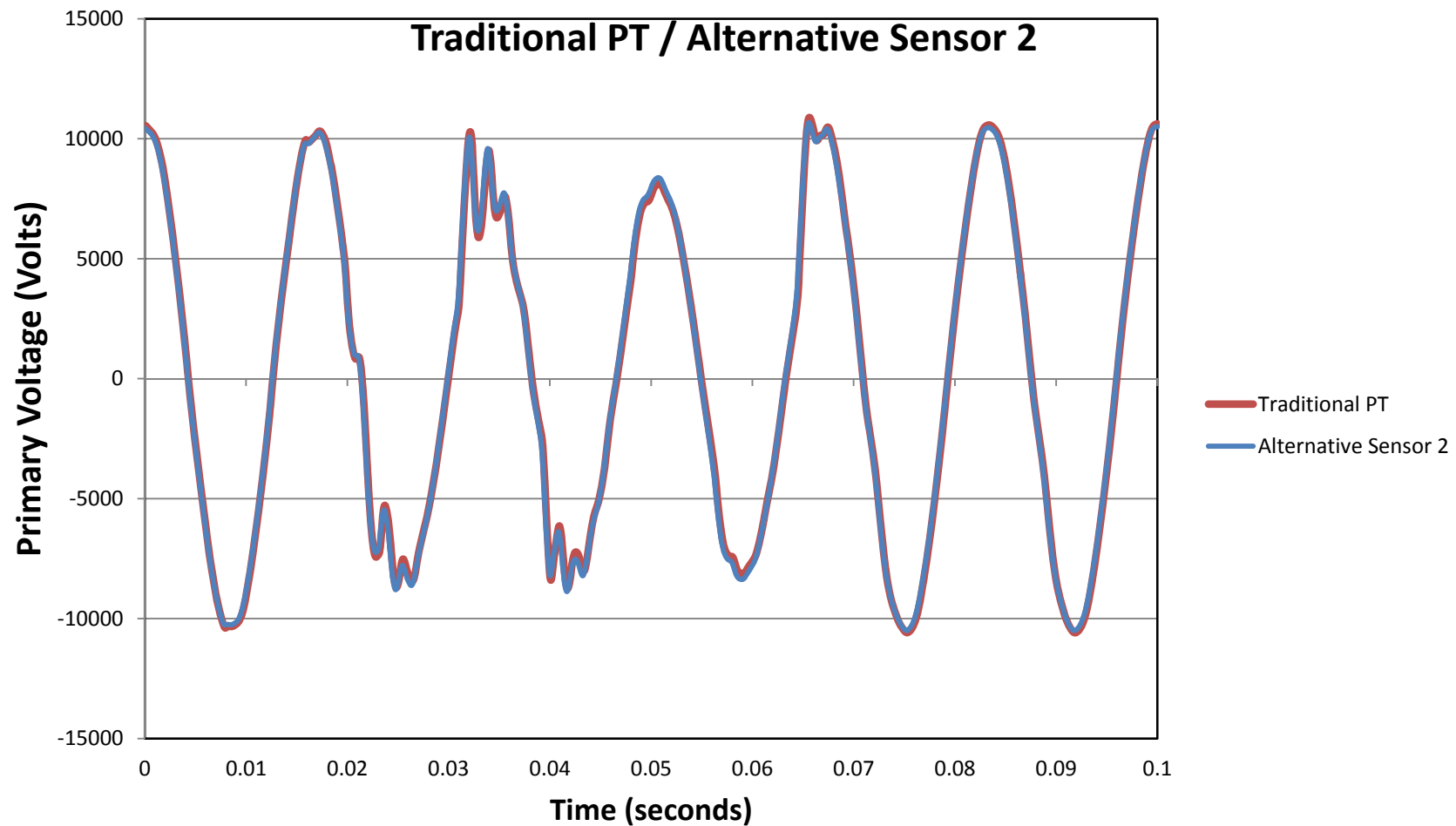


Waveform Overlay: Voltages During Overcurrent Fault #1



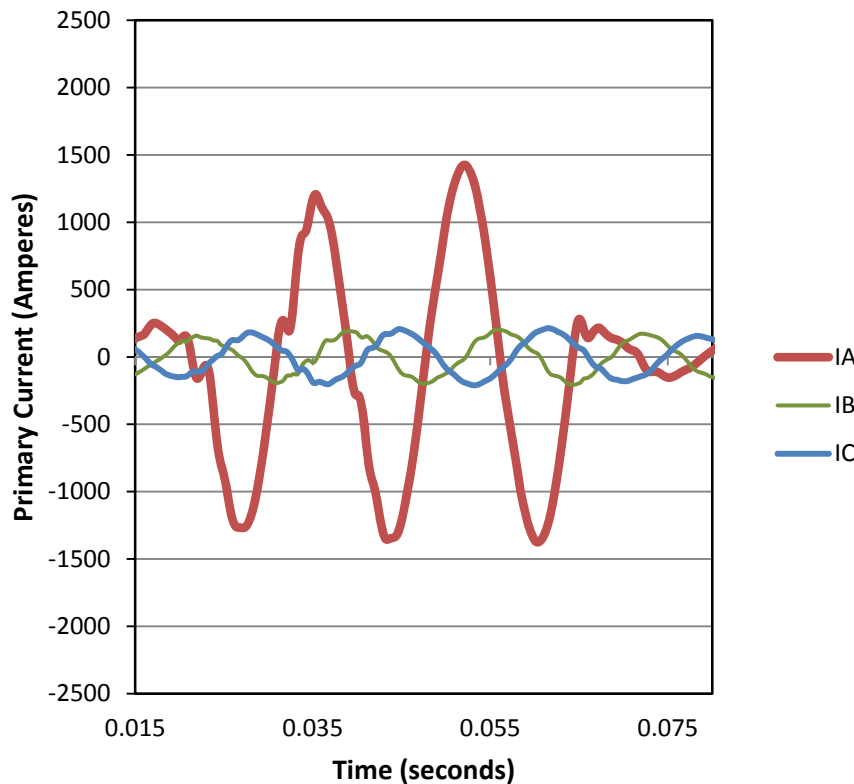


Waveform Overlay: Voltages During Overcurrent Fault #1

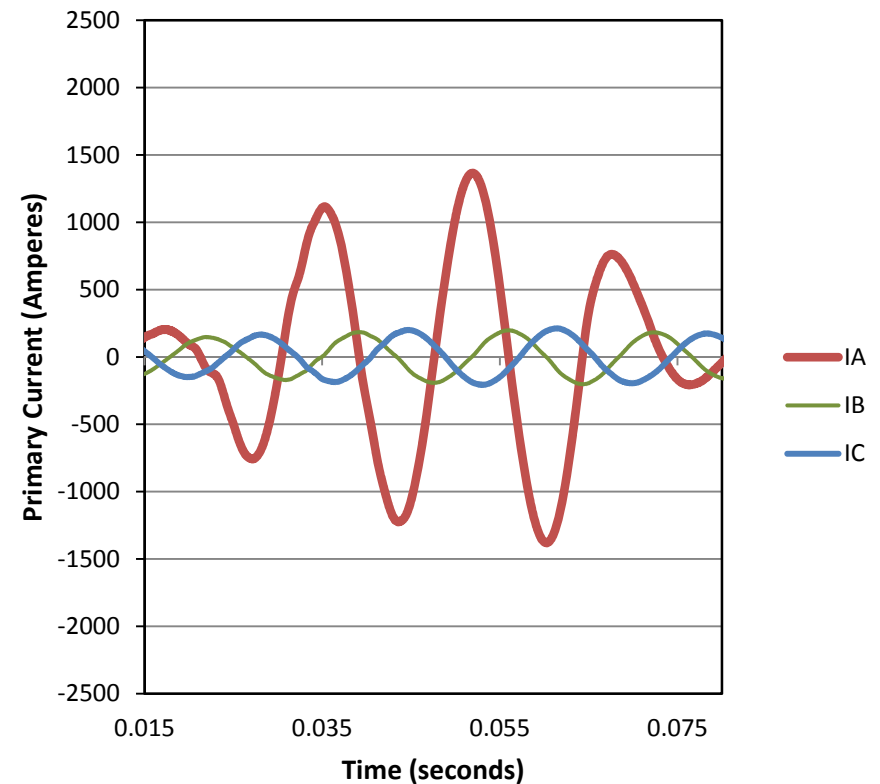


Waveform Comparison: Currents During Overcurrent Fault #1

Traditional CT

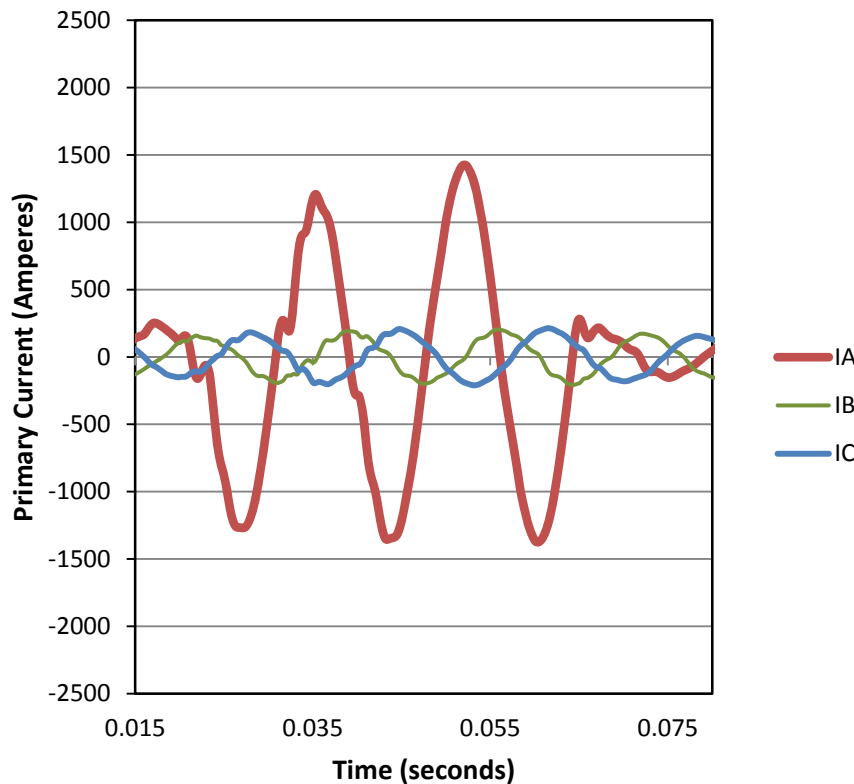


Alternative Sensor 1

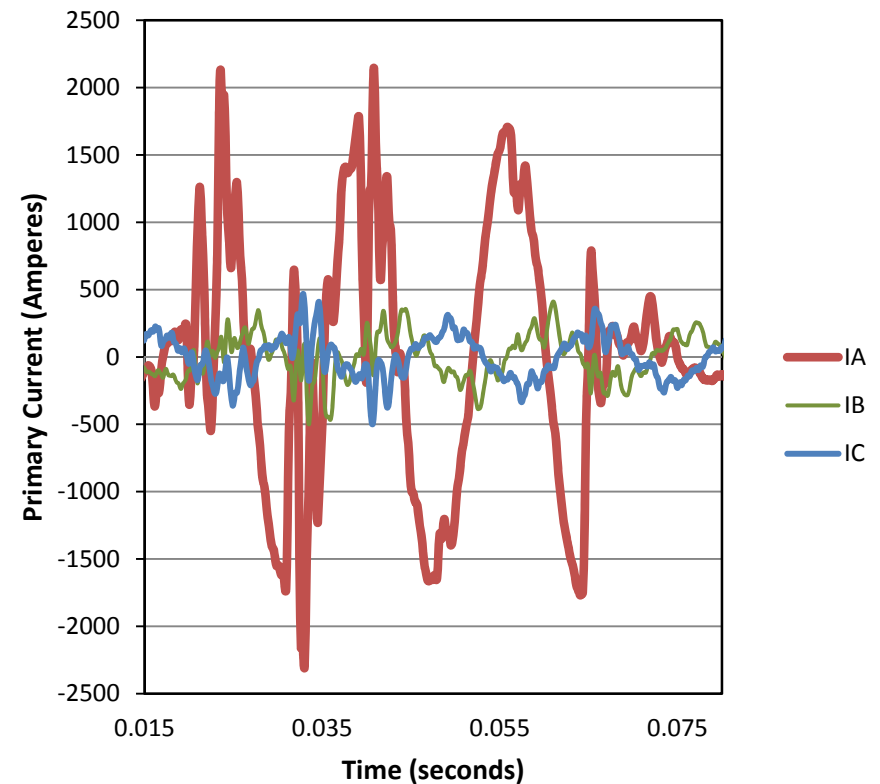


Waveform Comparison: Currents During Overcurrent Fault #1

Traditional CT

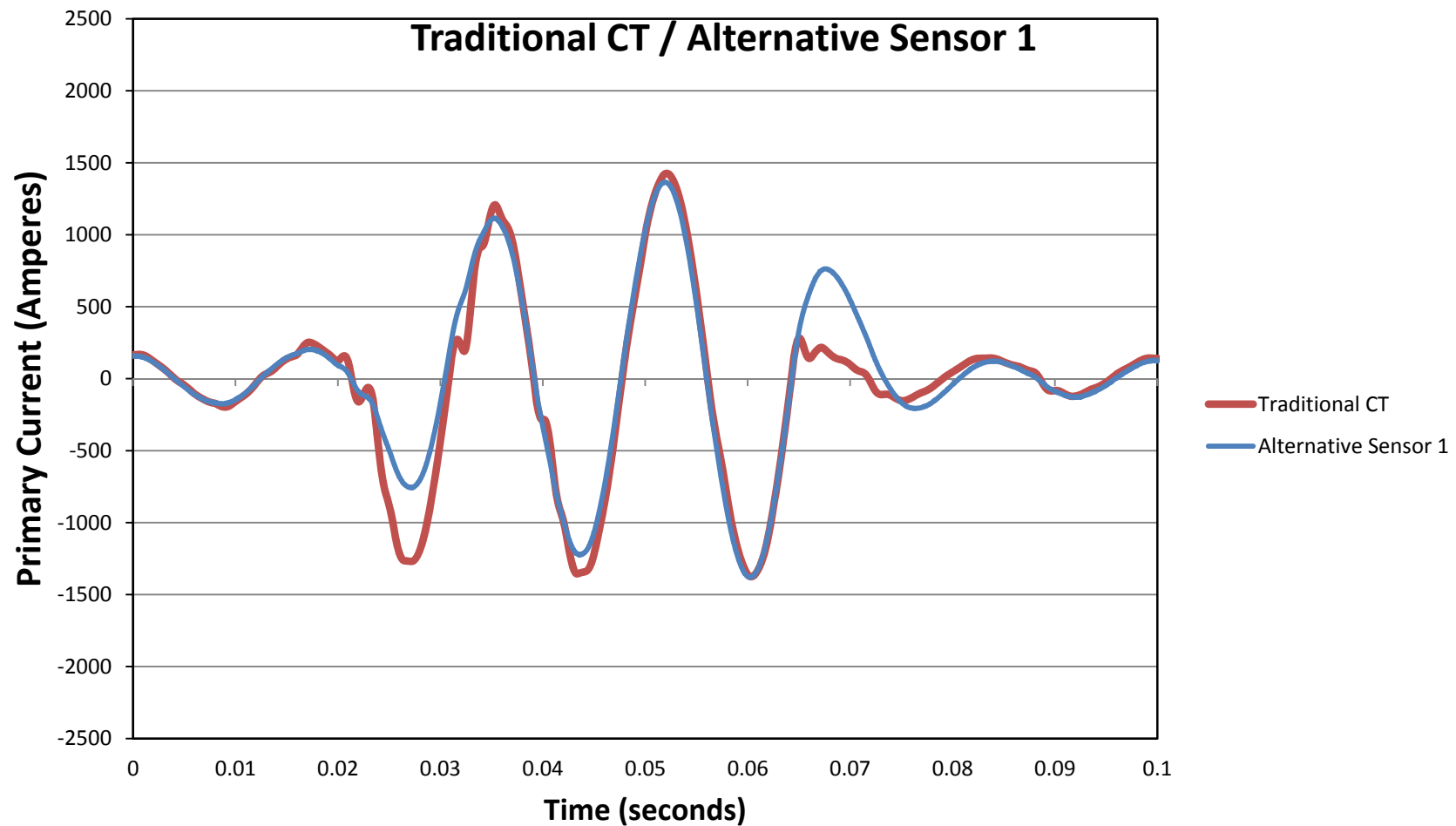


Alternative Sensor 2



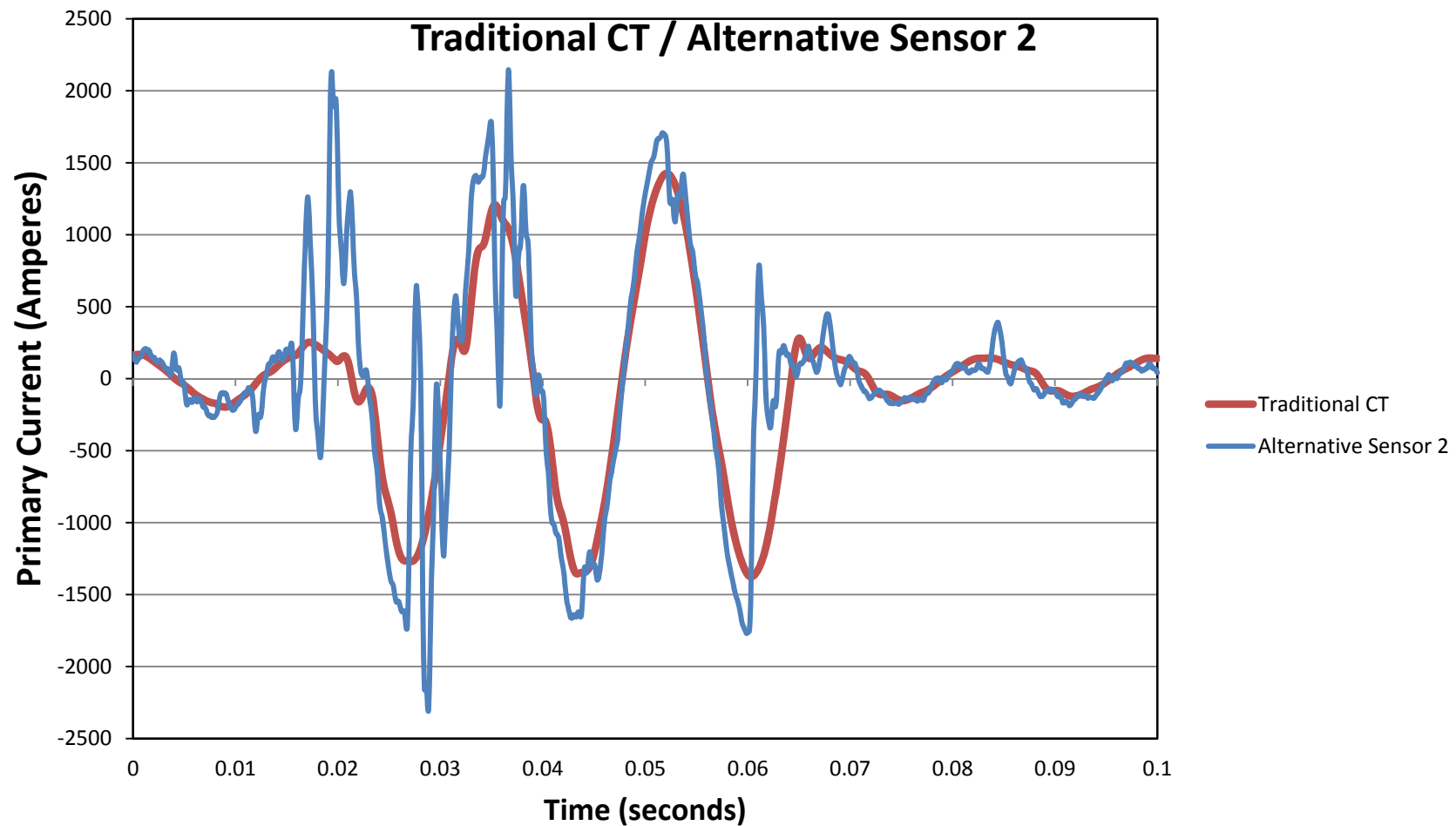


Waveform Overlay: Currents During Overcurrent Fault #1





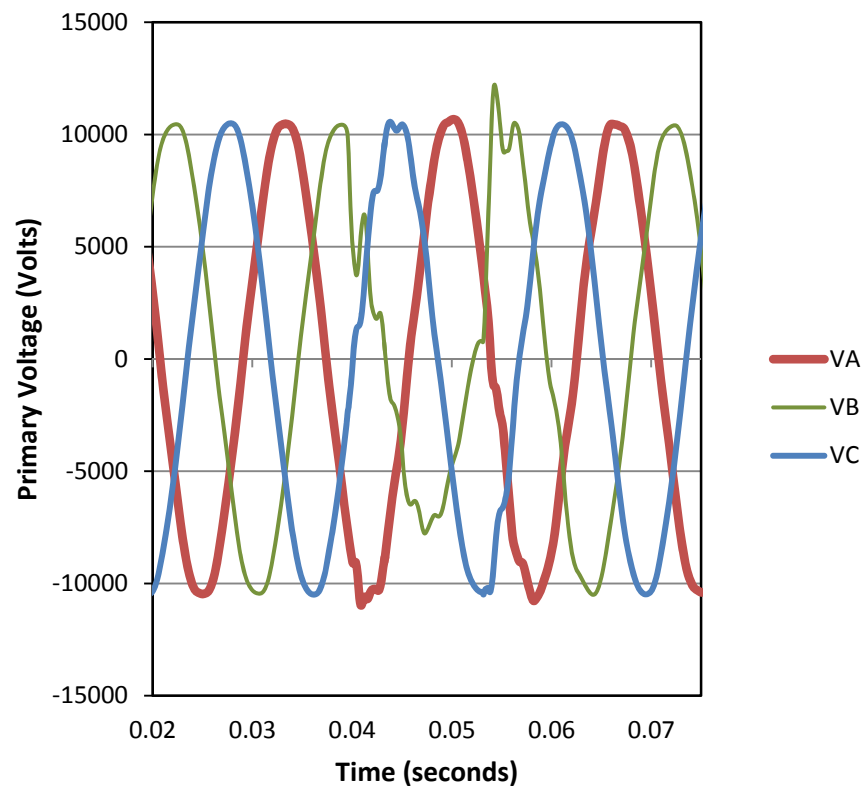
Waveform Overlay: Currents During Overcurrent Fault #1



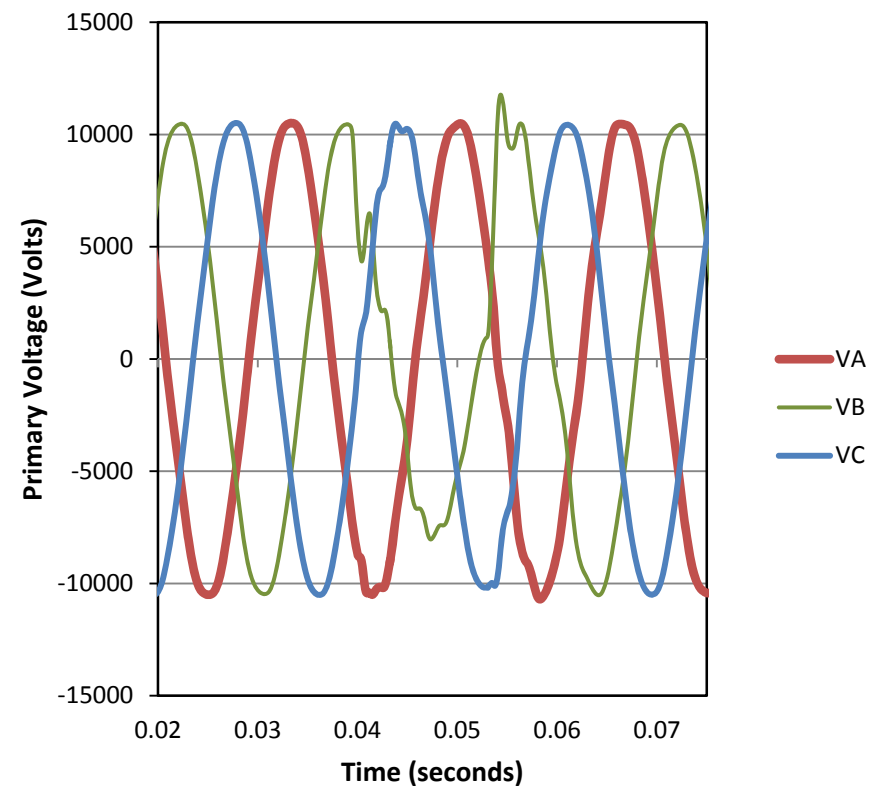


Waveform Comparison: Voltages During Overcurrent Fault #2

Traditional PT



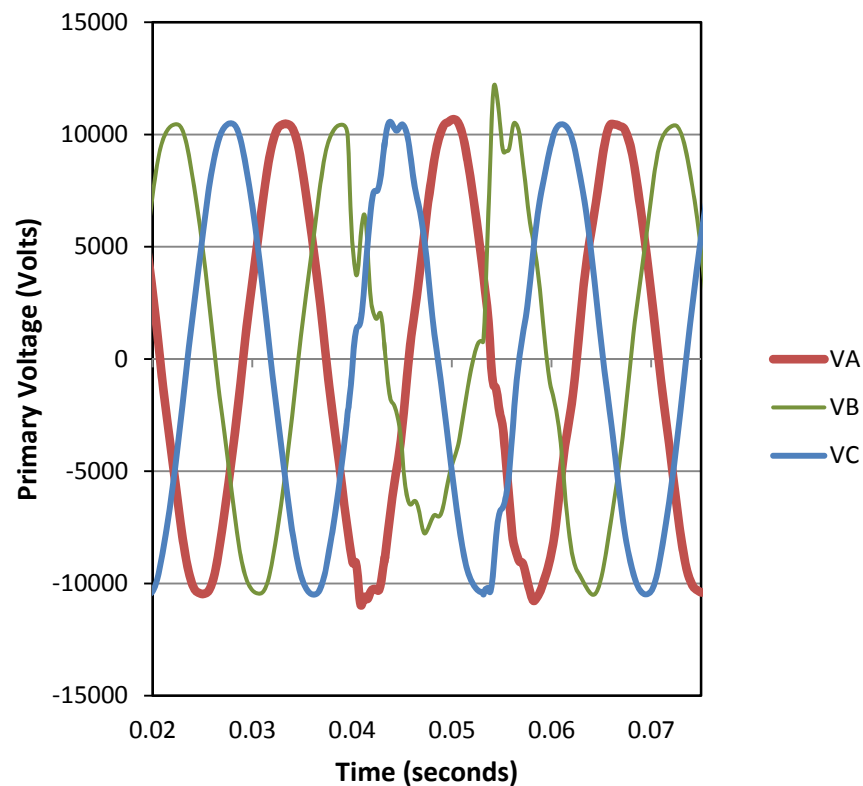
Alternative Sensor 1



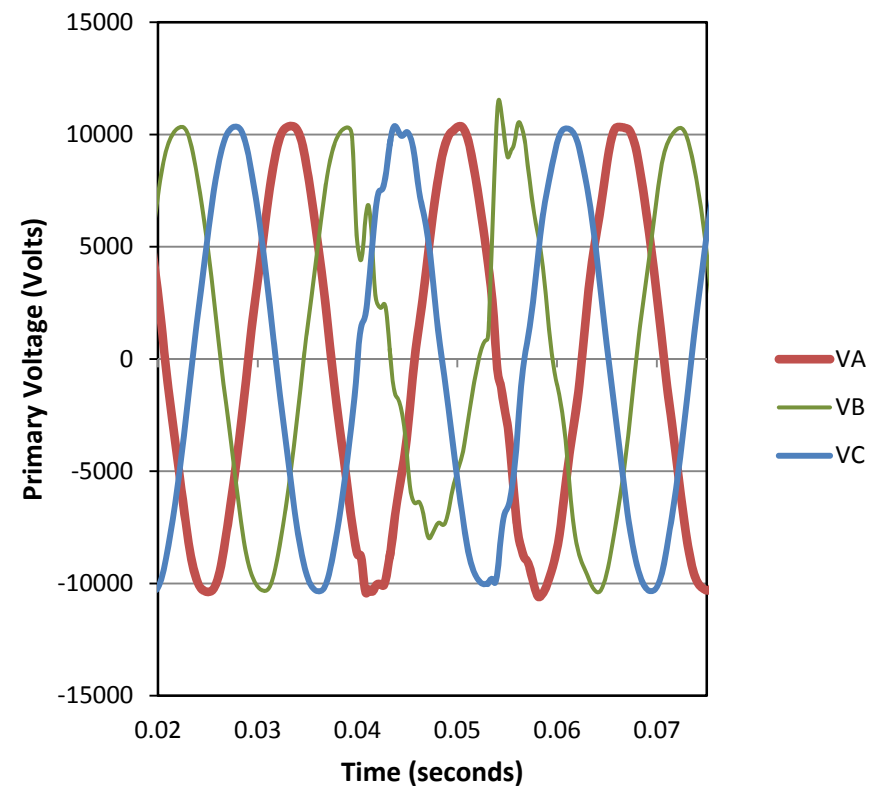


Waveform Comparison: Voltages During Overcurrent Fault #2

Traditional PT

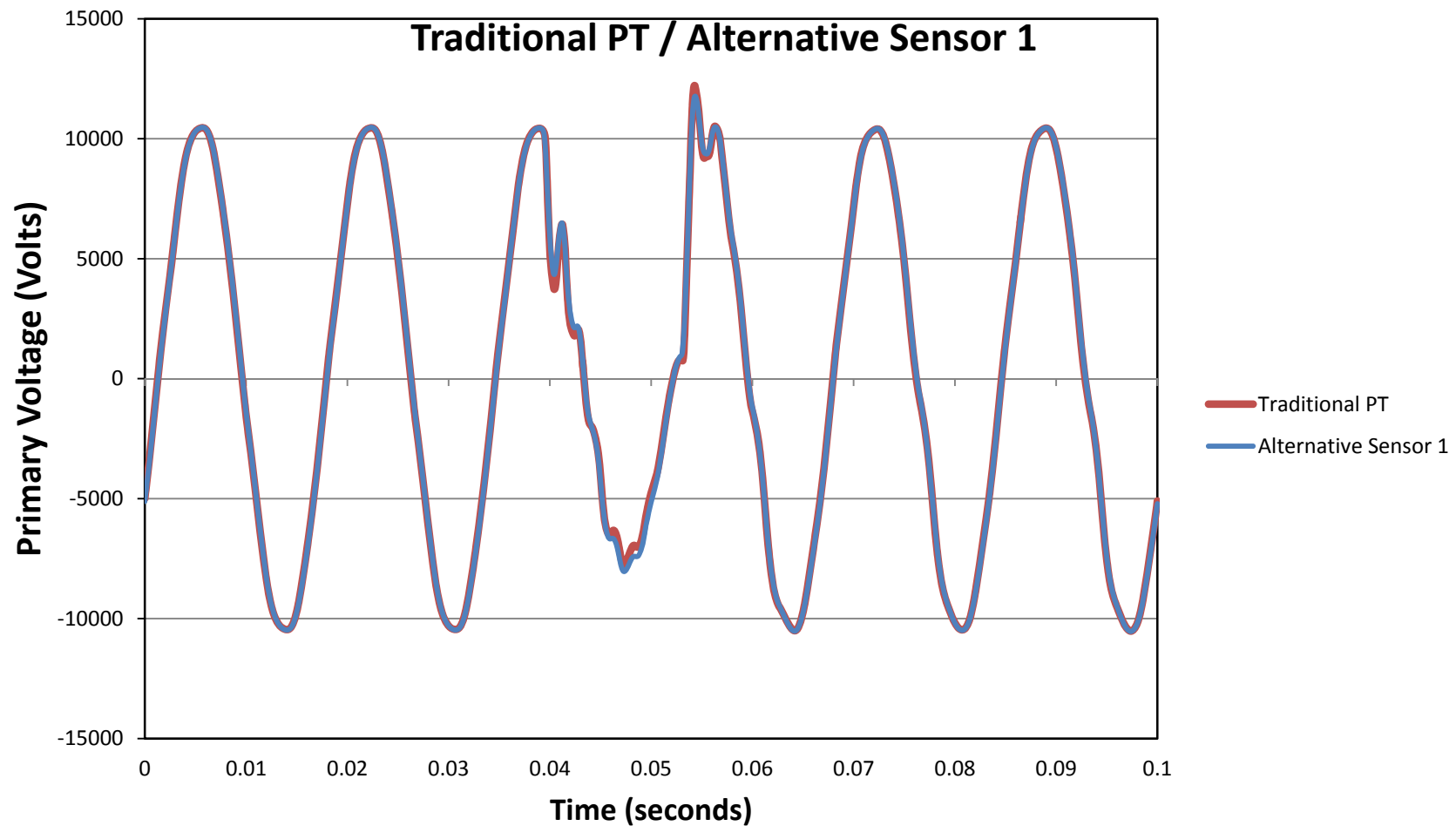


Alternative Sensor 2



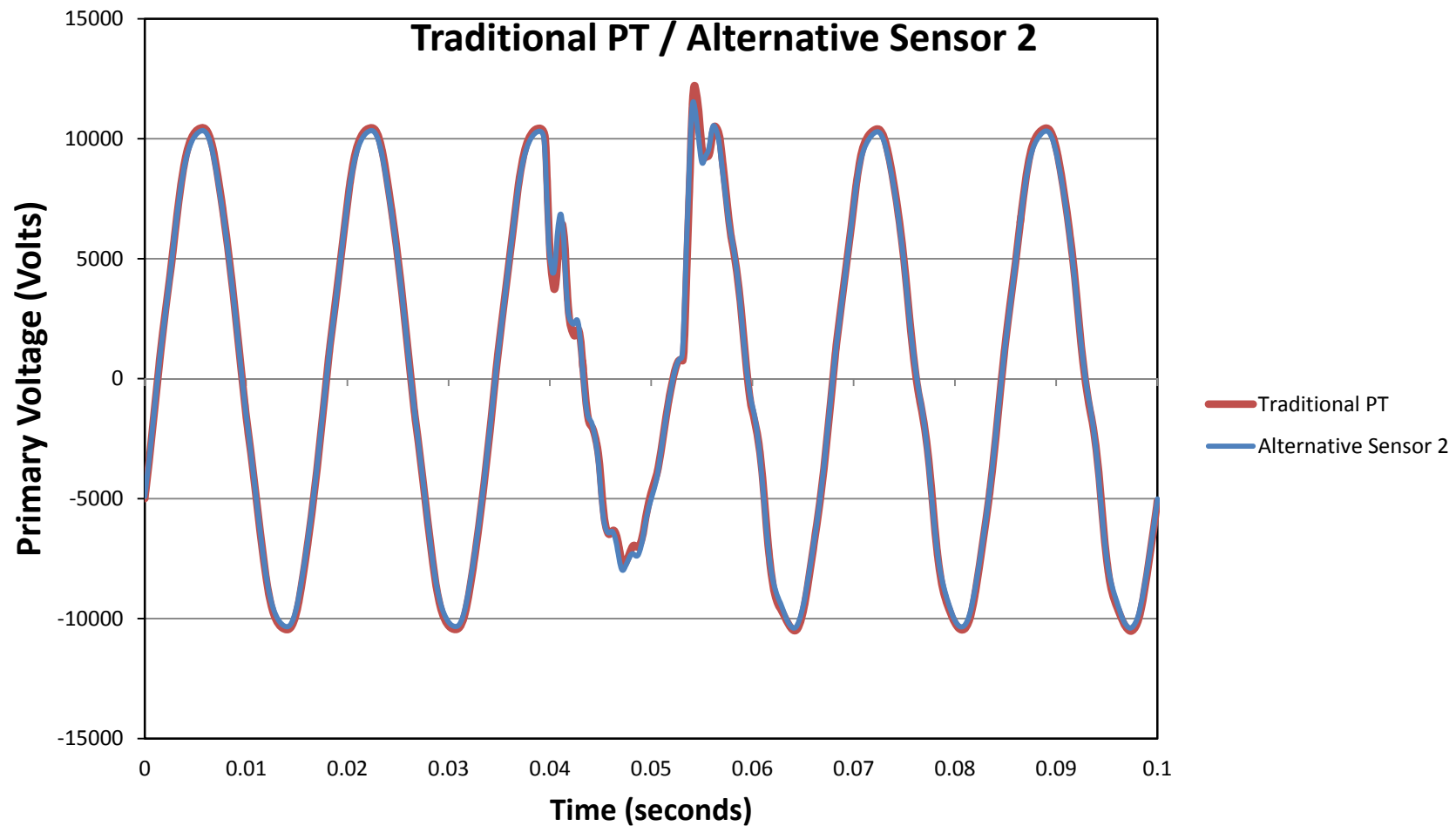


Waveform Overlay: Voltages During Overcurrent Fault #2



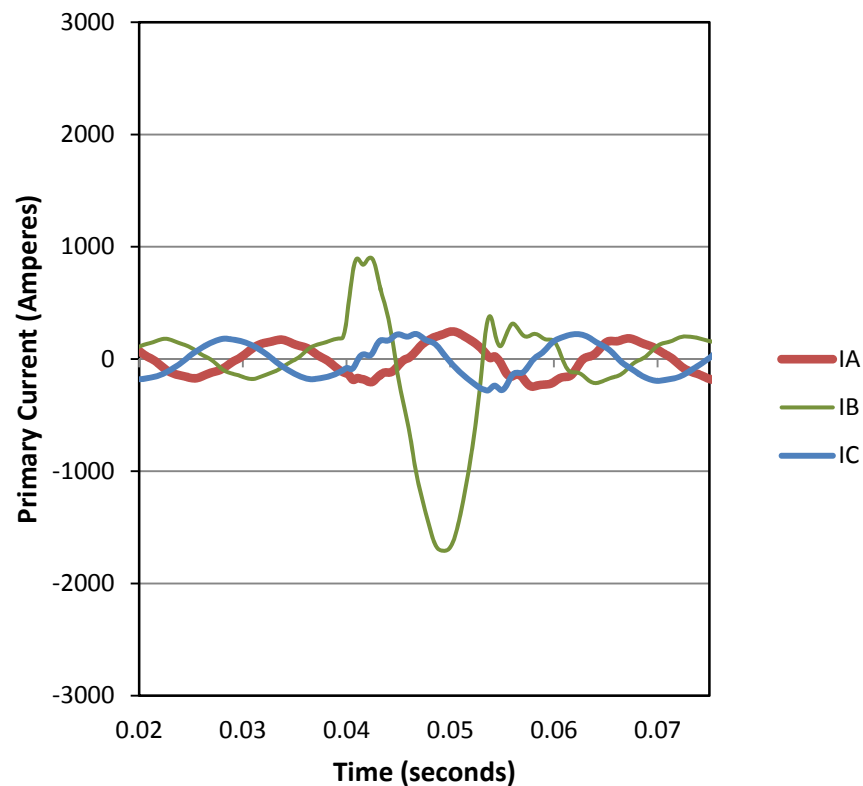


Waveform Overlay: Voltages During Overcurrent Fault #2

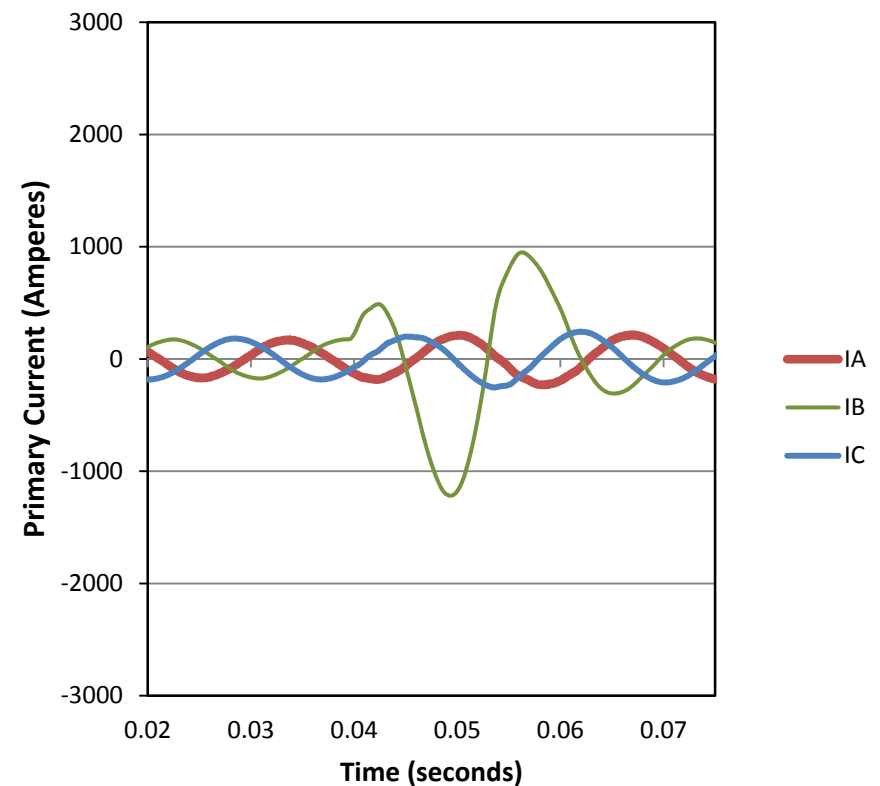


Waveform Comparison: Currents During Overcurrent Fault #2

Traditional CT

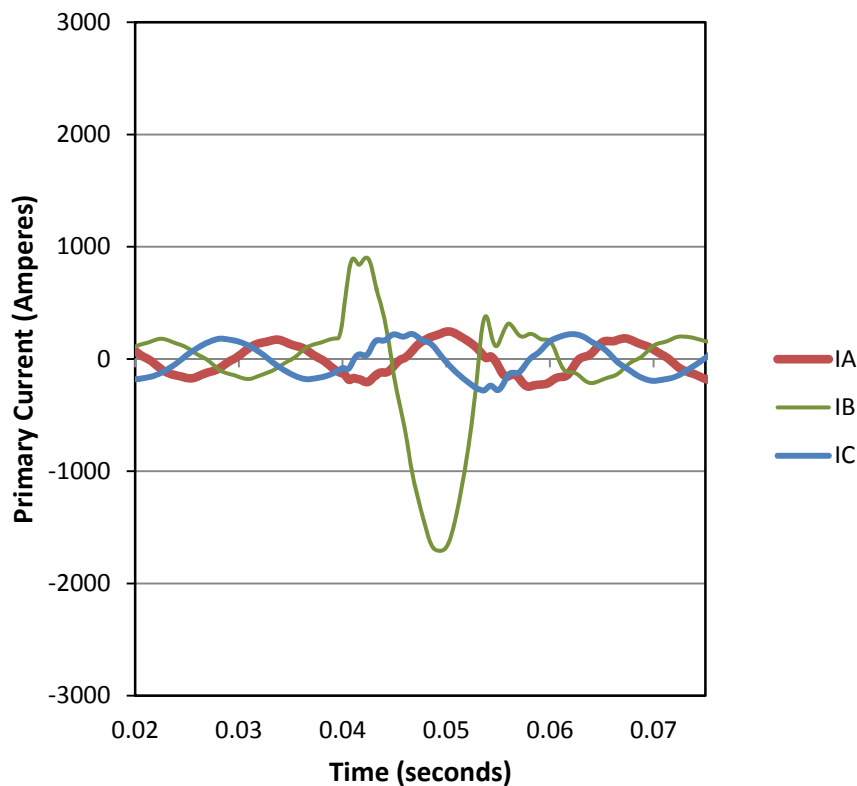


Alternative Sensor 1

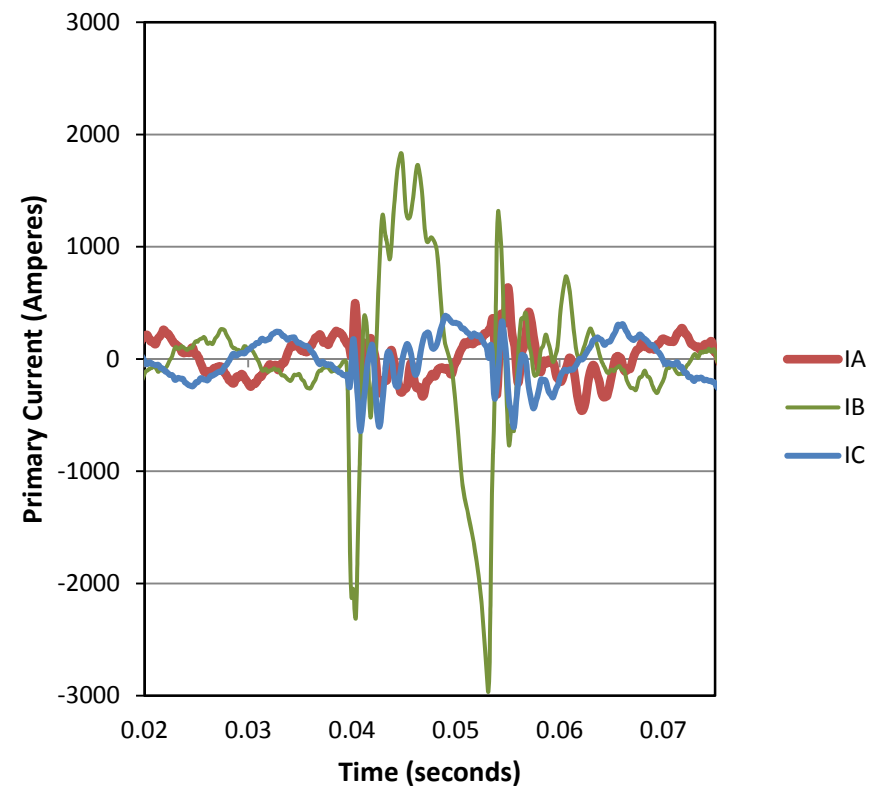


Waveform Comparison: Currents During Overcurrent Fault #2

Traditional CT

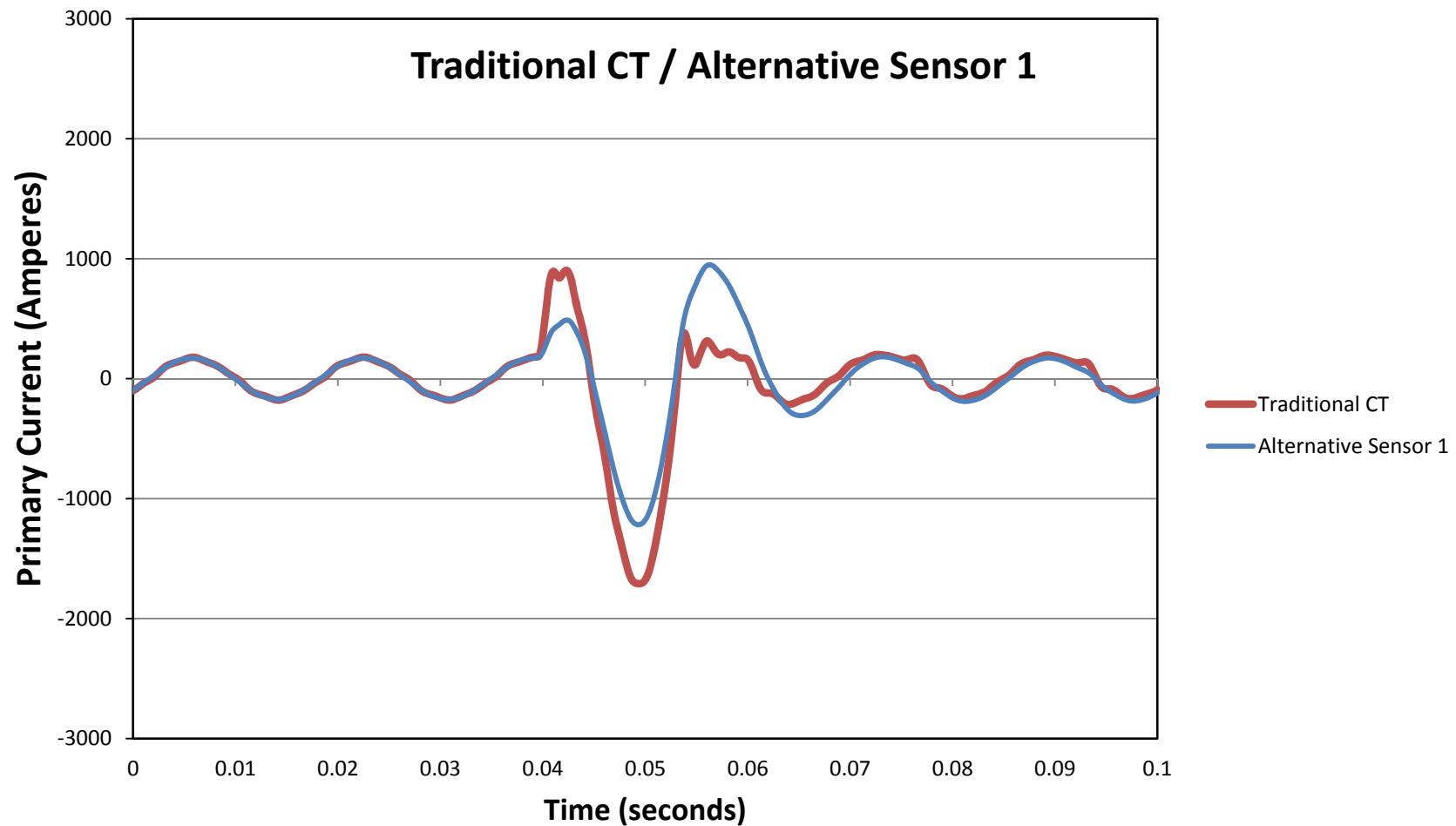


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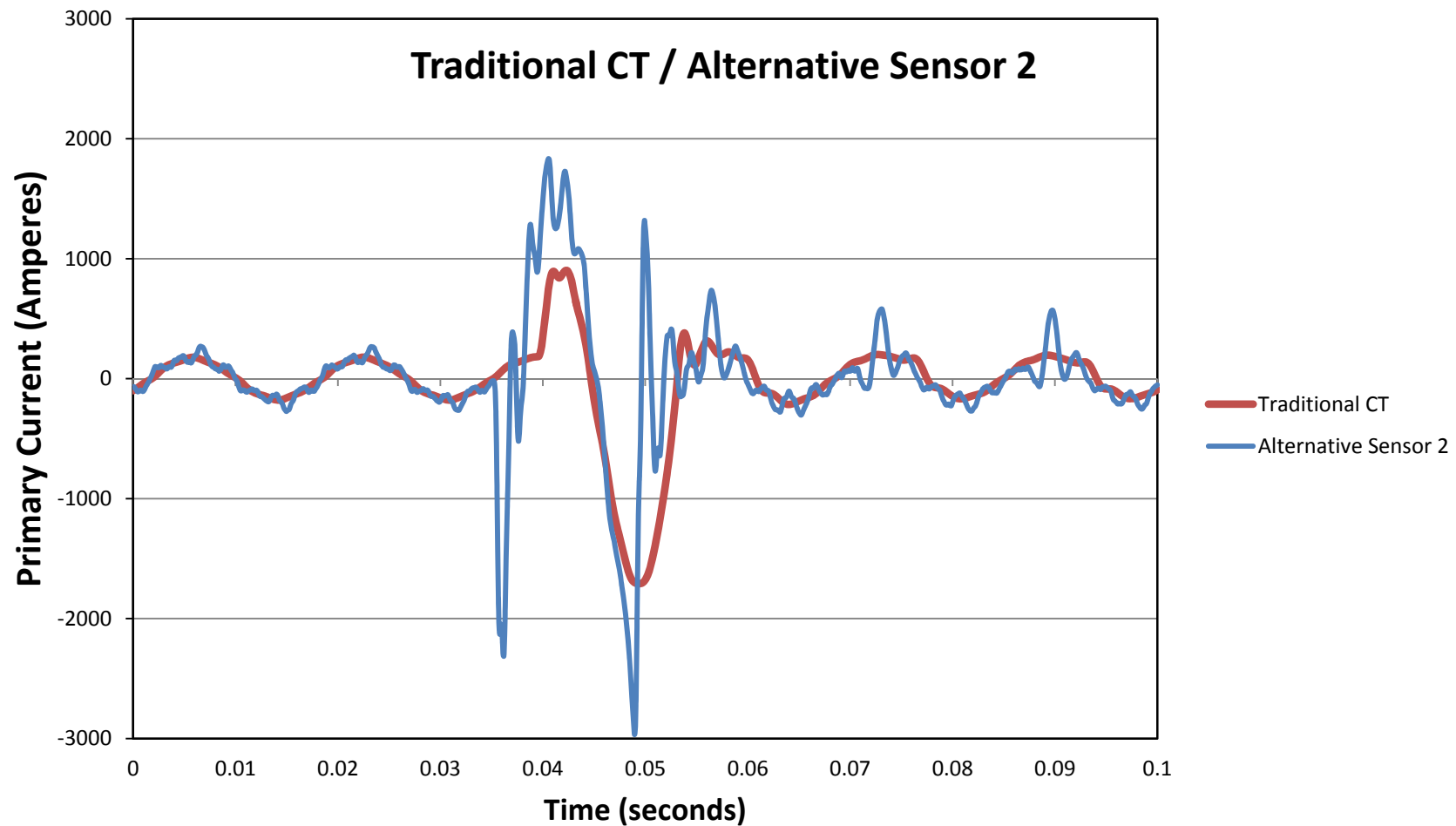


Waveform Overlay: Currents During Overcurrent Fault #2



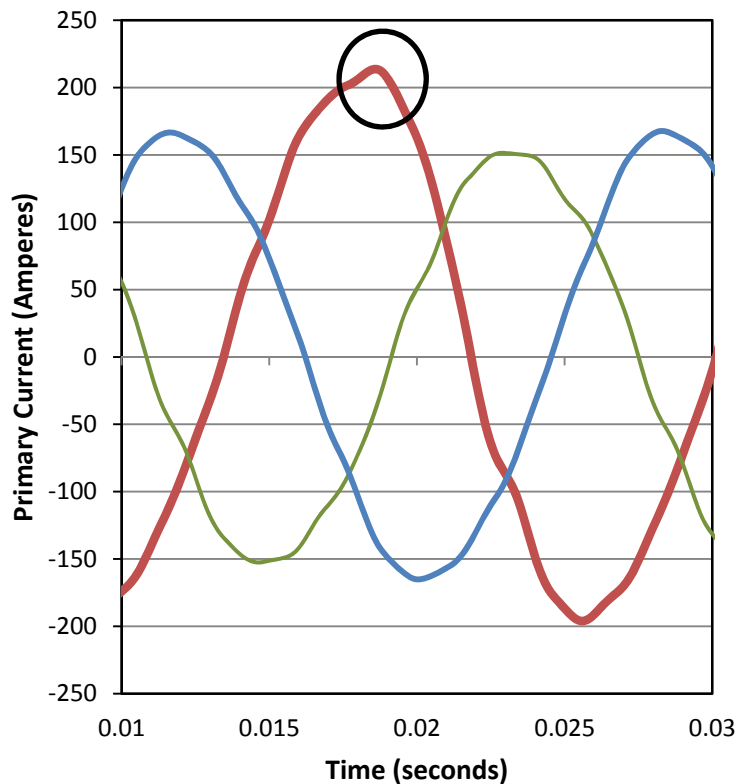


Waveform Overlay: Currents During Overcurrent Fault #2

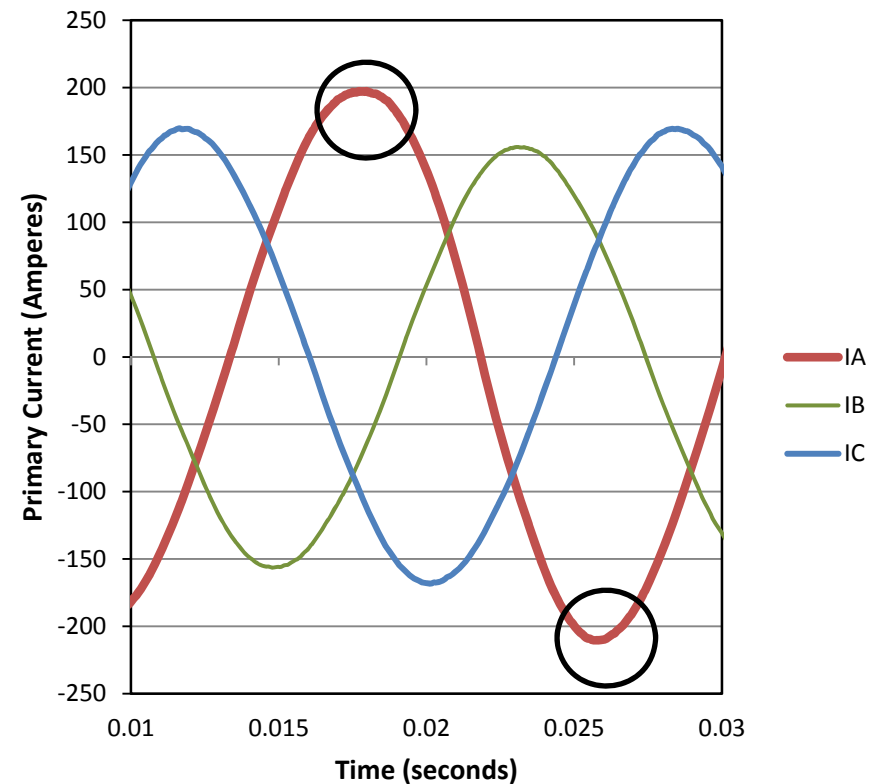


Waveform Comparison: Currents from Incipient Arcing Event 1

Traditional CT

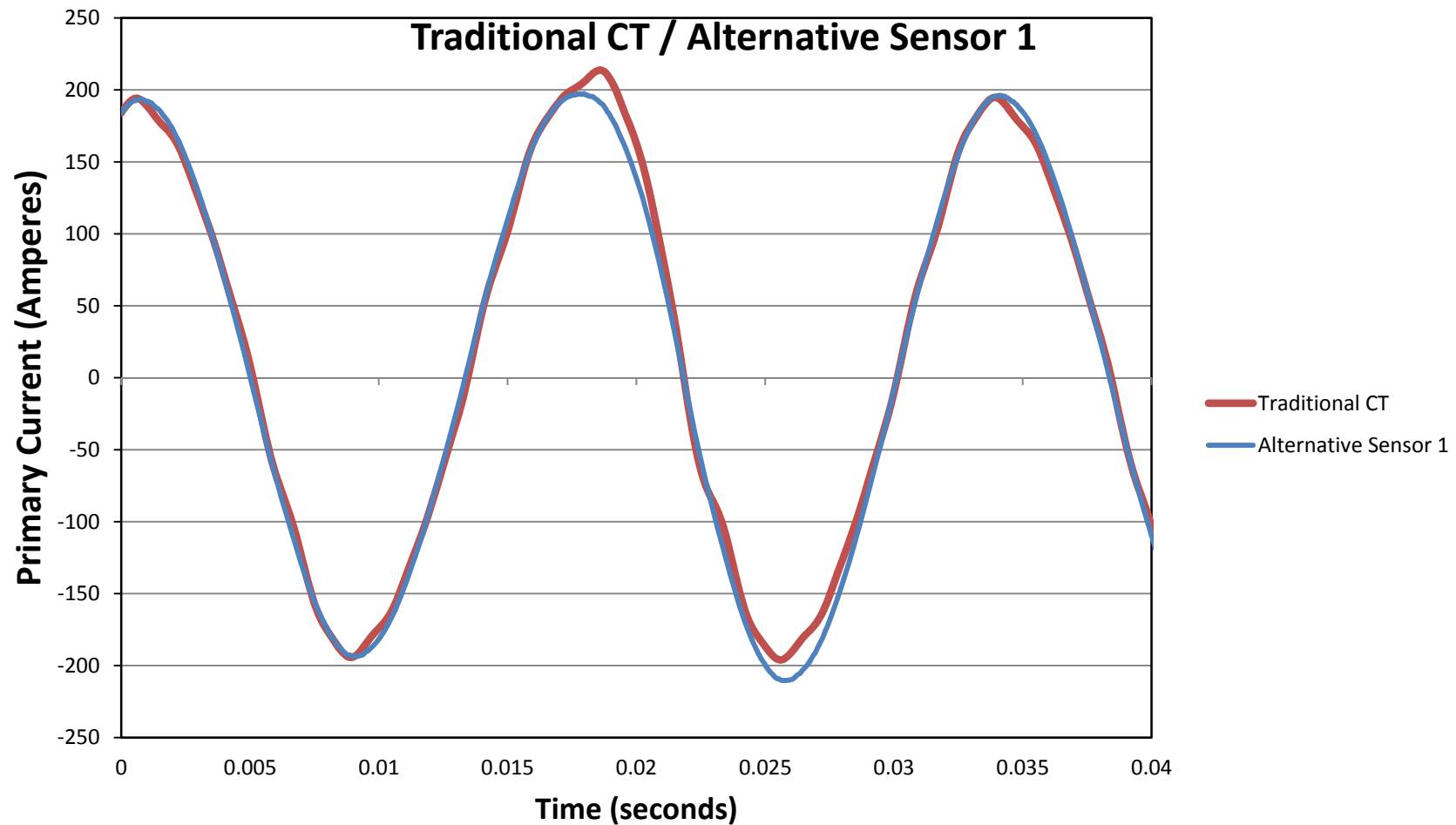


Alternative Sensor 1



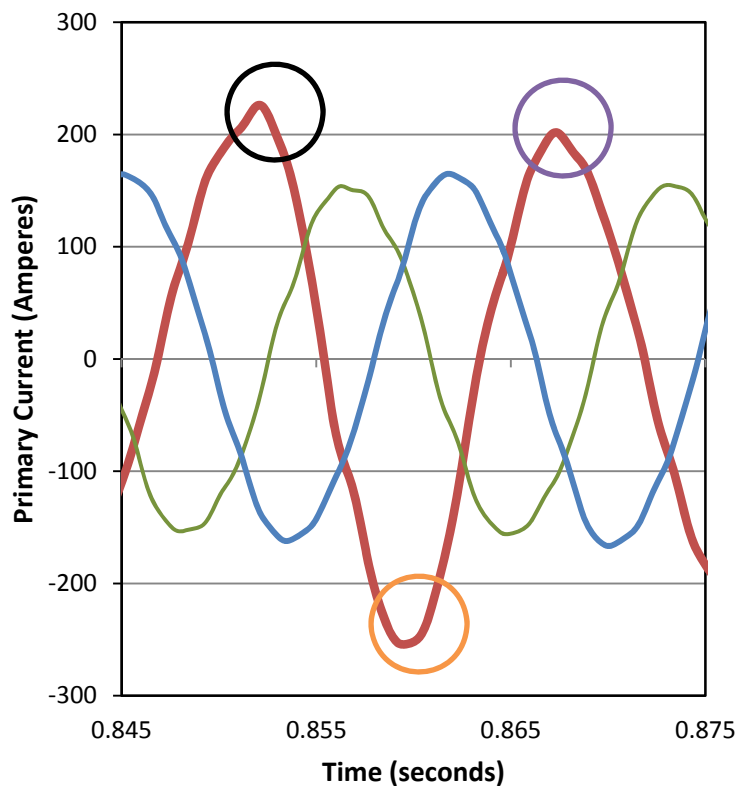


Waveform Overlay: Currents from Incipient Arcing Event 1

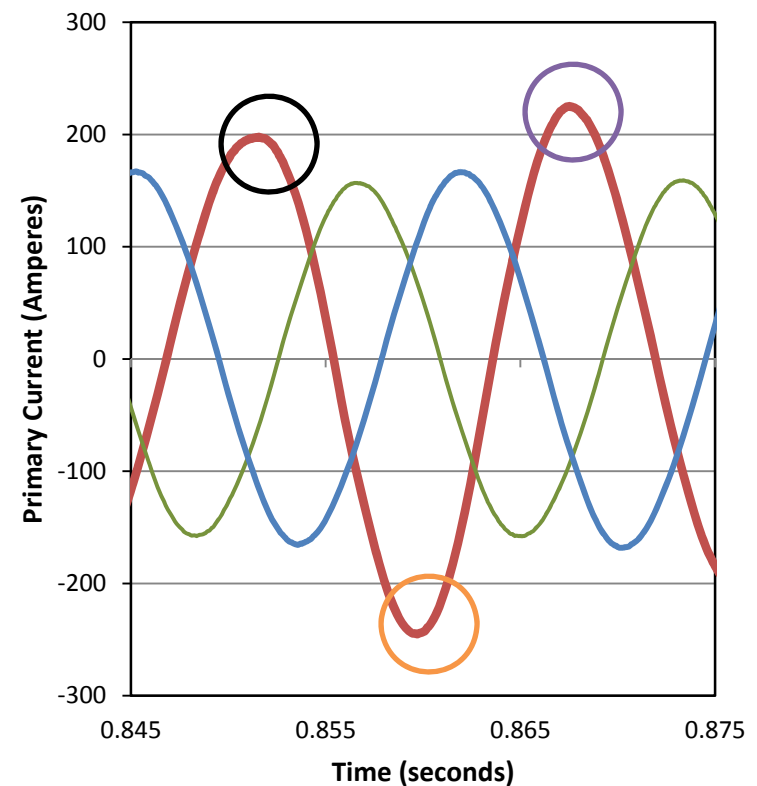


Waveform Comparison: Currents from Incipient Arcing Event 2

Traditional CT

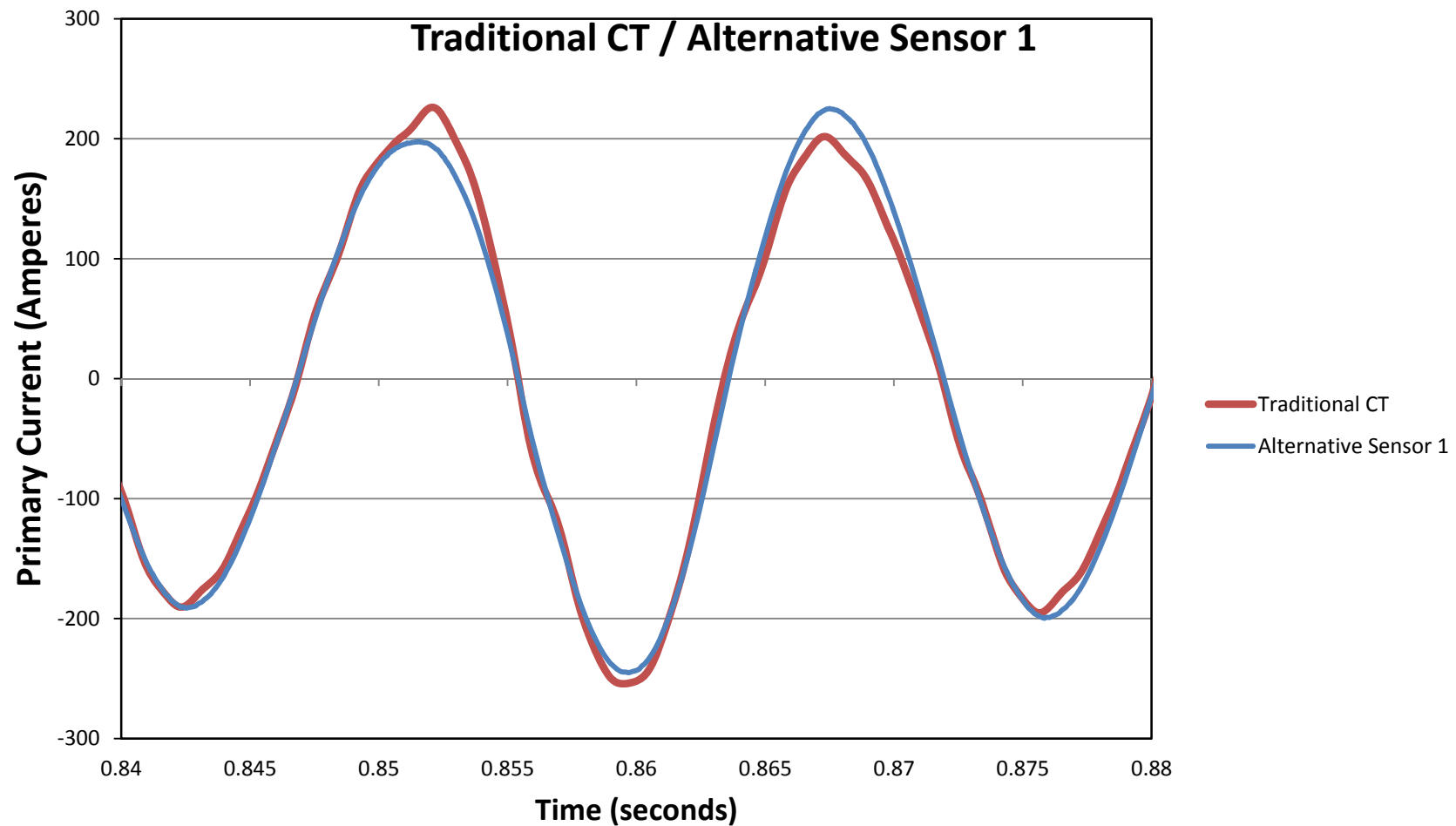


Alternative Sensor 1



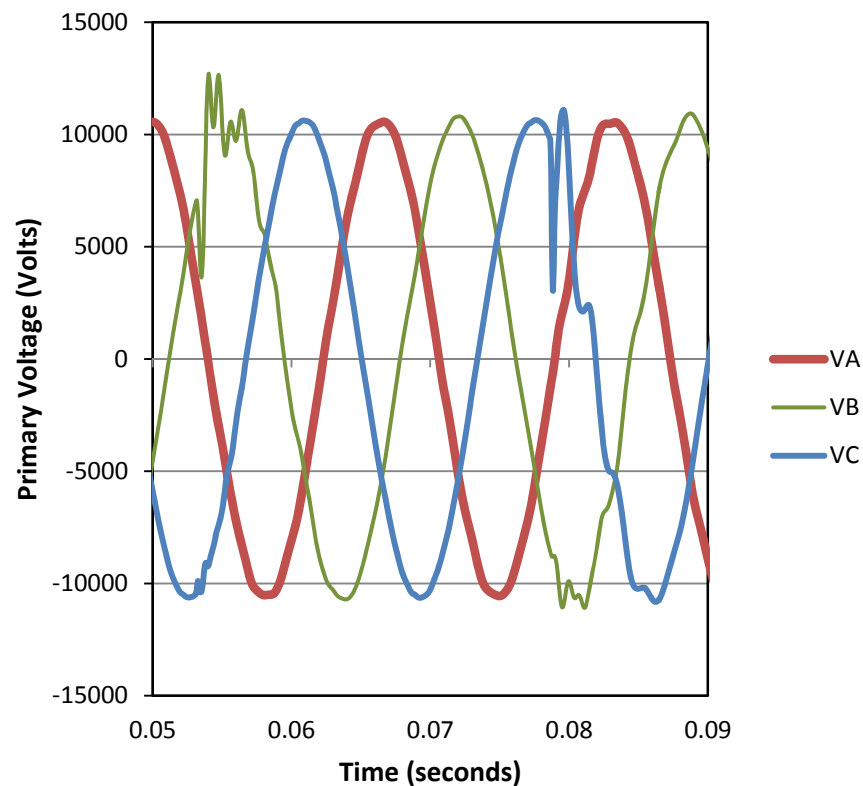


Waveform Overlay: Currents from Incipient Arcing Event 2

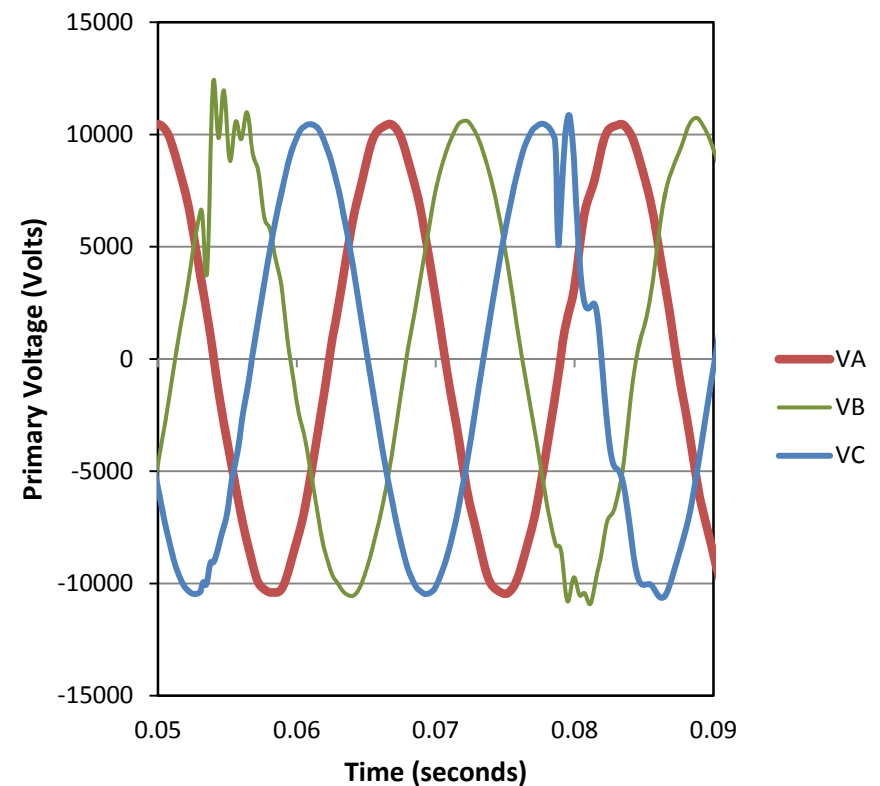


Waveform Comparison: Voltages during Capacitor Switching

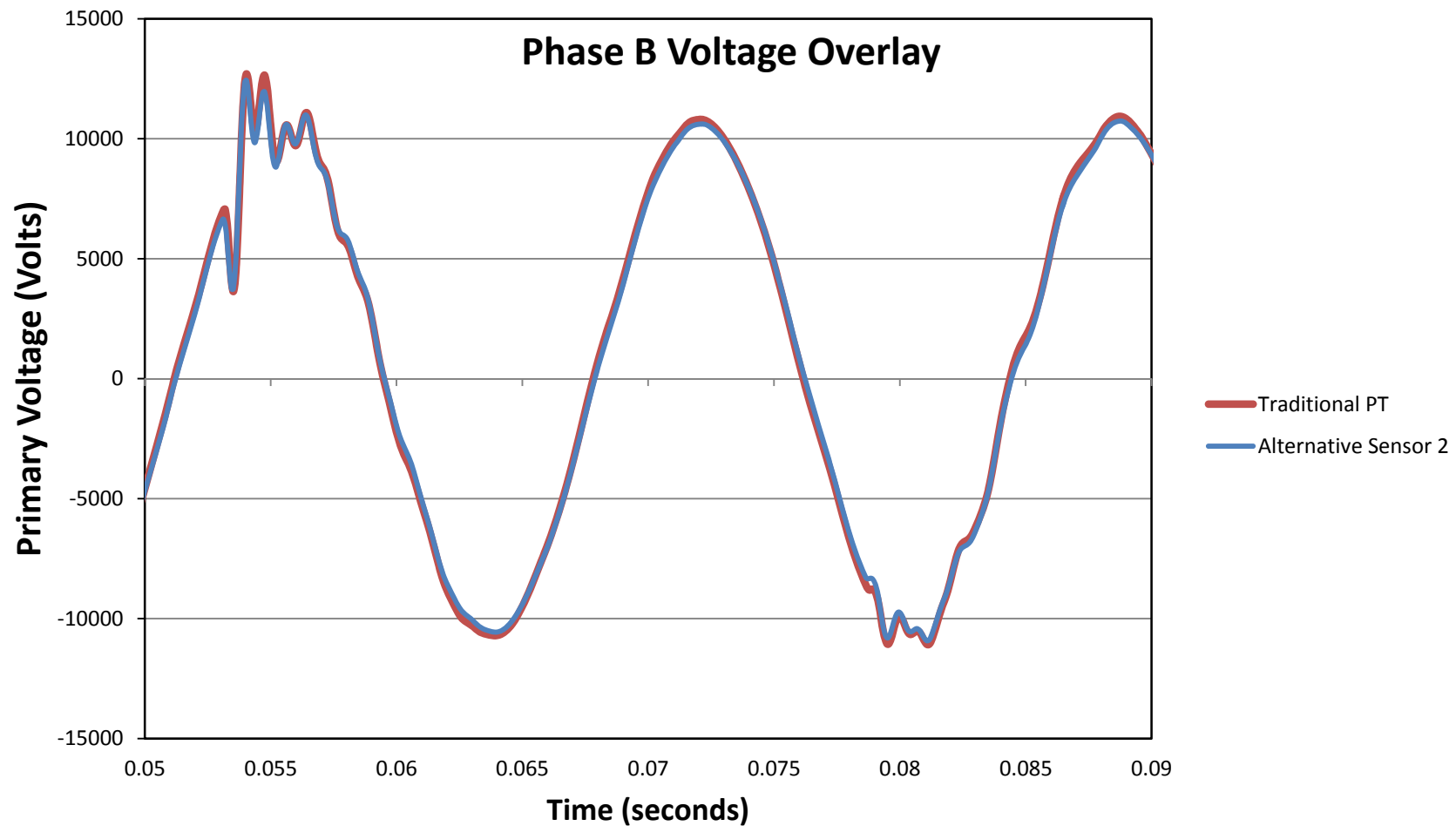
Traditional PT



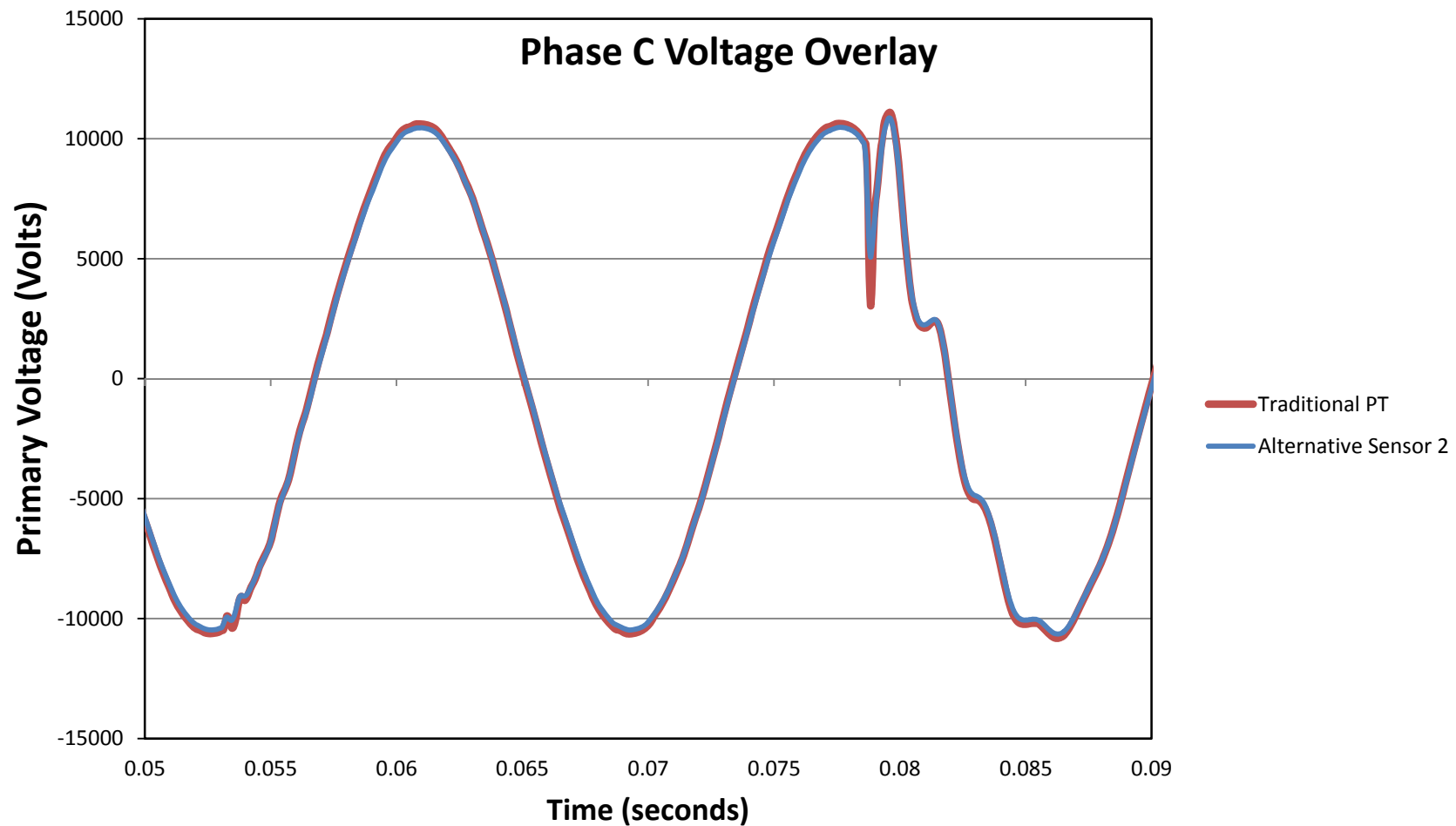
Alternative Sensor 2



Waveform Overlay: Voltages during Capacitor Switching

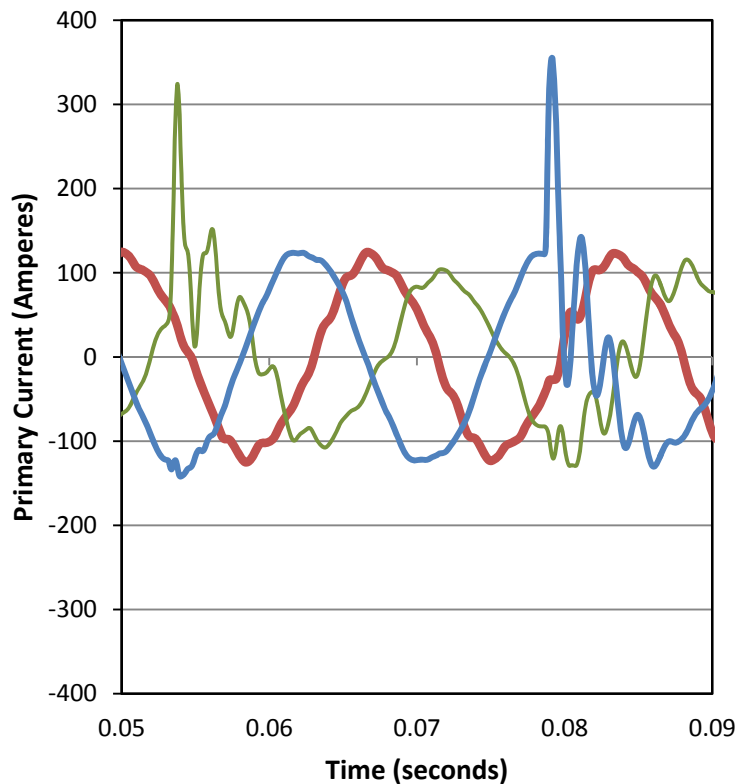


Waveform Overlay: Voltages during Capacitor Switching

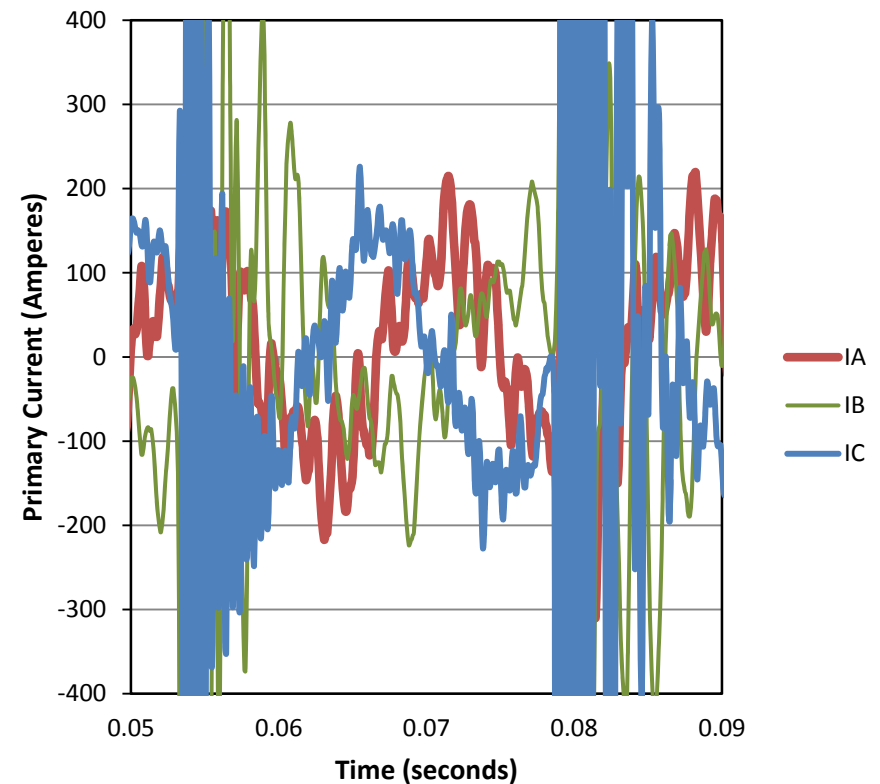


Waveform Comparison: Currents during Capacitor Switching

Traditional CT

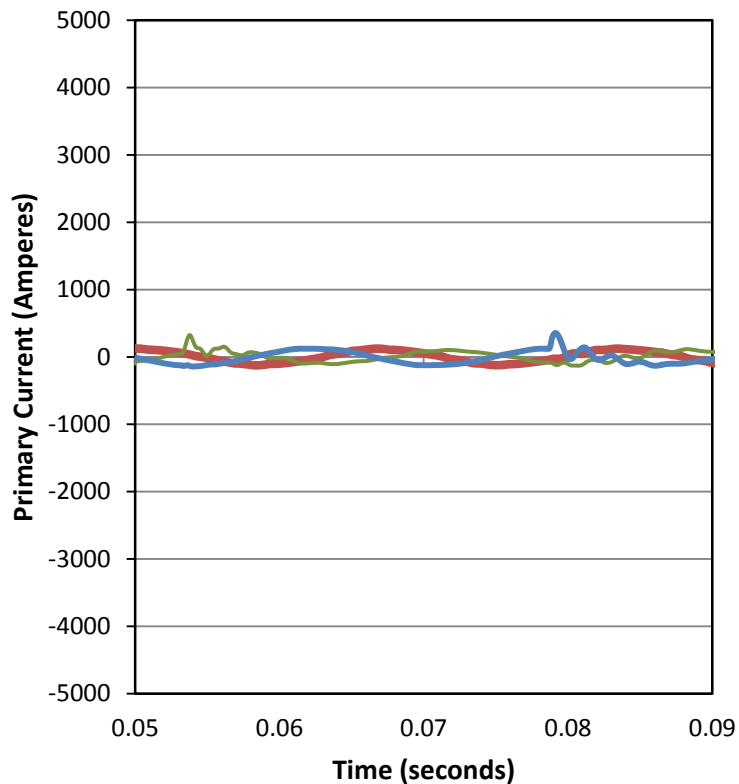


Alternative Sensor 2

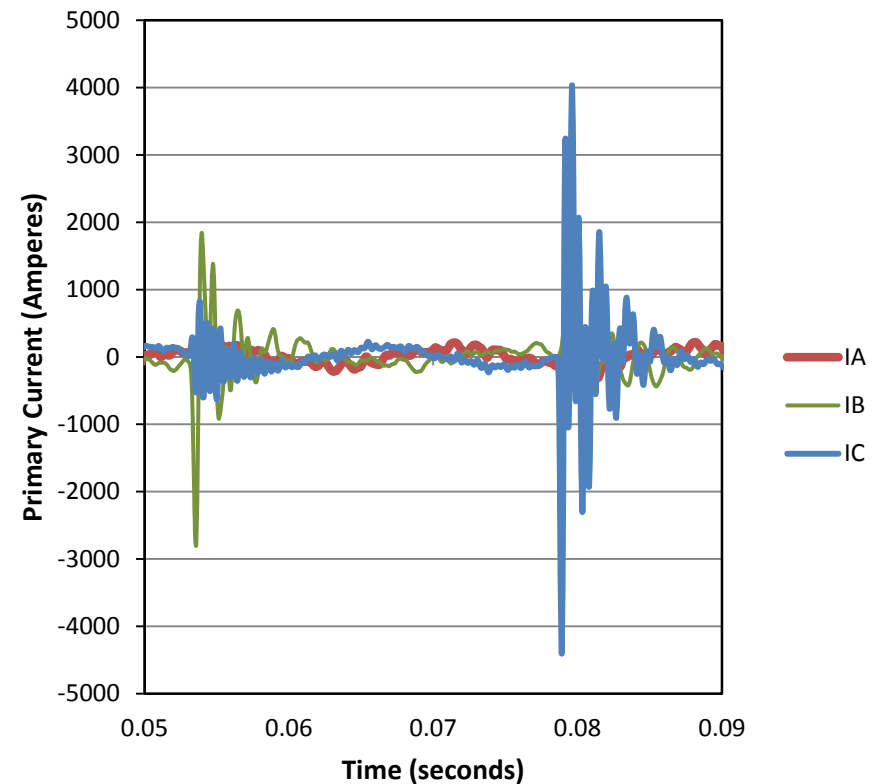


Waveform Comparison: Currents during Capacitor Switching

Traditional CT



Alternative Sensor 2



Harmonic Spectrum Comparison



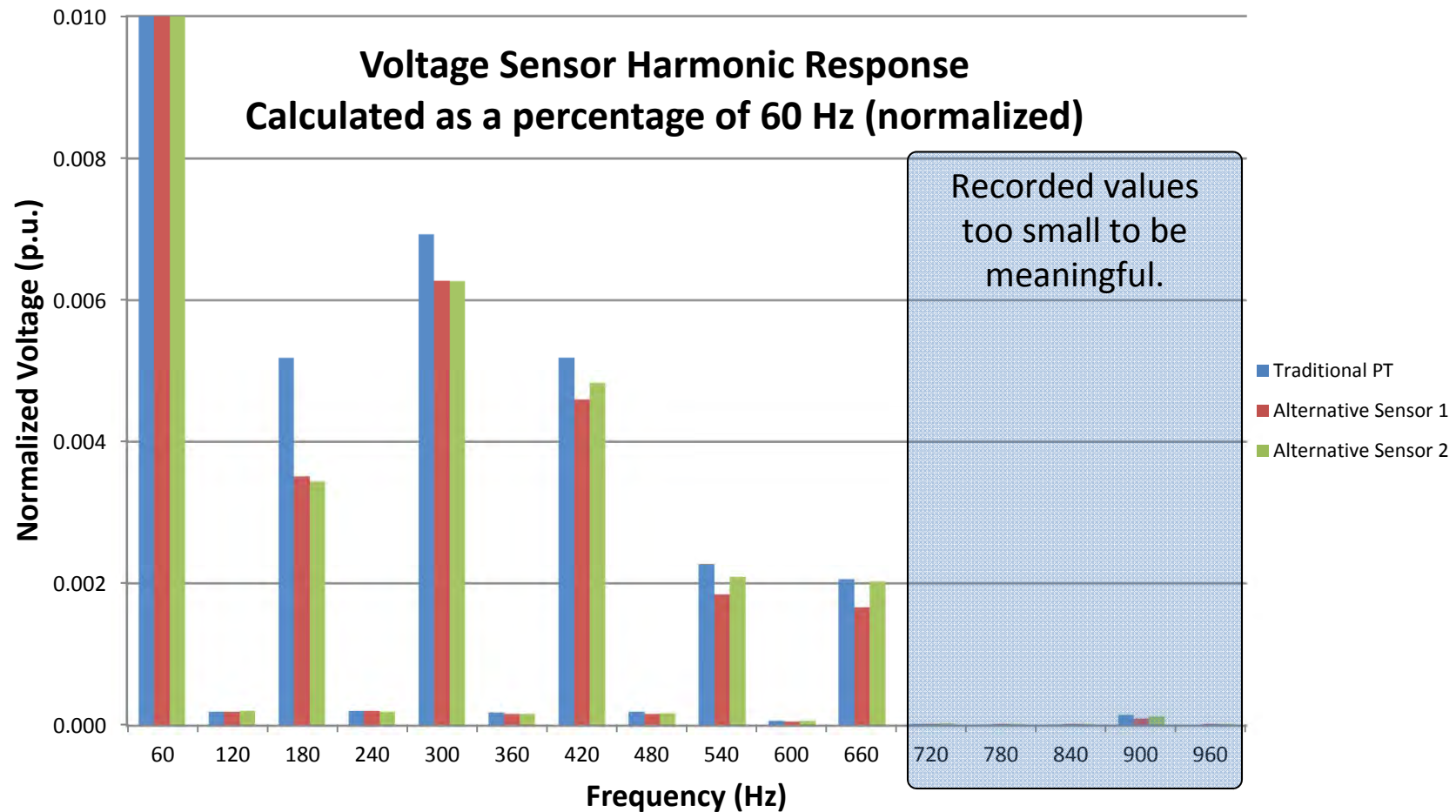
- To analyze differences in spectral content, researchers recorded waveforms under various system load conditions (e.g. weekday/weekend, morning/afternoon/evening, etc).
- For each of these recordings, researchers computed 2-cycle FFTs over the length of the capture.
- Researchers then performed two normalizations on the FFT data from each set of recordings to obtain the spectral characteristic for each sensor.

Harmonic Spectrum Comparison

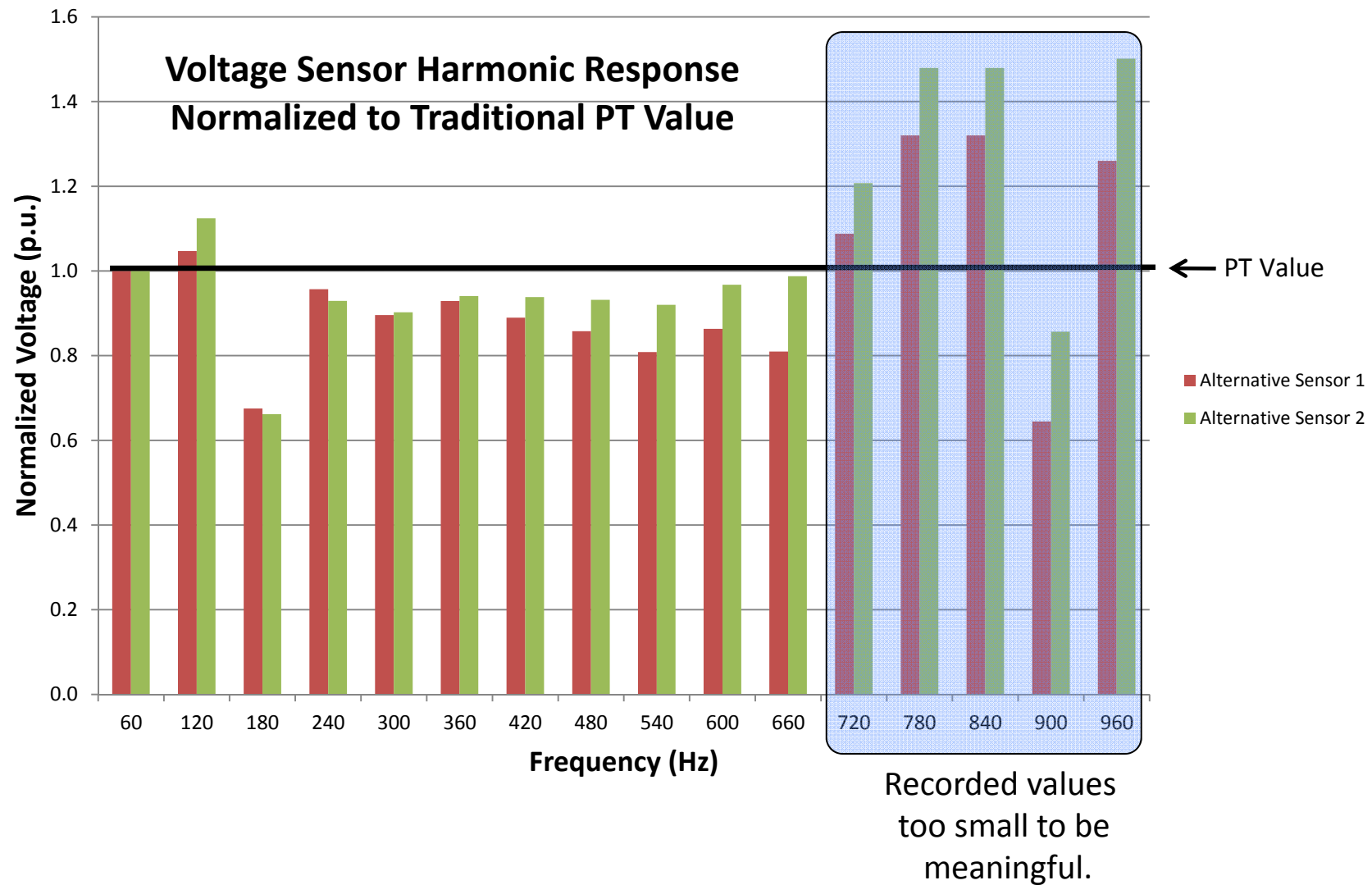


- First normalization: For each sensor, each harmonic component was normalized to that sensor's 60 Hz value. This yielded values for each harmonic as a percentage of fundamental.
- Second normalization: Values from the first normalization were then normalized to the CT/PT value at the corresponding harmonic frequency. This normalization produced a measure of how different the sensor's measured value was from the CT/PT's measured value. Values near unity represent levels similar to conventional CTs/PTs.

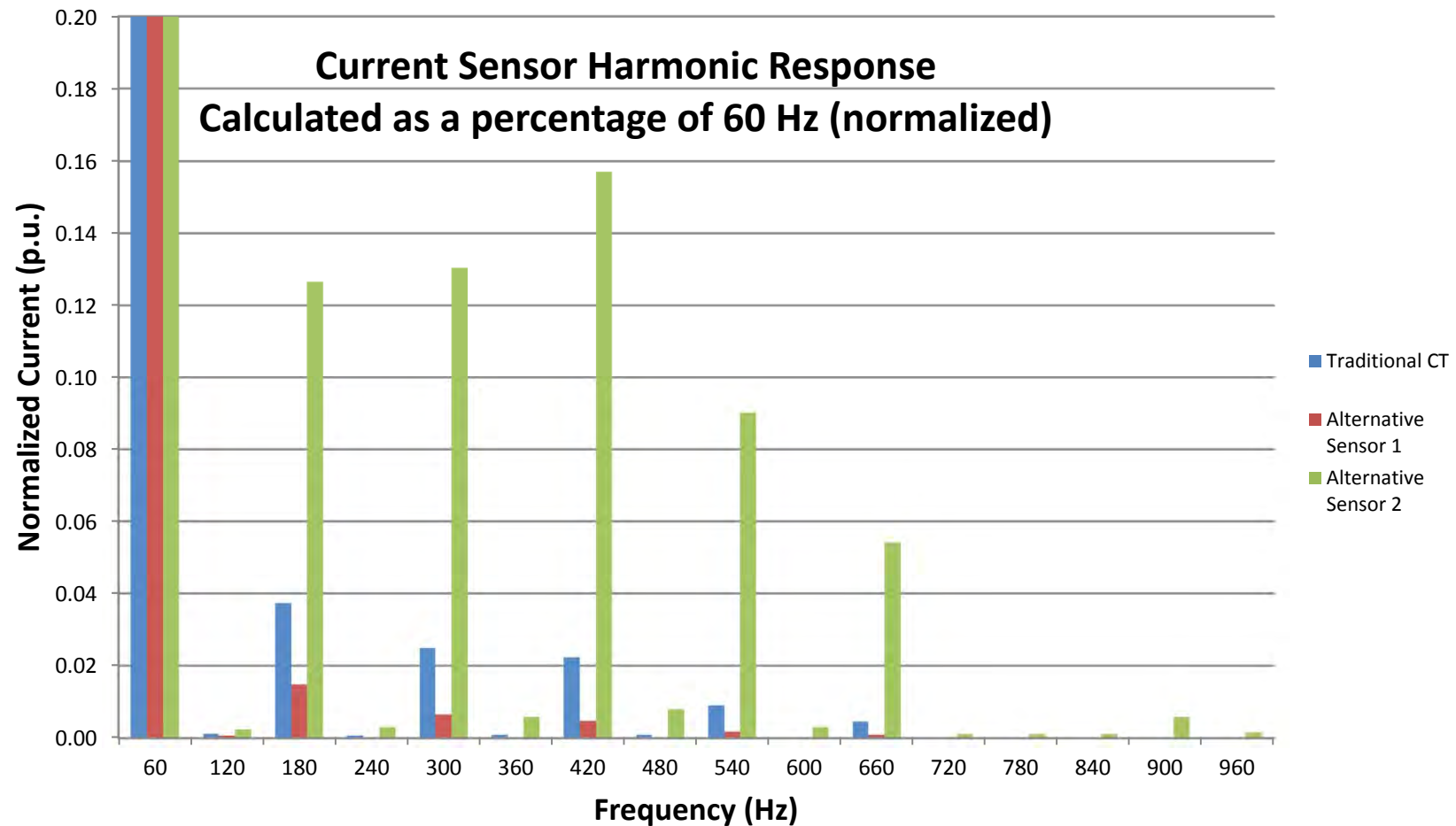
Harmonic Spectrum Comparison: Voltage



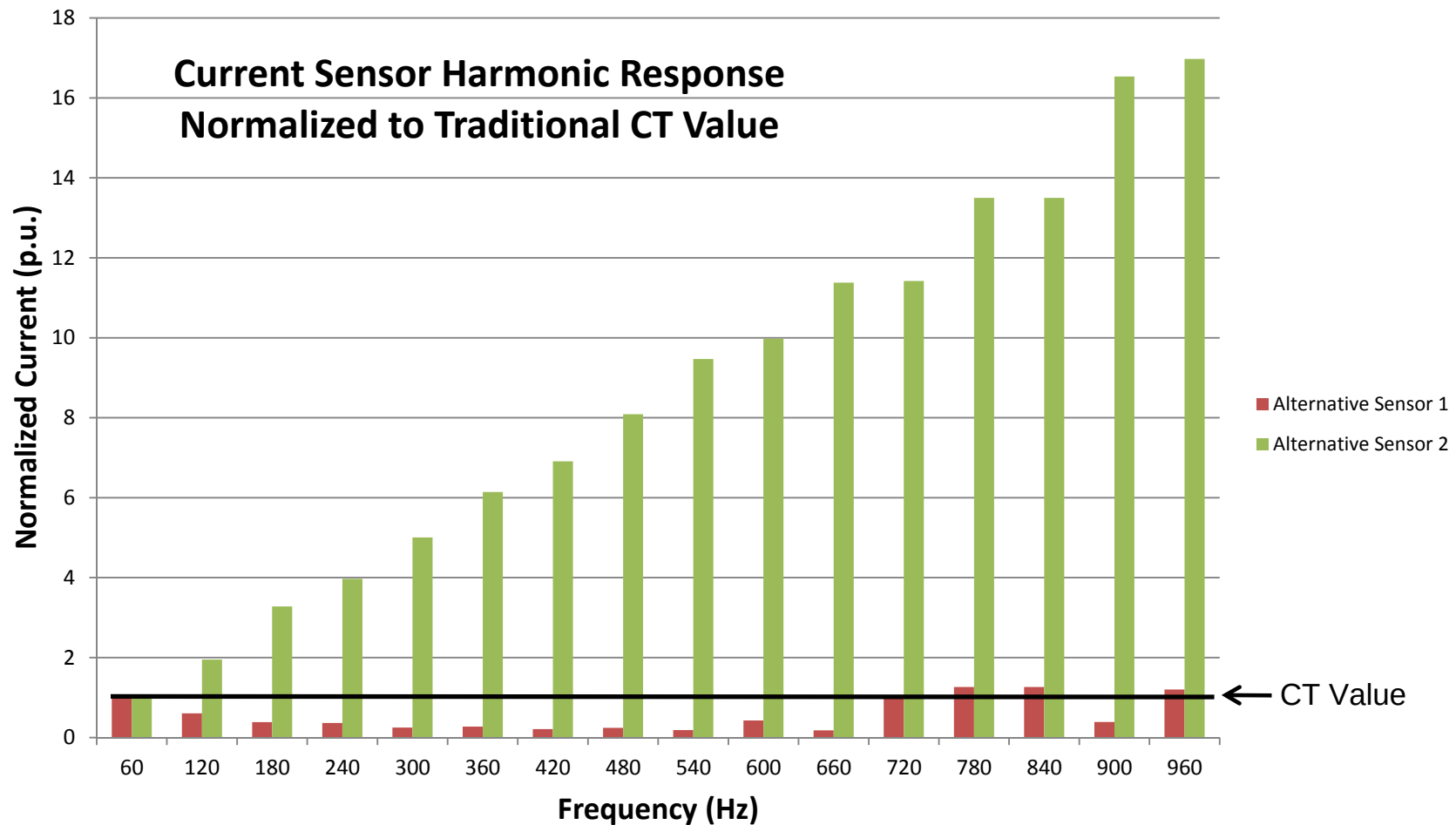
Harmonic Spectrum Comparison: Voltage



Harmonic Spectrum Comparison: Current



Harmonic Spectrum Comparison: Current



Performance Summary



- Both alternative sensors provided reasonably good representations of voltage waveforms.
- Both alternative sensors substantially altered current waveforms.
 - One substantially suppressed harmonics.
 - The other substantially amplified harmonics, with amplification increasing with frequency.
- Analyzing effect of sensor characteristics on a device's function would require detailed knowledge of device and would be specific to that device and that sensor.



Generalized Conclusions

- The accuracy and usefulness of any measurement or control system is limited to the quality of the sensors used to provide inputs to that system.
- Even a device with perfect resolution and sample rate would produce unpredictable results if the signals supplied to it did not faithfully represent the underlying power system quantities.

Generalized Conclusions (cont.)



- It is the experience of the researchers in this project that application engineers may incorrectly assume sensor characteristics are “good enough” for a particular application.
- Performance of current sensors, in particular, may have substantial impact on fault-location algorithms and systems many utilities are deploying or considering.

Generalized Conclusions (cont.)



- Sensor datasheets may specify accuracy under lab conditions, but perhaps for steady-state conditions only and/or for fundamental frequency only. Harmonic and transient response affect many functions, but sensor response to these types of signals is poorly understood and cannot be assumed.

Generalized Conclusions (cont.)



- Based on side-by-side comparisons of this project's selected sensors and conventional CTs and PTs, practitioners should not assume the adequacy of any alternative sensor. It is imperative they investigate and understand a sensor's performance, and its implications for the application under consideration.
- It is insufficient to understand a sensor's characteristics. Instead, it is necessary to understand the sensor's characteristics and how those characteristics will affect the particular application under consideration.

Generalized Conclusions (cont.)



- There were substantial differences in the waveforms from the two alternative sensors used in this project. Therefore, an additional caution is that sensors from different manufacturers should not be mixed for a given application, at least not without understanding their characteristics and the ramifications for the application.

Generalized Conclusions (cont.)



- Users seeking additional information regarding specific characteristics of particular alternative sensors should be aware of a concurrent EPRI report which analyzed frequency and phase response for multiple alternative sensors under laboratory conditions, and reached similar conclusions about sensors currently on the market.

“Sensor Technologies for Real-Time Distribution System Monitoring”,
Electronic Power Research Institute, 2009. EPRI Report No. 1017832.