Applicability of Synchrophasor Data for Fault Analysis

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Outline

- Introduction
- PMU data for fault analysis
  - Phasors and sequence components
  - Impedance based fault location estimations
- Factors considered
  - Filter type (P/M)
  - Fault duration
- Analysis of data
  - Faults
  - SSO/SSR
- Conclusions

Introduction

- The synchrophasor standard IEEE C37.118.1a-2014 presents two performance class filters.
  - P & M
- This presentation focuses on the applicability of the P and M class synchrophasor data for fault analysis.
- The synchrophasor data captured from an industrial PMU implemented as per IEEE C37.118.1a- 2014 was used for this analysis.
  - Simulated data from a Real Time Digital Simulator (RTDS)
  - Field reported events
- Data is captured using the in-built PDC program available with the device.

Important Considerations

- Typical fault durations
  - Depends on the response of the protection and speed of the circuit breakers.
    - Response of the conventional relays: **~1 cycle**, high speed CBs : **~1 cycle**
      - **~2 cycle**
- Effect of the filters (P/M)
  - Finite Impulse Response with ~2 cycles (P) and ~ 5 cycle (M)

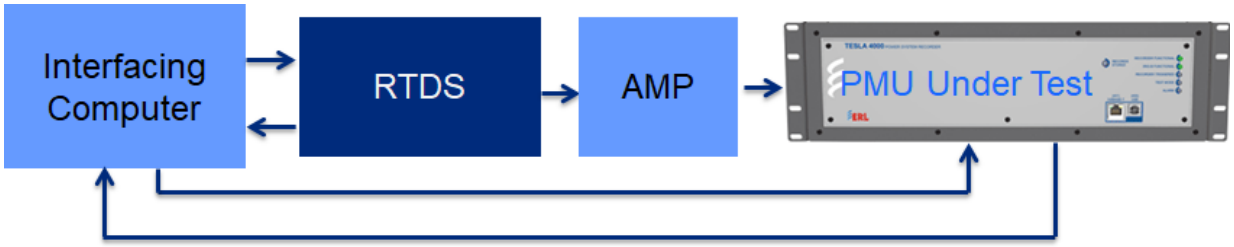
- Reporting rates available

System frequency	50 Hz			60 Hz					
Reporting rates (F_s—frames per second)	10	25	50	10	12	15	20	30	60

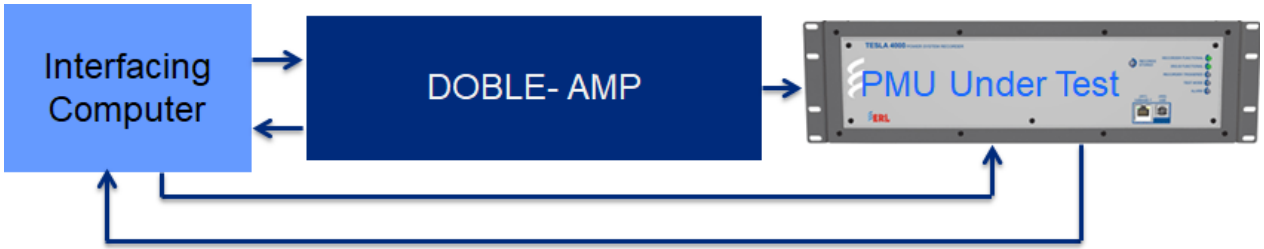
- **<u>Testing Considerations/ Parameters</u>**
  - Testing was done with the faults simulated at 2 cycles and above
  - Selected reporting rate = 60 Hz (60 Hz system)

Test Setup

- RTDS Testing: Simulated Waveforms

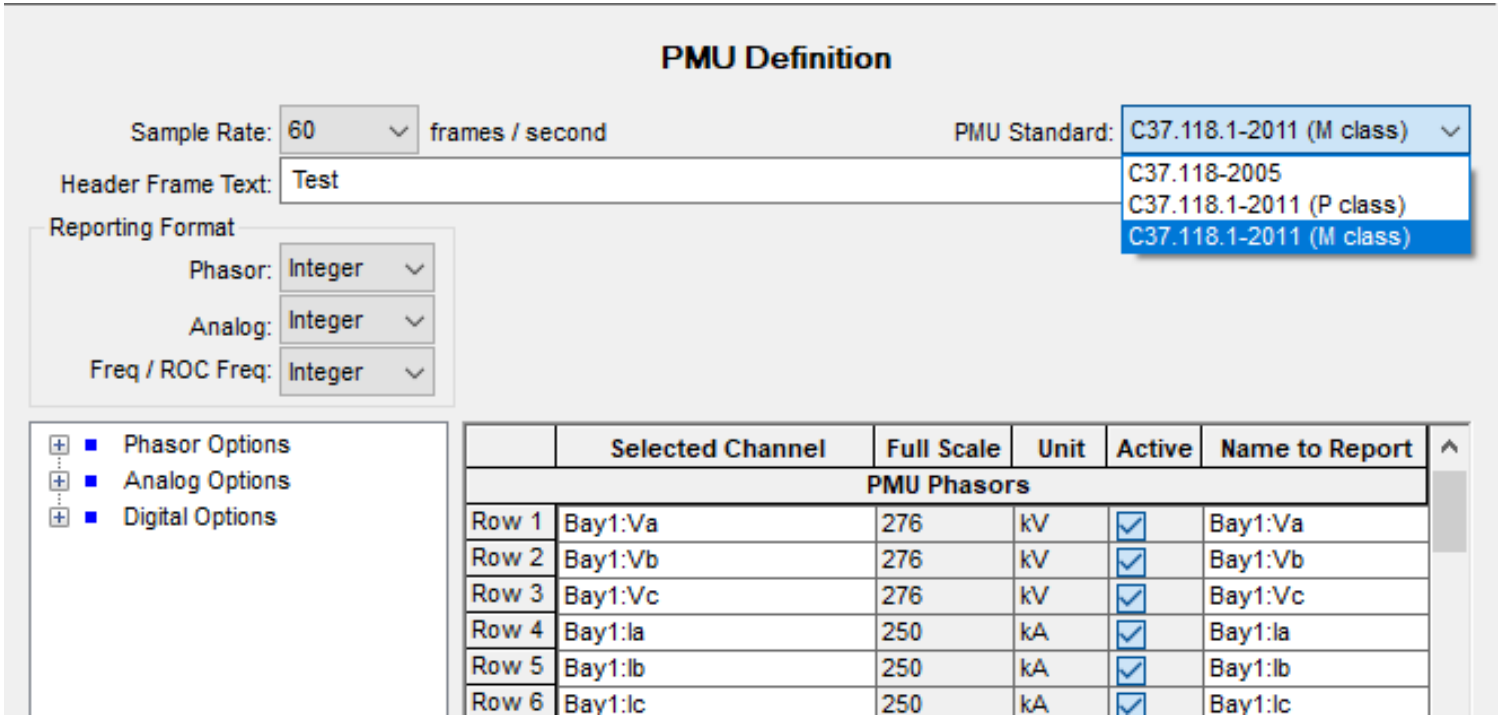


- DOBLE Amplifier: Real time playback of recorded waveforms



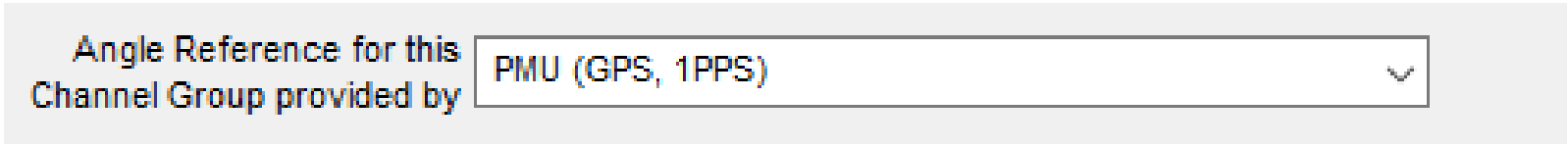
PMU Settings

- Basic PMU Settings

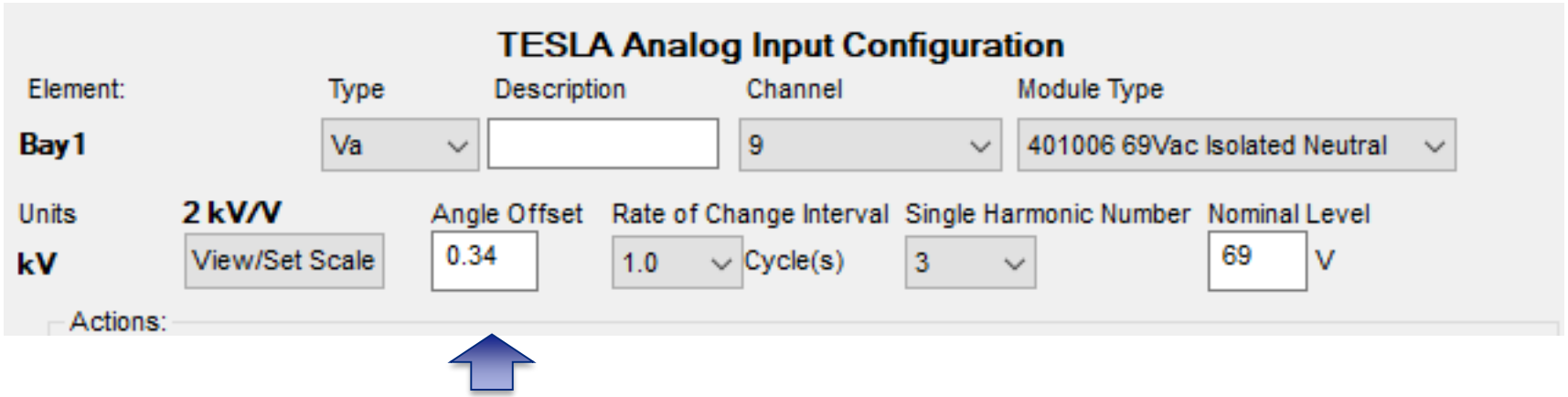


PMU Calibration

- Angle Reference – PMU Settings



- Angle Calibration
  - RTDS and PMU – Connected to GPS – 1 PPS

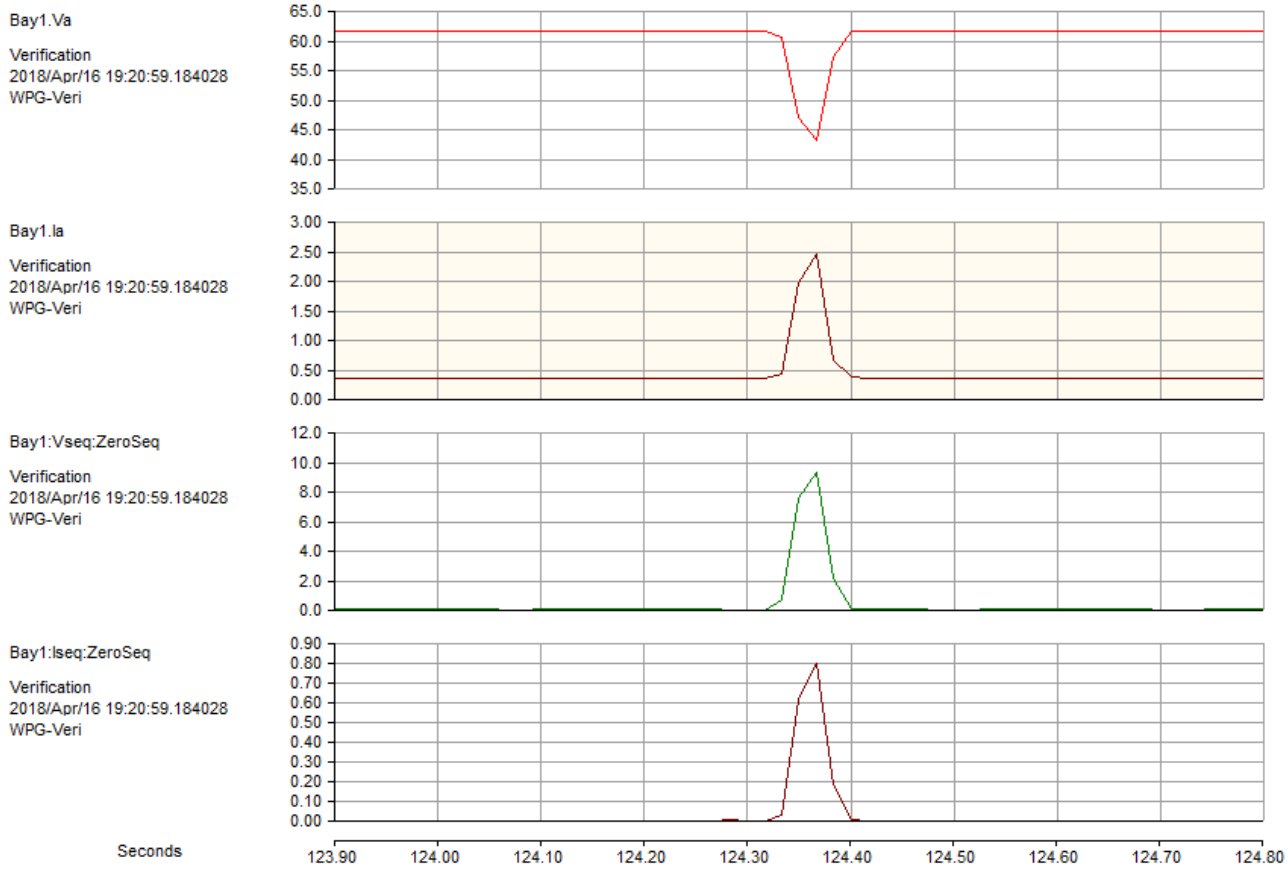


Analysis of Simulated Faults: RTDS

- Test Cases
  - Effect of fault during - P class estimation
  - Effect of fault during - M class estimation
  - Fault location calculation – M class

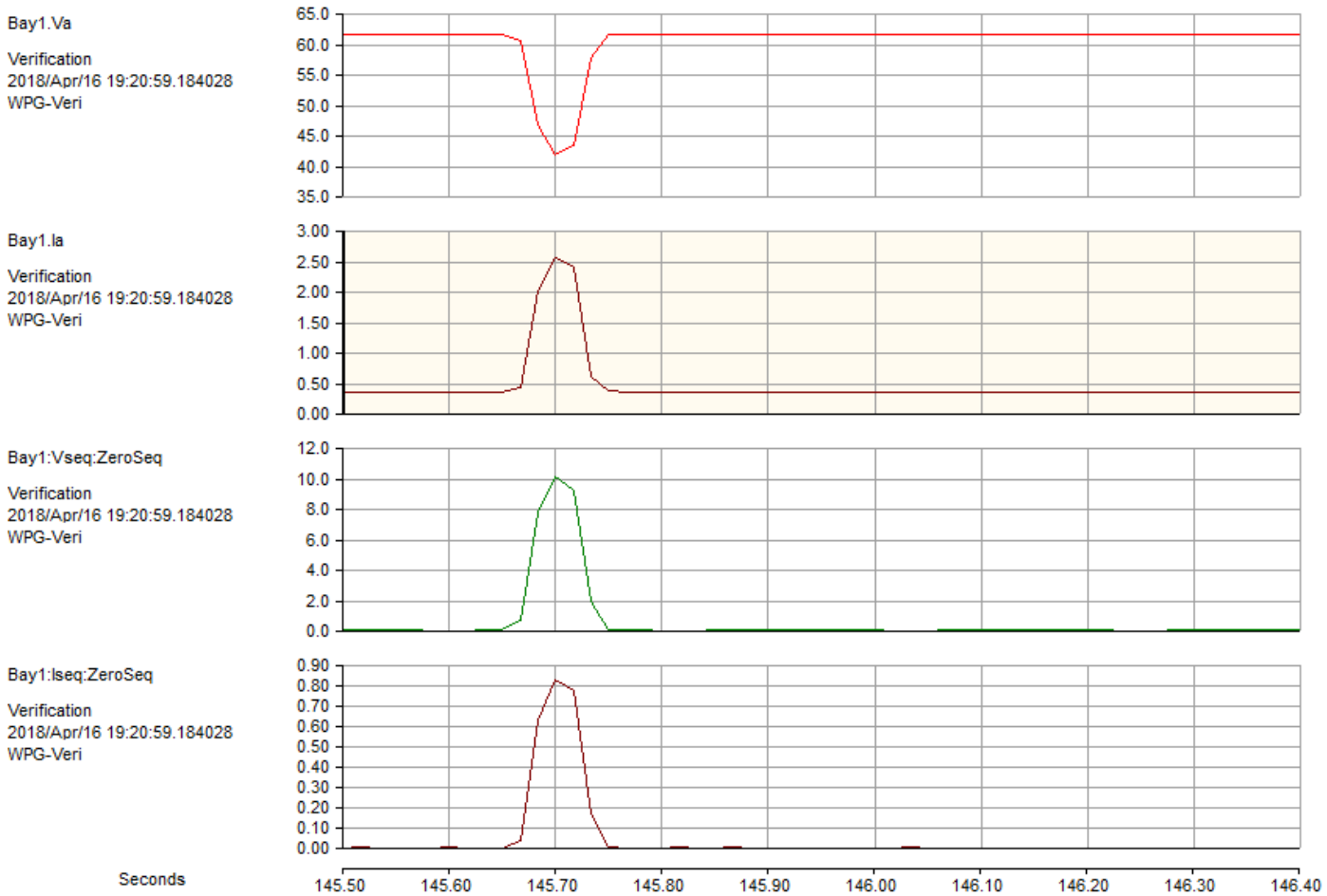
PMU Data During Faults : P Class

- 2 cycle faults: PMU reporting at 60Hz



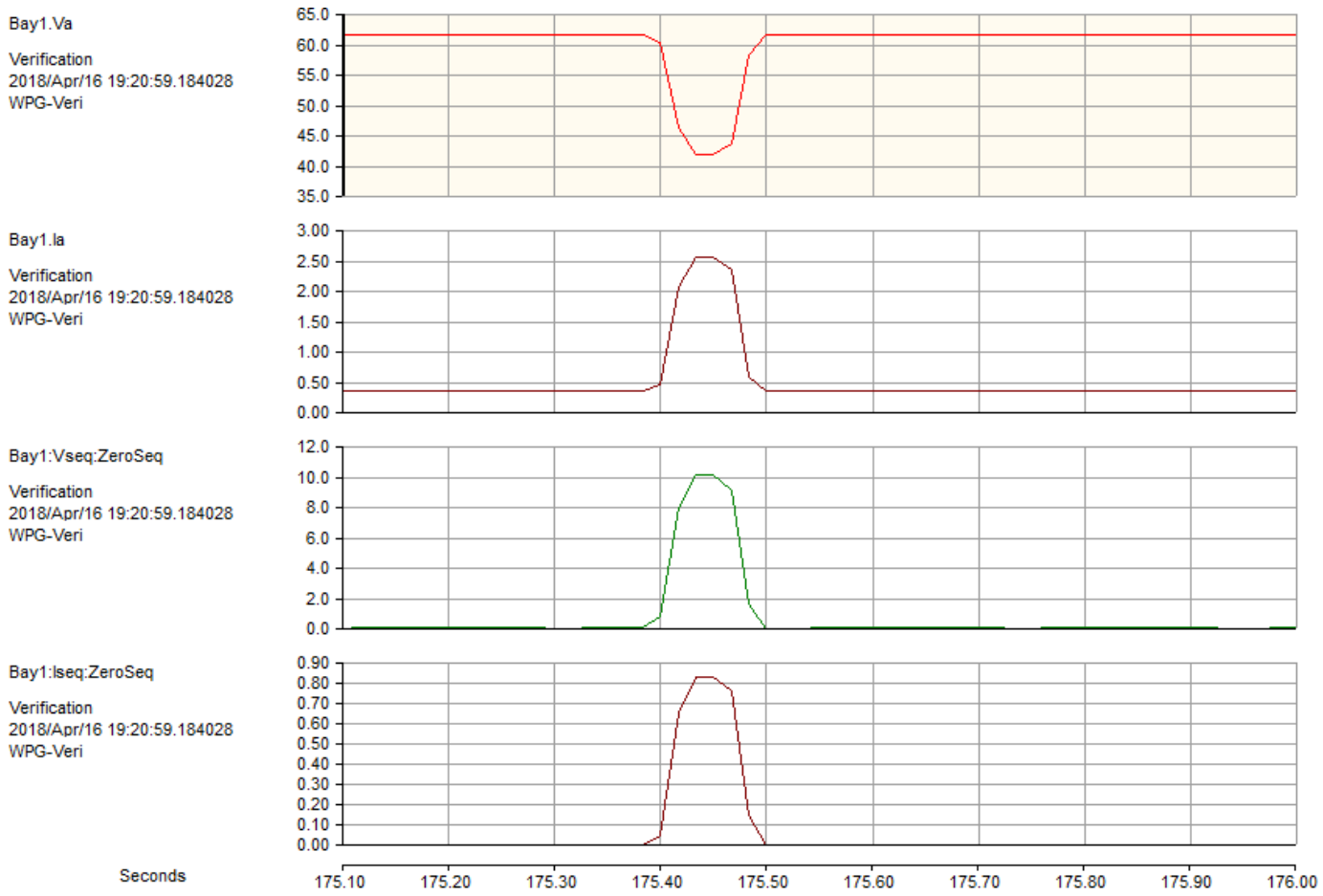
PMU Data During Faults : P Class

- 3 cycle faults: PMU reporting at 60Hz



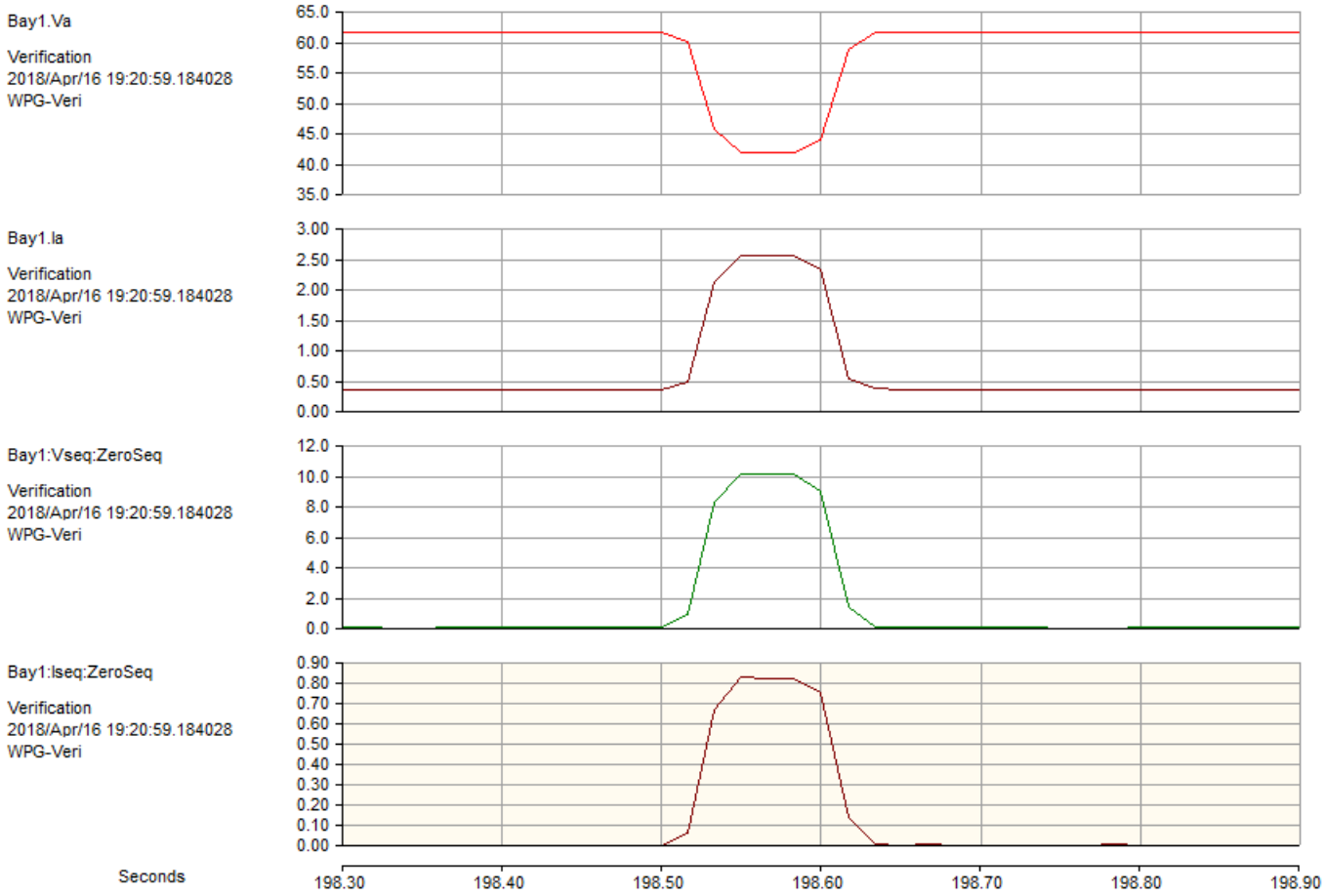
PMU Data During Faults : P Class

- 4 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : P Class

- 5 cycle faults: PMU reporting at 60Hz



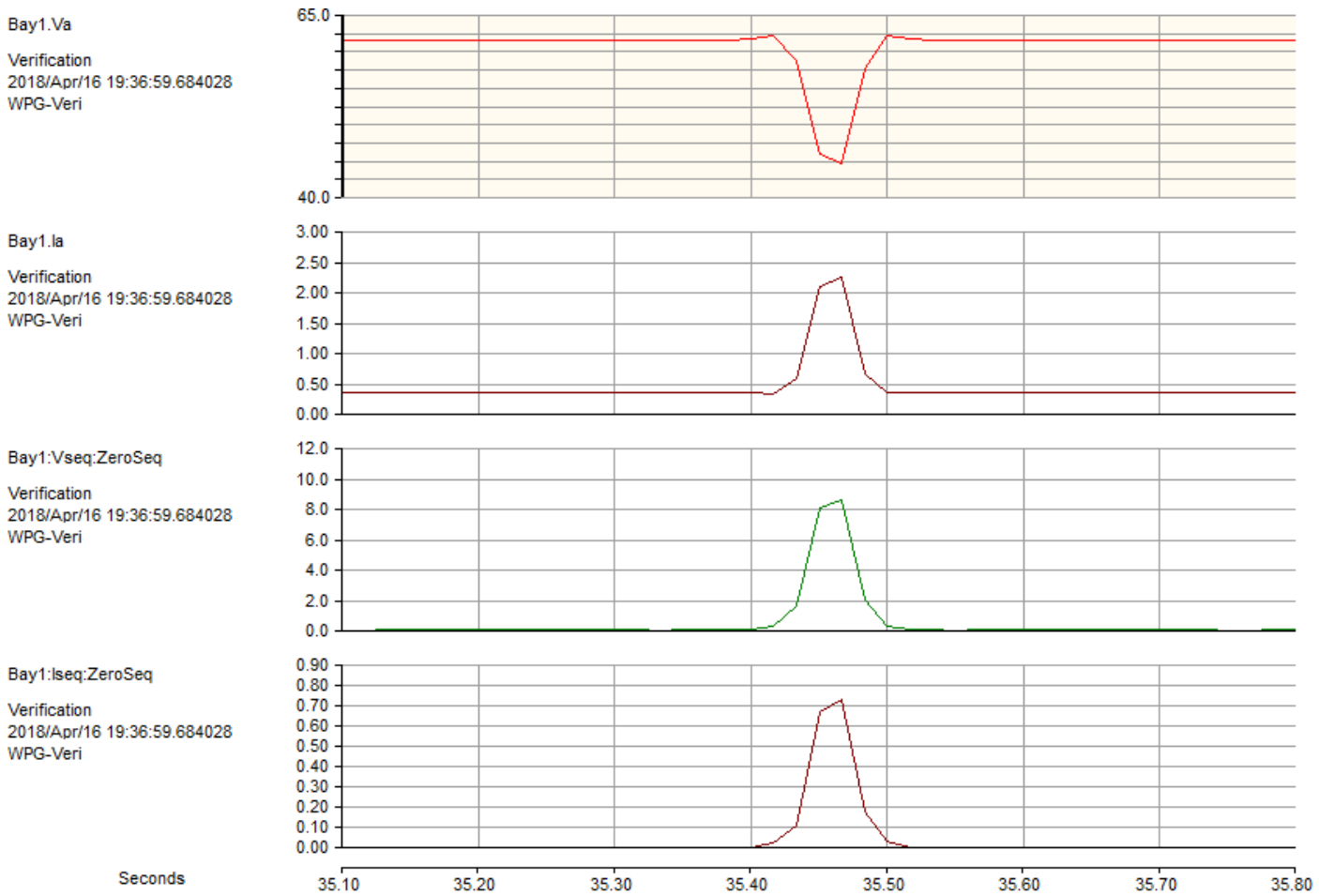
PMU Data During Faults : P Class

- Summary: PMU reporting at 60Hz

Duration (cycles)	Zero Seq. Voltage (V)	Zero Seq. Current (A)
2	9.5 V	0.72 A
3	10.1 V	0.83 A
4	10.1 V	0.83 A
5	10.1 V	0.83 A

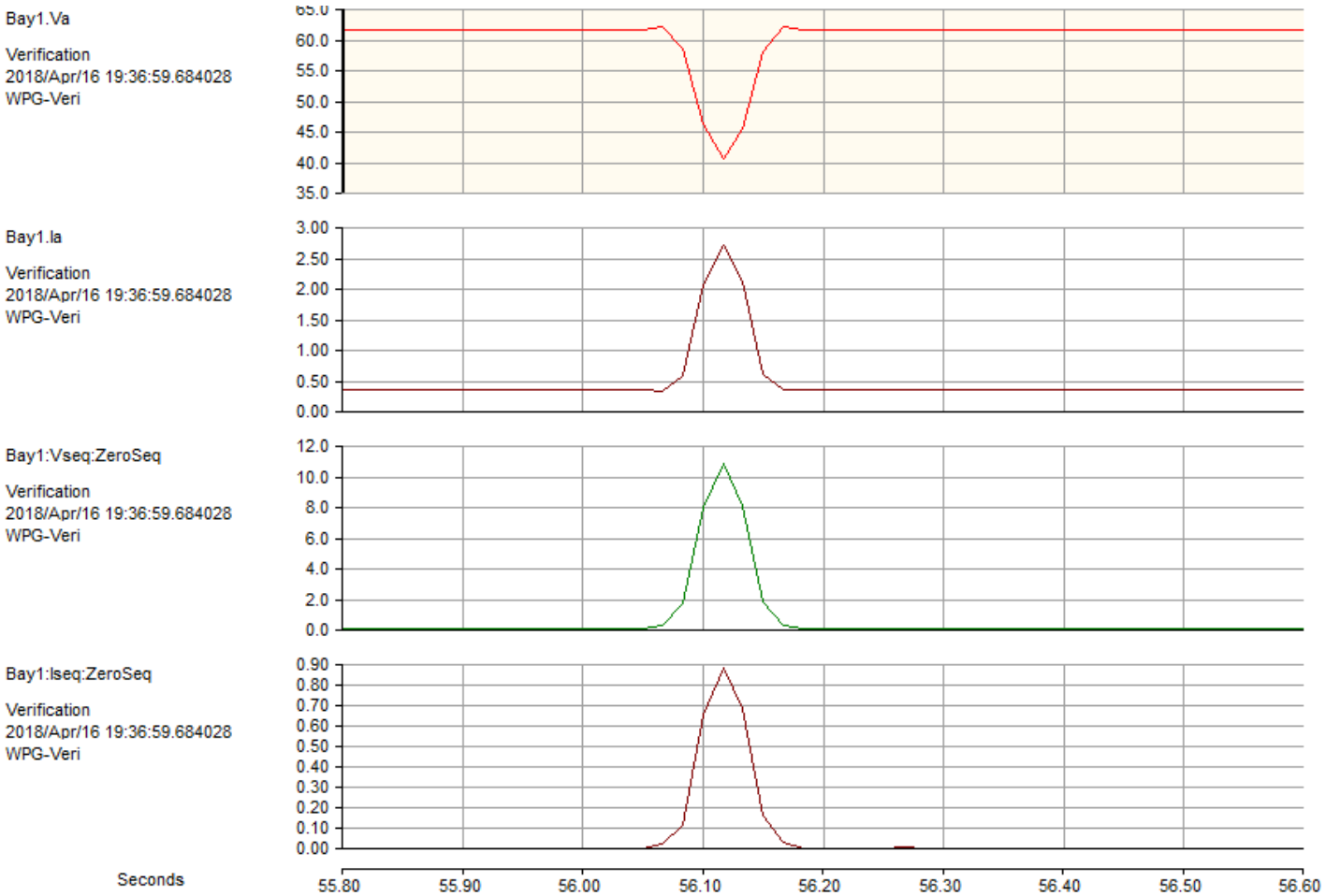
PMU Data During Faults : M Class

- 2 cycle faults: PMU reporting at 60Hz



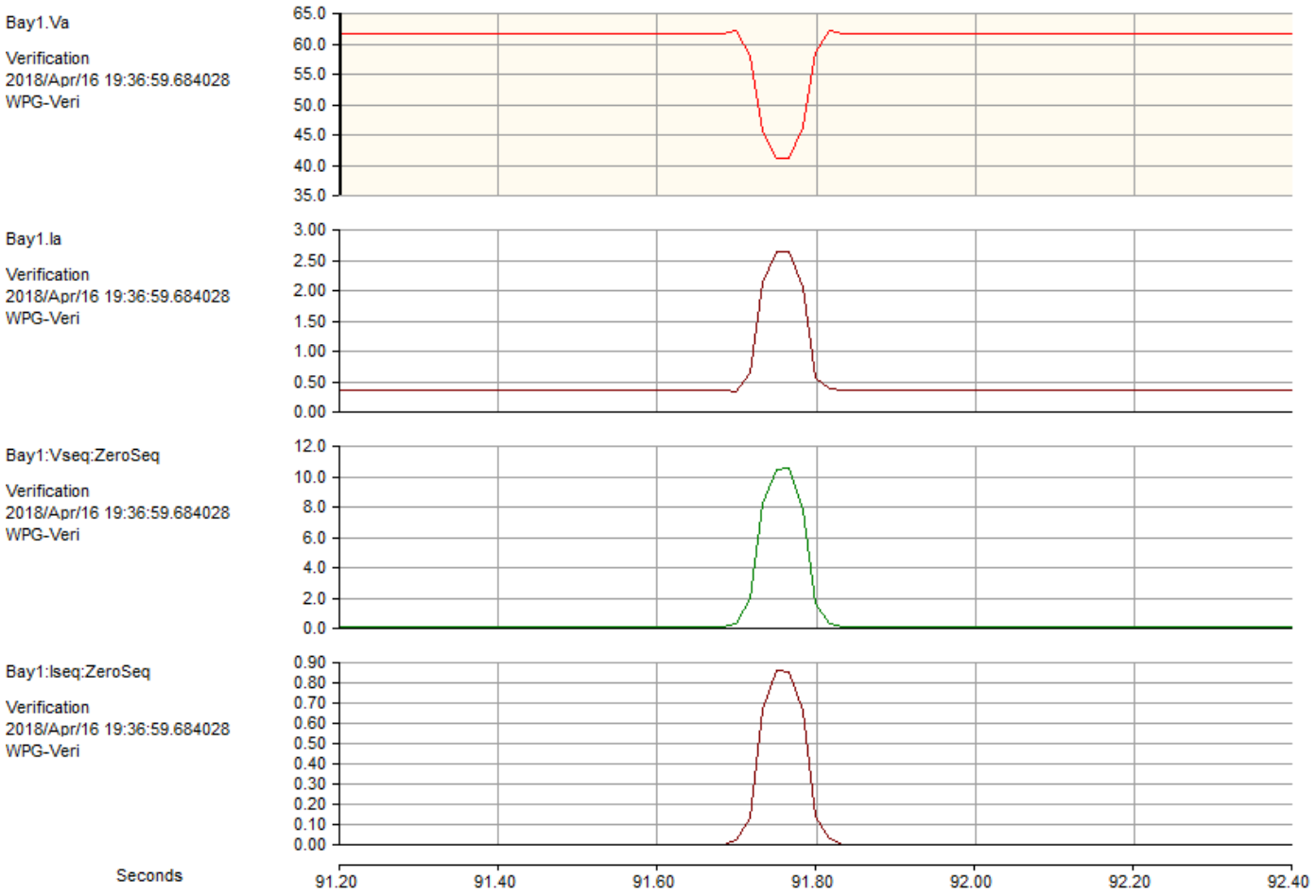
PMU Data During Faults : M Class

- 3 cycle faults: PMU reporting at 60Hz



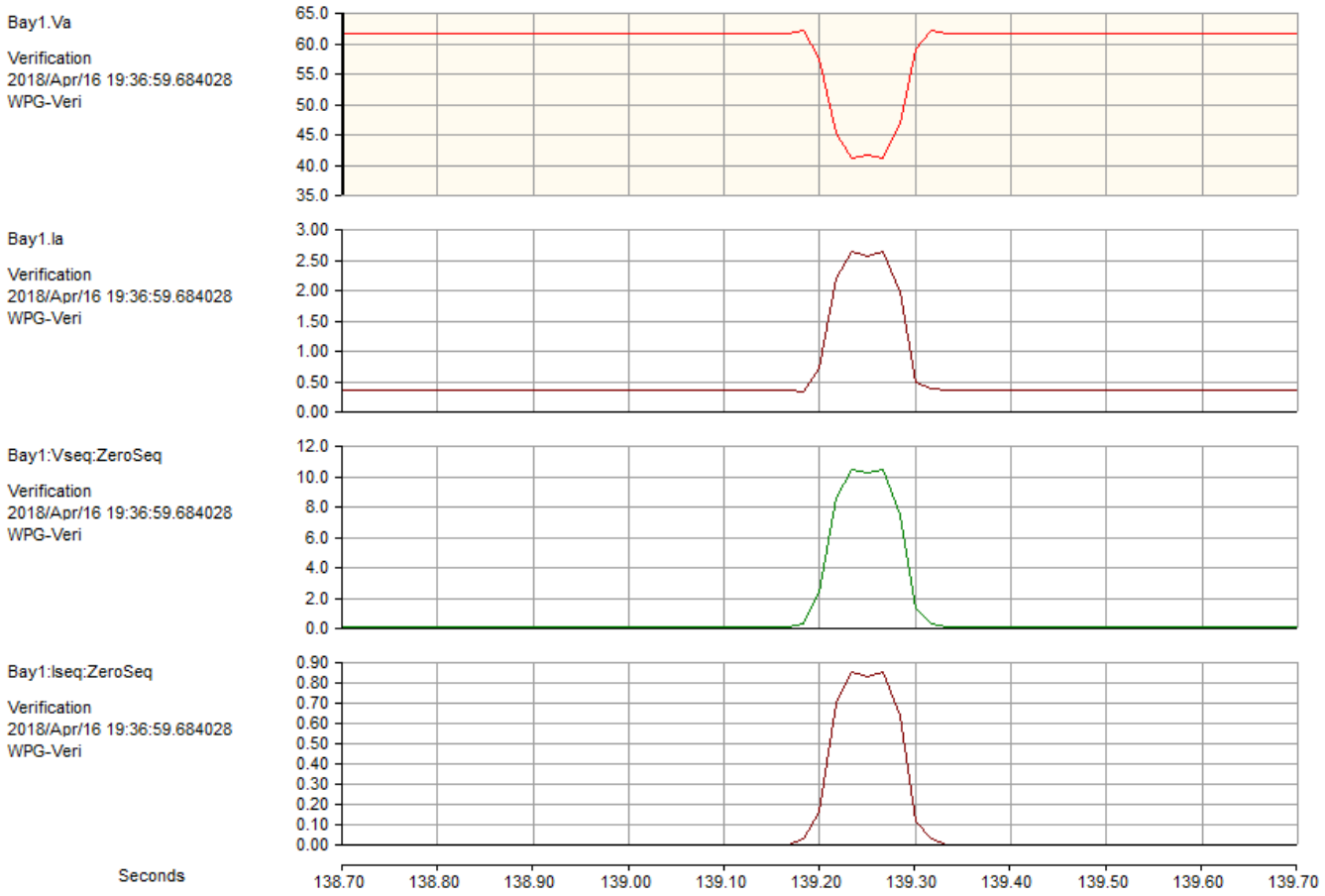
PMU Data During Faults : M Class

- 4 cycle faults: PMU reporting at 60Hz



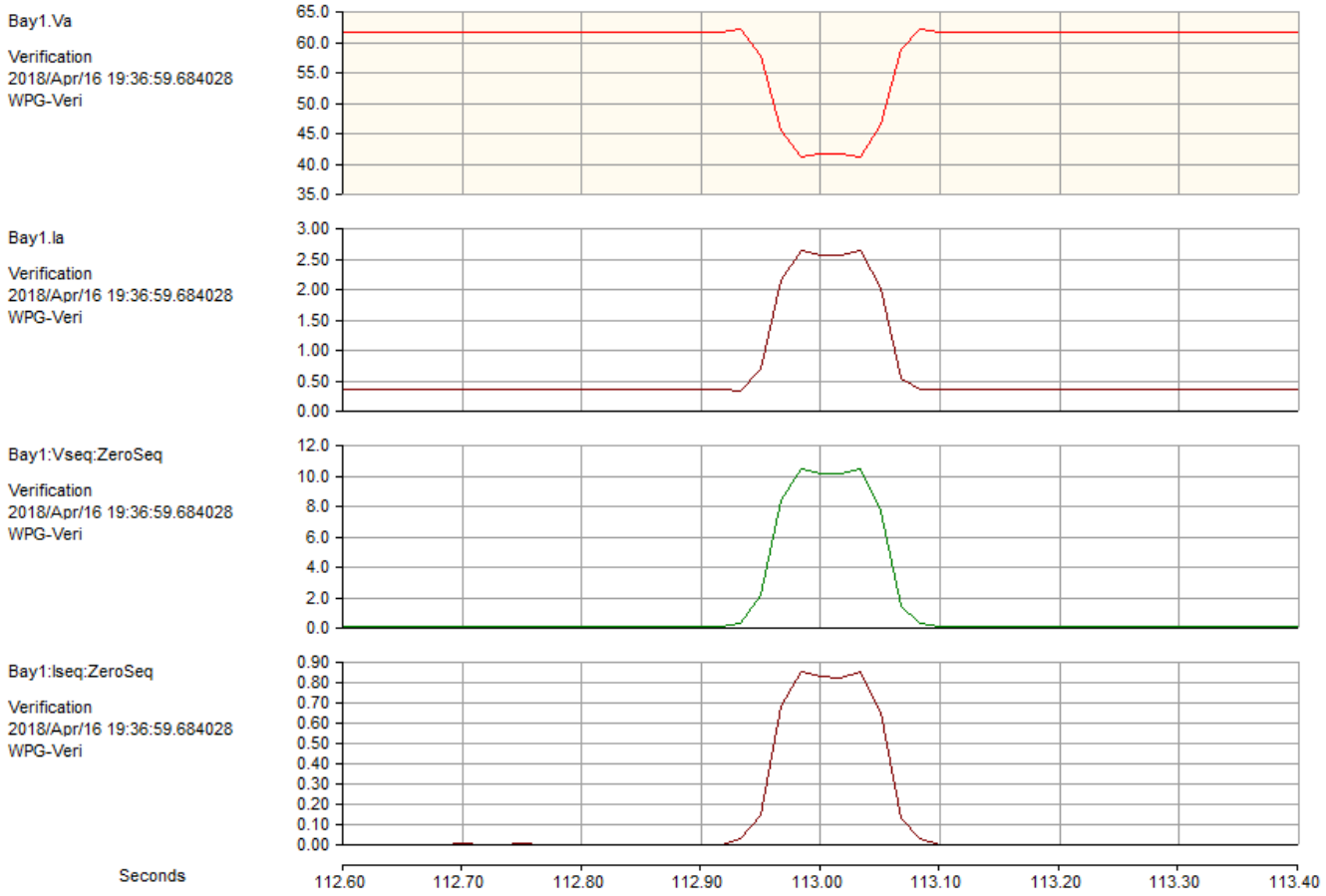
PMU Data During Faults : M Class

- 5 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : M Class

- 6 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : M Class

- Summary: PMU reporting at 60Hz

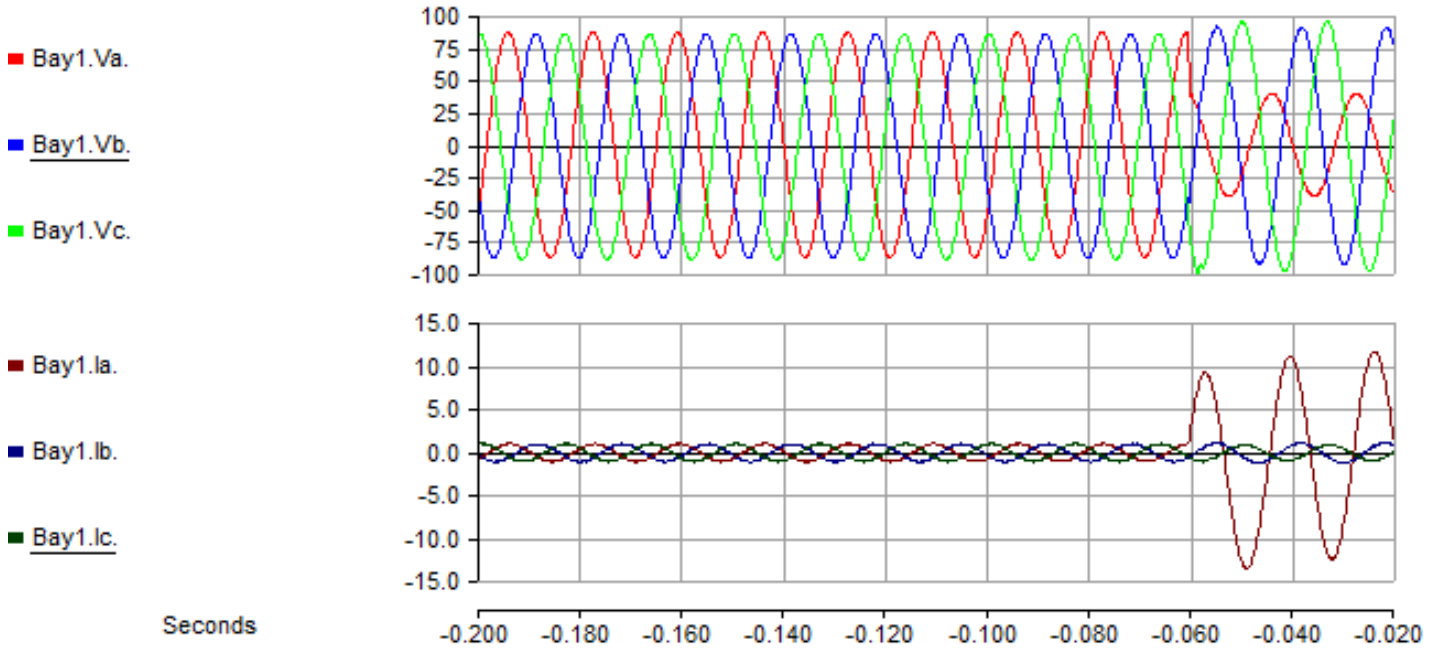
Duration (cycles)	Zero Seq. Voltage (V)	Zero Seq. Current (A)
2	8.2 V	0.71 A
3	10.9 V	0.9 A
4	10.4 V	0.87A
5	10.1 V	0.83 A
6	10.1 V	0.83 A

Over-shoot

Impedance Based Fault Location : M Class

- Method: Takagi Algorithm
  - PMU data (**120** samples/sec = 2 samples/cycle)
  - M class (C37.118.1a-2014)

- 3 cycle fault
  - Actual: 3 km; Estimated: 6.7 km



Impedance Based Fault Location : M Class

- Effect of the fault duration (single phase to ground fault)

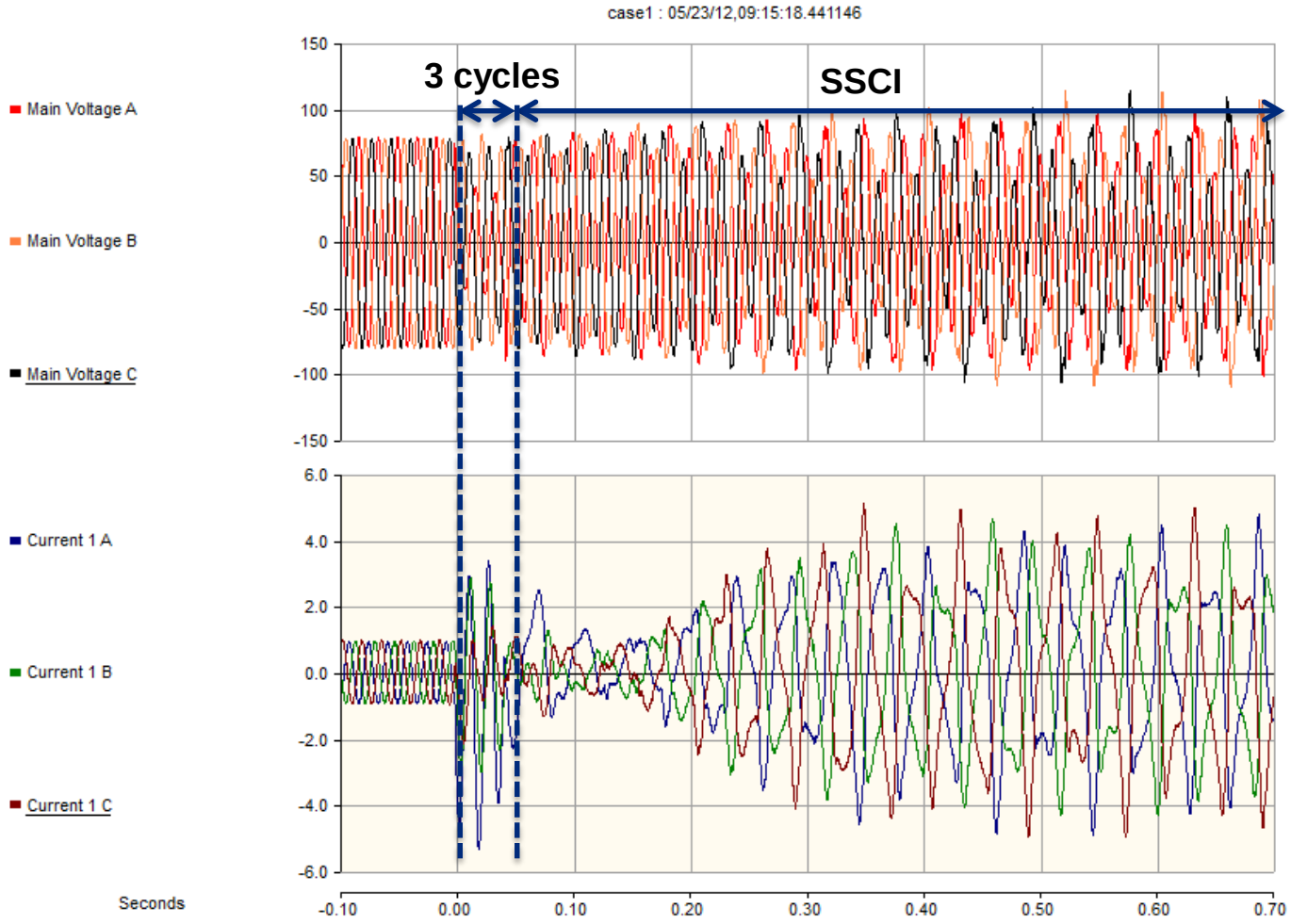
Duration (cycles)	Actual Distance (km)	Estimated Distance (km)
3	4.0 km	6.7 km
4	4.0 km	3.8 km
5	4.0 km	3.9 km
6	4.0 km	4.0 km

Analysis of Actual Fault Records

- Test Cases
  - 3-cycle fault leading to SSO/SSCI condition
    - Application: a windfarm connected to a series compensated line
  - SSO/SSCI
    - Application: a windfarm connected to a series compensated line

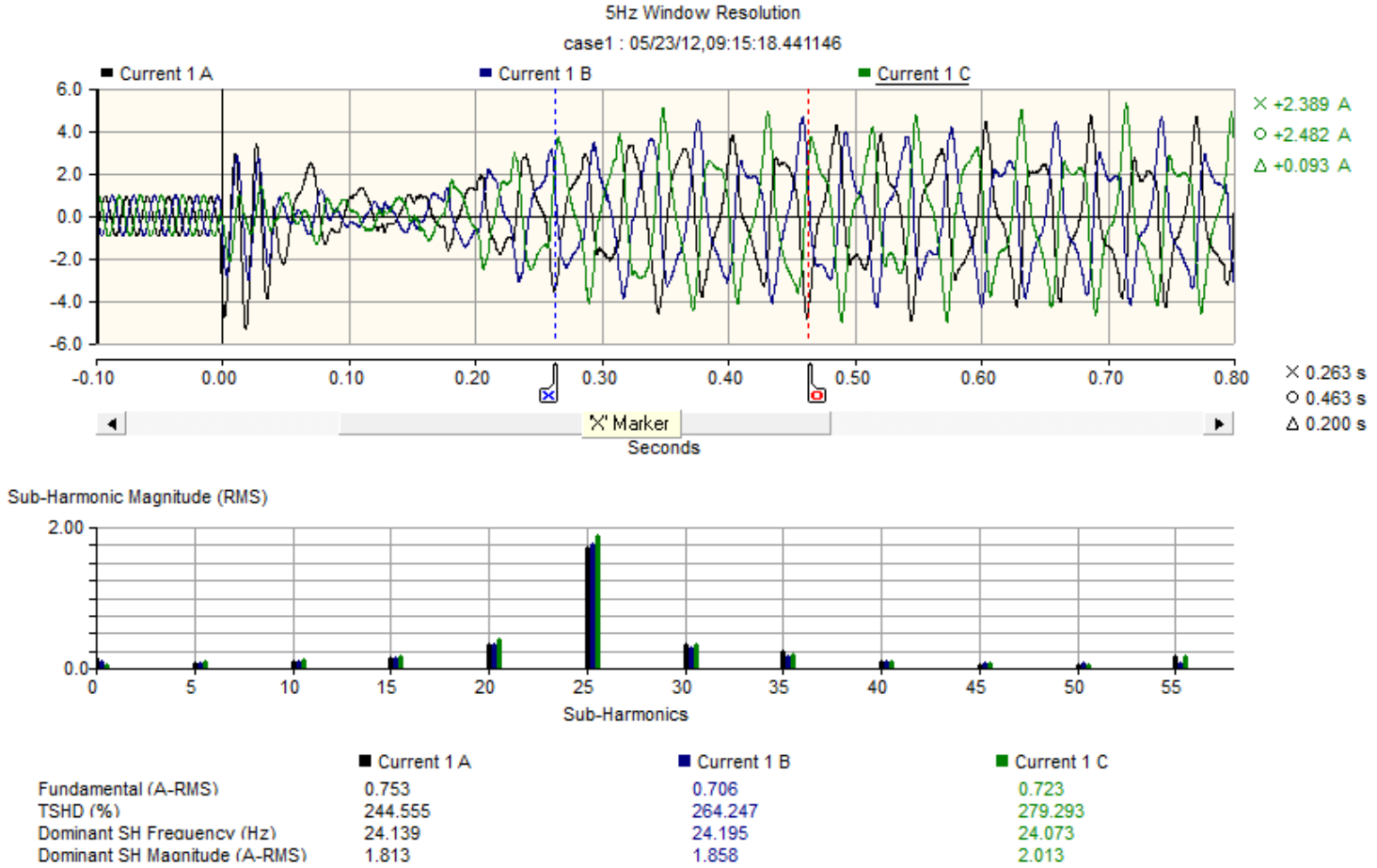
3- cycle fault leading to a SSO/SSCI

- High Speed Record



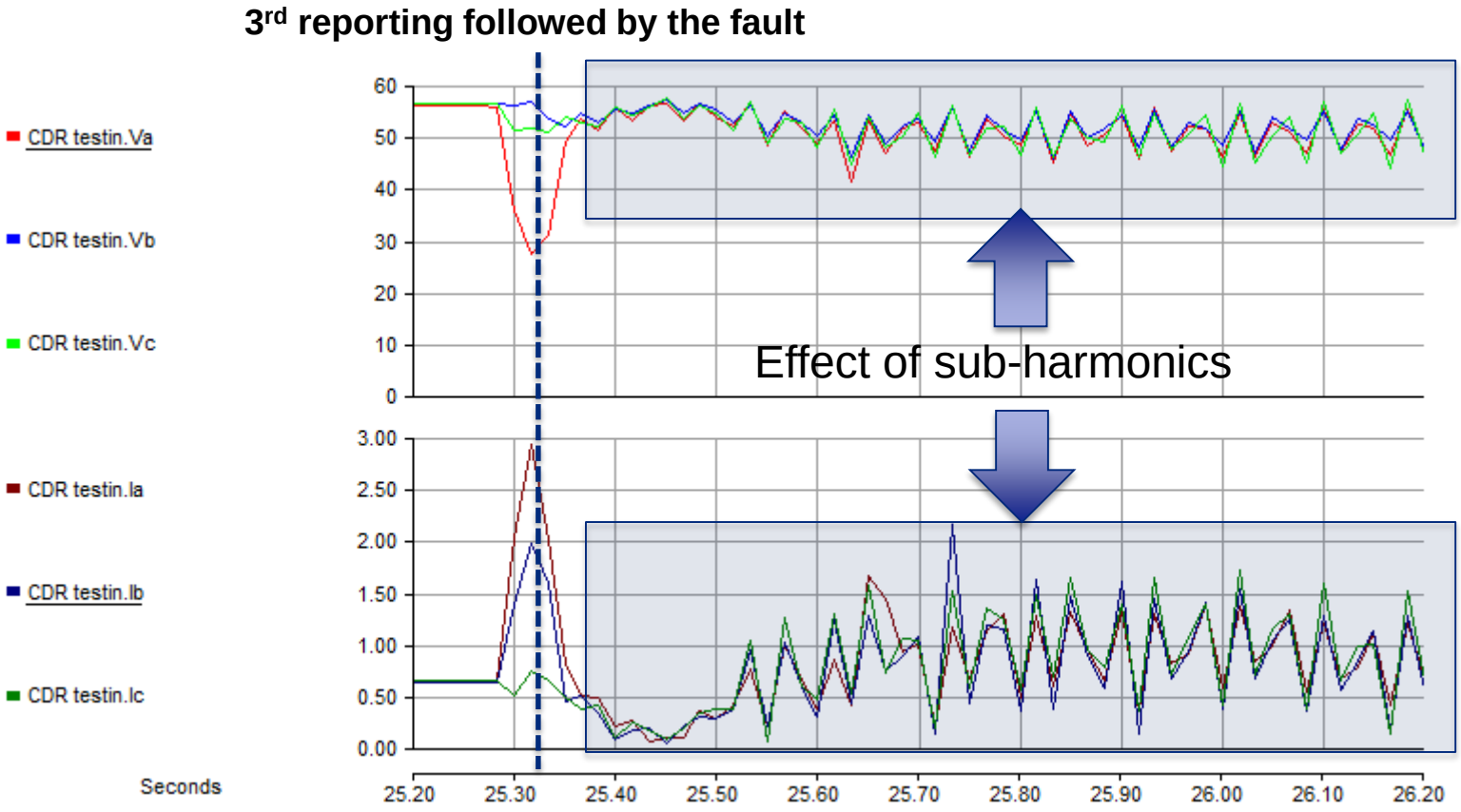
3- cycle fault leading to a SSO/SSCI

- Sub-harmonics



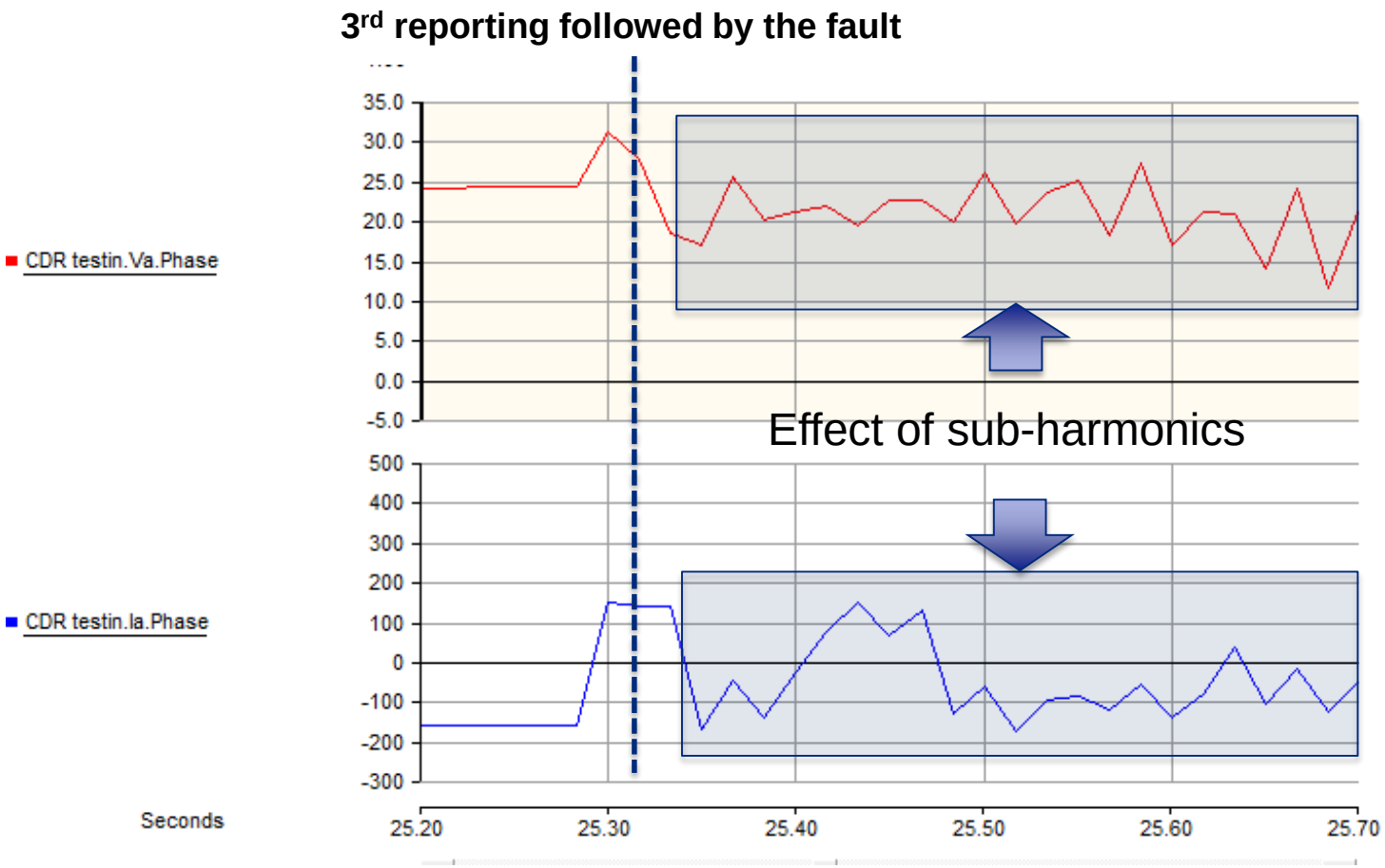
3- cycle fault leading to a SSO/SSCI

- PMU Calculations: P- Class, 60 samples/sec : Magnitudes



3- cycle fault leading to a SSO/SSCI

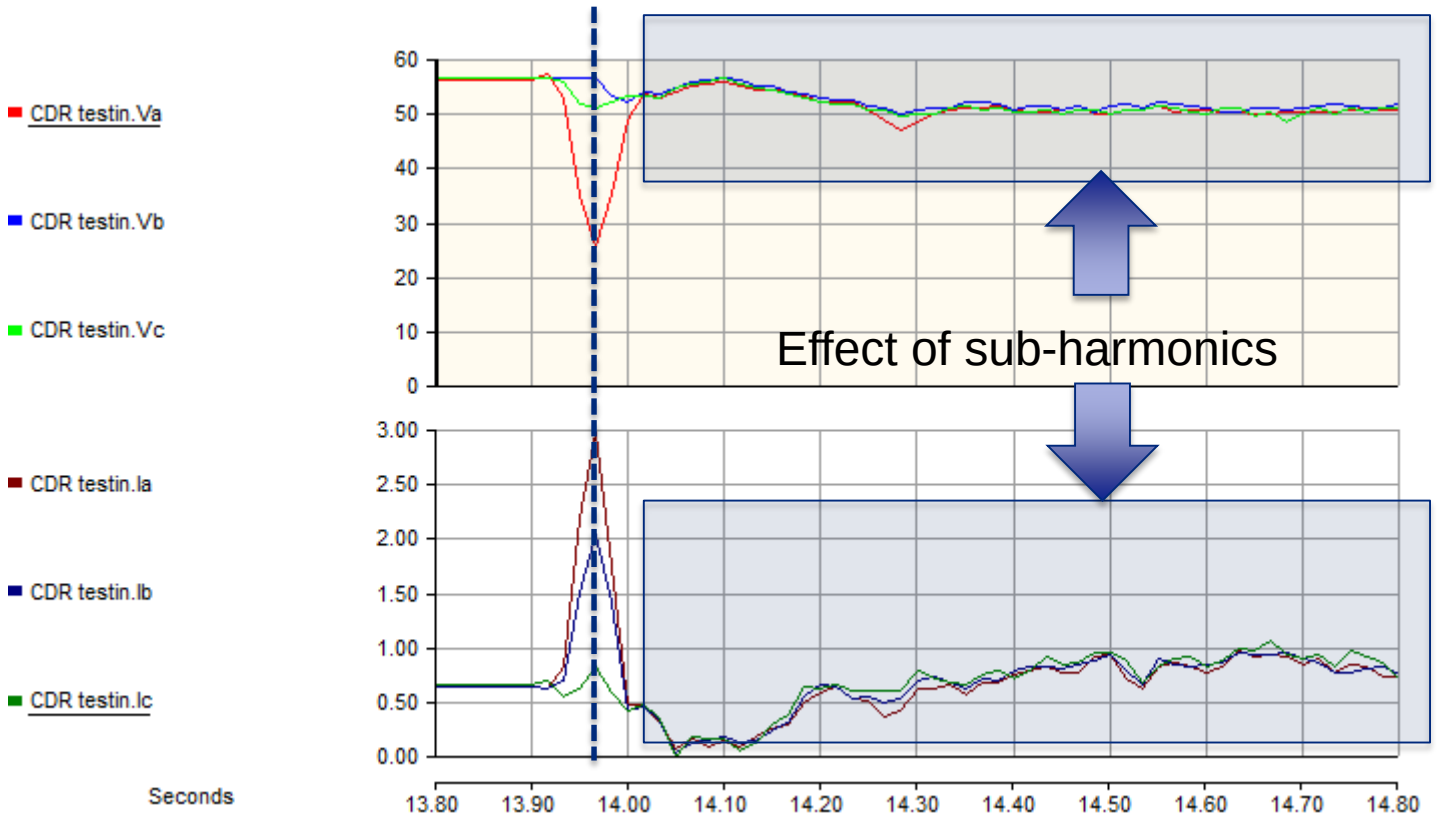
- PMU Calculations: P- Class, 60 samples/sec: Angles



3- cycle fault leading to a SSO

- PMU Calculations: M- Class, 60 samples/sec: Magnitudes

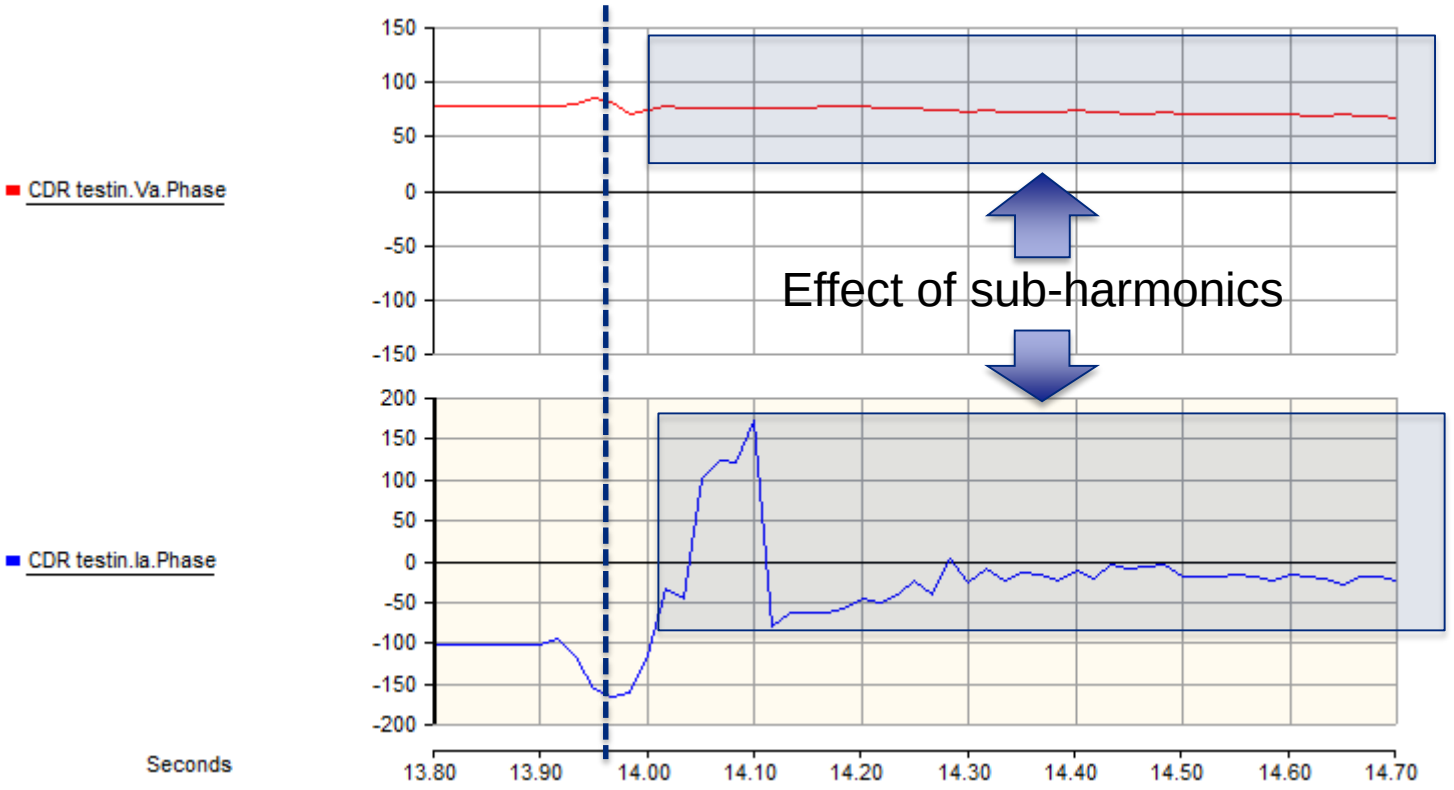
3rd reporting followed by the fault



3- cycle fault leading to a SSO

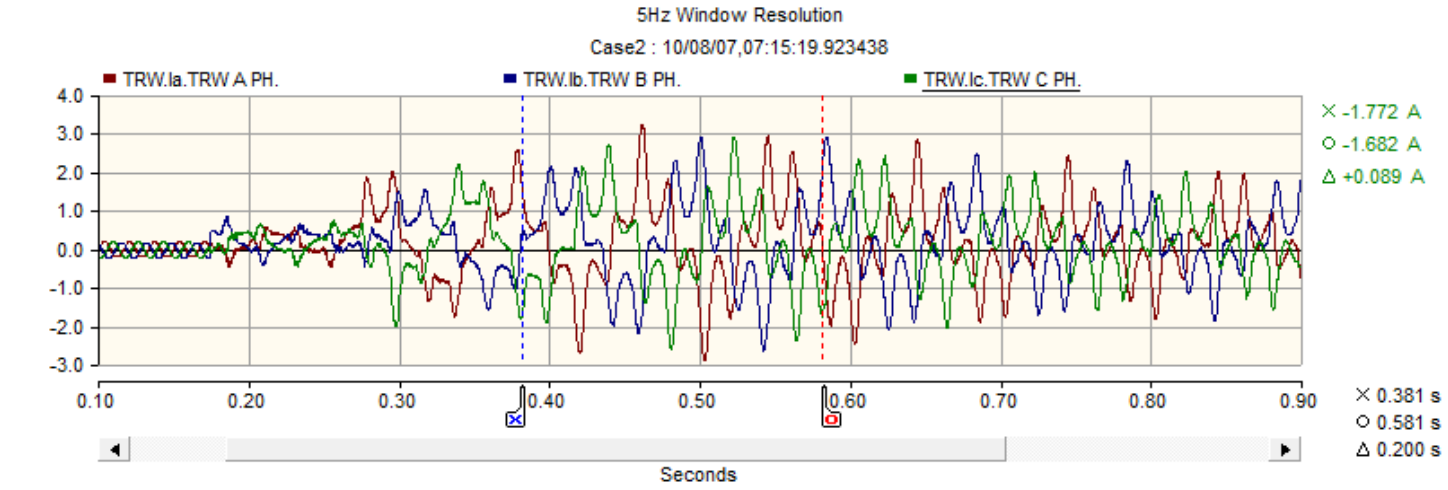
- PMU Calculations: M- Class, 60 samples/sec: Magnitudes

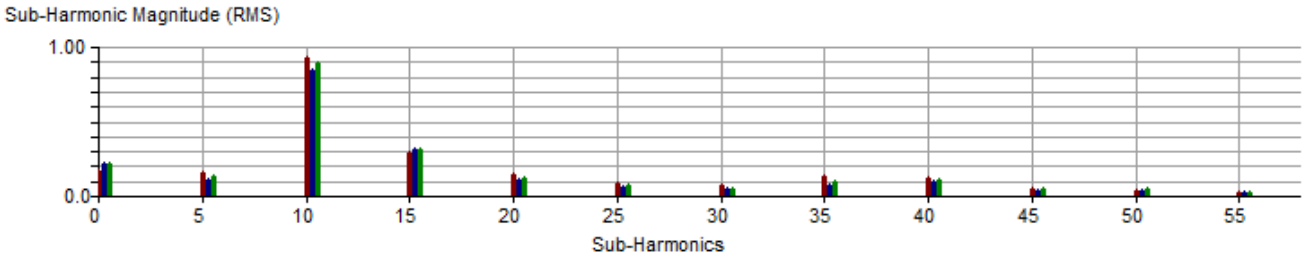
3rd reporting followed by the fault



SSO/SSCI Event

- Sub-harmonics

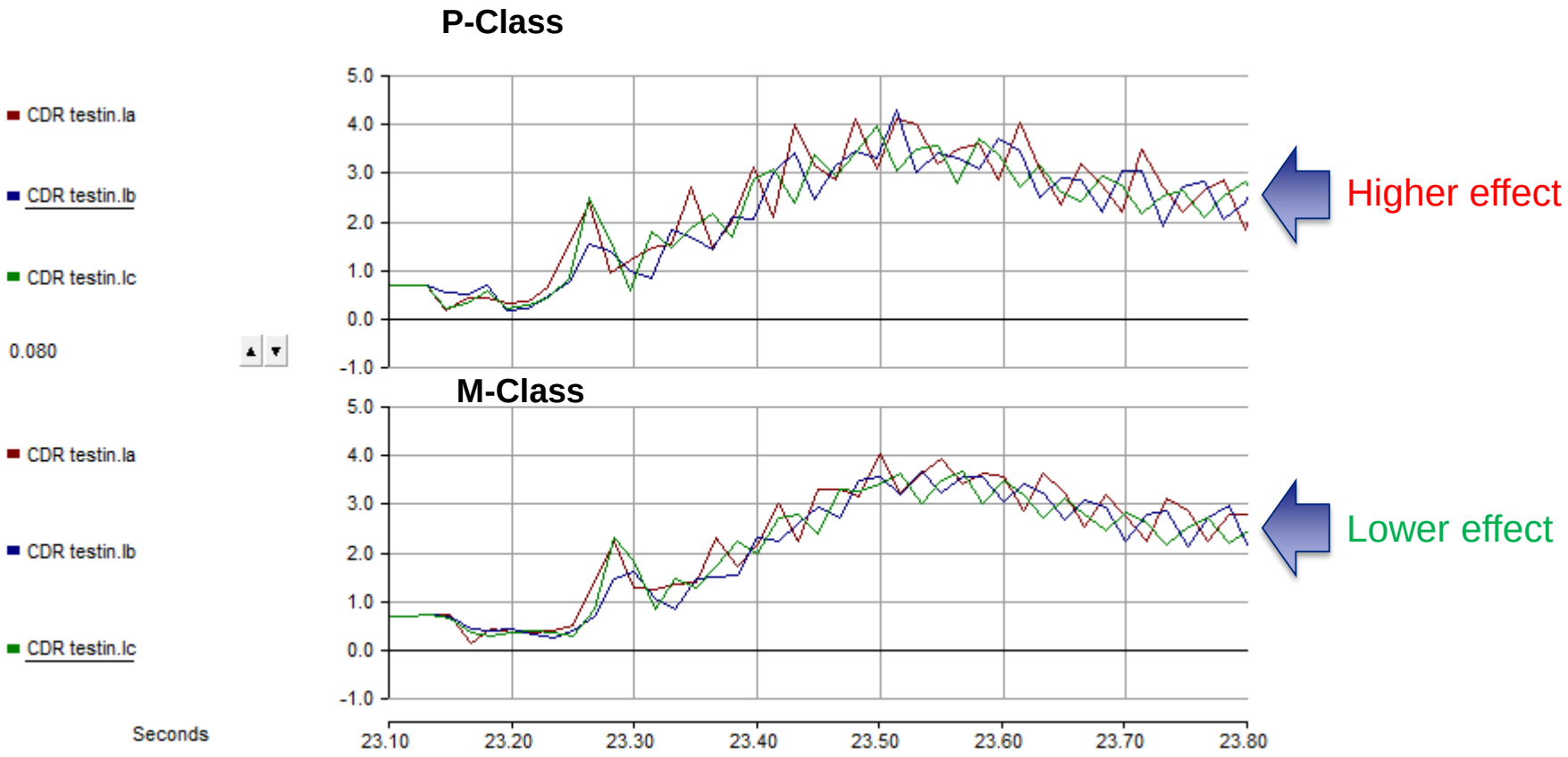




	TRW.Ia.TRW A PH.	TRW.Ib.TRW B PH.	TRW.Ic.TRW C PH.
Fundamental (A-RMS)	0.646	0.636	0.635
TSHD (%)	159.726	146.783	156.706
Dominant SH Frequency (Hz)	11.204	11.351	11.327
Dominant SH Magnitude (A-RMS)	1.028	0.960	1.012

SSO/SSCI Event – PMU Reporting

- PMU Calculations: 60 samples/sec: Magnitudes



Summary

- Use of synchrophasor data for fault analysis purposes was investigated for P and M filter applications(C37.118.1a -2014).
  - Phasor data, Sequence components and impedance
- Analysis was carried out using simulated and actual fault data.
  - P class filters require ~2+ cycle data to provide an acceptable accuracy
  - M class filters require ~5 cycle data to provide an acceptable accuracy
- Impact of the sub-harmonics on the synchrophasor data was analyzed using field reported SSO/SSR events.
  - P class filter outputs showed higher impact compared to M class filter outputs.
- Further testing is being carried out with more recorded/simulated events to make this analysis comprehensive
  - Report for PRSV Task Team

Thank you !
Questions ?