



Electric Power Group

Applicability of Synchrophasor Data for Fault Analysis

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- 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

- 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

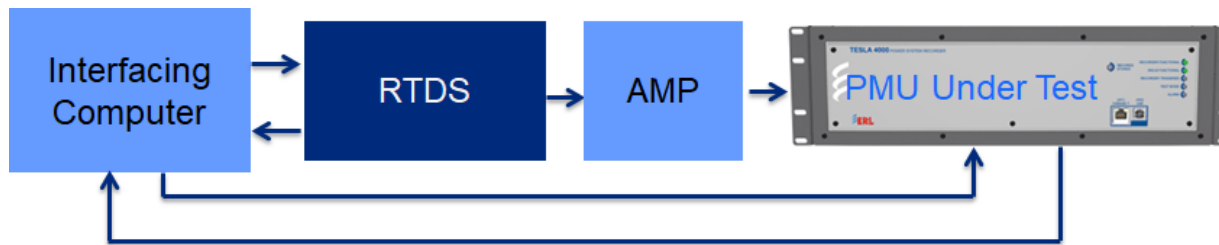
- Typical fault durations
 - Depends on the response of the protection and speed of the circuit breakers.
 - Response of the conventional relays: **~1 cycle**, high speed CBs : **~1 cycle**
 - **~2 cycle**
- Effect of the filters (P/M)
 - Finite Impulse Response with ~2 cycles (P) and ~ 5 cycle (M)
-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

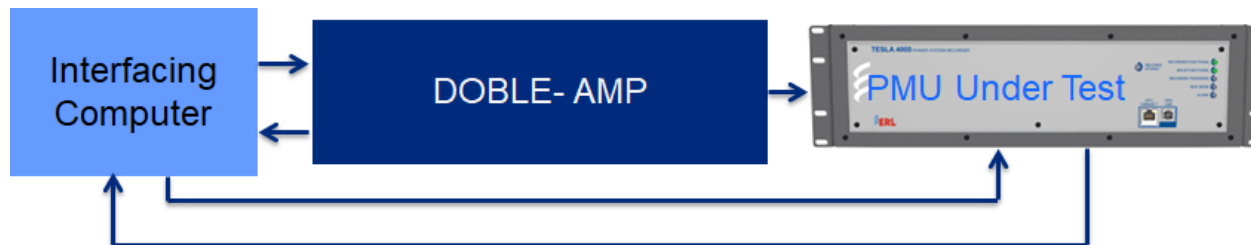
- Testing Considerations/ Parameters
 - Testing was done with the faults simulated at 2 cycles and above
 - Selected reporting rate = 60 Hz (60 Hz system)

Test Setup

- RTDS Testing: Simulated Waveforms



- DOBLE Amplifier: Real time playback of recorded waveforms



PMU Settings



- Basic PMU Settings

PMU Definition

Sample Rate: 60 frames / second PMU Standard: C37.118.1-2011 (M class)

Header Frame Text: Test

Reporting Format

Phasor: Integer

Analog: Integer

Freq / ROC Freq: Integer

	Selected Channel	Full Scale	Unit	Active	Name to Report
PMU Phasors					
Row 1	Bay1:Va	276	kV	<input checked="" type="checkbox"/>	Bay1:Va
Row 2	Bay1:Vb	276	kV	<input checked="" type="checkbox"/>	Bay1:Vb
Row 3	Bay1:Vc	276	kV	<input checked="" type="checkbox"/>	Bay1:Vc
Row 4	Bay1:Ia	250	kA	<input checked="" type="checkbox"/>	Bay1:Ia
Row 5	Bay1:Ib	250	kA	<input checked="" type="checkbox"/>	Bay1:Ib
Row 6	Bay1:Ic	250	kA	<input checked="" type="checkbox"/>	Bay1:Ic

Phasor Options
 Analog Options
 Digital Options

- Angle Reference – PMU Settings

Angle Reference for this Channel Group provided by

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

TESLA Analog Input Configuration

Element:	Type	Description	Channel	Module Type	
Bay 1	<input type="text" value="Va"/>	<input type="text"/>	<input type="text" value="9"/>	<input type="text" value="401006 69Vac Isolated Neutral"/>	
Units	2 kV/V	Angle Offset	Rate of Change Interval	Single Harmonic Number	Nominal Level
kV	<input type="text" value="View/Set Scale"/>	<input type="text" value="0.34"/>	<input type="text" value="1.0"/> Cycle(s)	<input type="text" value="3"/>	<input type="text" value="69"/> V

Actions:

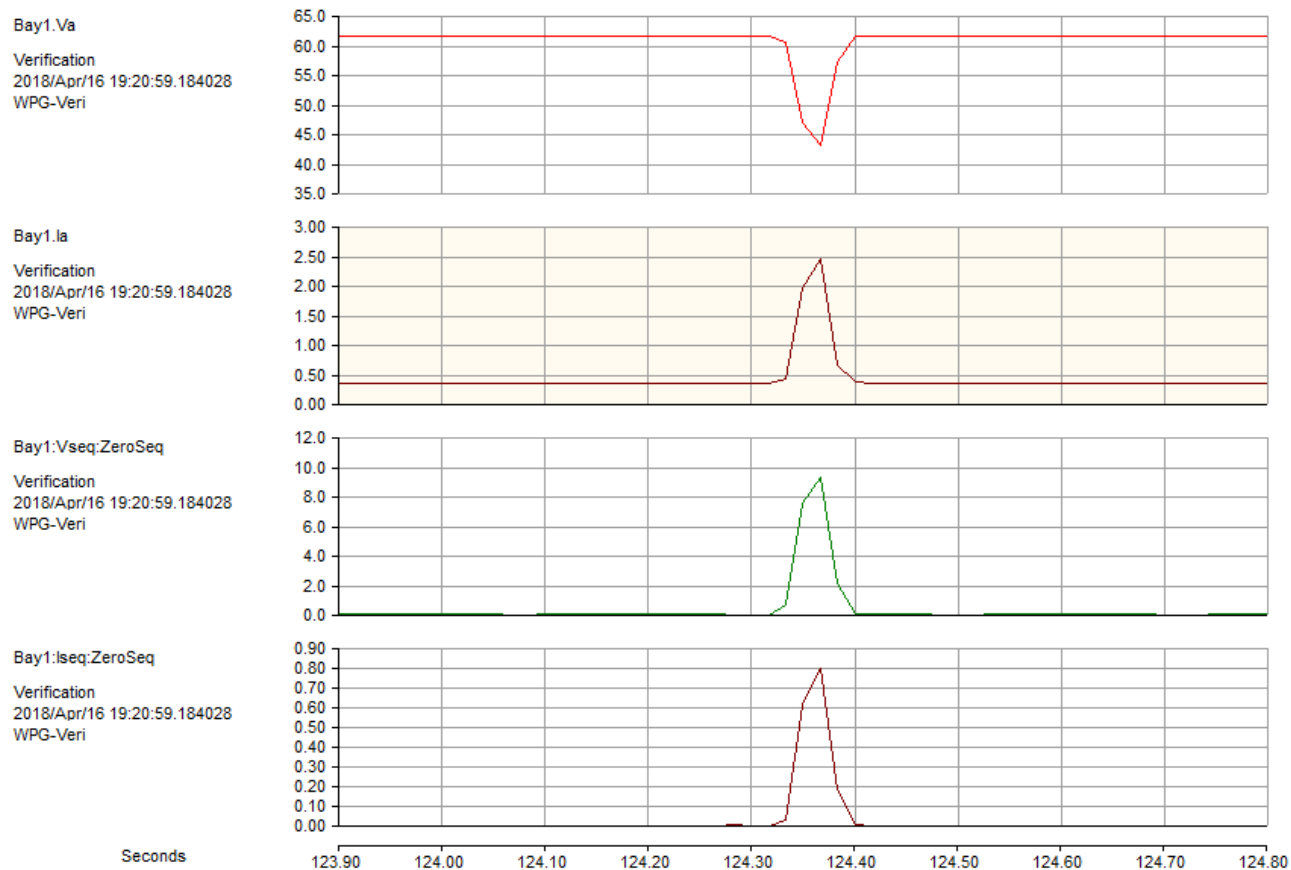


- Test Cases
 - Effect of fault during - P class estimation
 - Effect of fault during - M class estimation
 - Fault location calculation – M class

PMU Data During Faults : P Class



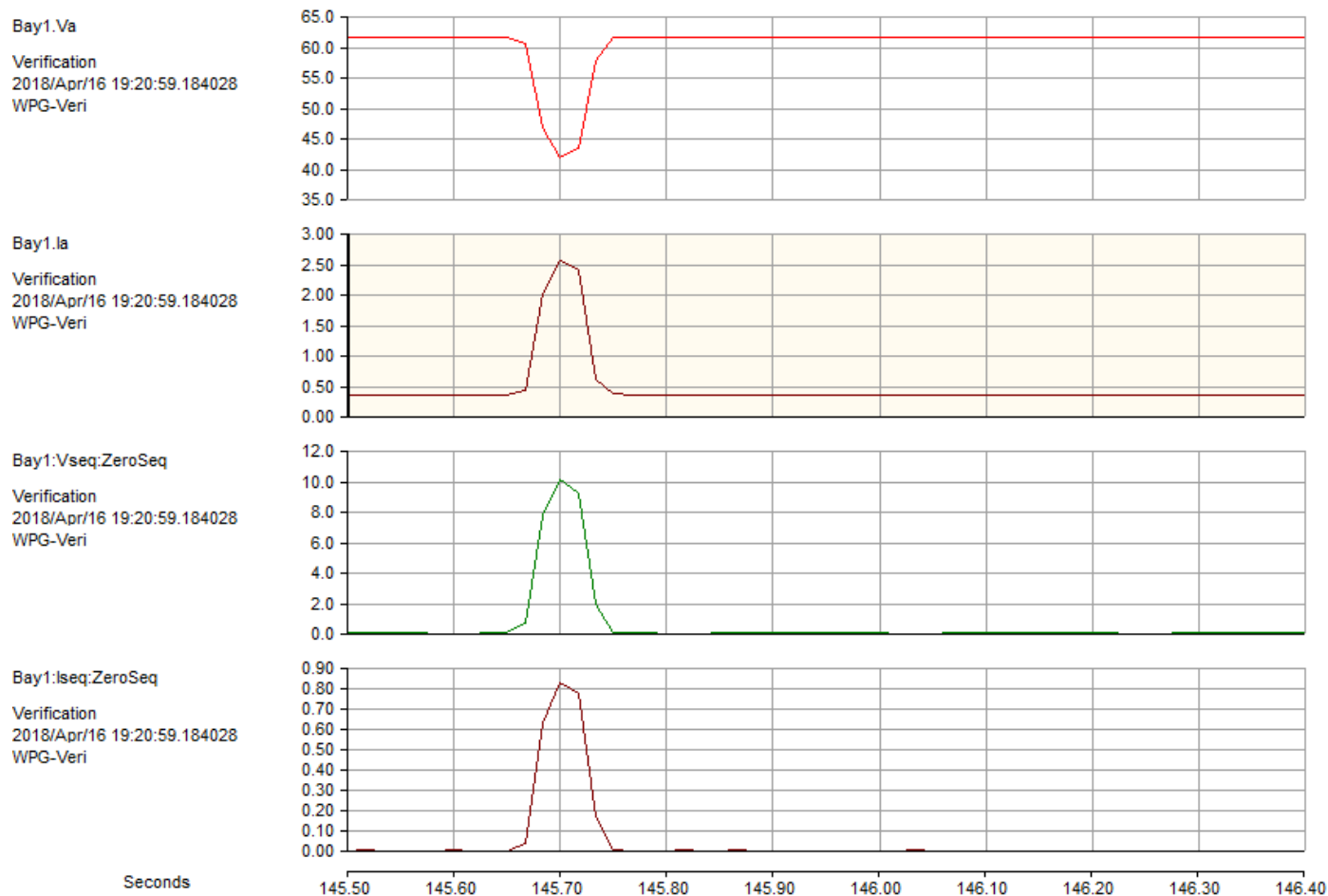
- 2 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : P Class



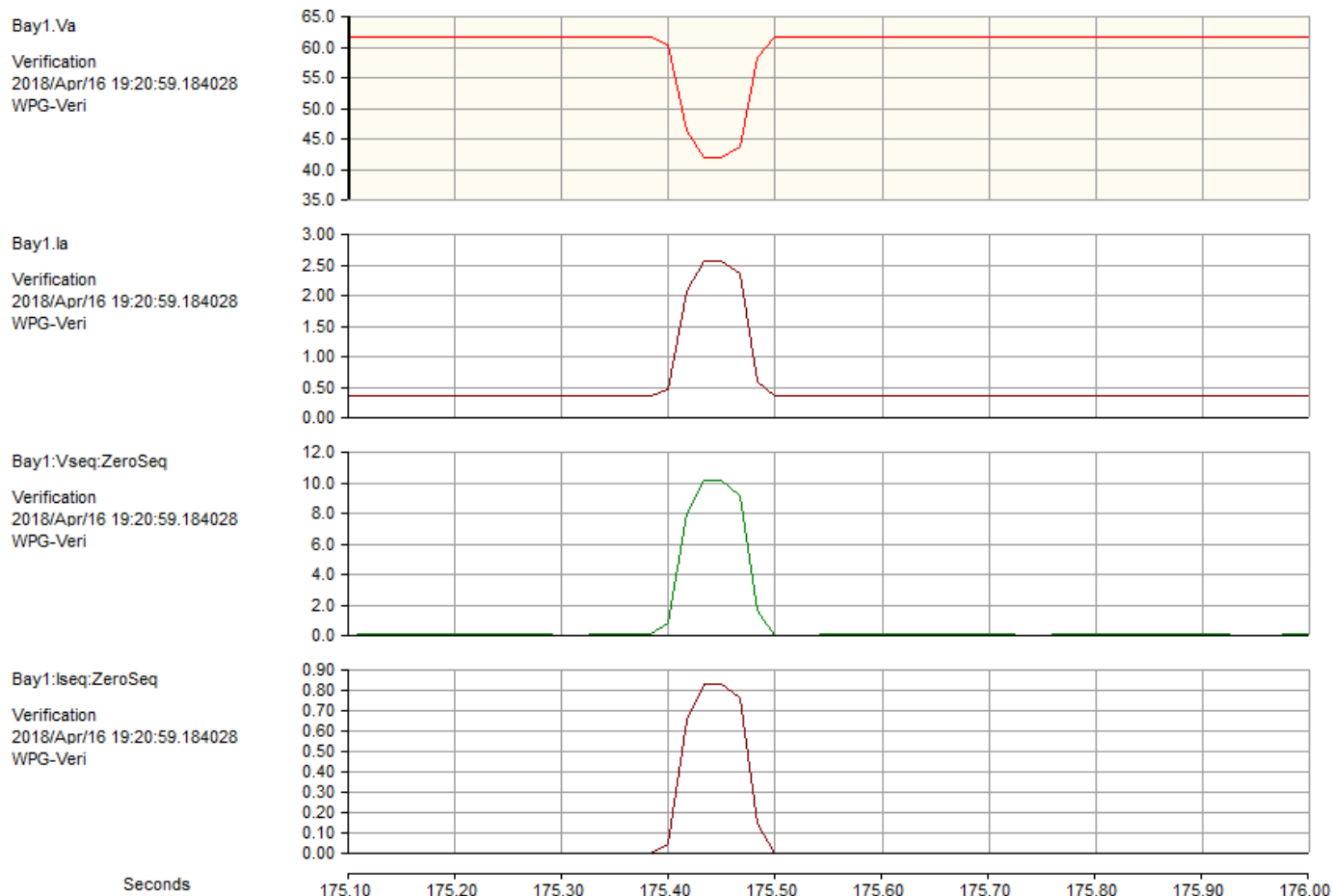
- 3 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : P Class



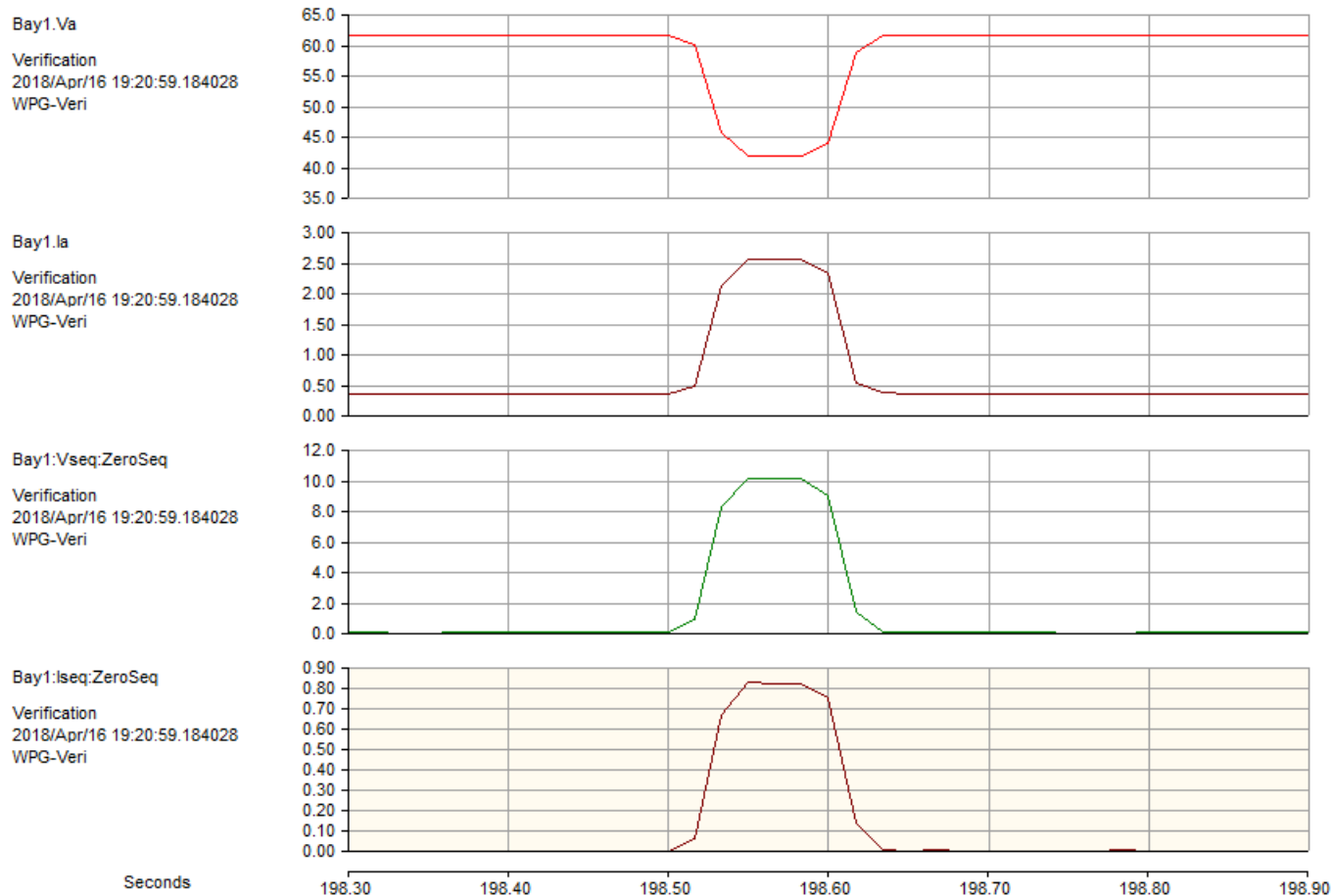
- 4 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : P Class



- 5 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : P Class

- Summary: PMU reporting at 60Hz

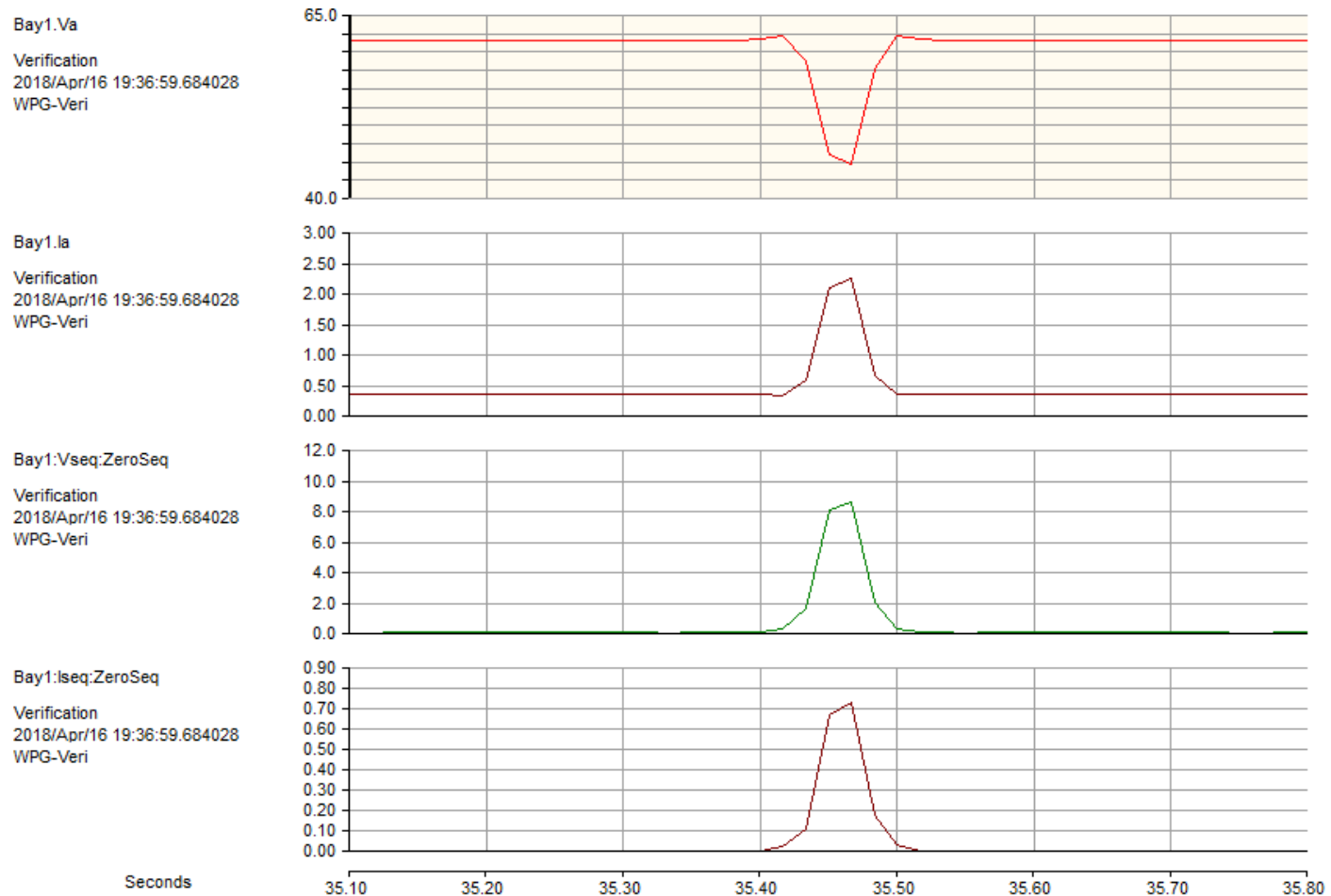
Duration (cycles)	Zero Seq. Voltage (V)	Zero Seq. Current (A)
2	9.5 V	0.72 A
3	10.1 V	0.83 A
4	10.1 V	0.83 A
5	10.1 V	0.83 A



PMU Data During Faults : M Class



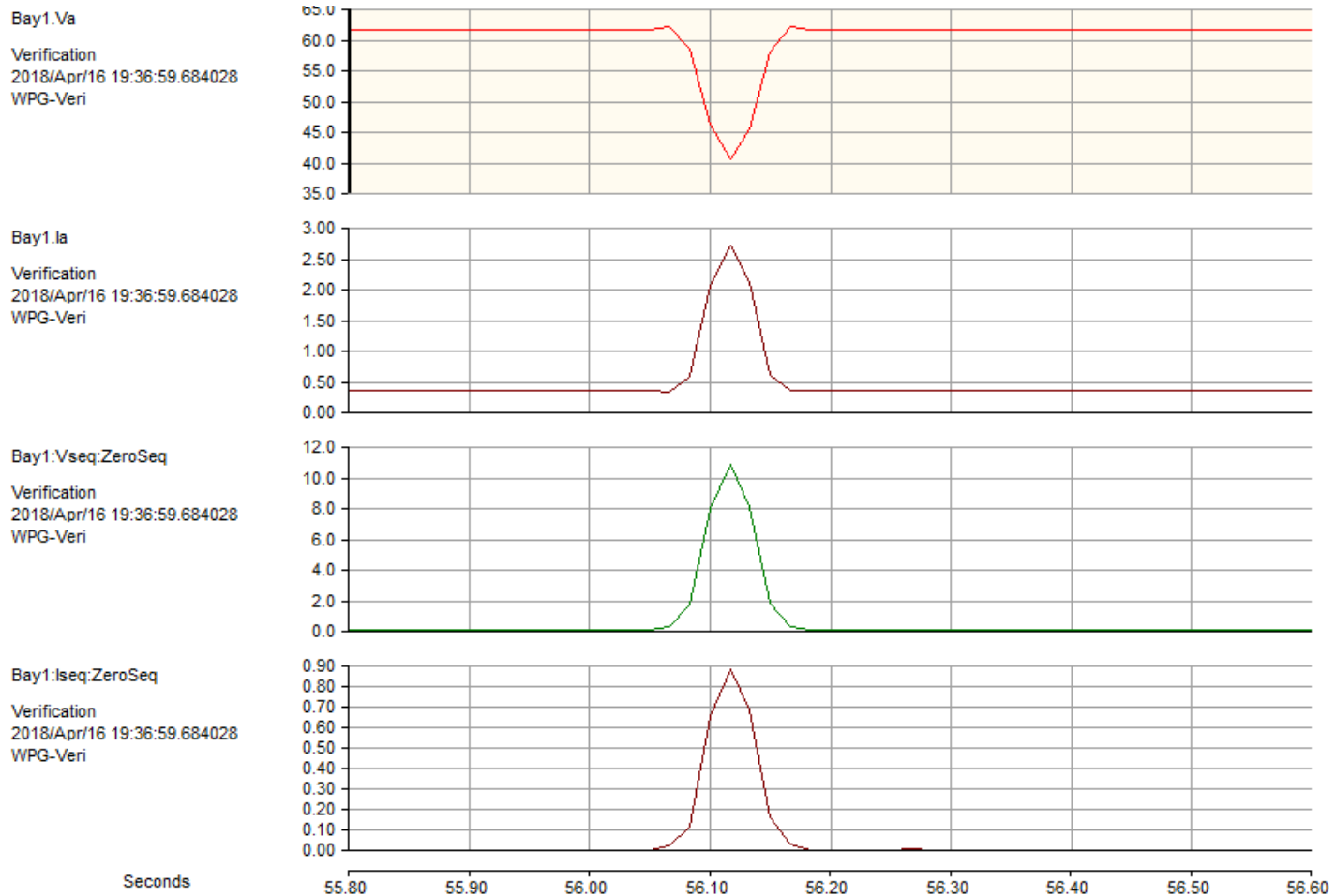
- 2 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : M Class



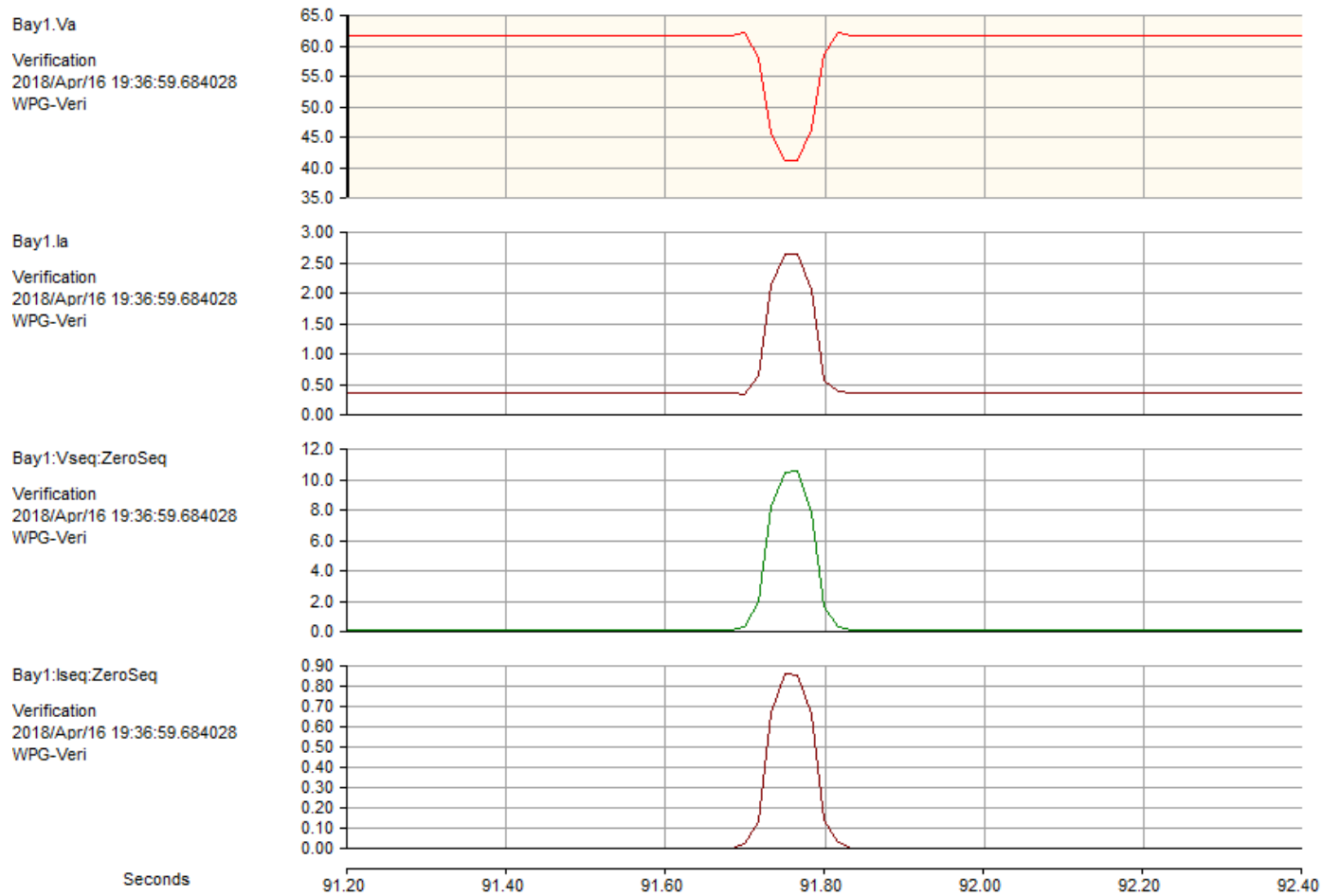
- 3 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : M Class



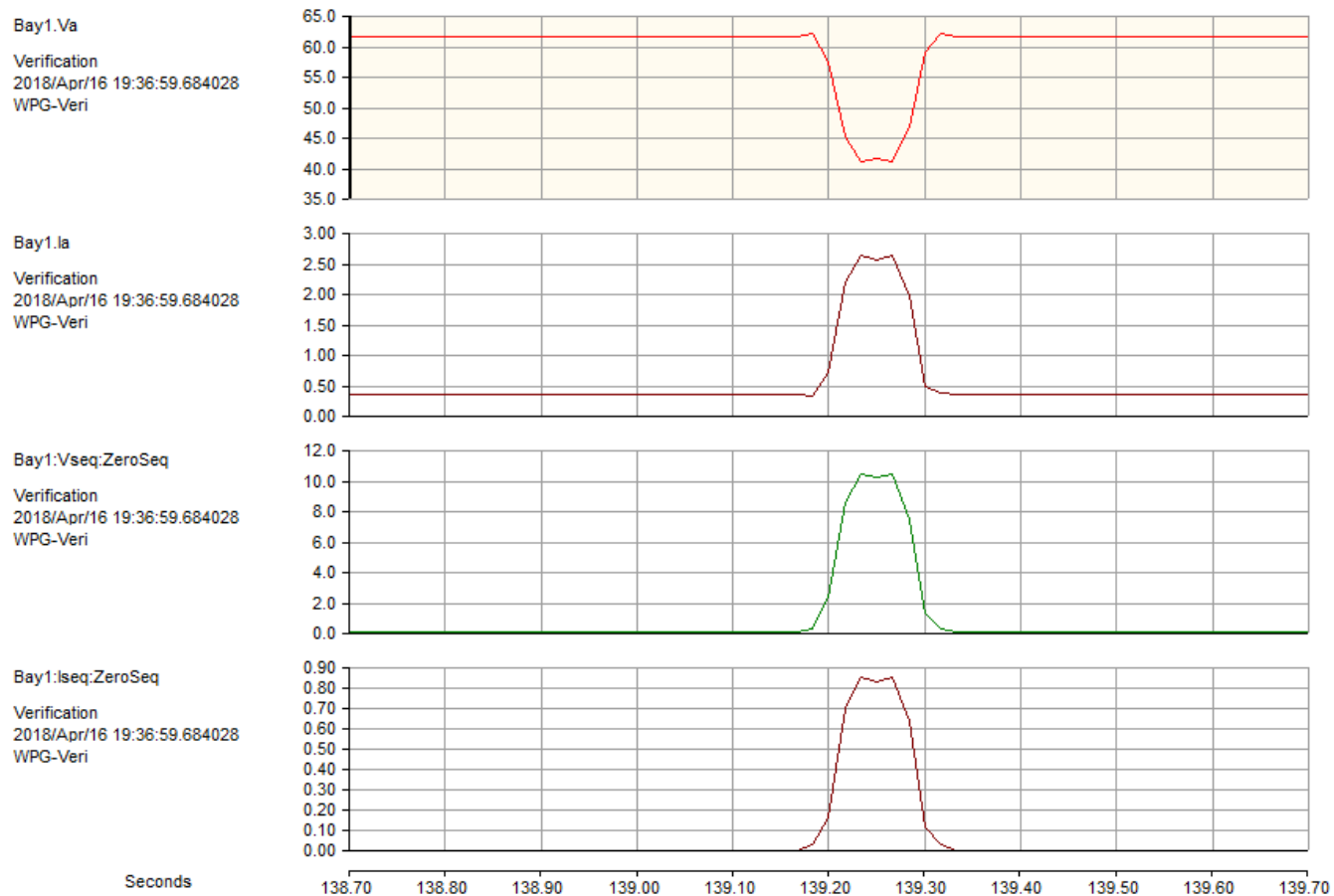
- 4 cycle faults: PMU reporting at 60Hz



PMU Data During Faults : M Class



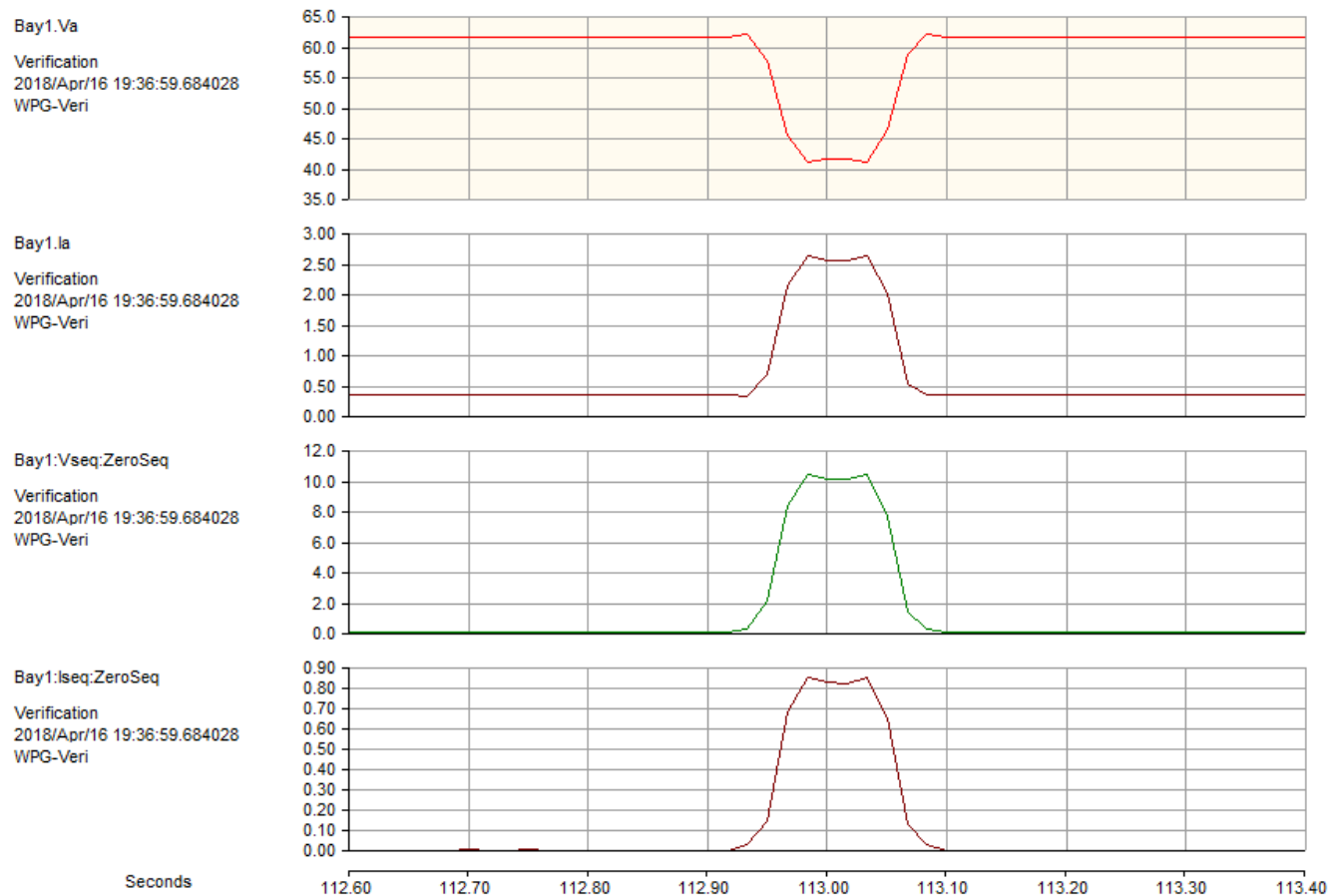
- 5 cycle faults: PMU reporting at 60Hz



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

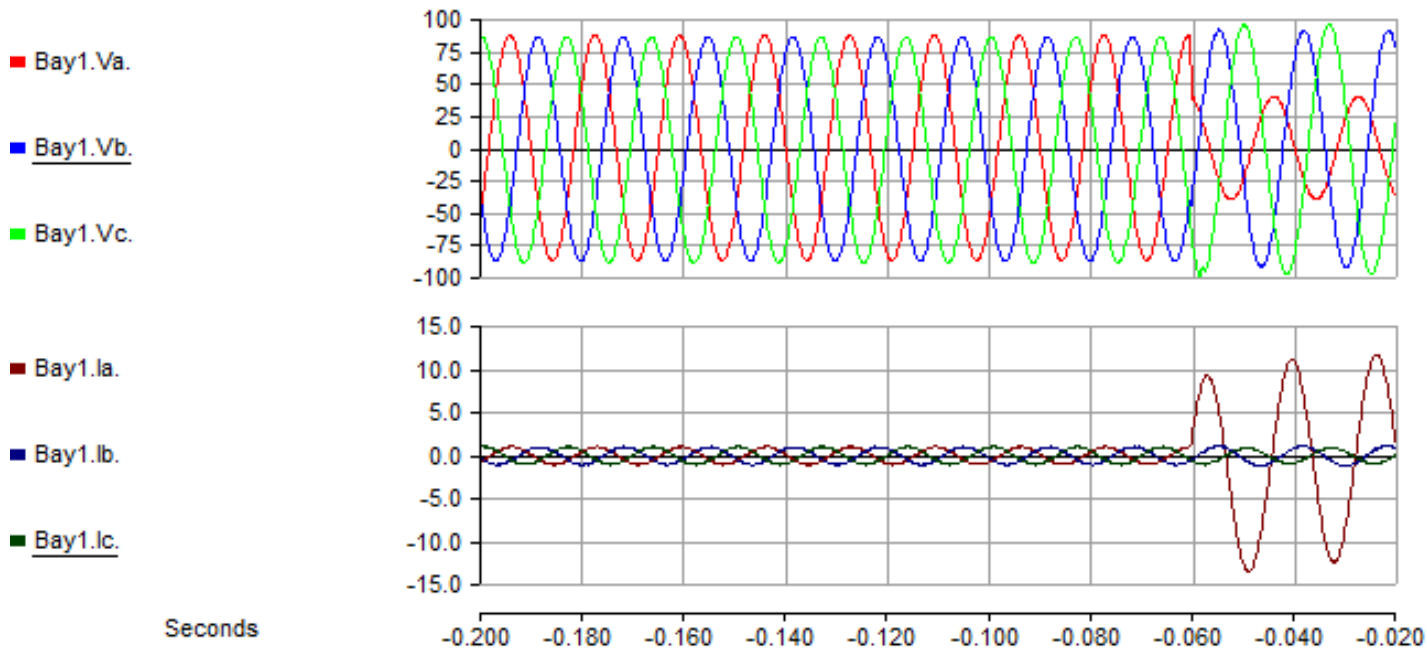
Over-shoot



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



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

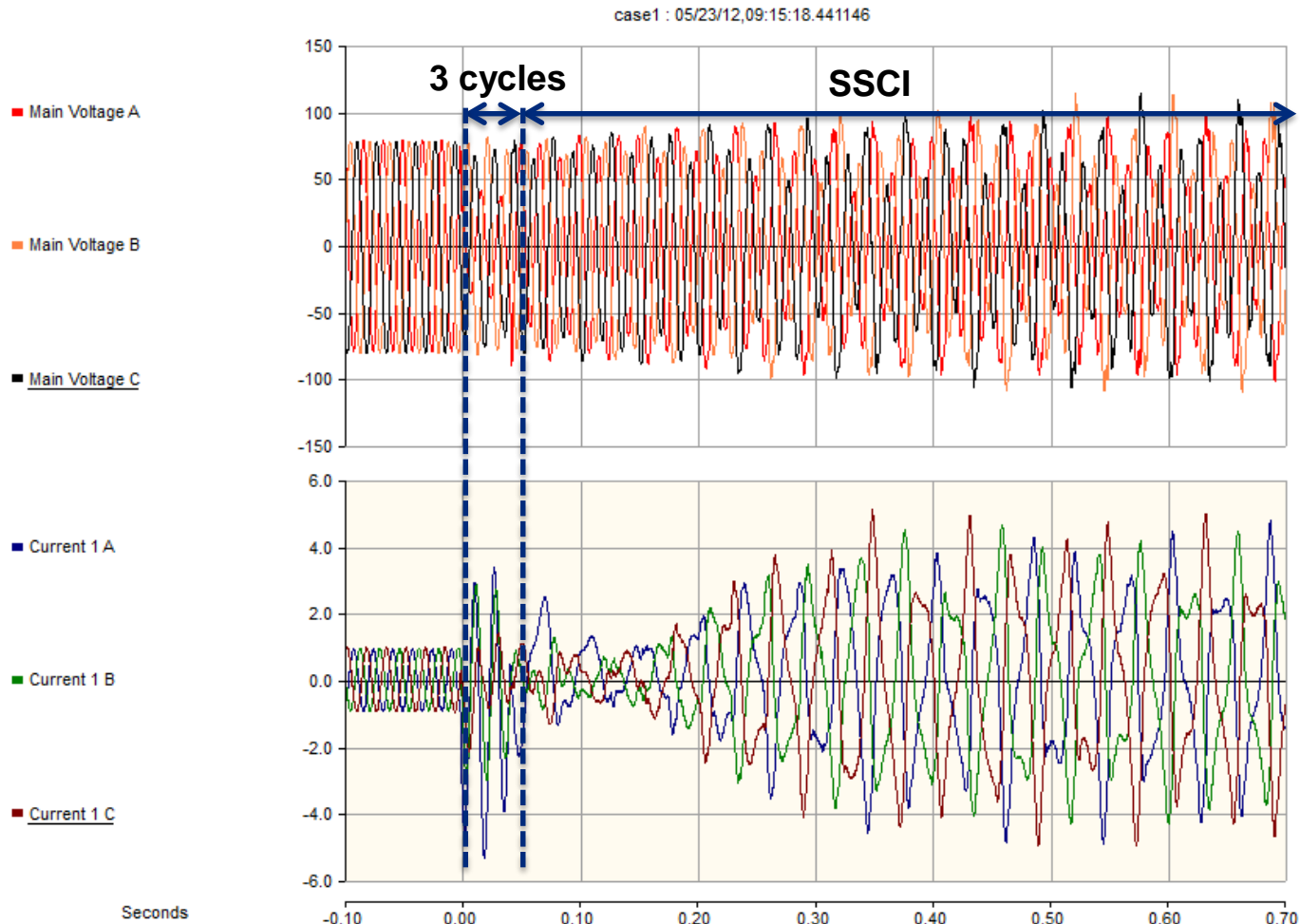
Duration (cycles)	Actual Distance (km)	Estimated Distance (km)
3	4.0 km	6.7 km
4	4.0 km	3.8 km
5	4.0 km	3.9 km
6	4.0 km	4.0 km



- 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

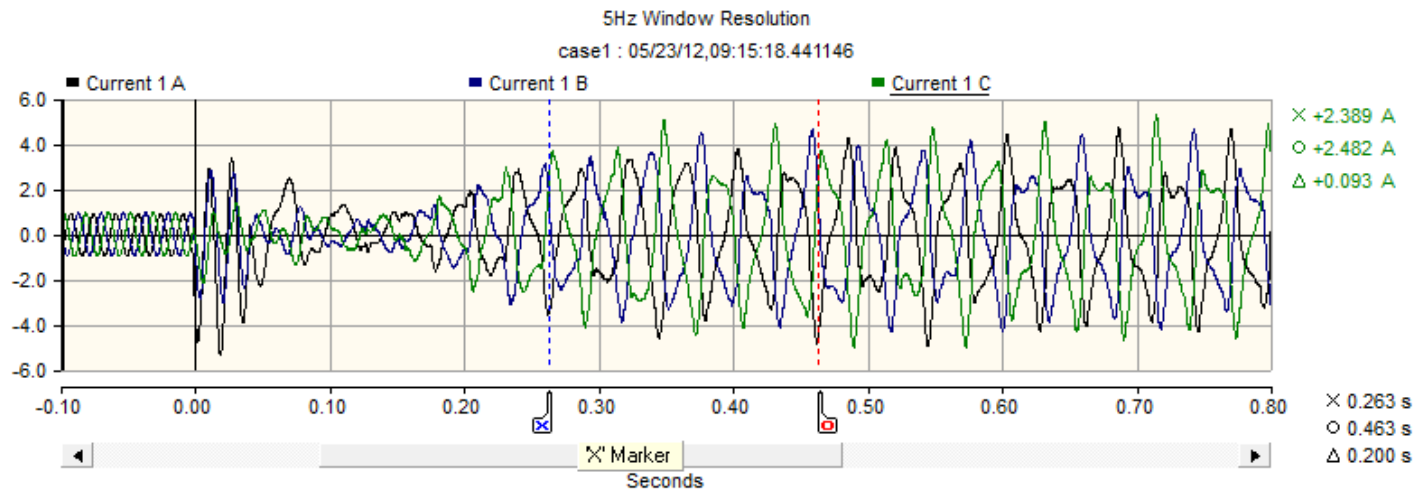
3- cycle fault leading to a SSO/SSCI

- High Speed Record

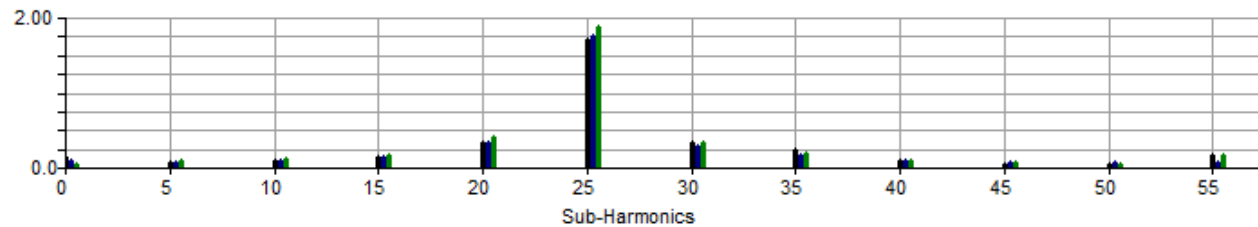


3- cycle fault leading to a SSO/SSCI

- Sub-harmonics



Sub-Harmonic Magnitude (RMS)

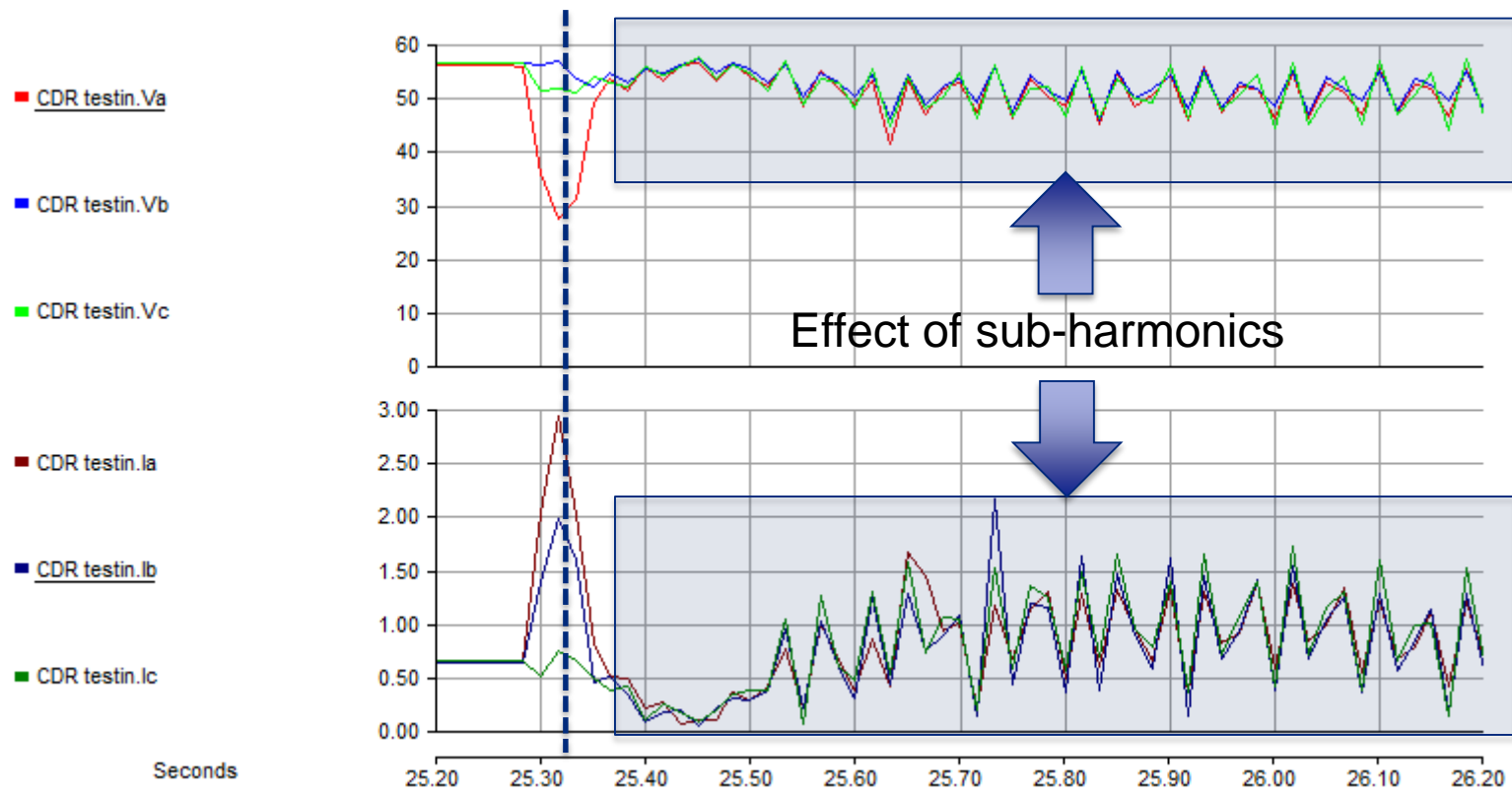


	Current 1 A	Current 1 B	Current 1 C
Fundamental (A-RMS)	0.753	0.706	0.723
TSHD (%)	244.555	264.247	279.293
Dominant SH Frequency (Hz)	24.139	24.195	24.073
Dominant SH Magnitude (A-RMS)	1.813	1.858	2.013

3- cycle fault leading to a SSO/SSCI

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

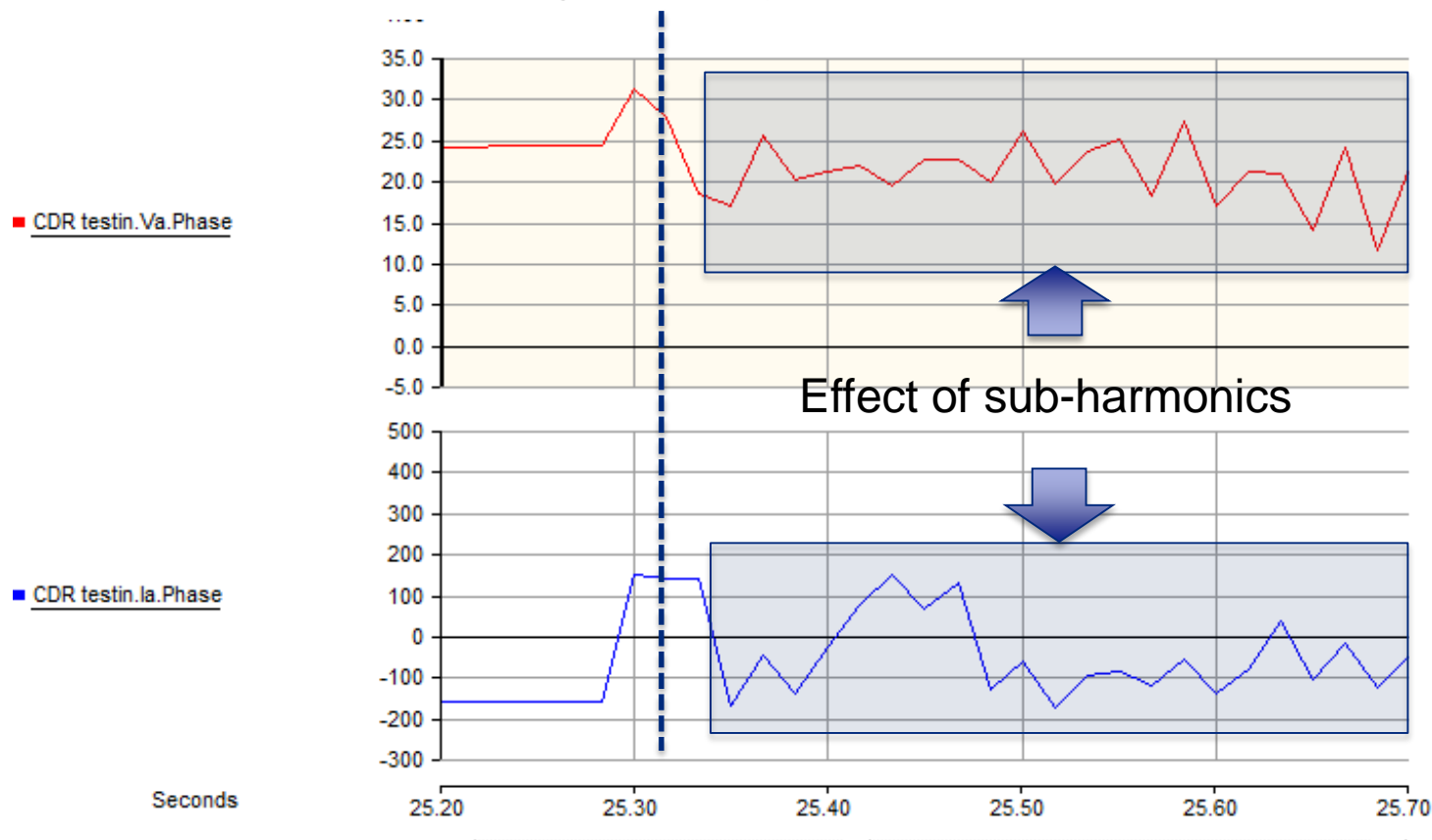
3rd reporting followed by the fault



3- cycle fault leading to a SSO/SSCI

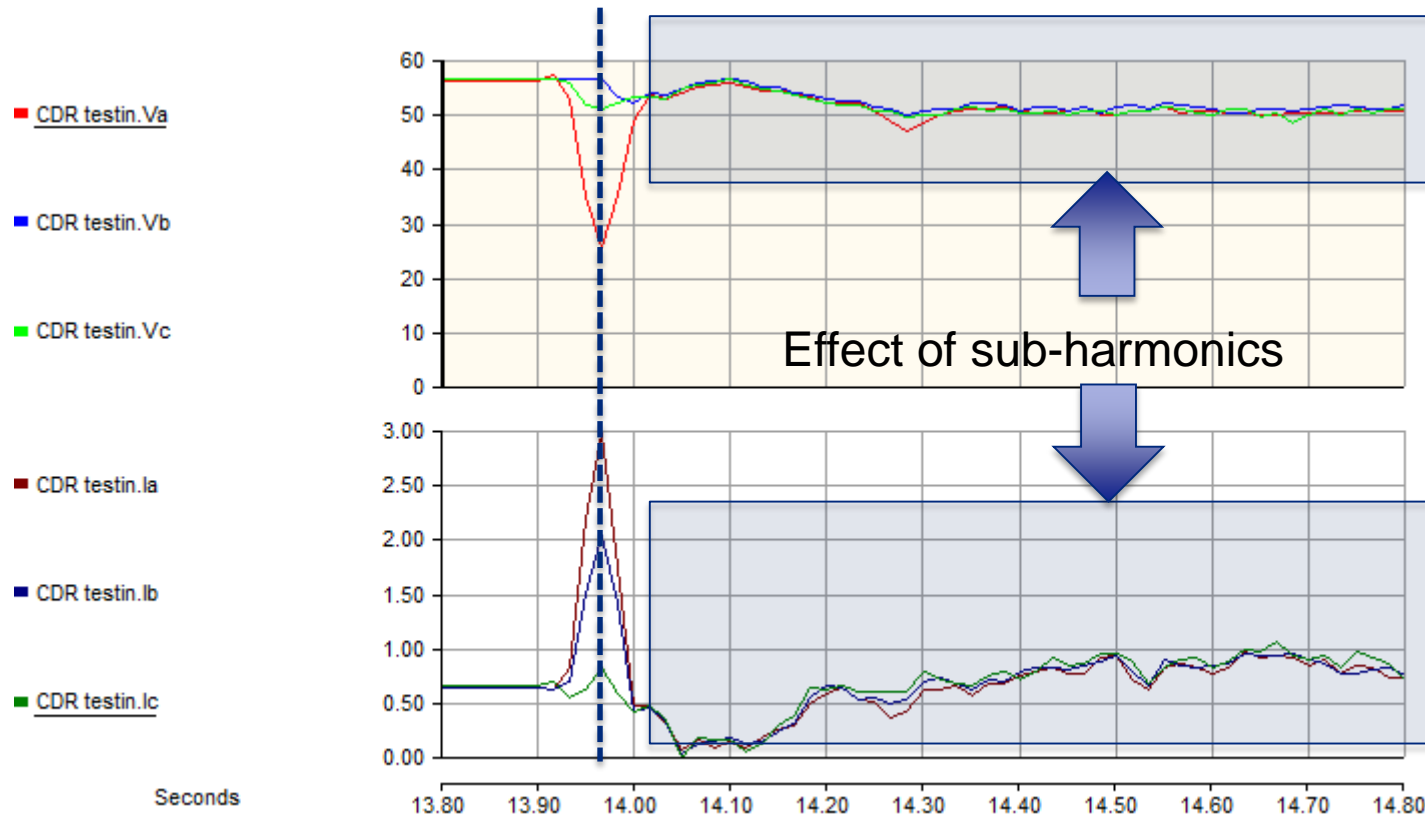
- PMU Calculations: P- Class, 60 samples/sec: Angles

3rd reporting followed by the fault



3- cycle fault leading to a SSO

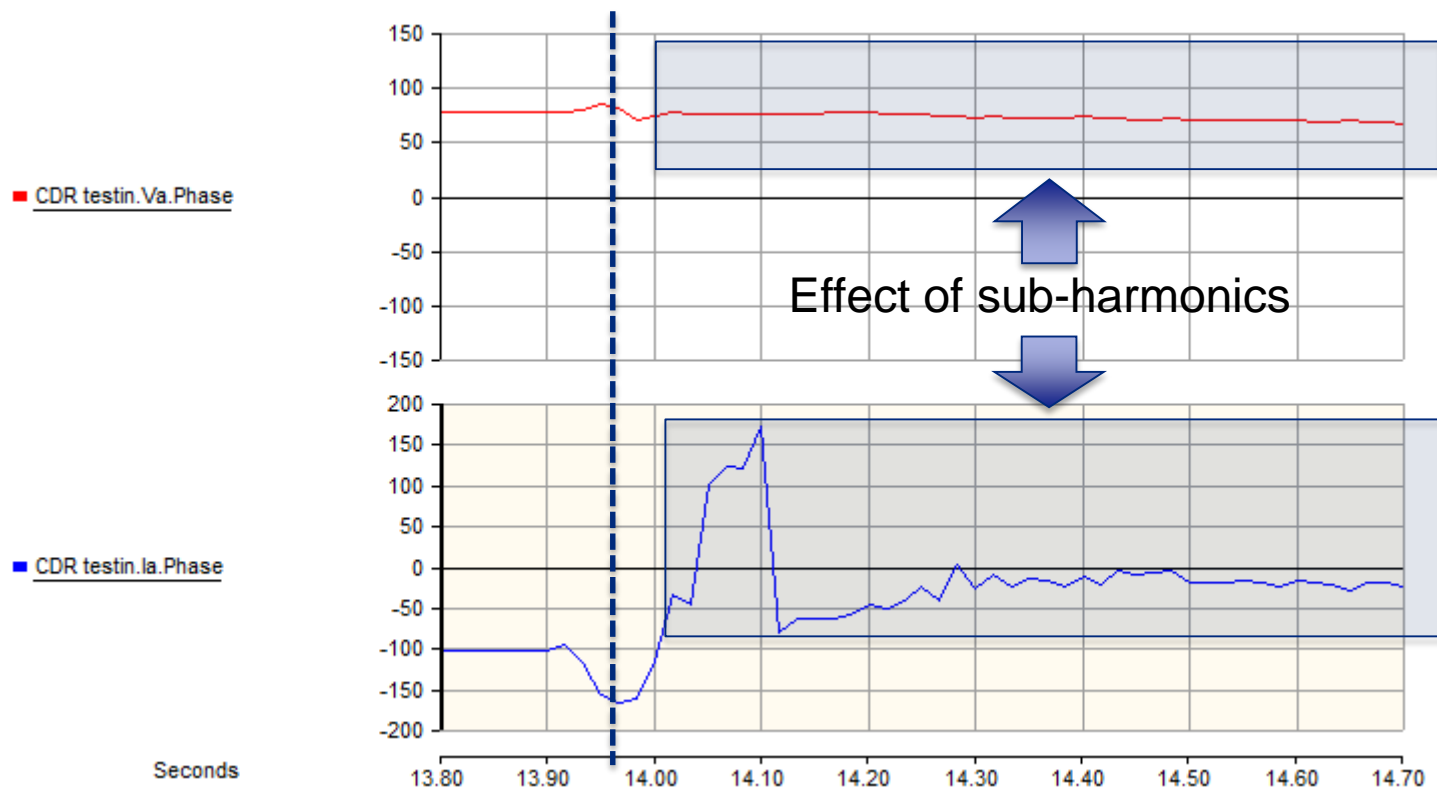
- PMU Calculations: M- Class, 60 samples/sec: Magnitudes
3rd reporting followed by the fault



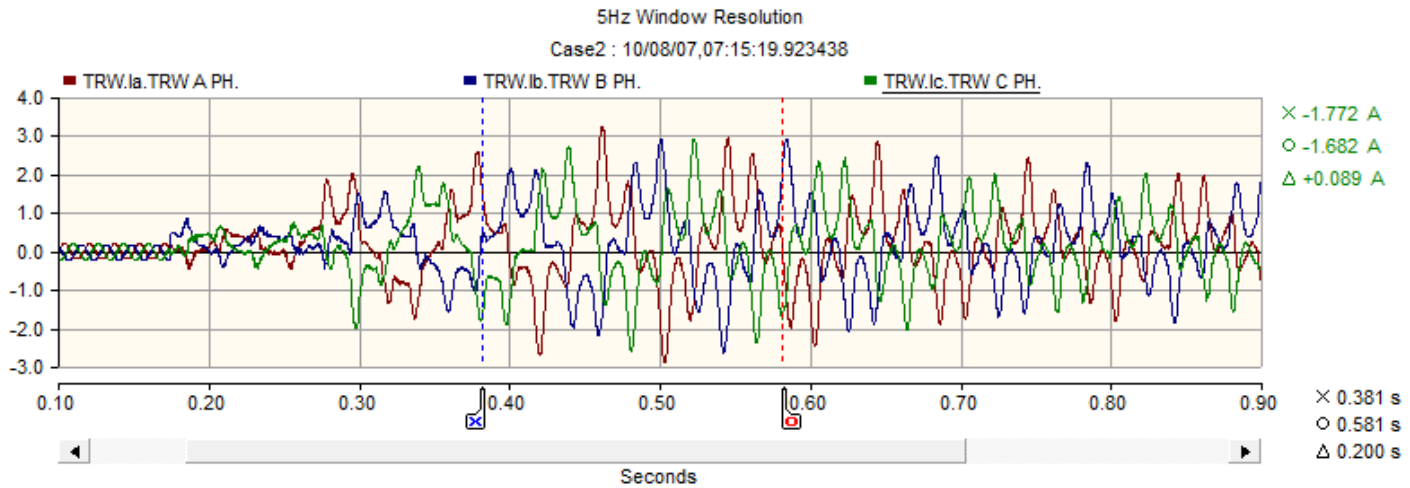
3- cycle fault leading to a SSO

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

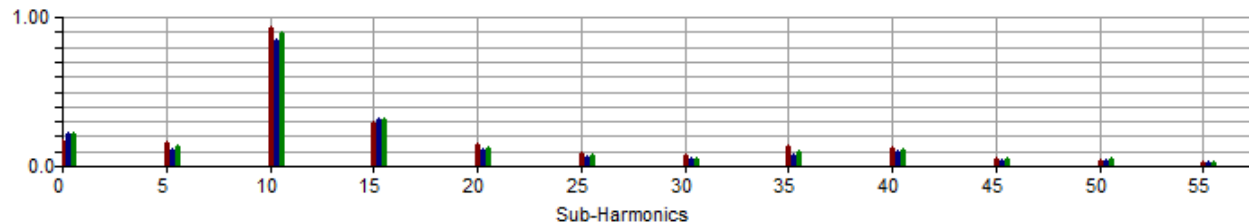
3rd reporting followed by the fault



- Sub-harmonics



Sub-Harmonic Magnitude (RMS)

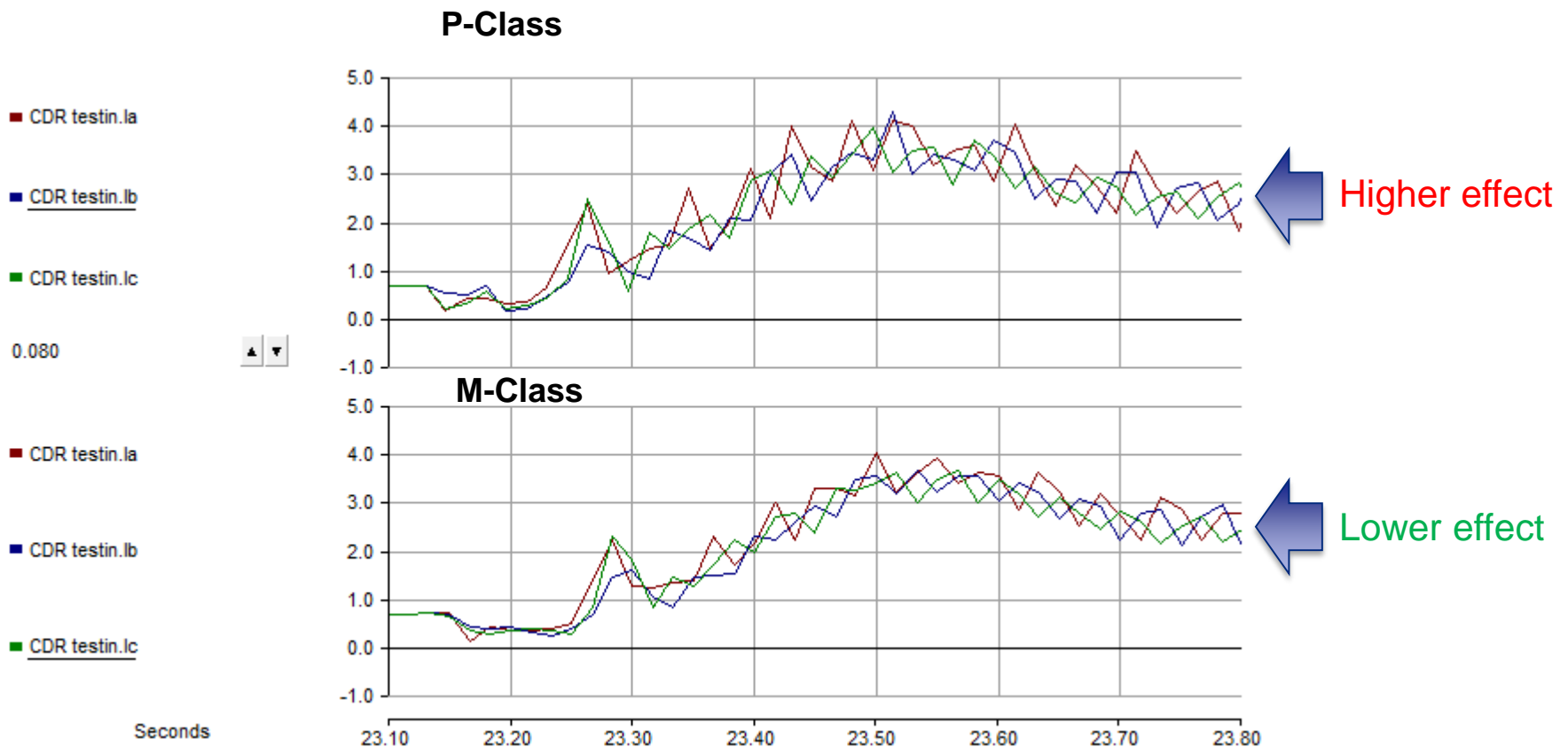


	TRW.Ia.TRW A PH.	TRW.Ib.TRW B PH.	TRW.Ic.TRW C PH.
Fundamental (A-RMS)	0.646	0.636	0.635
TSHD (%)	159.726	146.783	156.706
Dominant SH Frequency (Hz)	11.204	11.351	11.327
Dominant SH Magnitude (A-RMS)	1.028	0.960	1.012

SSO/SSCI Event – PMU Reporting



- PMU Calculations: 60 samples/sec: Magnitudes



- 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 ?**