



Synchro-waveform Data Analytics for Situational Awareness in Power Systems

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Synchro-waveforms



• Examples of Field Installations of Waveform Measurement Units (WMUs):



Three-Phase (12.47 kV)



Three-Phase (480 V)



Single-Phase (120 V)

Events in Continuous Waveform Measurements



• Per-Cycle THD in Continuous Voltage Waveforms:



Events in Continuous Waveform Measurements

• Per-Cycle THD in Continuous Voltage Waveforms:



• Example¹:



¹ H. Mohsenian-Rad and W. Xu, "Synchro-Waveforms: A Window to the Future of Power Systems Data Analytics," in *IEEE Power and Energy Magazine*, vol. 21, no. 5, Sept 2023.



Events in Continuous Waveform Measurements



• Per-Cycle THD in Continuous Voltage Waveforms:



• Example¹:



¹ H. Mohsenian-Rad and W. Xu, "Synchro-Waveforms: A Window to the Future of Power Systems Data Analytics," in *IEEE Power and Energy Magazine*, vol. 21, no. 5, Sept 2023.

Events in Synchro-Waveforms

• Events in Synchro-Waveforms²:



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² N. Ehsani, F. Ahmadi, Z.J. Ye, A. McEachern, and H. Mohsenian-Rad, "Sub-cycle Event Detection and Characterization in Continious Streaming of Synchro-waveforms: An Experiment Based on GridSweep Measurements," in *Proc. of the IEEE North American Power Symposium*, Asheville, NC, October 2023.









200





200







Analysis of Faults and Incipient Faults



Example⁴: •



Time (msec)

360

(Same Fault at **Different Locations**)

150

150

150

150

Time (msec)

200

200

200

200

⁴ H. Mohsenian-Rad and W. Xu, "Synchro-Waveforms: A Window to the Future of Power Systems Data Analytics," in IEEE Power and Energy Magazine, vol. 21, no. 5, Sept/Oct 2023.

Analysis of Faults and Incipient Faults



• Identifying *Repeated* Faults / Incipient Faults (e.g., Causing Wildfire)⁵:



(Same Fault at Different Locations)

⁵ H. Mohsenian-Rad, A. Shahsavari, and M. Majidi, "Analysis of Power Quality Events for Wildfire Monitoring: Lessons Learned from a California Wildfire," in *IEEE ISGT*, San Juan, Porto Rico, Nov. 2023.

Graphical Concepts





Plot v(t) versus i(t)



Plot $v_1(t) - v_2(t)$ versus $i_1(t) - i_2(t)$

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⁶ T. Hong, F. de León, "Lissajous Curve Methods for the Identification of Nonlinear Circuits", *IEEE Transactions* on Circuits and Systems I, Vol. 62, No. 12, pp. 2874-2885, December 2015.

⁷ M. Izadi and H. Mohsenian-Rad, "Characterizing synchronized Lissajous curves to scrutinize power distribution synchro-waveform measurements," in *IEEE Trans. on Power Systems*, vol. 36, Sept 2021.

Phasor Concepts

- Synchro-waveforms can provide various phasor representations:
 - Fundamental Phasors
 - Harmonic Phasors

- Wideband Phasors⁸
- Inter-harmonic Phasors

⁸ L. Chen, X. Xie, J. He, T. Xu, D. Xu, N. Ma, "Wideband oscillation monitoring in power systems with high-penetration of renewable energy sources and power electronics: A review," *Renewable and Sustainable Energy Reviews*, Volume 175, no. 113148, April 2023.

Phasor Concepts







⁹ A. Aligholian and H. Mohsenian-Rad, "GraphPMU: Event Clustering via Graph Representation Learning Using Locationally-Scarce Distribution-Level Fundamental and Harmonic PMU Data," in *IEEE Trans. on Smart Grid*, vol. 14, no. 4, pp. 2960-2972, July 2022.

Transient Event Location Identification



• Finding the Cause of Transient Events¹⁰:



¹⁰ M. Izadi and H. Mohsenian-Rad, "Synchronous waveform measurements to locate transient events and incipient faults in power distribution networks," in *IEEE Trans. on Smart Grid*, vol. 12, pp. 4295-4307, 2021.

Further Reading

[1] H. Mohsenian-Rad and W. Xu, "Synchro-Waveforms: A Window to the Future of Power Systems Data Analytics," in *IEEE Power and Energy Magazine*, vol. 21, no. 5, September/October 2023.

[2] F. Ahmadi and H. Mohsenian-Rad, "Data-Driven Models for Sub-Cycle Dynamic Response of Inverter-Based Resources Using WMU Measurements," in *IEEE Trans. on Smart Grid*, accepted for publication, May 2023.

[3] N. Ehsani, F. Ahmadi, Z.J. Ye, A. McEachern, and H. Mohsenian-Rad, "Sub-cycle Event Detection and Characterization in Continious Streaming of Synchro-waveforms: An Experiment Based on GridSweep Measurements," in *Proc. of the IEEE North American Power Symposium*, Asheville, NC, October 2023.

[4] M. Izadi and H. Mohsenian-Rad, "Characterizing synchronized Lissajous curves to scrutinize power distribution synchro-waveform measurements," in *IEEE Trans. on Power Systems*, vol. 36, Sept 2021.

[5] H. Mohsenian-Rad, A. Shahsavari, and M. Majidi, "Analysis of Power Quality Events for Wildfire Monitoring: Lessons Learned from a California Wildfire," in *Proc. of the IEEE ISGT*, San Juan, Porto Rico, November 2023.

[6] A. Aligholian and H. Mohsenian-Rad, "GraphPMU: Event Clustering via Graph Representation Learning Using Locationally-Scarce Distribution-Level Fundamental and Harmonic PMU Data," in *IEEE Trans. on Smart Grid*, vol. 14, no. 4, July 2022.

[7] M. Izadi and H. Mohsenian-Rad, "synchronous waveform measurements to locate transient events and incipient faults in power distribution networks," in *IEEE Trans. on Smart Grid*, vol. 12, pp. 4295-4307, September 2021.



IEEE Power and Energy Magazine, September 2023



Cambridge University Press, 2022 (Chapter 4)



Thank You!

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