Synchro-Waveforms for Situational Awareness with Application to Wildfire Monitoring

IEEE PES General Meeting (July 26, 2021)

Hamed Mohsenian-Rad*, Ph.D., IEEE Fellow*

Professor and Bourns Family Faculty Fellow
Department of Electrical Engineering, University of California, Riverside
Associate Director, Winston Chung Global Energy Center
Director, UC-National Lab Center for Power Distribution Cyber Security

Acknowledgement: Milad Izadi (Ph.D. Student)

Wildfire and Electric Power Issues

- Wildfire in California in 2020[1]:
  - Death: 33
  - Economic Cost: $12 Billion

www.npr.org

- Many of the California wildfires are caused by electric power issues[2]:

FIRE NAME *(CAUSE)*	DATE	COUNTY	ACRES	*STRUCTURES*	DEATHS
1 **CAMP FIRE** *(Powerlines)*	November 2018	Butte	153,336	**18,804**	85
2 **TUBBS** *(Electrical)*	October 2017	Napa & Sonoma	36,807	**5,636**	22
3 **TUNNEL - Oakland Hills** *(Rekindle)*	October 1991	Alameda	1,600	**2,900**	25
4 **CEDAR** *(Human Related)*	October 2003	San Diego	273,246	**2,820**	15
5 **NORTH COMPLEX** *(Under Investigation)**	August, 2020	Butte, Plumas, & Yuba	318,935	**2,352**	15
6 **VALLEY** *(Electrical)*	September 2015	Lake, Napa & Sonoma	76,067	**1,955**	4
7 **WITCH** *(Powerlines)*	October 2007	San Diego	197,990	**1,650**	2
8 **WOOLSEY** *(Under Investigation)*	November 2018	Ventura	96,949	**1,643**	3
9 **CARR** *(Human Related)*	July 2018	Shasta County, Trinity	229,651	**1,614**	8
10 **GLASS FIRE** *(Under Investigation)**	September 2020	Napa & Sonoma	67,484	**1,520**	0
11 **LNU LIGHTNING COMPLEX** *(Under Investigation)**	August 2020	Napa, Solano, Sonoma, Yolo, Lake, & Colusa	363,220	**1,491**	6
12 **CZU LIGHTNING COMPLEX** *(Lightning)*	August 2020	Santa Cruz, San Mateo	86,509	**1,490**	1
13 **NUNS** *(Powerline)*	October 2017	Sonoma	54,382	**1,355**	3
14 **THOMAS** *(Powerline)*	December 2017	Ventura & Santa Barbara	281,893	**1,063**	2
15 **OLD** *(Human Related)*	October 2003	San Bernardino	91,281	**1,003**	6

[1] https://www.fire.ca.gov/incidents/2020/

[2] https://www.fire.ca.gov/media/t1rdhizr/top20_destruction.pdf

Example

- Vegetation Caused Burning of a Power Line[3]

  - A tree branch broke and fell on a single-phase section of a line.
  - It caused a momentary fault that was cleared by a recloser.

  1 Hour

  - Another momentary fault occurred and it was cleared.

  16 Hours

  - Multiple intermittent momentary faults occurred and cleared.

  8 Hours

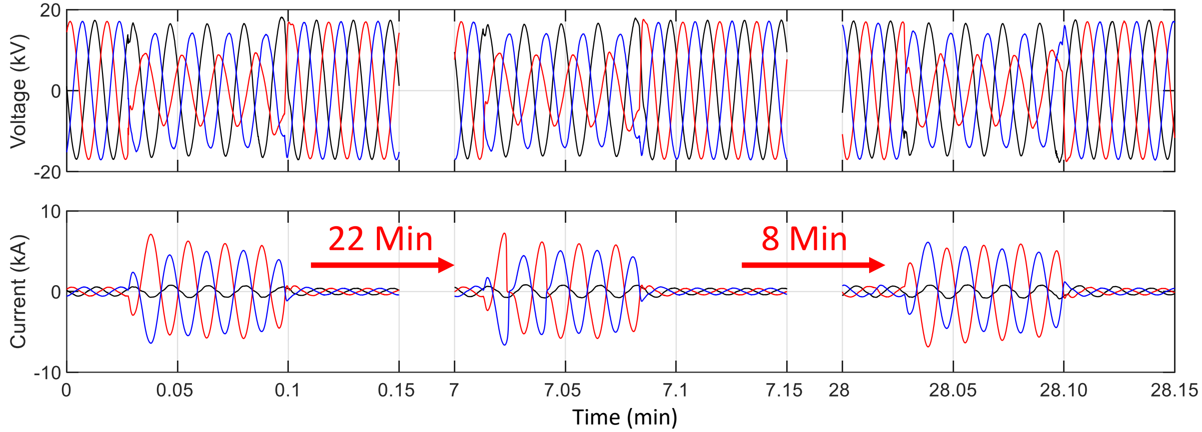
  - Final fault burned the power line down.

24 Hours!

[3] J. A. Wischkaemper, C. L. Benner, B. D. Russell, K. Muthu Manivannan, "Application of Advanced Electrical Waveform Monitoring and Analytics for Reduction of Wildfire Risk", in *Proc. of IEEE ISGT*, Washington, DC, 2014.

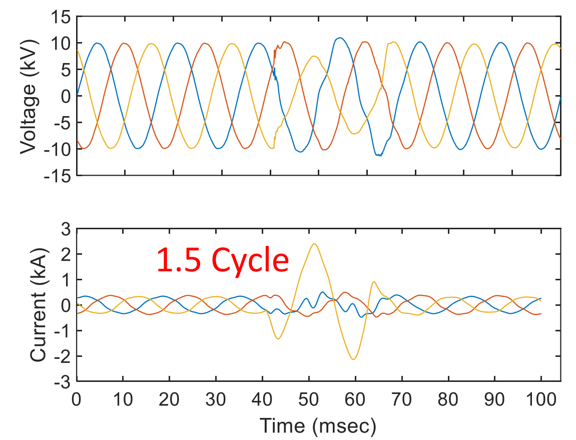
Advanced Grid Monitoring Can Help

- A series of waveform disturbances due to tree-contact on a windy day[4]:



- Other causes, e.g., equipment failure, create their own waveform disturbances[4]:

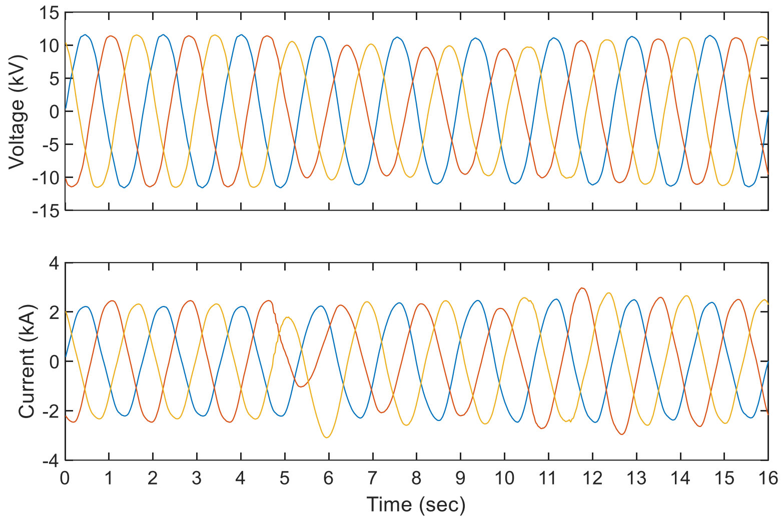
Shorter Signature (e.g., Sub-Cycle)



[4] https://pqmon.epri.com/see_all.html

Waveform vs. Synchro-Waveform

- Waveform Measurements (PQ Meters, DRF, etc.)[4]:



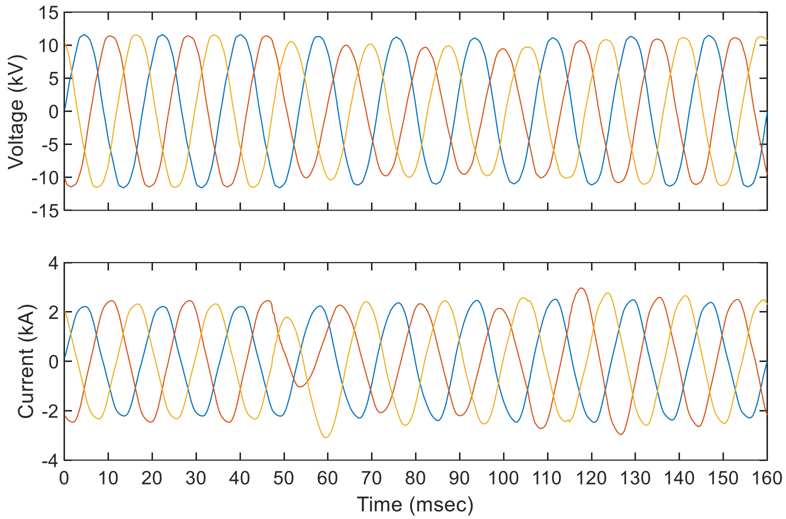
POW: Point-on-Wave

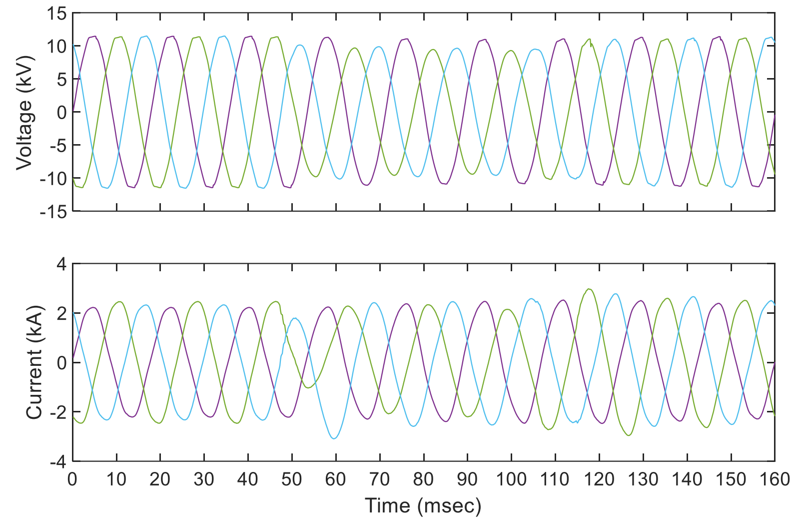
CPOW: Continuous Point-on-Wave

Waveform vs. Synchro-Waveform

- Synchro-Waveform Measurements[4]:

(WMU: Waveform Measurement Unit)





Location 1 / **WMU 1** ⟷ Location 2 / **WMU 2**

Time Synchronized

- They observe the same physical phenomena at different locations.

→ **Synchro-Waveform Situational Awareness**

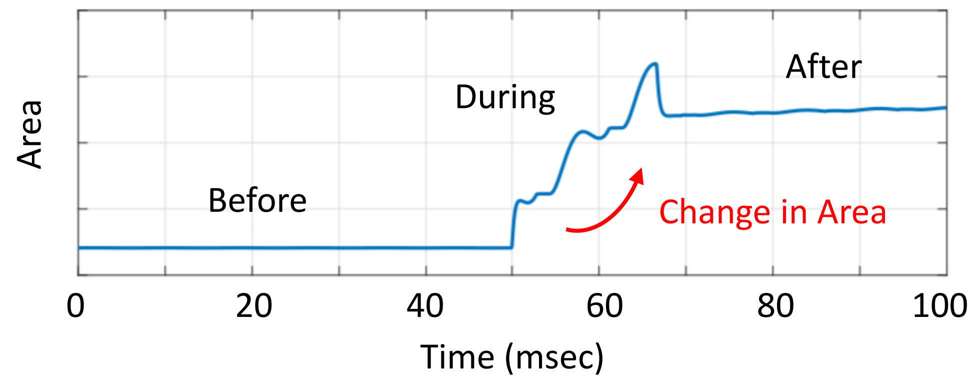
→ Covering Various Event Signatures (Multi-Cycle, Sub-Cycle, etc.)

Situational Awareness with Synchro-Waveforms

- Analysis of waveform disturbances using synchro-waveforms:
  - Detection
  - Characterization
  - Location Identification
  - …

Situational Awareness with Synchro-Waveforms

- Analysis of waveform disturbances using synchro-waveforms:
  - Detection[5]
  - Characterization
  - Location Identification
  - …



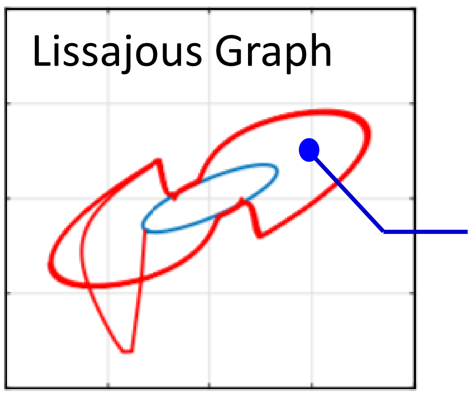
Location 1 / WMU 1

$v_1(t), i_1(t)$

Location 2 / WMU 2

$v_2(t), i_2(t)$

$v(t) = v_1(t) - v_2(t)$



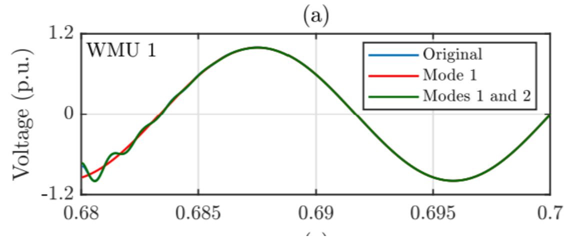
$i(t) = i_1(t) - i_2(t)$

$$\text{Area} = \left| \int_{i(t=0)}^{i(t=T)} v(t)\, di(t) \right|$$

[5] M. Izadi and H. Mohsenian-Rad, "Characterizing synchronized Lissajous curves to scrutinize power distribution synchro-waveform measurements," in ***IEEE Trans. on Power Systems***, accepted for publication, May 2021.

- Analysis of waveform disturbances using synchro-waveforms:
  - Detection
  - Characterization
  - Location Identification[6]
  - …

Multi-Signal Modal Analysis



Event starts at $t = 0.68$ sec (Sub-Cycle Event)

WMU 1

$v_1(t), i_1(t)$

WMU 2

$v_2(t), i_2(t)$

Number of Modes

$$v_1(t) \approx \sum_{p=1}^{P} A_{p,m}\, e^{\sigma_p t} \cos(2\pi f_p t + \theta_p)$$

Also for $i_1(t), v_2(t), i_2(t)$

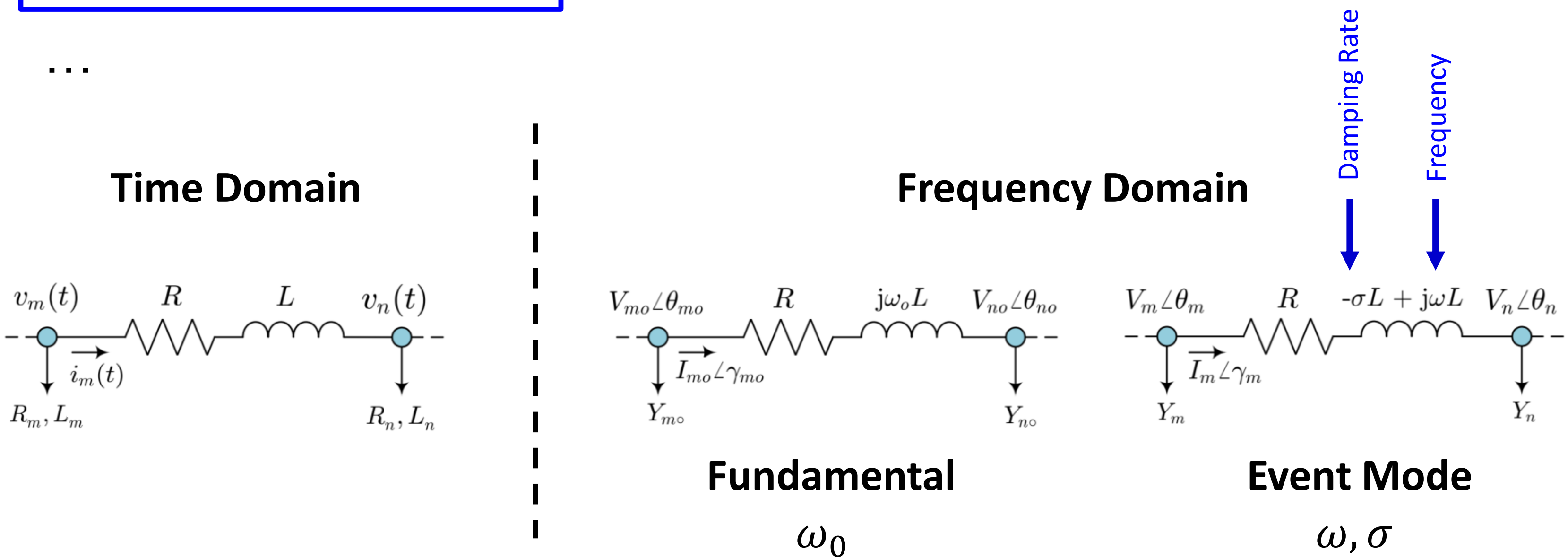
Damping Sinusoidal Modes
$(f_p, \sigma_p, A_{p,m}, \theta_p)$

[6] 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***, accepted for publication, May 2021.

Situational Awareness with Synchro-Waveforms

- Analysis of waveform disturbances using synchro-waveforms:
  - Detection
  - Characterization
  - Location Identification[6]
  - …

Analysis of Circuit at Event Mode.



[6] 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*, accepted for publication, May 2021.

Situational Awareness with Synchro-Waveforms

- Analysis of waveform disturbances using synchro-waveforms:
  - Detection
  - Characterization
  - Location Identification[6]
  - …

Discrepancy

$$k^* = \underset{i}{\operatorname{argmin}}\ \Psi_i$$

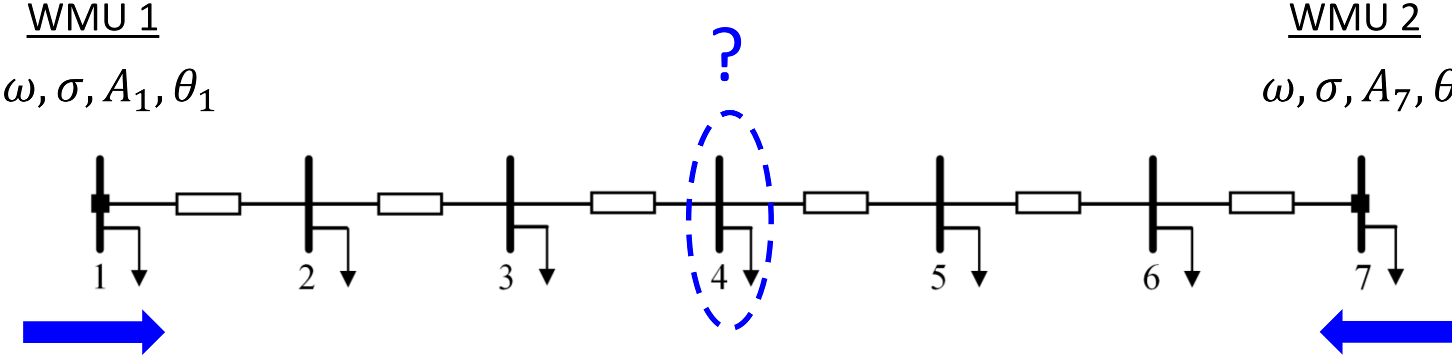
$$\text{where} \quad \Psi_i = \left| V_i^f - V_i^b \right|, \quad i = 1, \dots, 7.$$

WMU 1

$\omega, \sigma, A_1, \theta_1$

WMU 2

$\omega, \sigma, A_7, \theta_7$



Forward Sweep (Event Mode)

Backward Sweep (Event Mode)

[6] 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*, accepted for publication, May 2021.

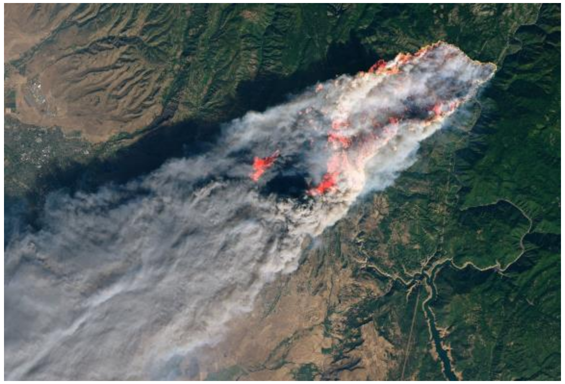
Situational Awareness with Synchro-Waveforms

- Analysis of waveform disturbances using synchro-waveforms:
  - Detection
  - Characterization
  - Location Identification
  - …

Asset Monitoring, Wildfire Monitoring, etc.

+

- Other wildfire detection technologies:



www.nasa.gov

www.milesight-iot.com

www.intecconinc.com

Conclusions

- Synchro-Waveforms: new frontier in power grid situational awareness.
- Waveform Events: may indicate vegetation, fire, incipient faults, etc.
- New method: Detection and Characterization
  - Analysis of synchronized Lissajous graphs
- New method: Location Identification
  - Analysis of the sub-cycle event mode(s)
- The results show accurate and robust performance.
- Synchro-waveform analysis has great potential in wildfire monitoring.

Further Reading

Synchro-Waveform Analysis:

[1] M. Izadi and H. Mohsenian-Rad, "Characterizing synchronized lissajous curves to scrutinize power distribution synchro-waveform measurements," in *IEEE Trans. on Power Systems*, *(accepted)*, May 2021.

[2] 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*, *(accepted)*, May 2021.

[3] M. Izadi and H. Mohsenian-Rad, "A Synchronized lissajous-based approach to achieve situational awareness using synchronized waveform measurements," in *Proc. of the IEEE PES General Meeting*, Jul 2021.

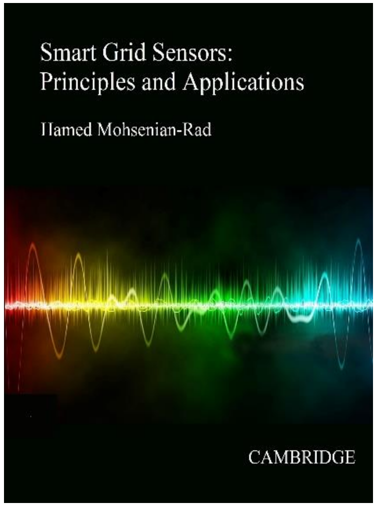
[4] M. Izadi and H. Mohsenian-Rad, "Event location identification in distribution networks using waveform measurement units," in *Proc. of IEEE PES ISGT - Europe*, The Hague, Netherlands, Oct 2020.

Textbook on Smart Grid Sensors:

- Working Principles
- Sample Data Sets
- Data-Driven Methods

Synchro-waveforms
Synchro-phasors
Smart meters
Building sensors
Probing
⋮

Textbook (in press)



Cambridge University Press
September 2021
360 Pages
120 Examples
150 Exercise Questions

Thank You!

Hamed Mohsenian-Rad, *Ph.D., IEEE Fellow*

Professor and Bourns Family Fellow
Department of Electrical and Computer Engineering
University of California, Riverside
E-mail: hamed@ece.ucr.edu
Homepage: www.ece.ucr.edu/~hamed