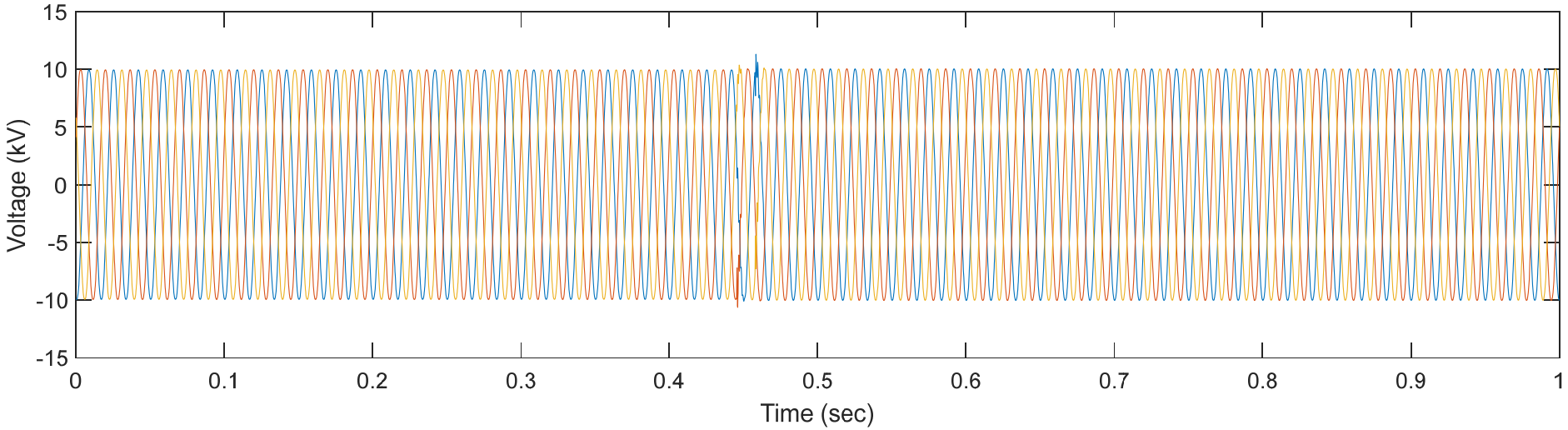
Data-Driven Representation of Synchro-Waveforms in Power Systems

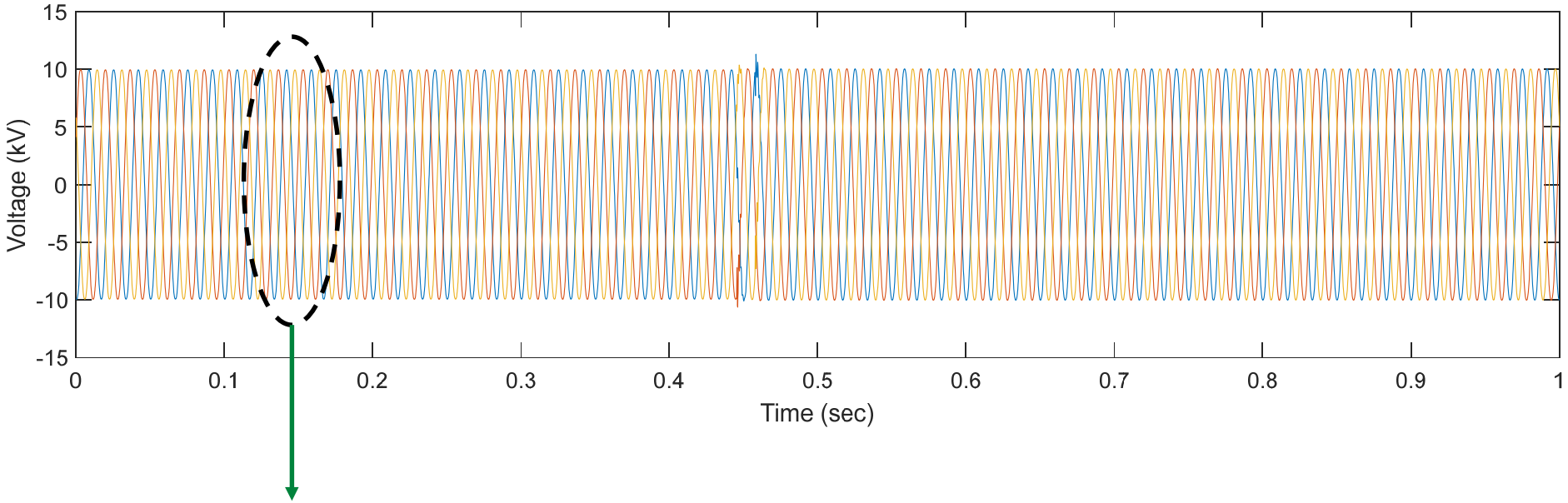
Hamed Mohsenian-Rad, *Ph.D., IEEE Fellow*
Winston Chung Endowed Chair Professor in Energy Innovation
University of California, Riverside

Collaborators: Narges Ehsani and Vishwa Saragadan

Background and Motivation:

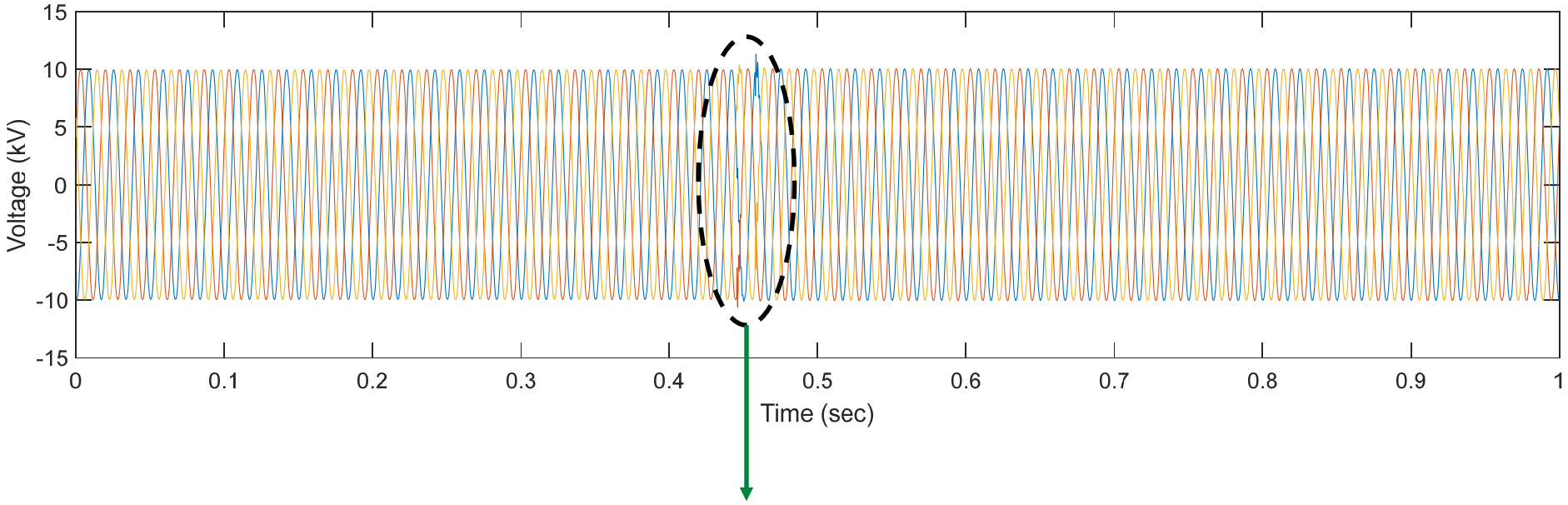


Background and Motivation:

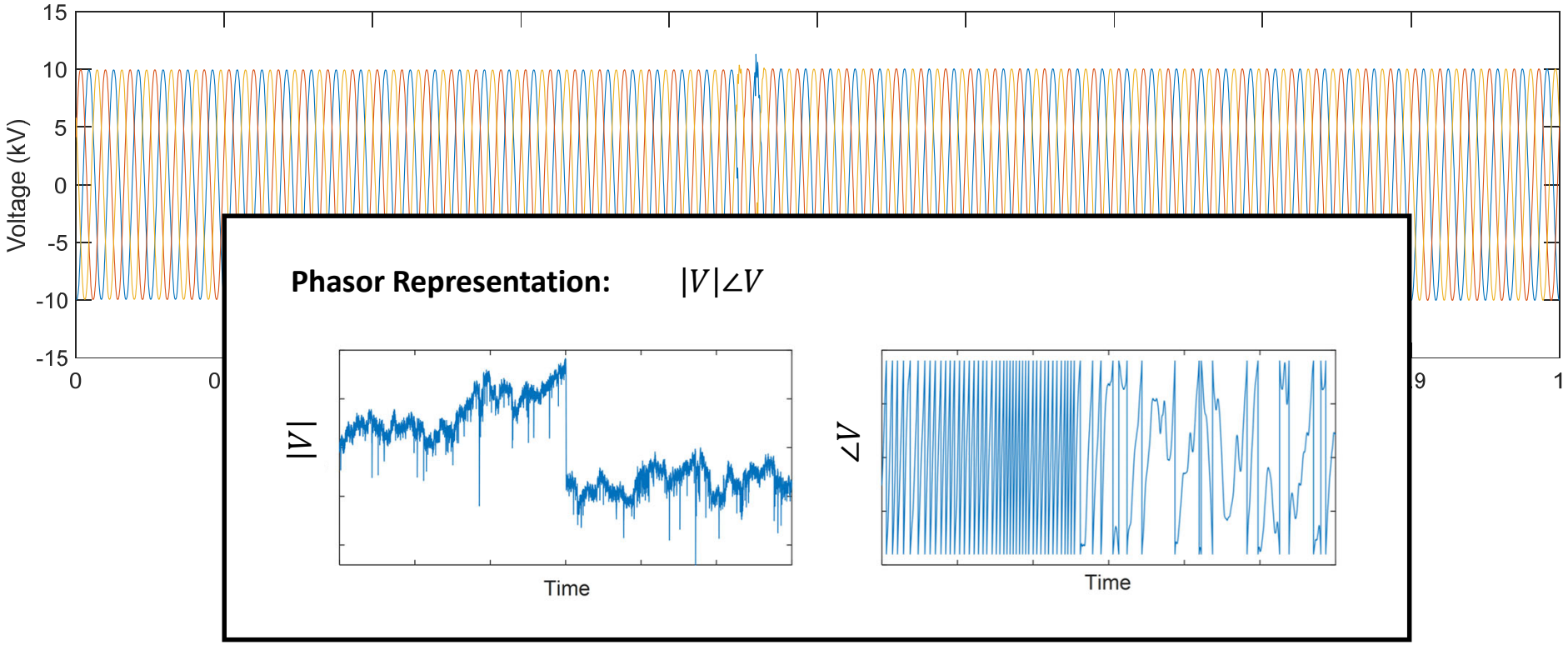


Mostly Sinusoidal Shape

Background and Motivation:



Background and Motivation:



Phasor Representation:

$$v(t) \approx a_2 \sin(a_1 t + b_1) + b_2$$

Magnitude

Frequency

Phase Angle

DC Term

Phasor Representation with Harmonics:

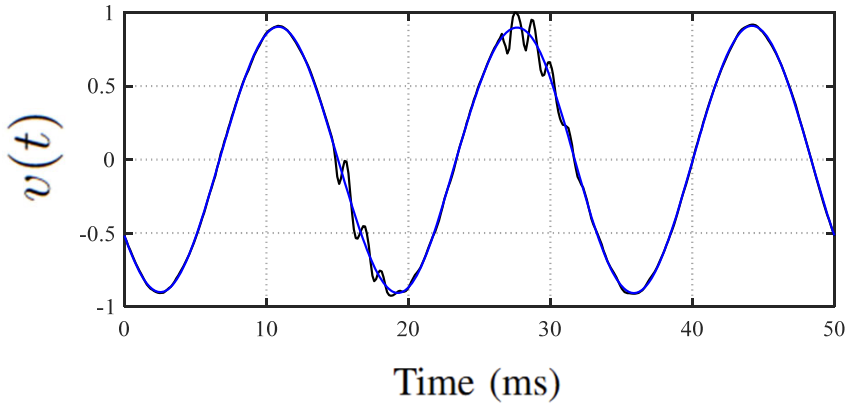
$$v(t) \approx \sum_{i=1}^{h} a_{2,i} \sin\left(a_{1,i} t + b_{1,i}\right) + b_2$$

Collection of Arbitrary Frequencies

Phasor Representation with Harmonics:

$$v(t) \approx \sum_{i=1}^{h} a_{2,i} \sin\left(a_{1,i} t + b_{1,i}\right) + b_2$$

Collection of Arbitrary Frequencies

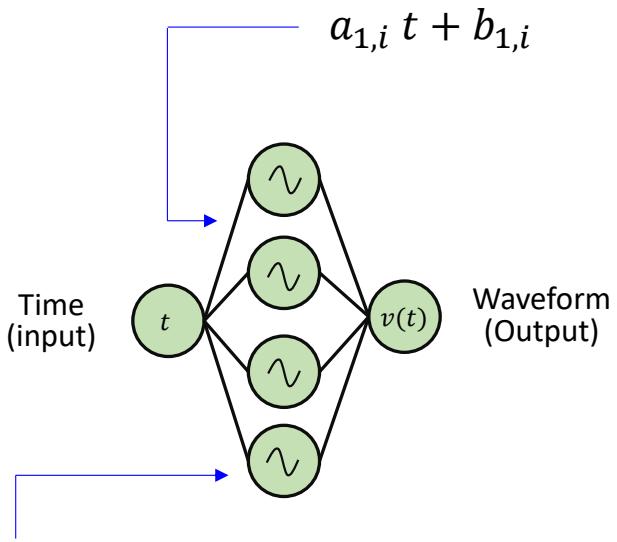


Conclusion: This formulation ***cannot*** properly represent the waveform.

Phasor Representation with Harmonics:

$$v(t) \approx \sum_{i=1}^{h} a_{2,i} \sin\left(a_{1,i} t + b_{1,i}\right) + b_2$$

Equivalent **Neural Network:**

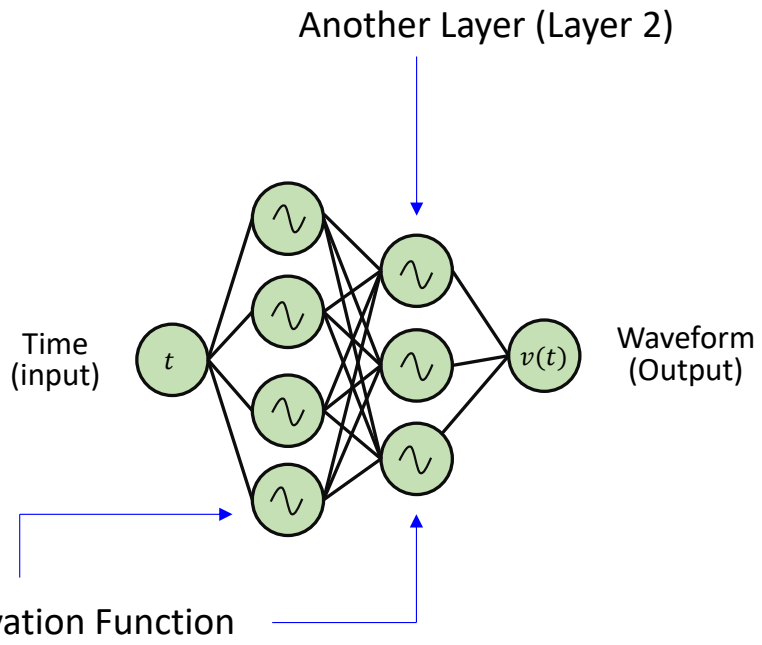


Sinusoidal Activation Function

Implicit Neural Representation (INR):

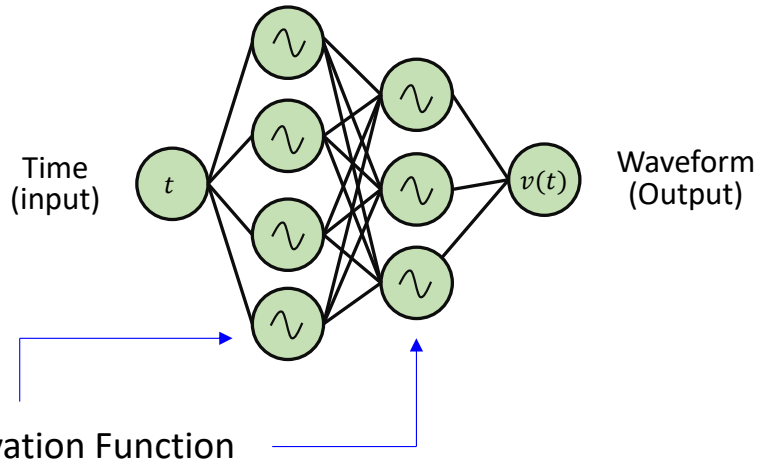
$$v(t) \approx \sum_{i=1}^{h} a_{2,i} \sin\left(a_{1,i} t + b_{1,i}\right) + b_2$$

Another Layer



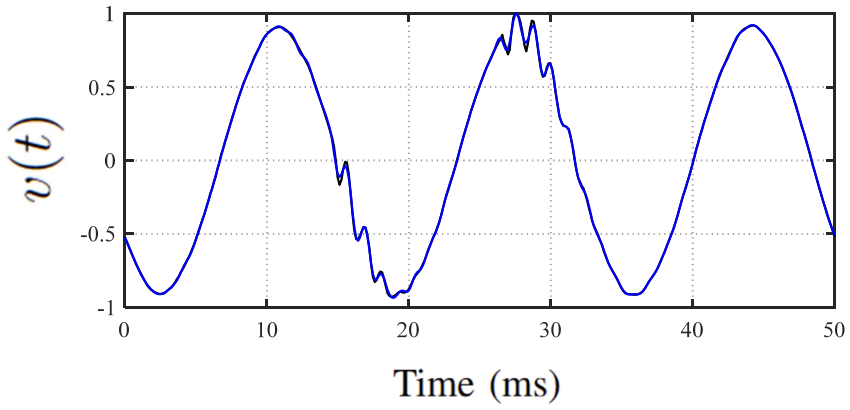
Implicit Neural Representation (INR):

$$v(t) \approx \sum_{j=1}^{h_2} a_{3,j} \sin\left(\sum_{i=1}^{h_1} a_{2,i,j} \sin\left(a_{1,i}t + b_{1,i}\right) + b_{2,i}\right) + b_3.$$



Implicit Neural Representation (INR):

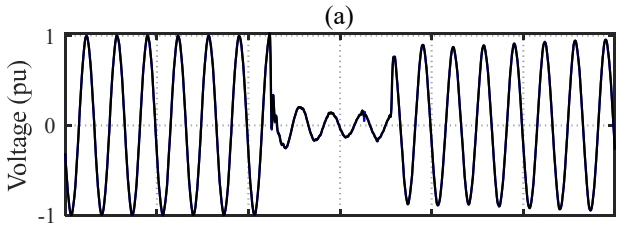
$$v(t) \approx \sum_{j=1}^{h_2} a_{3,j} \sin\left(\sum_{i=1}^{h_1} a_{2,i,j} \sin\left(a_{1,i}t + b_{1,i}\right) + b_{2,i}\right) + b_3.$$

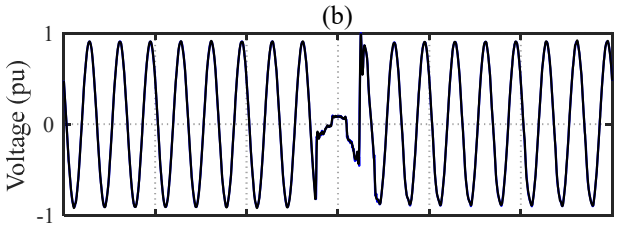


Conclusion:
INR ***properly*** represents the waveform.

More Real-World Examples:

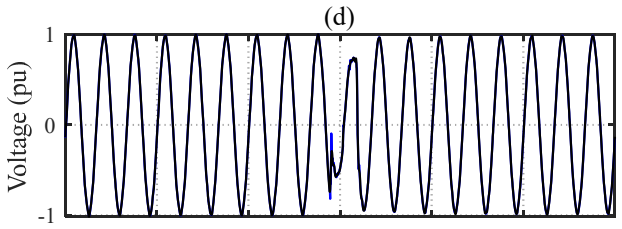
MSE = 0.77%

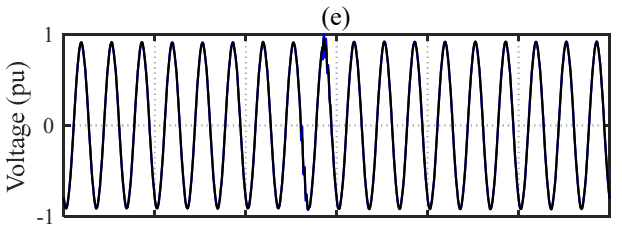




MSE = 1.24%

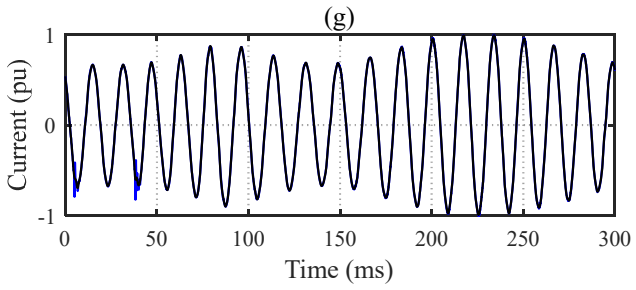
MSE = 1.04%

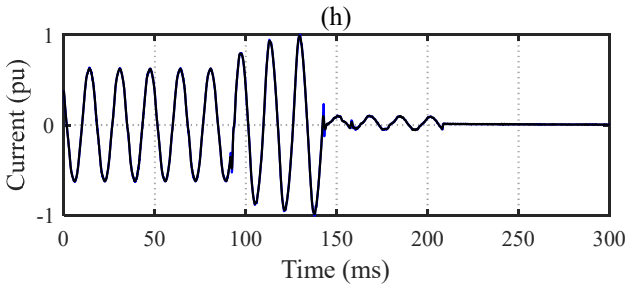




MSE = 1.16%

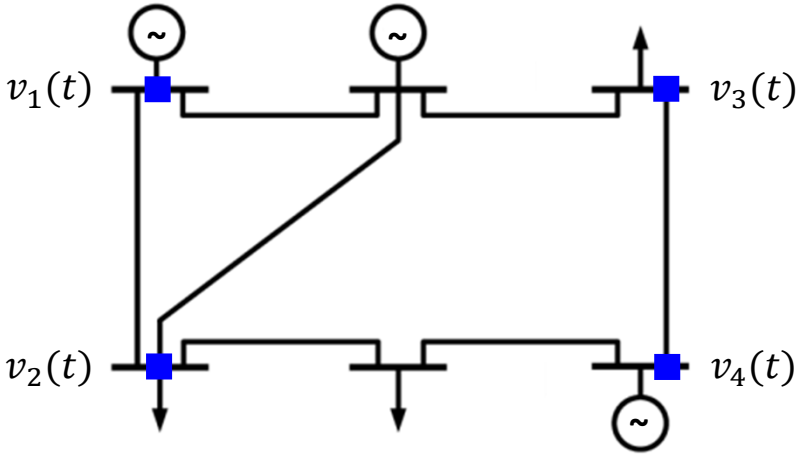
MSE = 1.77%



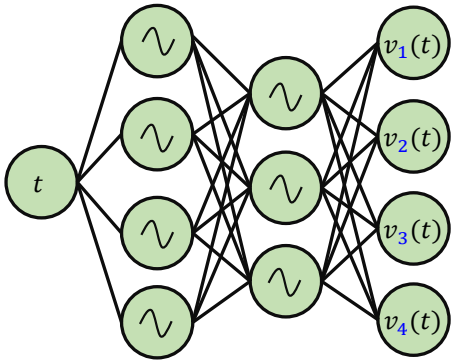


MSE = 2.77%

Representation of Synchro-Waveforms:



■ Waveform Measurement Unit (WMU)



Shared Layers

Synchronized Waveforms (Output)

Additional Details:

Narges Ehsani, Vishwanath Saragadam, and Hamed Mohsenian-Rad, "Implicit Neural Representation of Waveform Measurements in Power Systems Waveform Data Analysis," in *Proc. of the IEEE PES General Meeting*, Austin, TX, July 2025.

Contact:

Hamed Mohsenian-Rad, Ph.D., IEEE Fellow
Winston Chung Endowed Chair Professor in Energy Innovation
University of California, Riverside, USA
E-mail: hamed@ece.ucr.edu
Website: www.ece.ucr.edu/~hamed