Synchro-waveforms for Monitoring IBRs (A Case Study)

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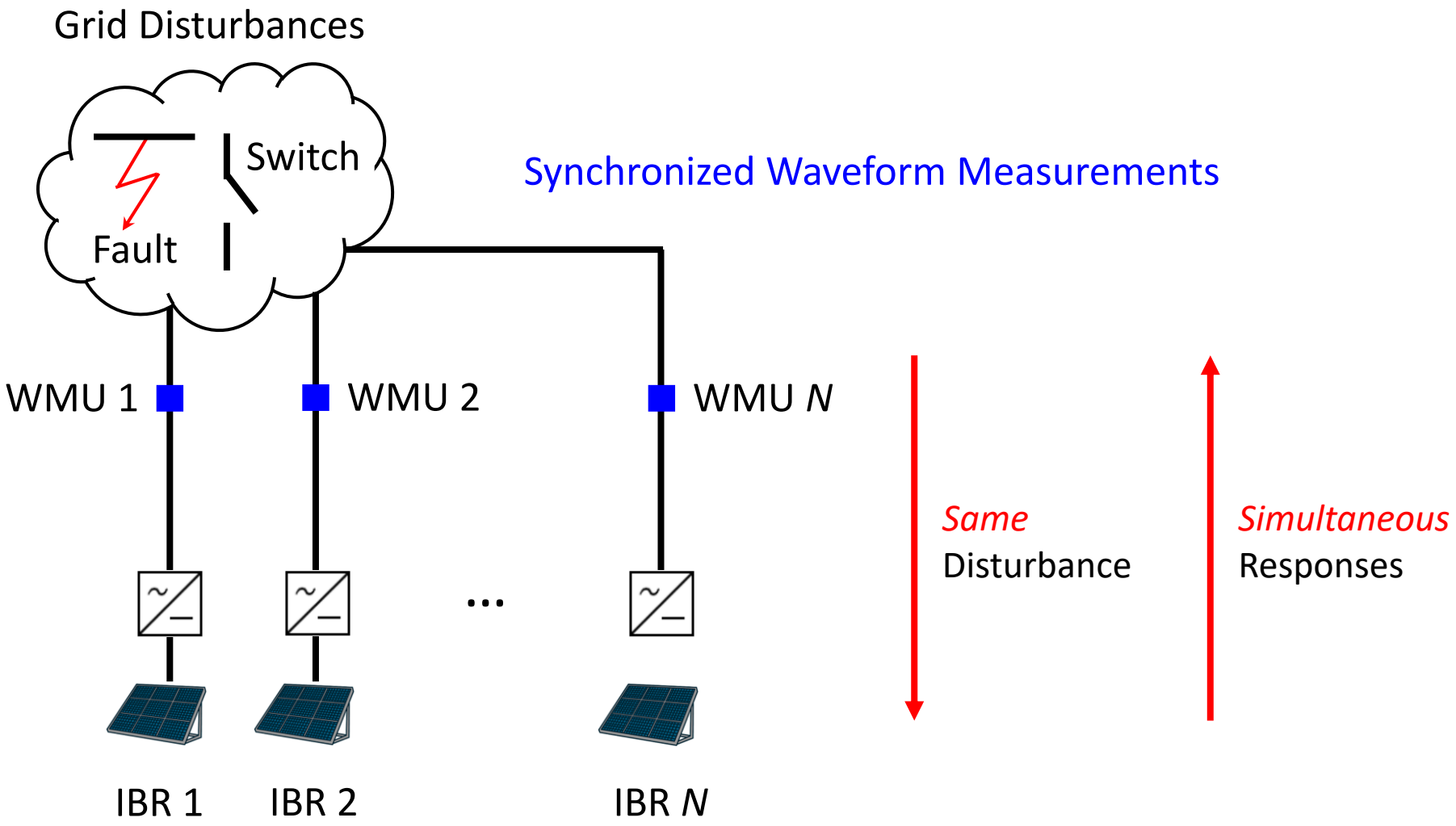
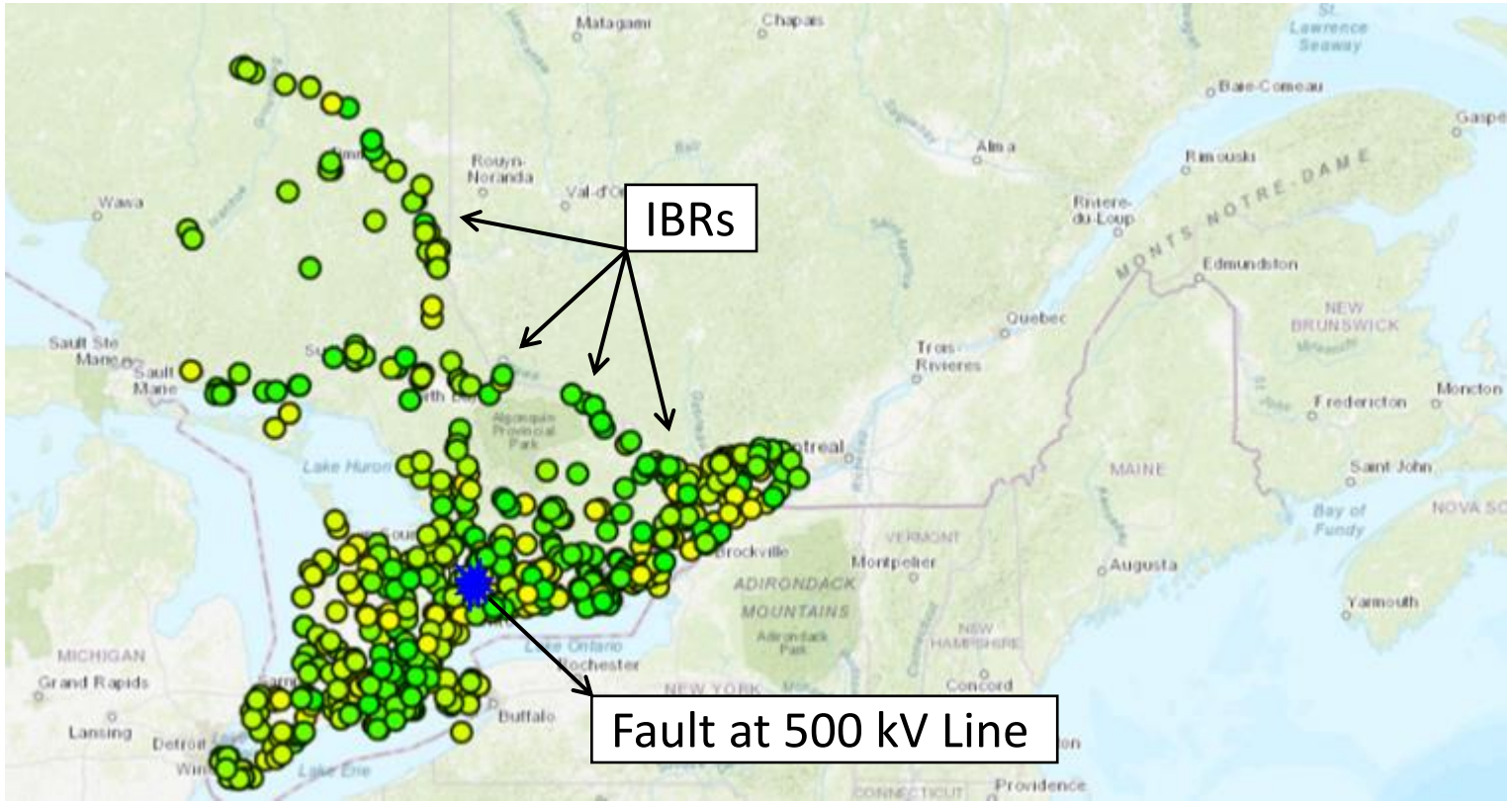
Monitoring IBRs with WMUs



System-Wide Disturbance

500 kV Fault Causes a System-Wide Disturbance

Ontario, Canada



Synchro-Waveforms During System-Wide Disturbance

Voltage

Current

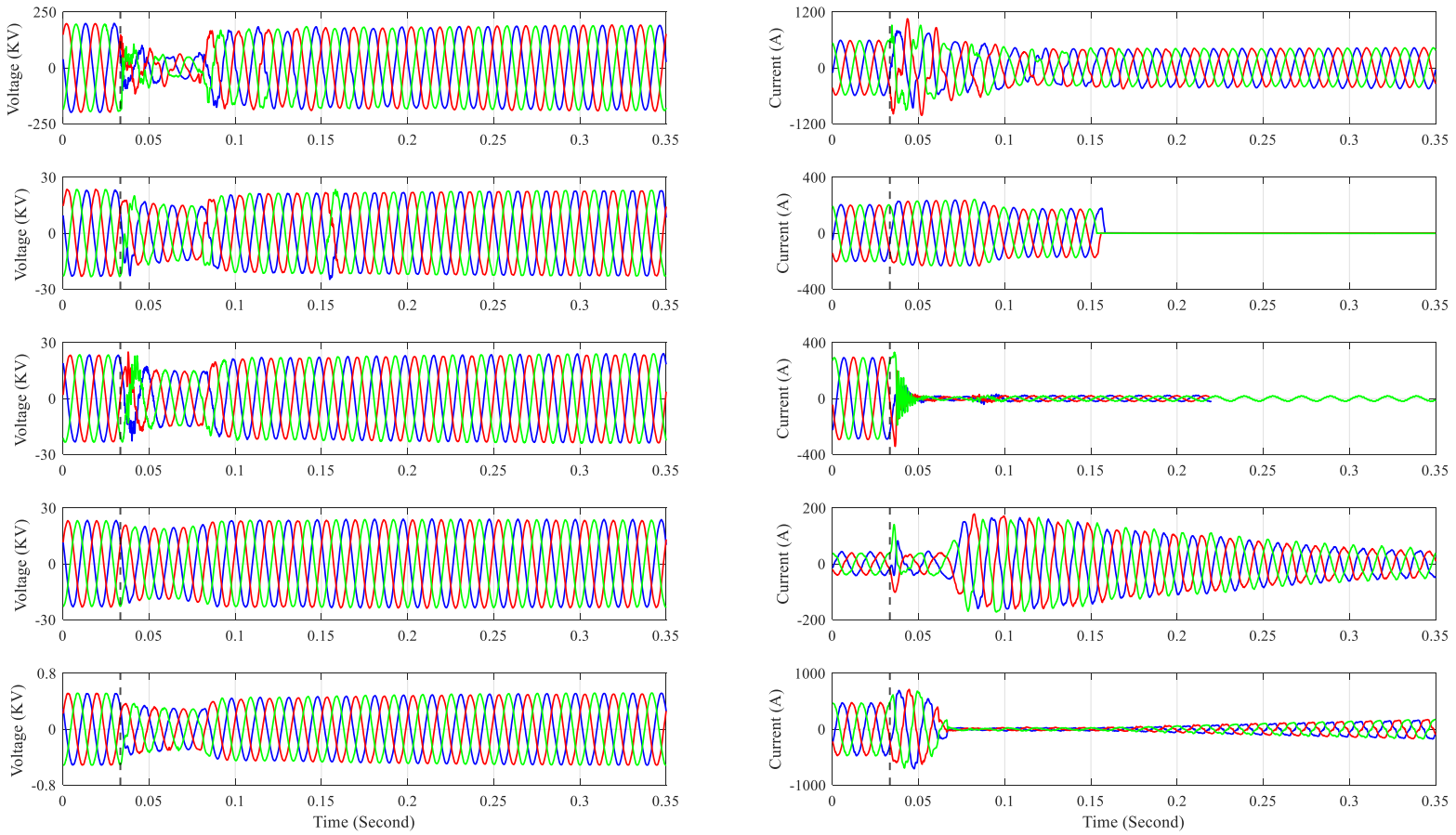
IBR 1

IBR 2

IBR 3

IBR 4

IBR 5



Data From 80 IBRs

Comparison with Synchro-Phasors

Voltage (Magnitude)

Voltage (Angle)

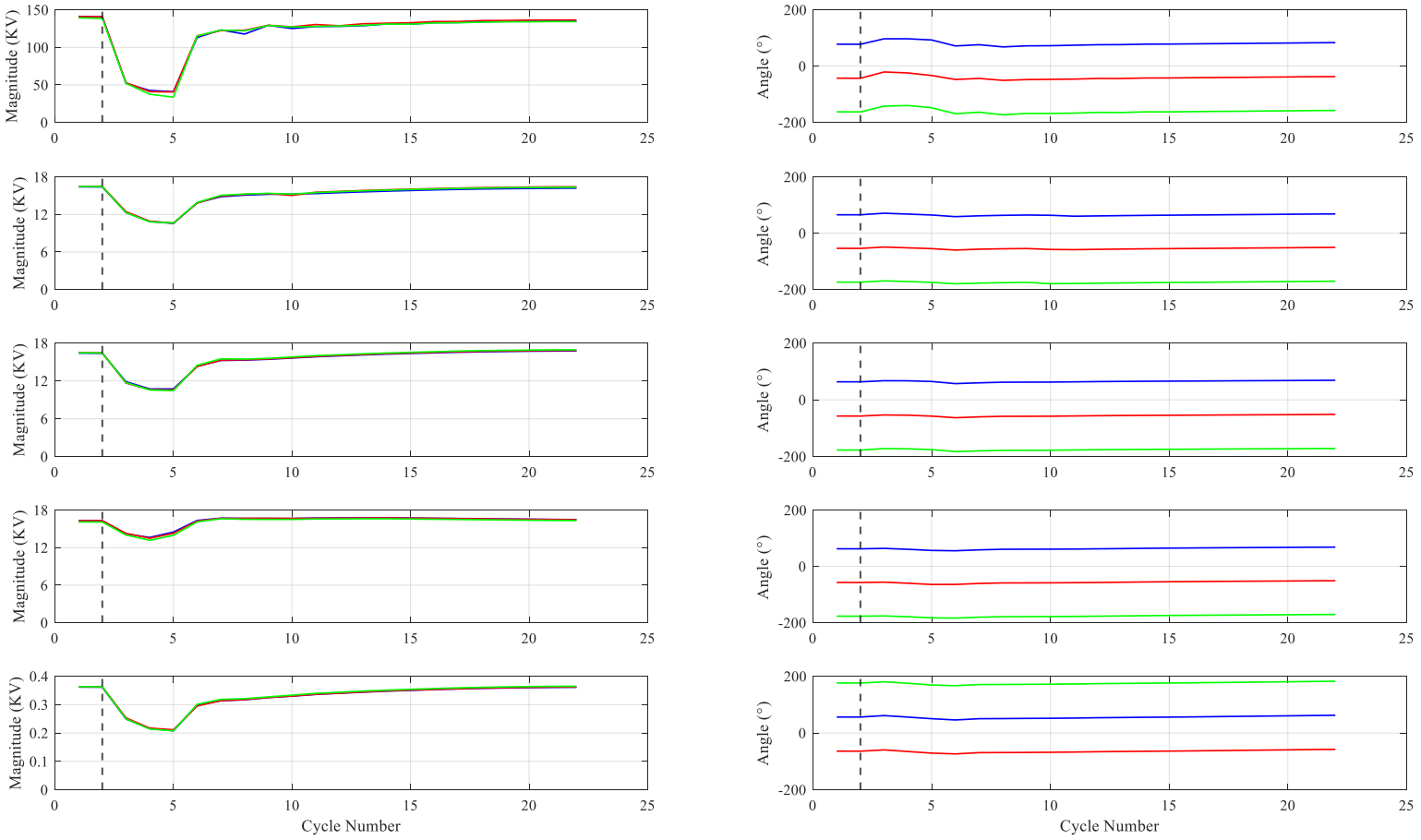
IBR 1

IBR 2

IBR 3

IBR 4

IBR 5



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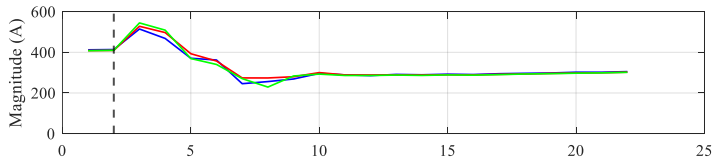
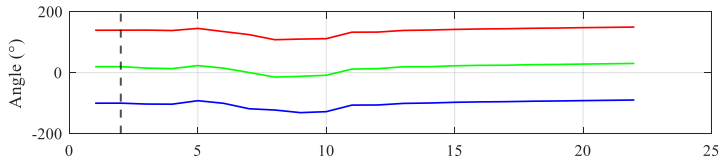
Comparison with Synchro-Phasors

Current (Magnitude)

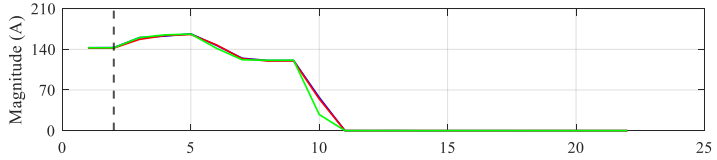
Current (Angle)

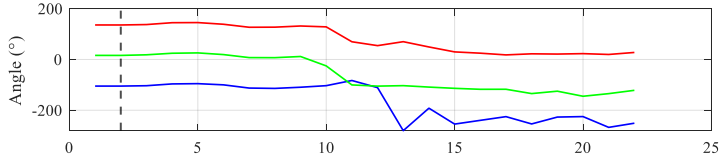
IBR 1



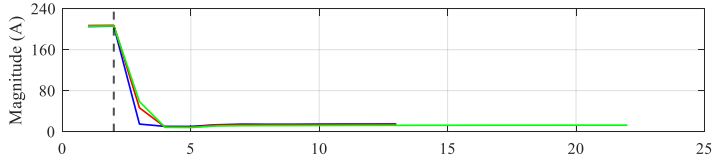


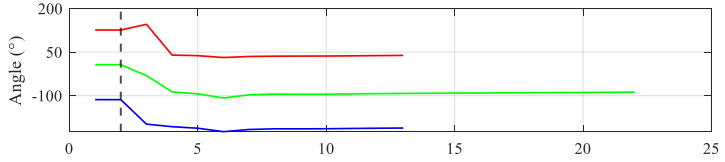
IBR 2



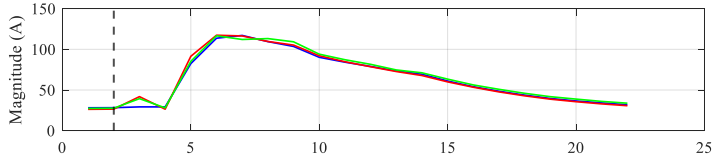


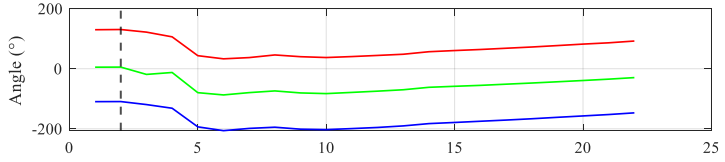
IBR 3



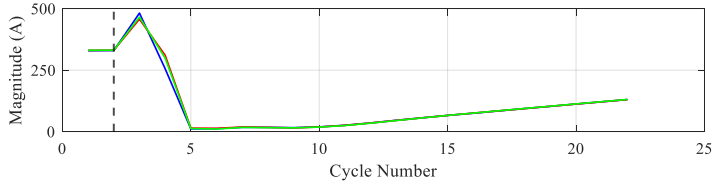


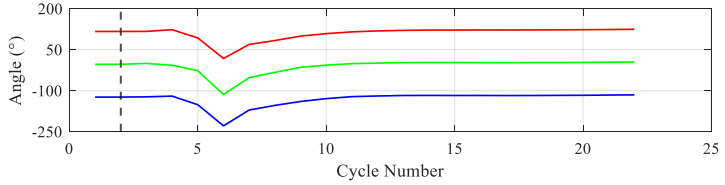
IBR 4





IBR 5



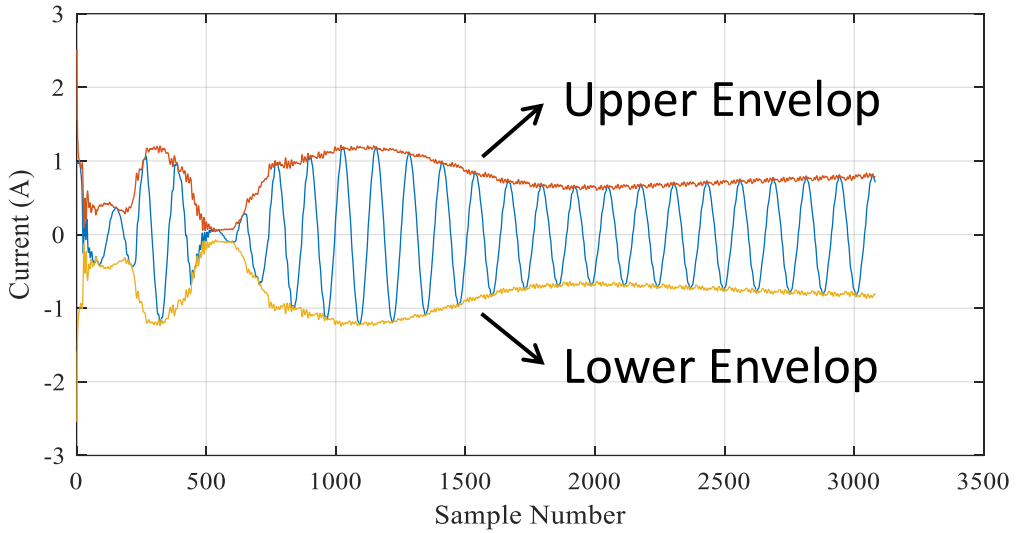


Data From 80 IBRs

Feature Analysis for Response Classification

Example: Upper and Lower Envelop Distances

- Upper Envelop for Current Waveform 1: $\boldsymbol{u}_1 = [u_{1,1}, u_{1,2}, u_{1,3}, \dots, u_{1,n}]$
- Upper Envelop for Current Waveform 2: $\boldsymbol{u}_2 = [u_{2,1}, u_{2,2}, u_{2,3}, \dots, u_{2,n}]$



$$D_u = \|\boldsymbol{u}_1 - \boldsymbol{u}_2\|_2$$

$$D_u = \|\boldsymbol{l}_1 - \boldsymbol{l}_2\|_2$$

… and other features.

Distance between envelopes

(Pair-wise Feature)

[1] J. Ren and M. Kezunovic, "An Adaptive Phasor Estimator for Power System Waveforms Containing Transients," in *IEEE Transactions on Power Delivery*, vol. 27, no. 2, April 2012.

[2] H. Mohsenzadeh-Yazdi, C. Li, H. Mohsenian-Rad, “Real-World Synchro-Waveform Data Analysis and Pattern Classification of IBR Responses During a System-Wide Disturbance," to be submitted, August 2024.

Data-Driven Classification of IBR Responses

Classes:

- Trip During Fault
- Trip After Fault
- Fault Ride-Through
- Momentary Reduction
- Partial Trip
- Side Band Oscillation
- Prolonged High Current

⋮

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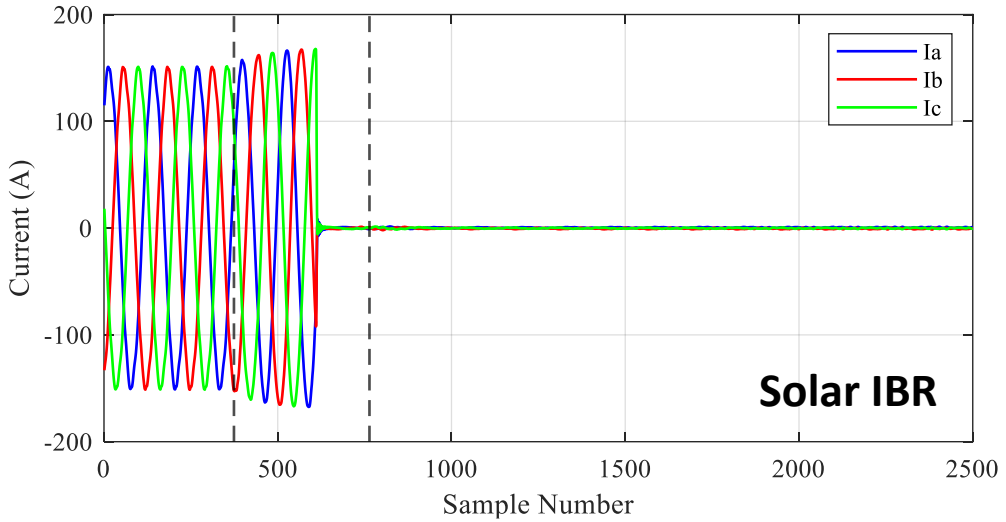

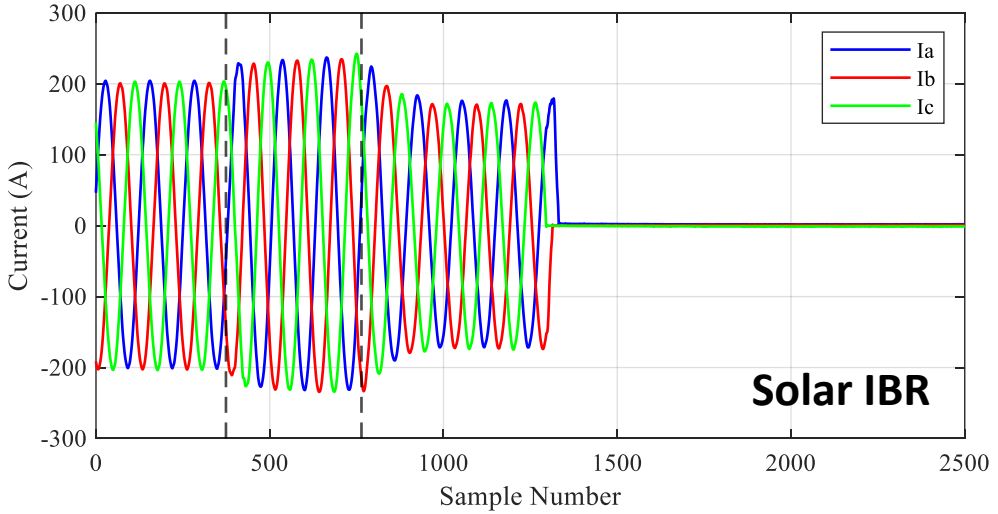

Also among wind IBRs

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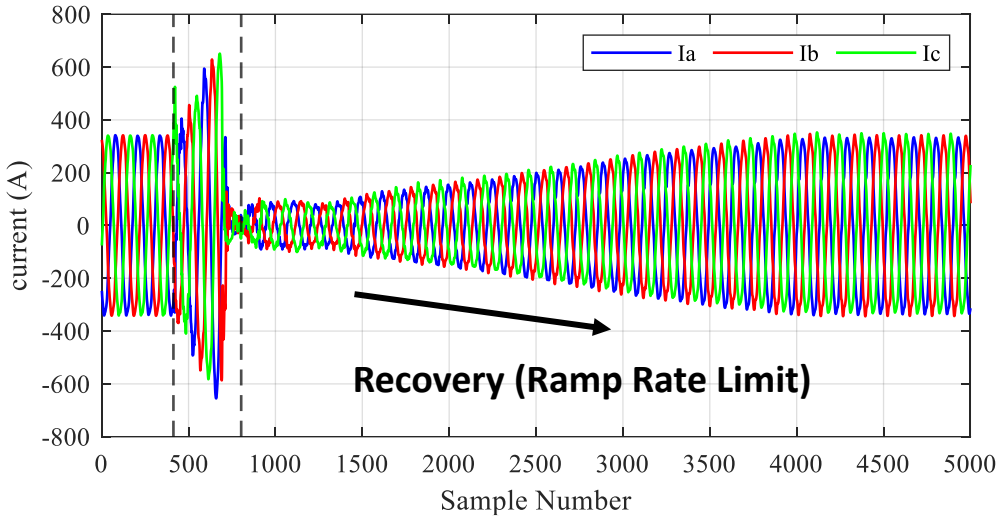

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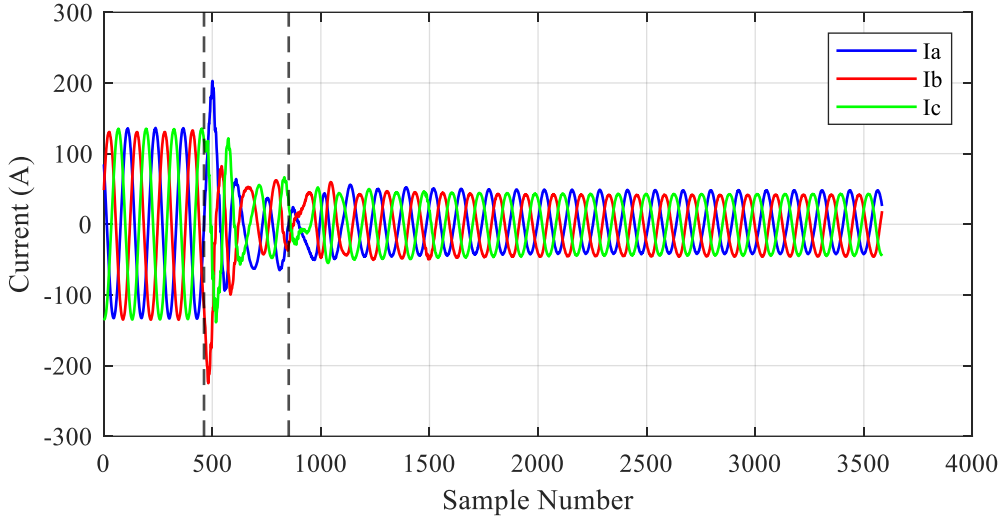

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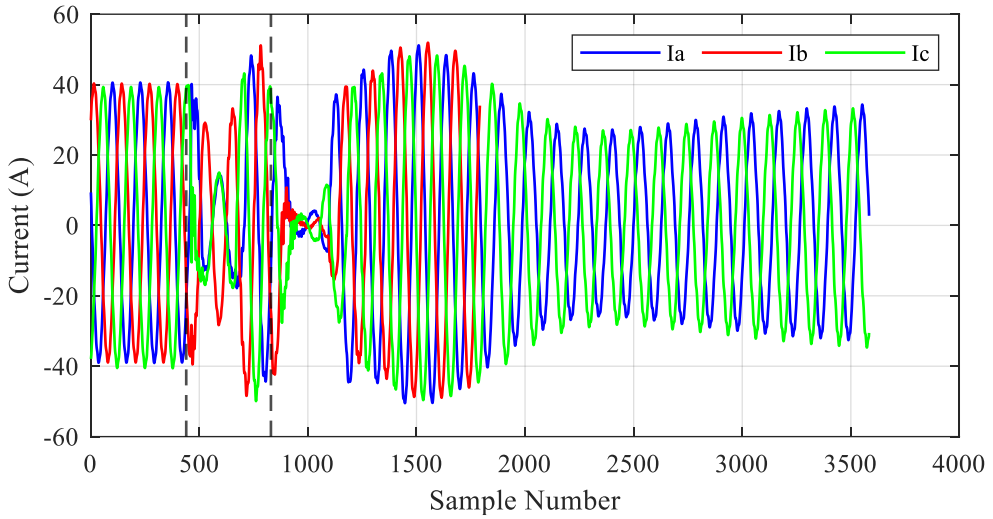

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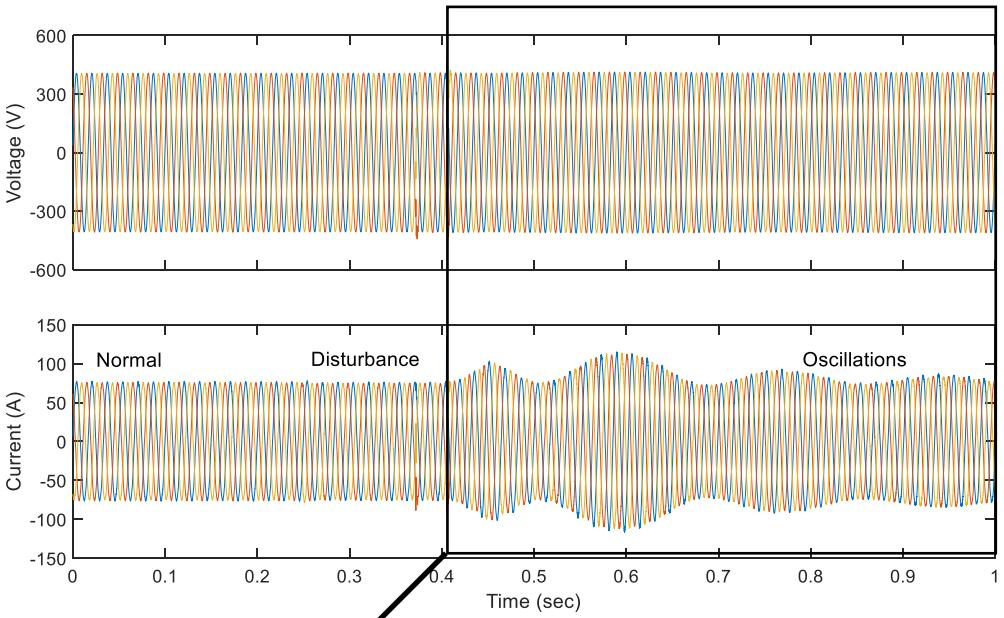
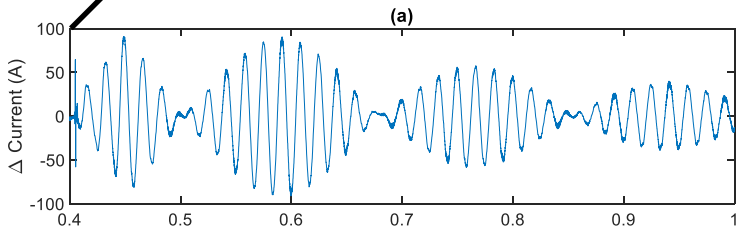


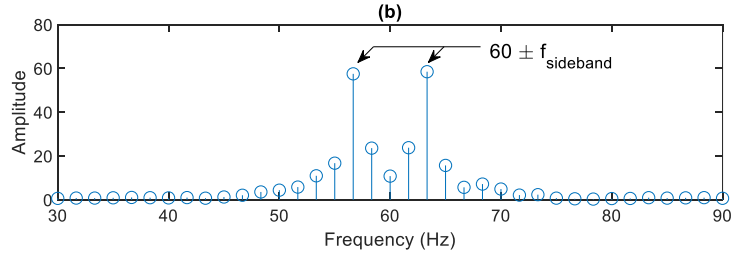
Different Case Study

$\Delta i(t)$



Amplitude Modulation

$\text{FFT}\{\Delta i(t)\}$



Side Band Oscillations

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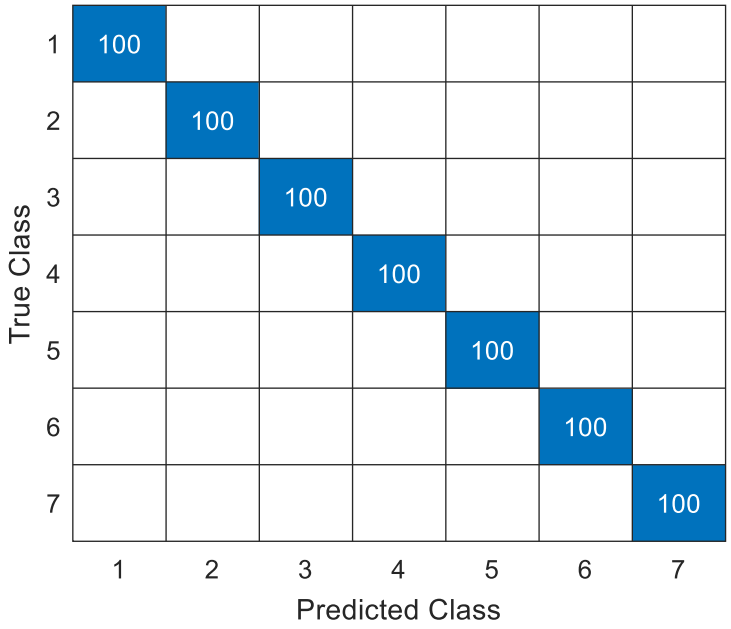
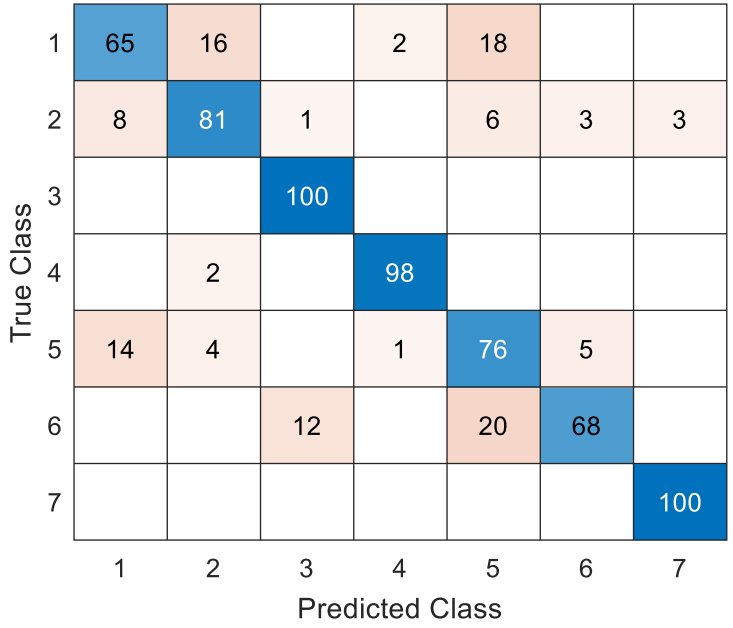


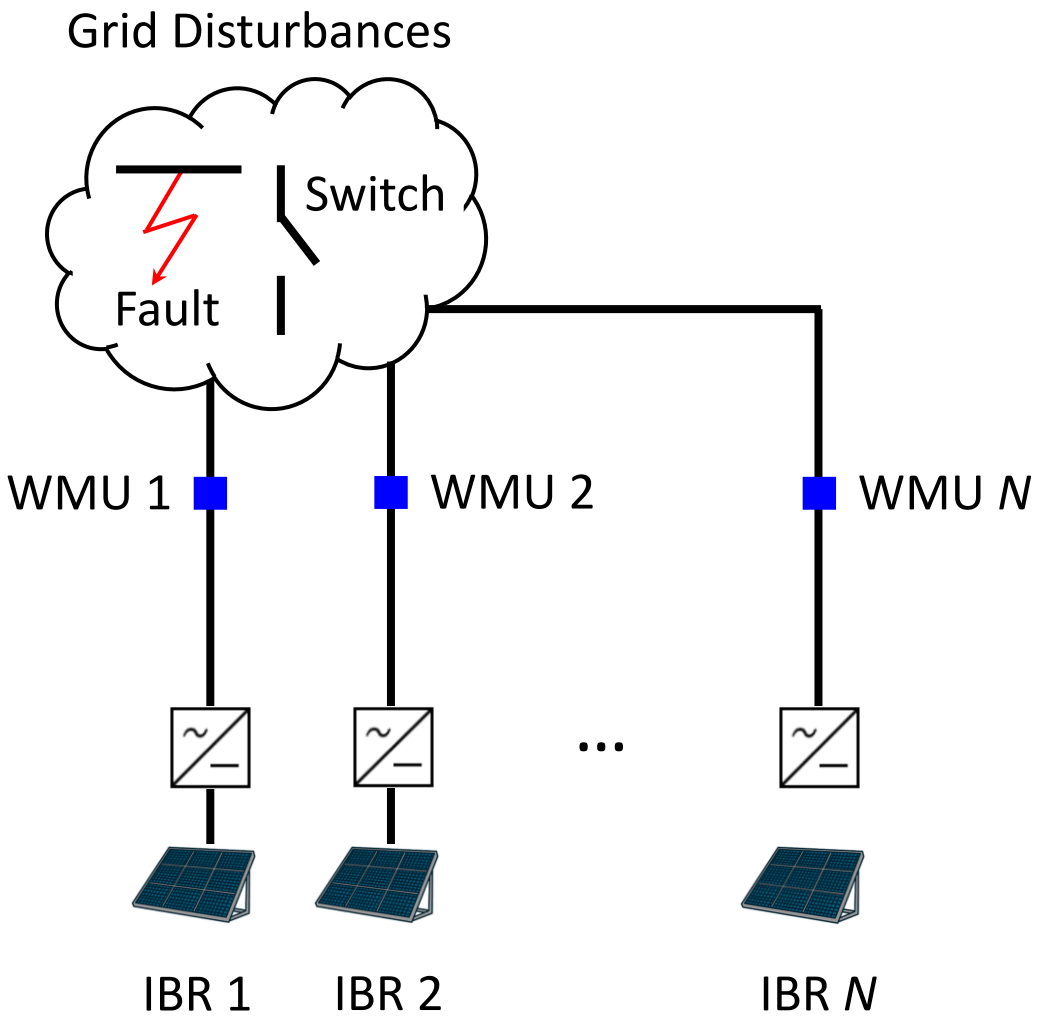
100% Training



80% Training

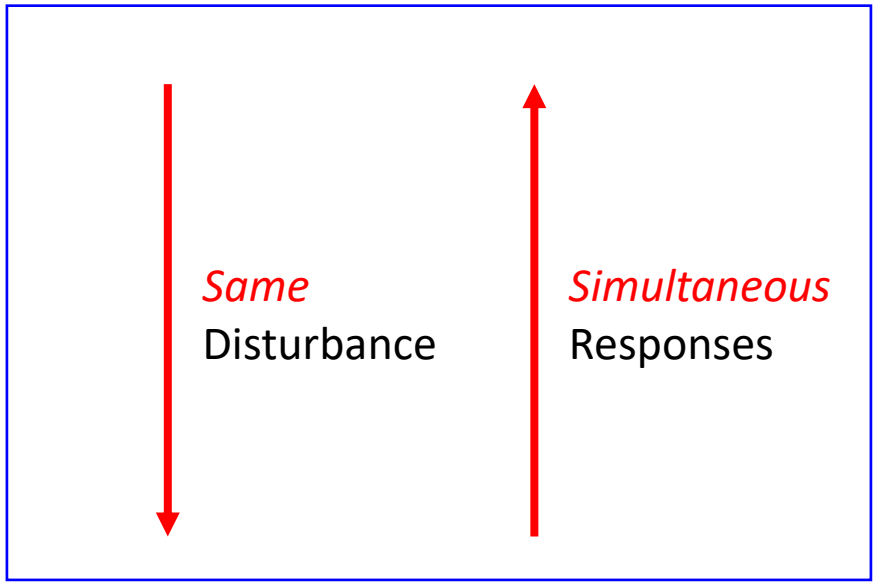
(Classes are Separable)

Monitoring IBRs with WMUs



Impact on *System Dynamics and Control*

Impact on *Protection System*



Thank You!

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