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):

  - Single-Phase (120 V)
  - Three-Phase (12.47 kV)
  - Three-Phase (480 V)
Events in Continuous Waveform Measurements

- Per-Cycle THD in Continuous Voltage Waveforms:

![Graph showing Per-Cycle THD and ∆THD over time.](image-url)
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:

\[ \Delta v(t) = v(t) - v_{\text{ref}}(t) \]

Events in Synchro-Waveforms

- Events in Synchro-Waveforms$^2$:

Dynamic Response of Inverter-Based Resources (IBRs)

Grid Disturbances

Fault

Switch

IBR 1

IBR 2

WMU 1

WMU 2

IBR 1

IBR 2

Voltage (V)

Current (A)

Time (msec)
Dynamic Response of Inverter-Based Resources (IBRs)
Dynamic Response of Inverter-Based Resources (IBRs)

Grid Disturbances

Fault

Switch

WMU 1

WMU 2

IBR 1

IBR 2

IBR 1

IBR 2

Voltage (V)

Current (A)

Time (msec)
Dynamic Response of Inverter-Based Resources (IBRs)

Grid Disturbances

Sub-cycle Dynamic Modeling\(^3\):

\[\Delta v(t) \rightarrow \text{IBR} \rightarrow \Delta i(t)\]

(Real Data / Originally Three Phase)

(ML-Based Model Library)

Analysis of Faults and Incipient Faults

• Example⁴:

(Same Fault at Different Locations)

Analysis of Faults and Incipient Faults

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

\[\text{(Same Fault at Different Locations)}\]

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Graphical Concepts

- **Lissajous Curves**\(^6,7\): 

\[ v(t), i(t) \]

WMU 1

Plot \( v(t) \) versus \( i(t) \)

\[ v_1(t), i_1(t) \quad v_2(t), i_2(t) \]

WMU 1

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

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Phasor Concepts

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

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Phasor Concepts

- Phasor Representations During an Event:\n
  ![Graphs showing phasor representations](image)

  **Fundamental**

  **3\(^{rd}\) Harmonic**

  **5\(^{th}\) Harmonic**

  **PMU**

  **Harmonic PMU**

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Transient Event Location Identification

- Finding the Cause of Transient Events:\(^\text{10}\):

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

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

Equivalent Circuit in Dominant Event Mode

Further Reading


Thank You!

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