

# Experiences of Using Synchrophasors at Duke Energy

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IEEE PES Tutorial

July 19<sup>th</sup>, 2016

# Duke Energy's Phasor Plans

- Carolinas West
  - Currently have 125 PMUs installed at 58 substations
  - Received \$4M DOE Smart Grid Ivestment Grant (SGIG) for synchrophasor installation completed May 2013
    - Upgrade of Substation Communications from Serial to IP
    - 13 - 500kV, 96 - 230kV, 10- 100kV, and 6 - 24kV PMUs
    - Covers all 500kV and 230kV substations
    - Multiple Phasor Data Concentrators (6 total)
    - Visualization Software (EPG's RTDMS)
    - Post Event Analysis Tool (EPG's PGDA)
    - SAN Storage for PI Historian
    - Alstom EMS Upgrade to 2.6 allows integration of phasors
    - SIEGate device to exchange data with external entities



# Duke Energy's Phasor Plans

- Duke Energy Progress and Florida
  - 4 PMUs in each location by end of 2014
- Additional PMU Location Considerations
  - At point of interconnection for large generators
  - On High Voltage any time existing capital work requires an outage (reconductoring, terminal upgrades, etc.)

# Major operational applications using phasor data

- Wide-area situational awareness (Visualization)
  - RTDMS by EPG
  - Deployed in control room Spring 2014
  - Operational August 2013
- Post-Event Analysis & Model “Validation”
  - PI Processbook
  - PGDA by EPG
  - Operational August 2013
- State estimation
  - Alstom EMS
  - Operational December 2012 (after upgrade to 2.6 Platform)

All applications are being currently deployed to our operations support engineers and control rooms.

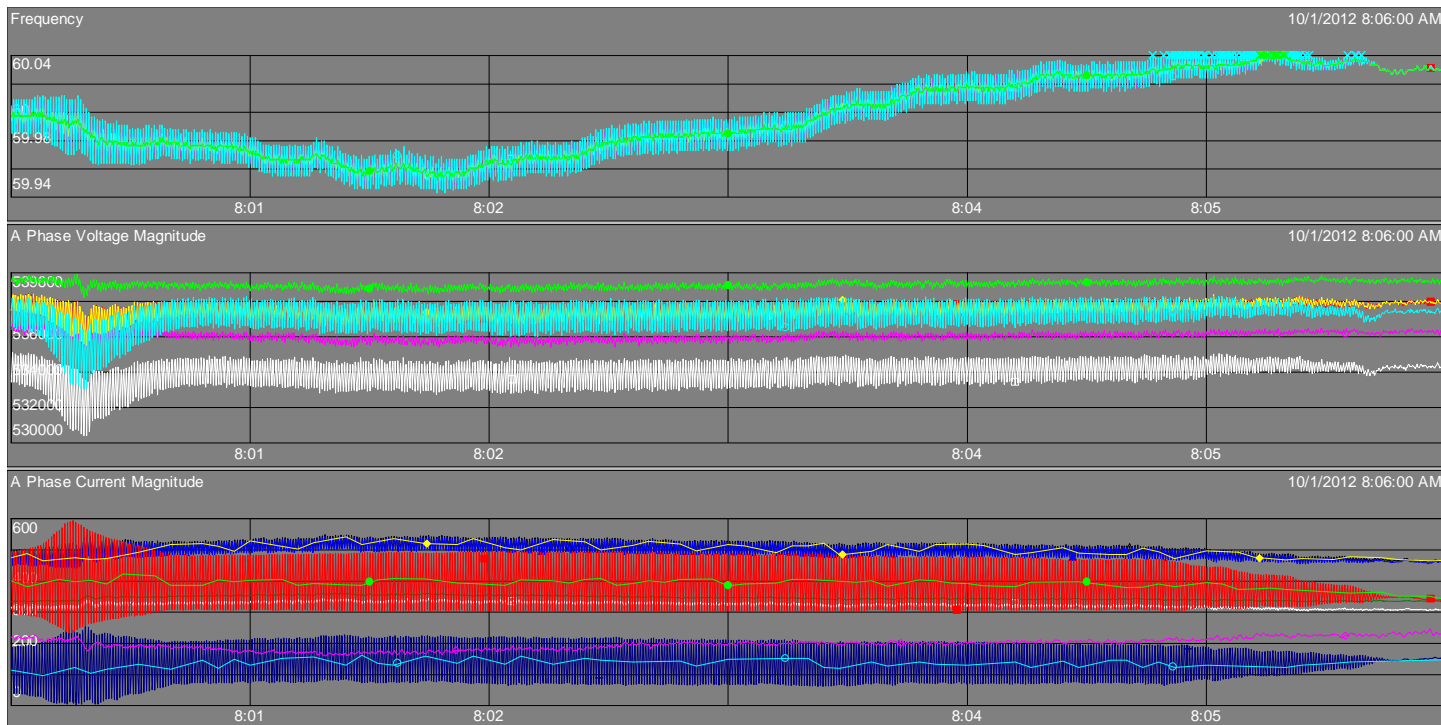
# Success Stories

- A unit's control system (AVR) misbehaved as a result of a low voltage transformer fault. The plant wanted to know how low the voltage dipped and could not see via SCADA. Using phasors, we were able to determine the voltage on the 230kV dipped to 150.6kV momentarily, well outside the control system tolerances.



# Success Stories

- A nuclear station reported MW oscillations created by the Transmission System when the 500/230kV transformer at a nearby station was outaged. Using the PMU data, we were able to determine that a nearby hydro unit was oscillating and use this information to tune some setpoints within the units to limit the oscillations.



# Success Stories

- Lightning initiated an event where a 100kV breaker was slow to trip, causing a fault to stay on the system for 2 seconds. As a result, the 230 to 100kV transformers at the station tripped by overload and Zone 2 protection was engaged. In addition, a tree was found in a portion of the cleared 100kV lines leaving the station. The magnitude and time duration of the fault was accurately captured by PMU data, making analysis more efficient.



# Challenges and lessons learned

- What have been your biggest technical challenges to date?
  - Complex network architecture
- What have been your biggest programmatic or execution challenges to date?
  - Coordination between field personnel and engineering groups
- Other lessons or insights about
  - PMU and PDC Performance – Data flags showing “valid” don’t always mean data is good quality
  - Frequency of new software releases – PDC and Applications
  - Communications system design and performance – High availability has been designed in-house because many vendors have not considered yet; UDP protocol worked best for us because of latency
  - Interoperability – sometimes challenging to integrate different vendors’ tools because of proprietary software
  - Physical or cyber-security – Need to be ready to accommodate ever-changing requirements
  - Data archiving – Difficult to anticipate necessary storage size with compression tuning parameters
  - Time Synchronization – COAX cable limitations
- Research needs – Analysis performed by back-hall operators transitioning to real-time applications that can be used by the control room operators to increase situational intelligence



# Synchrophasor Training

- General training on Phasor Technology, specialized on Visualization and Post-Event Analysis tools
- Training Operators, Engineers, and Planners separately
- General training provided in pre-scheduled quarterly sessions (not phasor specific). Specialized training provided as needed (about a day per application).
- Developed by in-house phasor SME's
- Currently no shareable training information

# Phasor data-sharing

- Currently not sharing in industry because edge device not yet installed, plan to share in the future
- Sharing some data for research purposes
  - Universities and Data Analytics companies
  - Various projects including baselining, fault location, stability analysis, situational intelligence, generator model validation

# Synchrophasor Research Effort

- Research Team
  - Duke Energy
  - SAS Institute
  - North Carolina State University
- Goal: develop tools that provide useful information for real-time operations.
- Short-Term Voltage Stability Assessment
  - Lyapunov Exponent
  - Decision Tree
- Event Detection and Identification
  - SAS Event Detection Algorithm
  - Similarity Analysis

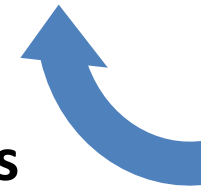
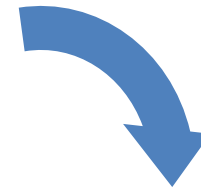


# Voltage Stability

## Using Simulation Data for Prediction and Determining Critical System States

### Problem: How to predict events which are rare

- situations that are vulnerable to voltage collapse



### Solution: Learning loop system using simulation data and predictive models

- Use PSS/E simulation software to generate cases for voltage stability
- Build decision tree and use Lyapunov Exponent to identify vulnerable situations

# Lyapunov Exponent

- Characterizes the rate of convergence or divergence of non-linear dynamical systems.
- For stable/unstable systems the Lyapunov Exponent will be negative/positive

- General Equation

$$d(f^n(x_0), f^n(x_0 + \Delta x_0)) = e^{\lambda n} d(x_0, x_0 + \Delta x_0)$$

$$\lambda = \frac{1}{n} \ln \left[ \frac{d(f^n(x_0), f^n(x_0 + \Delta x_0))}{\Delta x_0} \right]$$

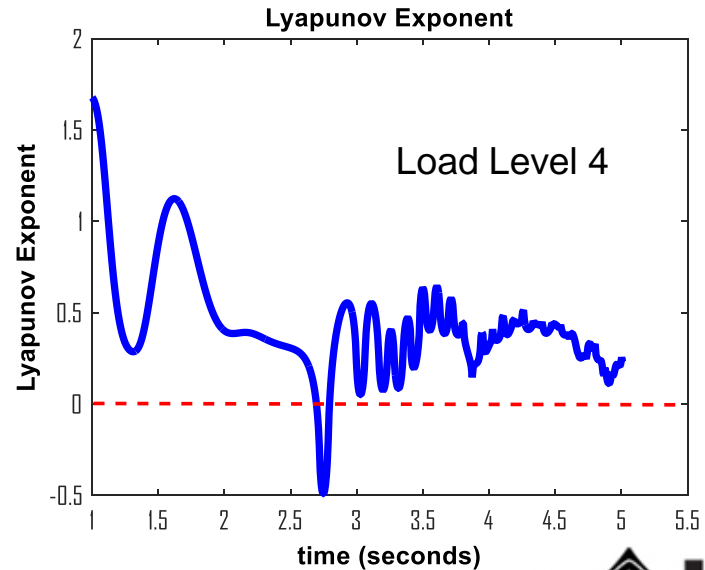
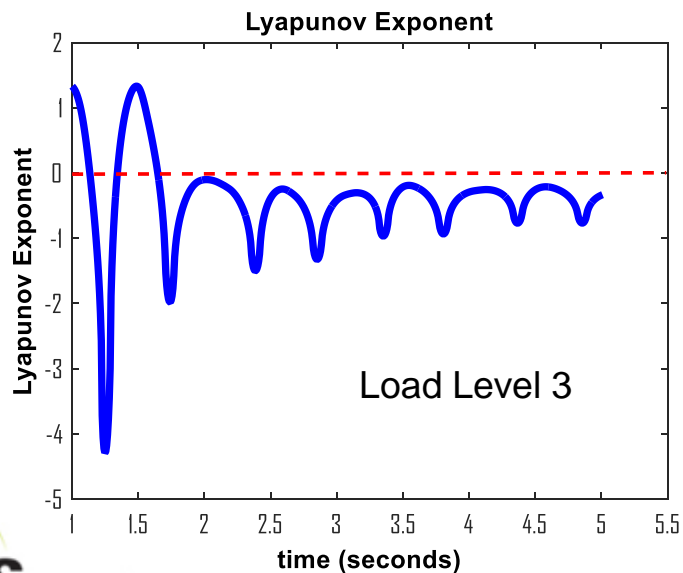
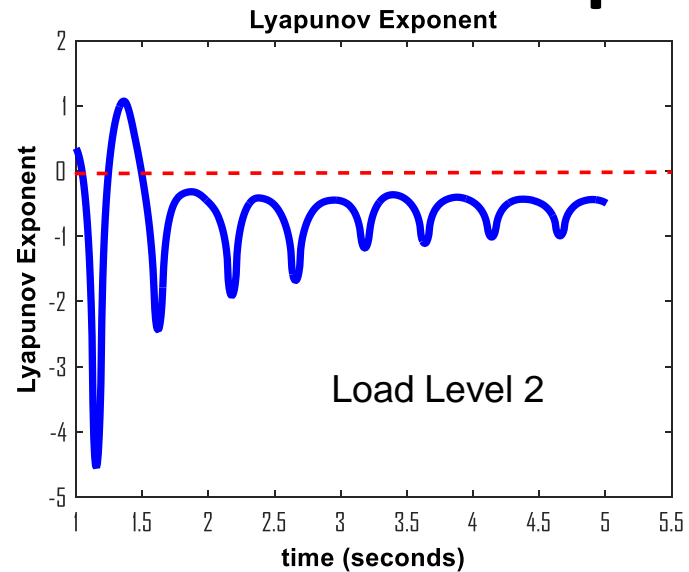
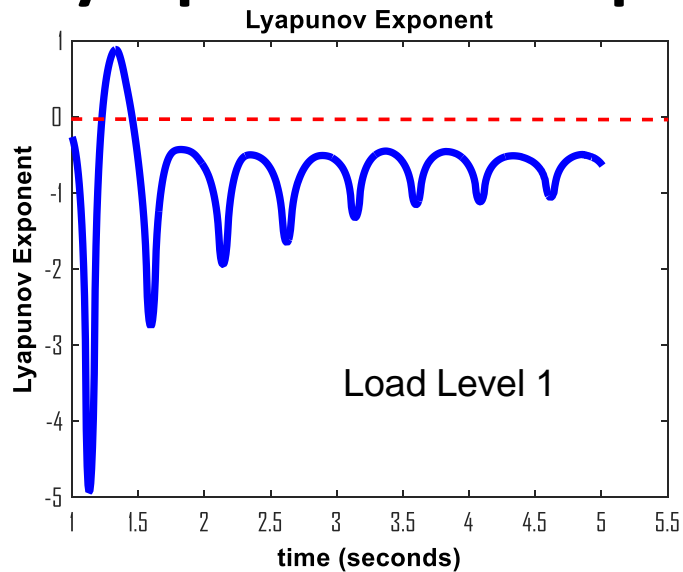
[reference 1]

- Time Series Calculation

$$\frac{1}{Nk\Delta t} \times \sum_{m=1}^N \log_{10} \frac{|v_{(k+m)\Delta t}^i - v_{(k+m-1)\Delta t}^i|}{|v_{m\Delta t}^i - v_{(m-1)\Delta t}^i|}, k > N$$

[reference 2]

# Lyapunov Exponent - Line Trip



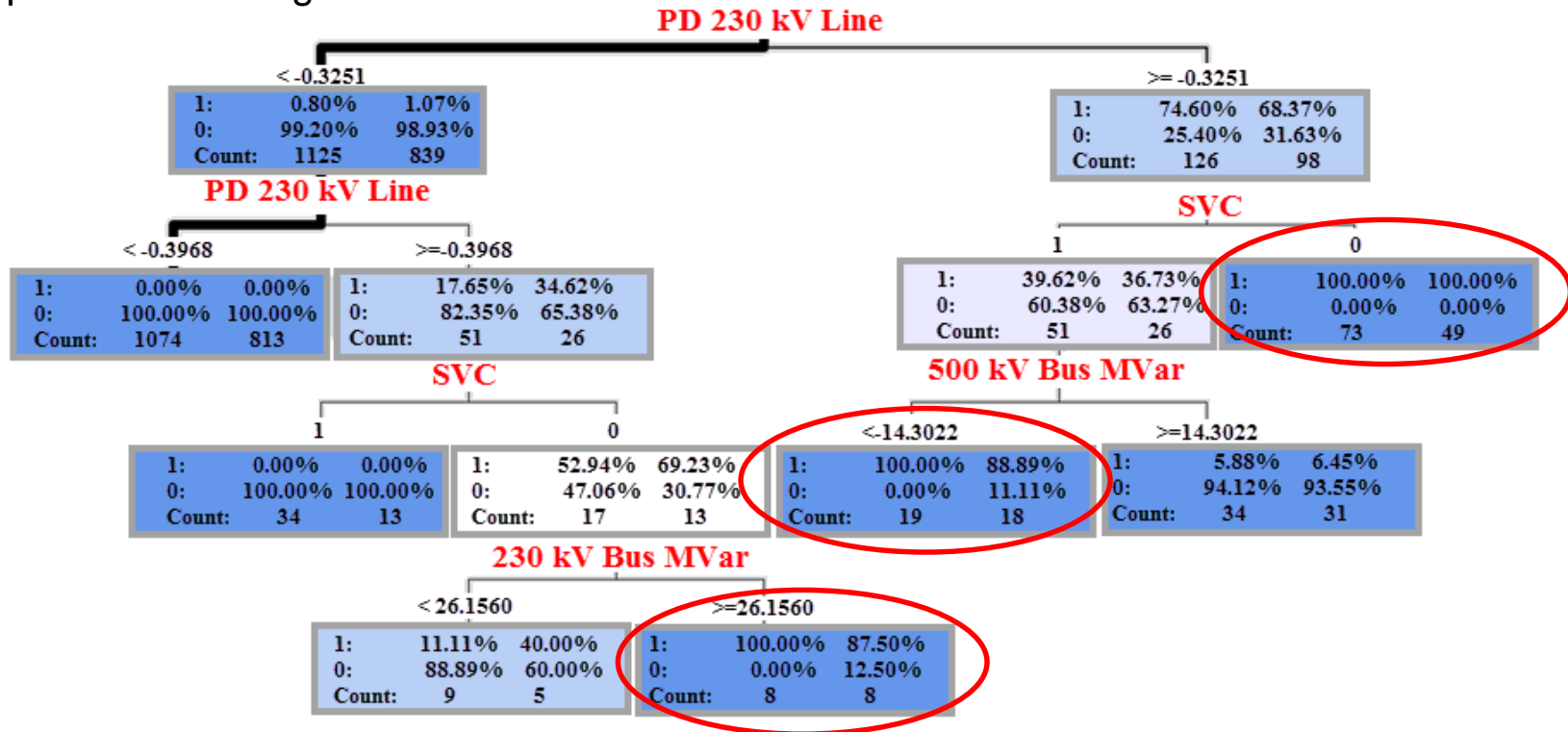
# Decision Tree - SAS Enterprise Miner

- Data collected from over 3,000 simulations for a single contingency
- 3 sets of rules that can be applied to incoming PMU data

Results from Testing Data Set

Statistics	Train	Validation
1:	8.23%	8.11%
0:	91.77%	91.89%
Count:	1251	937

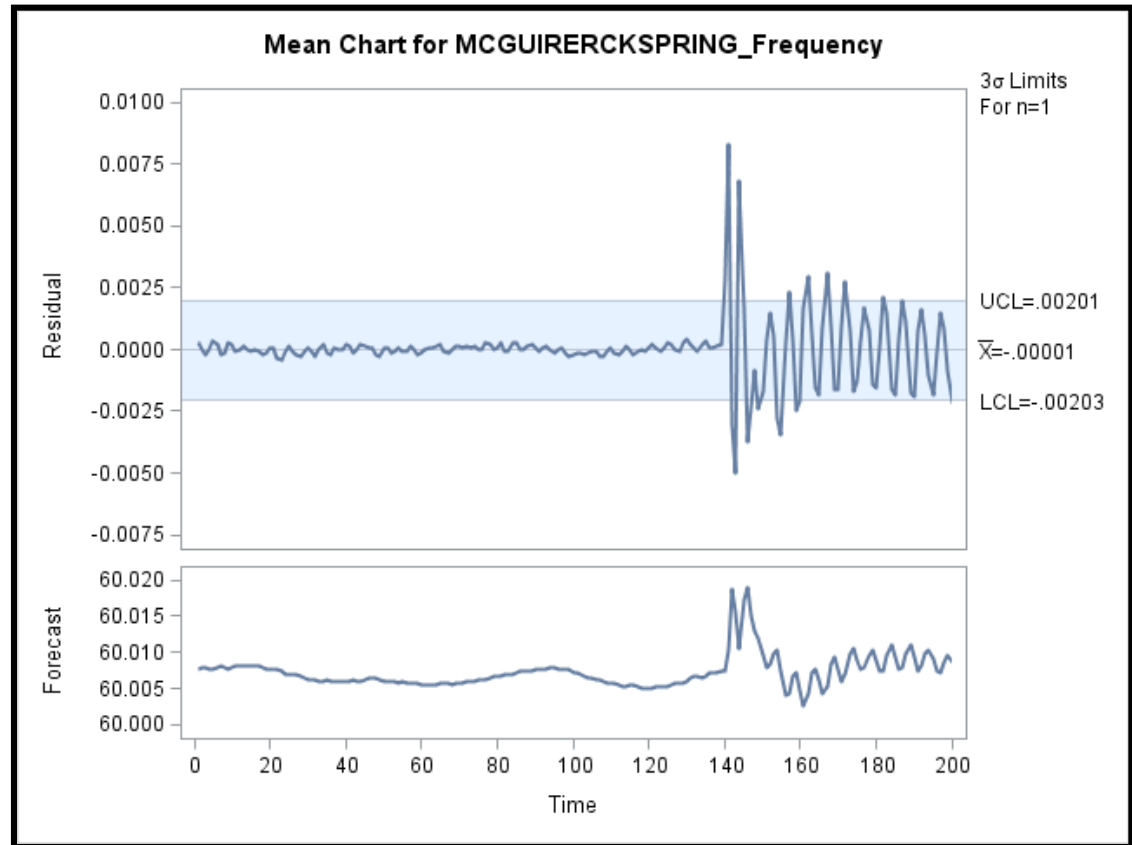
False Negative	True Negative	False Positive	True Positive
3	857	4	73



# Event Detection

**Solution: Forecast expected values and detect deviations**

- Residual – difference from expected value
- Expected value based on time series model



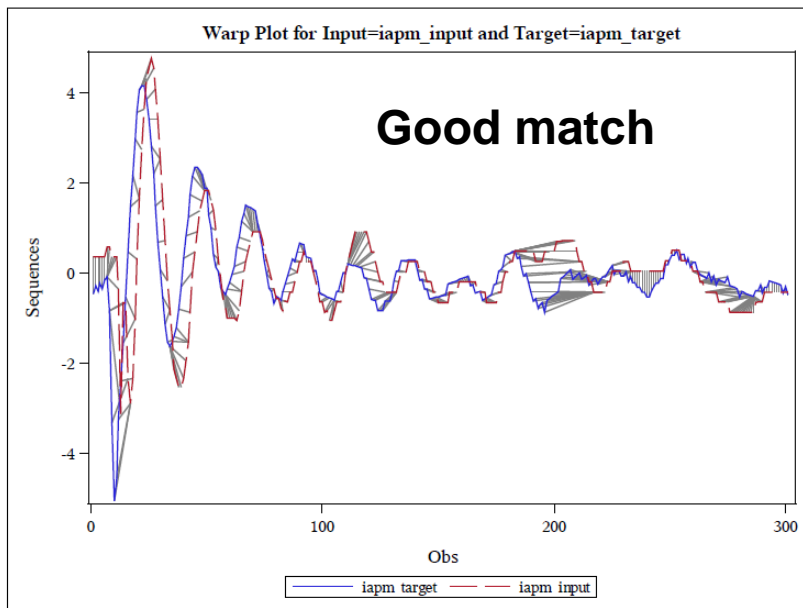


# Event Identification

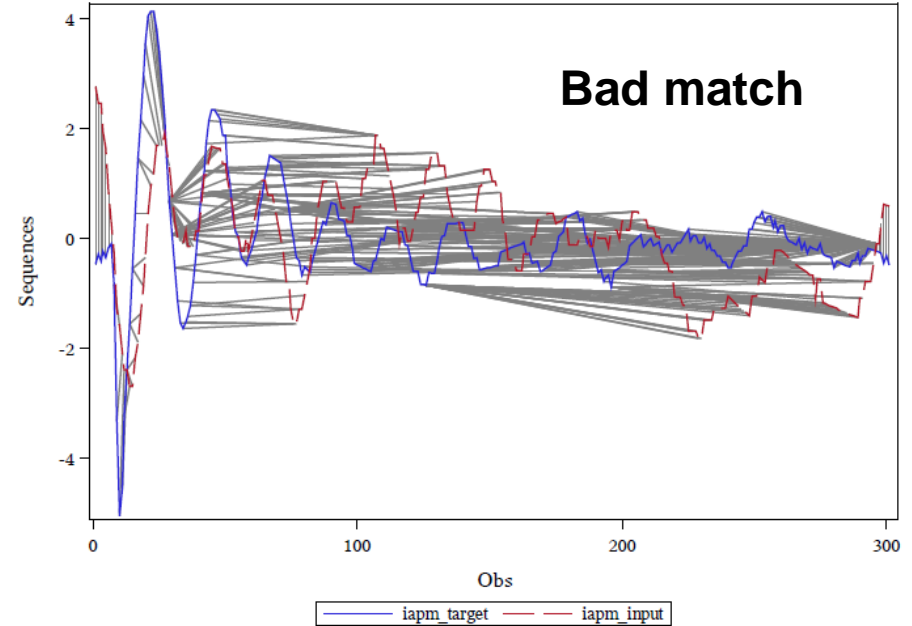
- Similarity Analysis

- Similarity between incoming stream and reference time series are measured and quantified

*The SIMILARITY Procedure*



Warp Plot for Input=iapm\_input and Target=iapm\_target



# Questions



# References

- [1] Lyapunov exponent: Lecture 24 Indian Institute of Technology Kharagpur. YouTube video <https://www.youtube.com/watch?v=-xSNqJQRoo4>. Accessed: 2014-10-10.
- [2] S. Dasgupta, M. Paramasivam, U. Vaidya, and V. Ajarapu, "Real-Time Monitoring of Short-Term Voltage Stability using PMU Data," 2013.