SYNCHROPHASOR DATA QUALITY ACTIVITY RESEARCH UPDATE

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SYNCHROPHASOR DATA QUALITY ACTIVITY
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FUNDING SUPPORT PROVIDED BY DOE-OE AND DHS S&T

Context

- Smart Grid initiatives envision very reliable synchrophasor data
- Power System operators report synchrophasor data significant gaps in data quality & availability

Goals

- Gain a fundamental understanding of phasor measurement challenges
- Characterize synchrophasor data quality (error, availability, reliability)
- Identify methods for **detecting** and **correcting** faulty synchrophasor data
- Attribute defective synchrophasor data to synchrophasor **data generation failure** at the measurement site, **losses in the data transmission** process, or **data processing errors** at intermediate or final data storage locations.

Purpose

- Outline the Activity's concept for systemically characterizing synchrophasor data quality
- Describe on-going research efforts – Accomplishments and Plans

Outline

- Synchrophasor Data Quality on ATC's Transmission System

  Kenta Kirihara

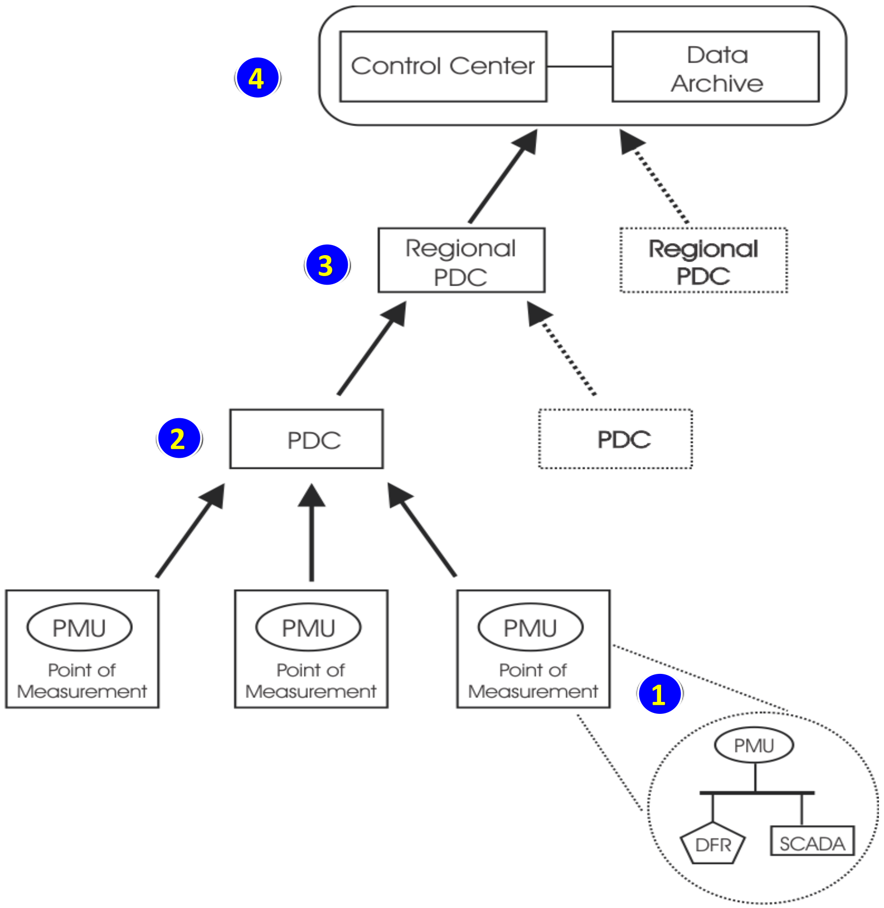
- Visualizing Cyber Security Requirement Relationships in NISTIR 7628, *Guidelines for Smart Grid Cyber Security*

  Dan Long, Brianna Drennan, John Lee

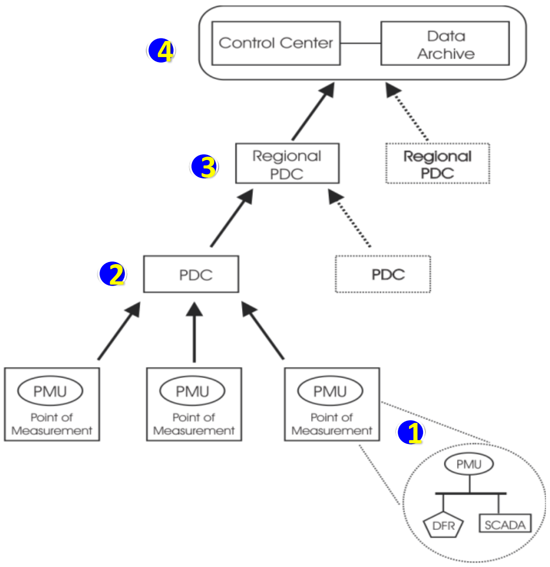
- Open-box Phasor Measurement Unit Development

  Bogdan Pinte, Mike Quinlan

Nominal Synchrophasor Data Network



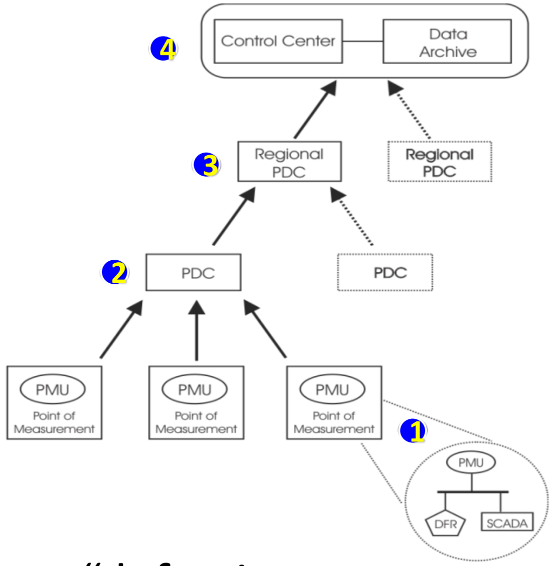
Research Plan



LEVEL 1 – POINT OF MEASUREMENT

- Synchrophasor data sets with known “defective data” at Levels 1, 2, 3, & 4
- Non-PMU data (e.g. data fault recorders, SCADA measurements) from same locations and times to be correlated with PMU data to evaluate data availability and quality
- System information, metadata, system topology to convert “raw” data into data forms that permit analysis

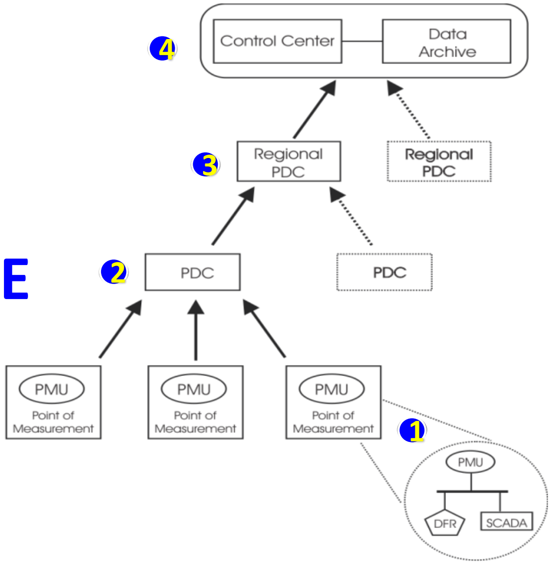
Research Plan



LEVELS 2 & 3 – NETWORK TRANSMISSION

- Synchrophasor data sets at levels 2 & 3 that include known "defective data" corresponding to level 1 and 4 data sets
- Relevant technical information about the network paths, protocols, and equipment to evaluate, assess, and attribute synchrophasor data loss causes.

Research Plan



LEVEL 4 – CONTROL CENTER and POINT of USE

- Synchrophasor data sets at level 4 that include known "defective data" at levels 1, 2, & 3 and corresponding state estimator solutions
- Relevant technical information about the network paths, protocols, and equipment to evaluate, assess, and attribute synchrophasor data loss causes.
- Corresponding metadata describing the signals, storage compression, and network topologies (if necessary) needed to convert and interpret the data.
- Data sets should be accompanied with information needed to convert and correlate C37.118, concentrated, and archived data into forms that can be analyzed.

Identified Error Sources and Proposed Error Type Classifications[1]

Error Source	Level(s)	Error Type
Status Code Errors	1,2,3	Data Processing
Data streams disordered / shifted in processing	1,2,3	Data Processing
Loss of PDC Configuration	2,3,4	Data Processing
Improperly configured PMUs (window length/ windowing method)	1	Digital Signal Processing
Frequency calculation discrepancies (C37.118.2005)	1	Digital Signal Processing
Quality of Metering	1	Equipment Specification
Accuracy Issues (CT/PTs not properly rated for application)	1	Equipment Specification
Calculation Uncertainty – Vendor Equipment operating differences	1	Equipment Specification
Metering Locations Separated by Breakers	1	Installation
Meters not installed at recorded locations	1	Installation
PMU data not named IAW policies	1	Installation
Asynchronous local behaviors (e.g. DC bias injections during solar storm)	1	Measurement
Malformed Network Packets	2,3,4	Network Failure
Network Data Loss	2,3,4	Network Failure
Mislabeled Phasor Data Streams	1,2,3	PMU Configuration
Differences between PMU Manufacturer calculation approaches	1	PMU Standards

Synchrophasor Data Quality on American Transmission Company's (ATC) Transmission System

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FUNDAMENTAL CHALLENGES

- Smart Grid initiatives envision very reliable synchrophasor data, but…

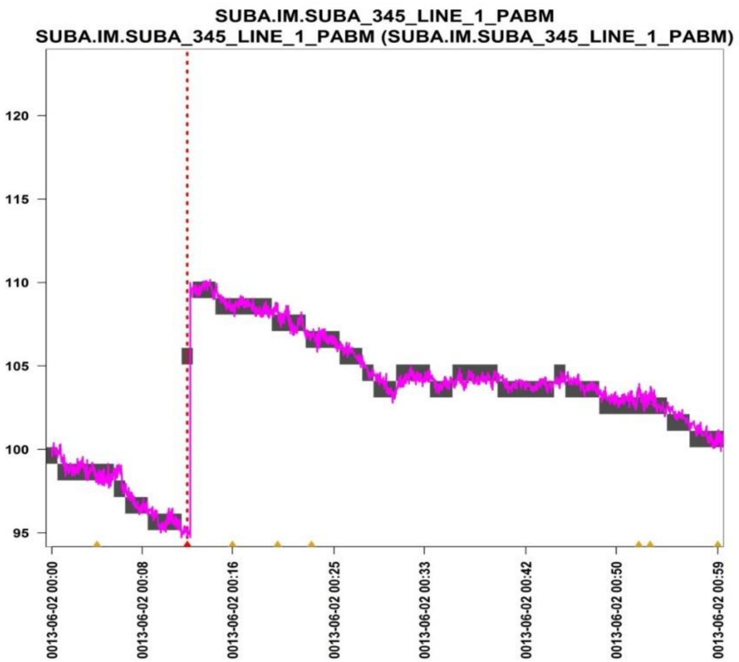
  …through early 2013, Power System operators report synchrophasor data significant gaps in data quality & availability

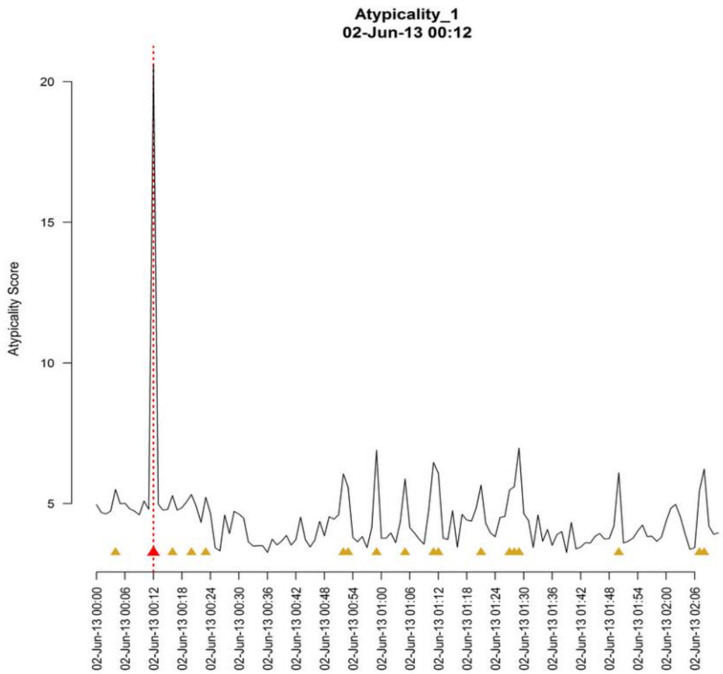
- Anemic partnerships between industry and researchers to facilitate synchrophasor data “discovery” research… specifically access to data with detailed context (i.e. system topology and operating state)
- Systematically characterizing synchrophasor data quality; easily recognizing and attributing faulty synchrophasor data
- Developing understood synchrophasor data signatures for system state changes to generate real-time alerts for operators…

  …and conversely recognizing extra-ordinary synchrophasor data sequences as malicious compromise attempts

PREVIOUS PROGRESS

- Sample data set of 20GB was received from American Transmission Company
- Using SitAAR(Situational Awareness and Alerting Report) developed by Brett Amidan of Pacific Northwest National Laboratory, signatures were found in the synchrophasor measurements





CHALLENGES PREVIOUSLY FACED

- Data set was far too small
  - Not enough time series data to investigate deeply
- SitAAR was far too complicated for use and computational time was expensive: 2 weeks for 3 PMUs, the time it took was 12 hours
  - Real-time integration was out of the question when clustering (memory limitation)
- Progress was difficult to showcase (beginner unfriendly)

ACQUIRING MORE DATA

After 2 years of effort, UIUC-ATC NDA has been signed by Jim Kleitsch of ATC and University of Illinois

Roughly **20TB** of Synchrophasor data (100 PMUs over the span of 2 years) is accessible for use

COMPUTATIONAL CHALLENGES

Fundamental questions:

Q: Is clustering necessary to detect anomalies in time series ?

---> Not really. There are other methods.

Q: Is clustering or some sort of computational method necessary to categorize events?

---> Yes.

Solution:

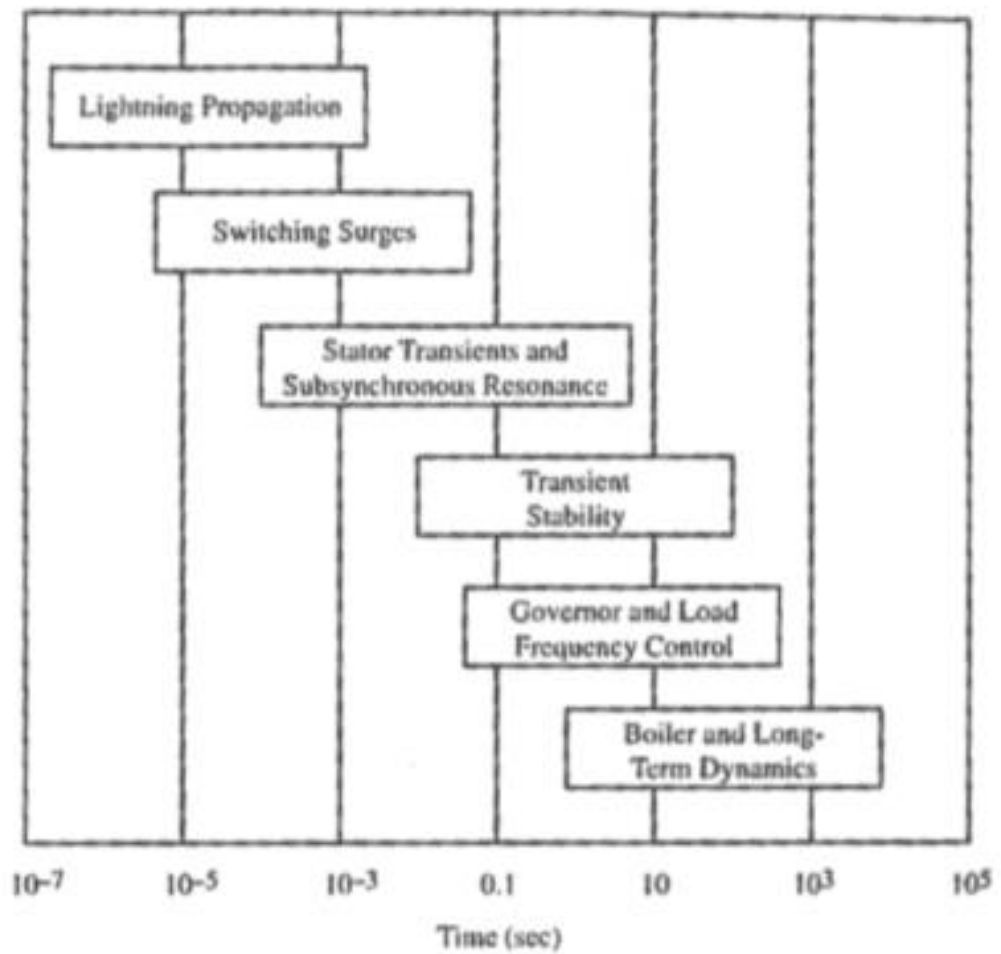
Use a computationally inexpensive technique to detect anomalies and categorize later.

EVENT DETECTION METHOD

Method:

By computing the density of 3000 points (100 seconds) in a sliding window for one phase of voltage magnitude, event is detected when more than 2 consecutive points are found outside four standard deviation.

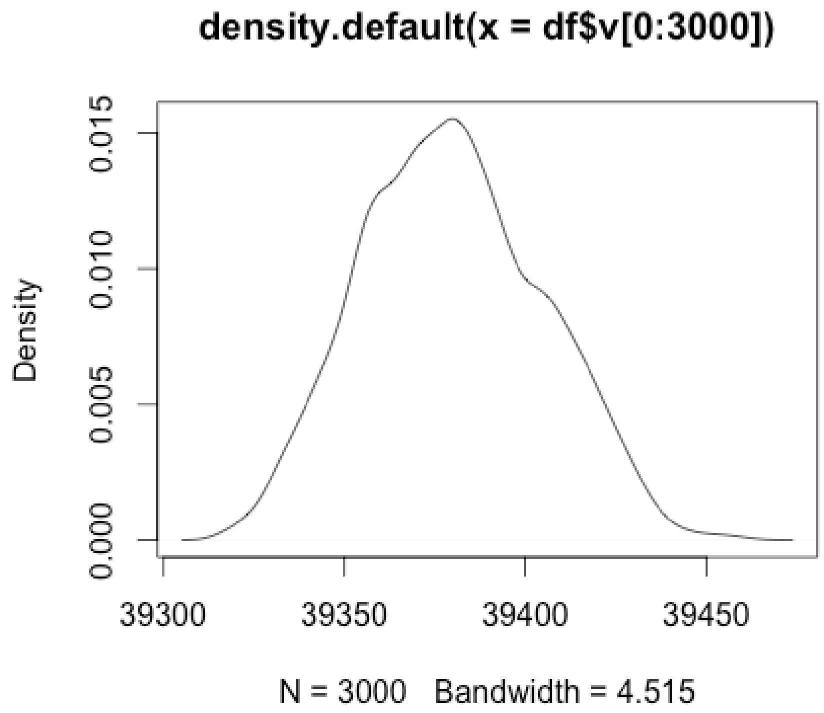
TIME WINDOW: WHY 100 SECONDS?



Time Ranges of Dynamic Phenomenon
Source: P. Sauer, M.A. Pai, "Power System Dynamics and Stability"

DENSITY FUNCTION

Due to **Central Limit Theorem**, the data points in a given window will form a psuedo-normal distribution



Given a perfectly normal distribution:

3σ → 99.7% of the data points

4σ → 99.93% of the data points

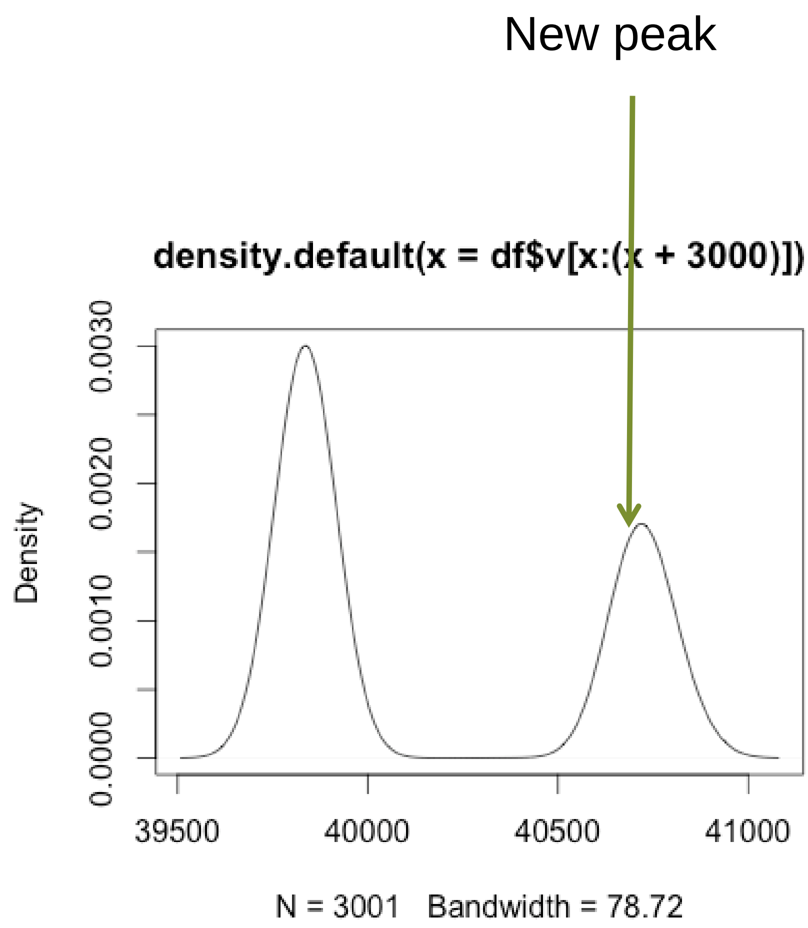
P(value>(μ+4σ)) twice consecutively is 1/250,000,000

EVENT DETECTION CONCEPT

Upon transience, density becomes multinomial

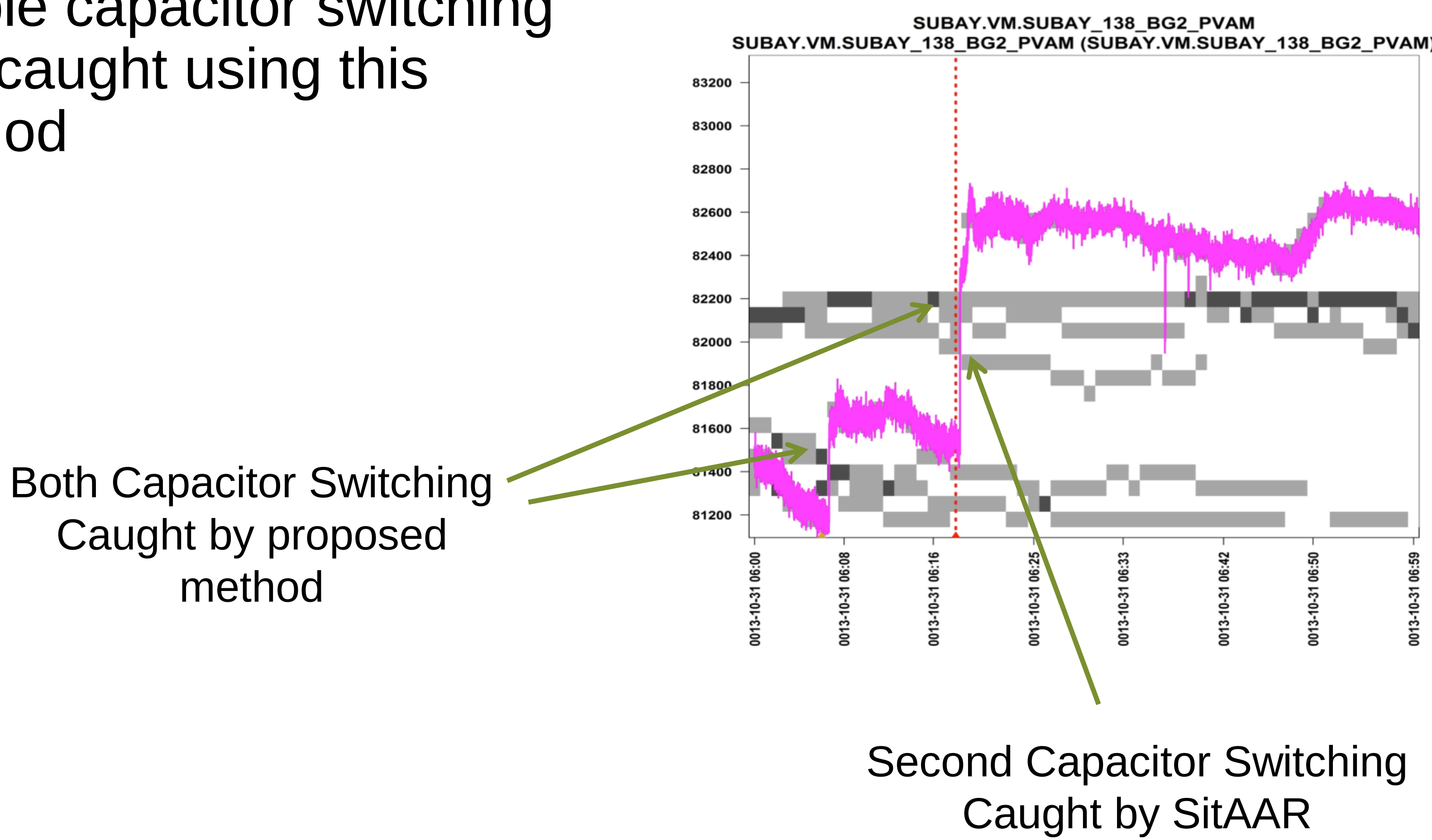
Method looks for the formation of the new peak

Very high confidence that this a real system change

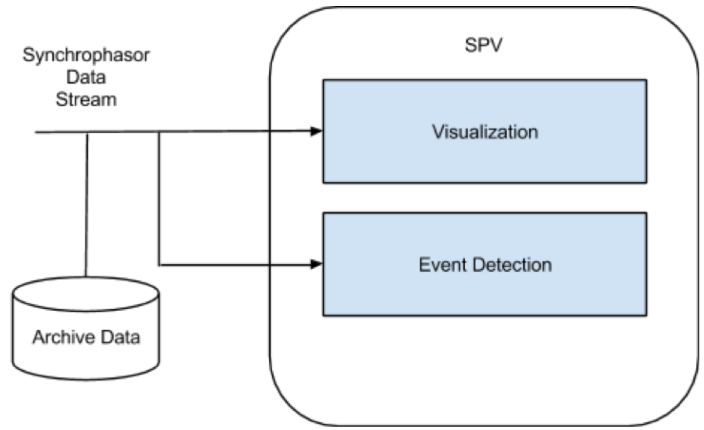


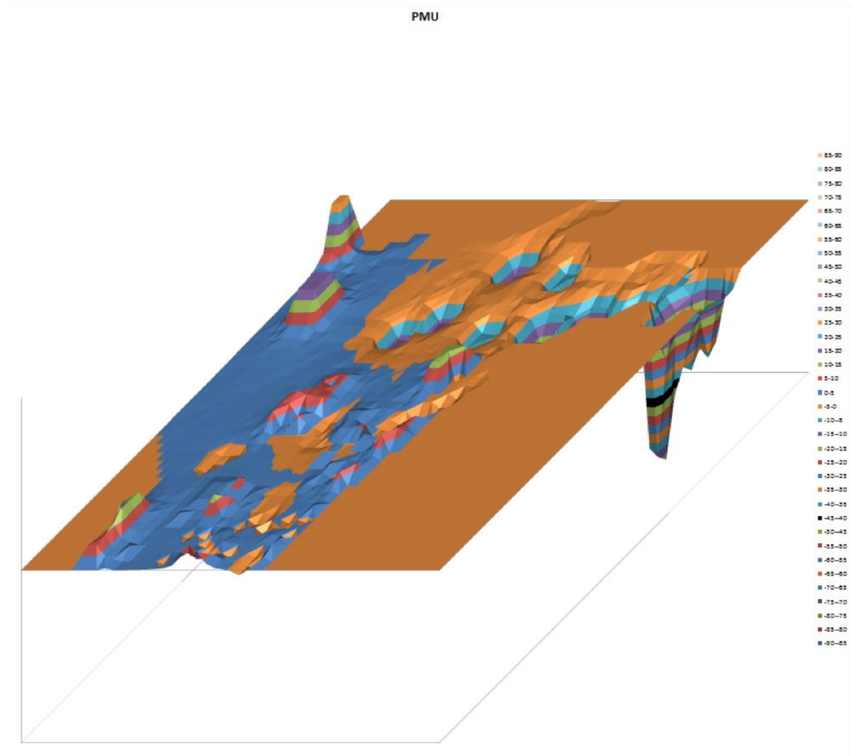
RESULTS OF DETECTION

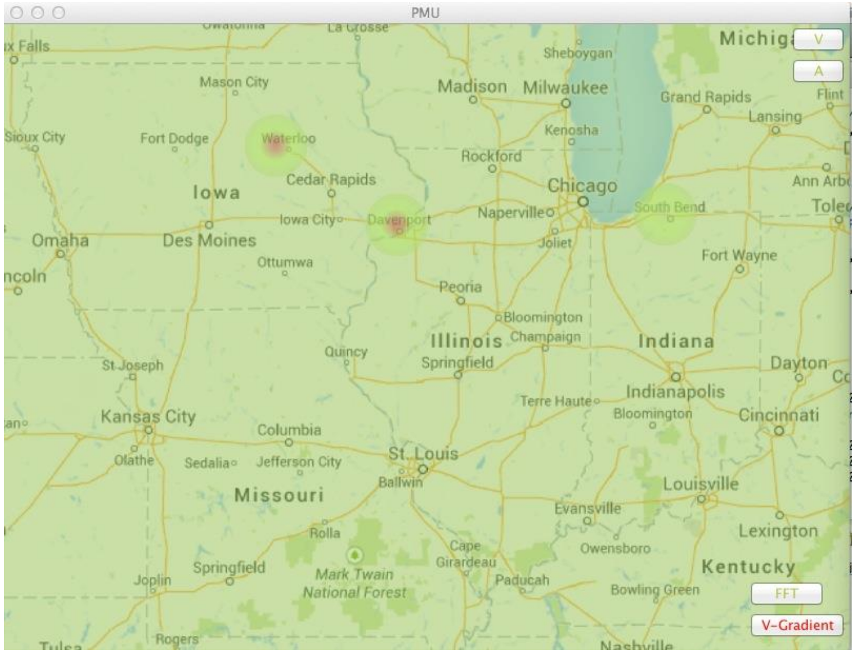
SitAAR and ATC confirmed double capacitor switching was caught using this method



VISUALIZATION







Angle Gradient (ATC)

Synchrophasor Visualizer

RESULTS

Success:

- Can successfully visualize events
- Was successful in validating one type of event: confirmed both by ATC and using a different outlier detection application

Next Step:

- Categorize the events found
- Test for more cases to determine success rate of algorithm
- Utilize cloud computing to extend the application to pattern detection

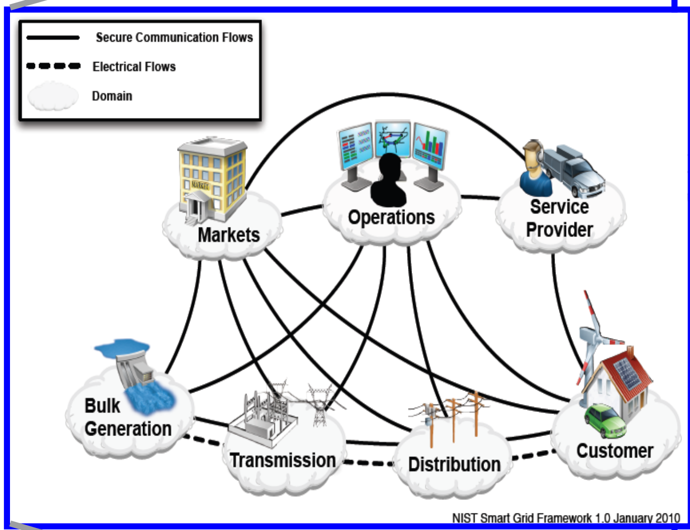
NISTIR 7628 Cyber Security Visualization

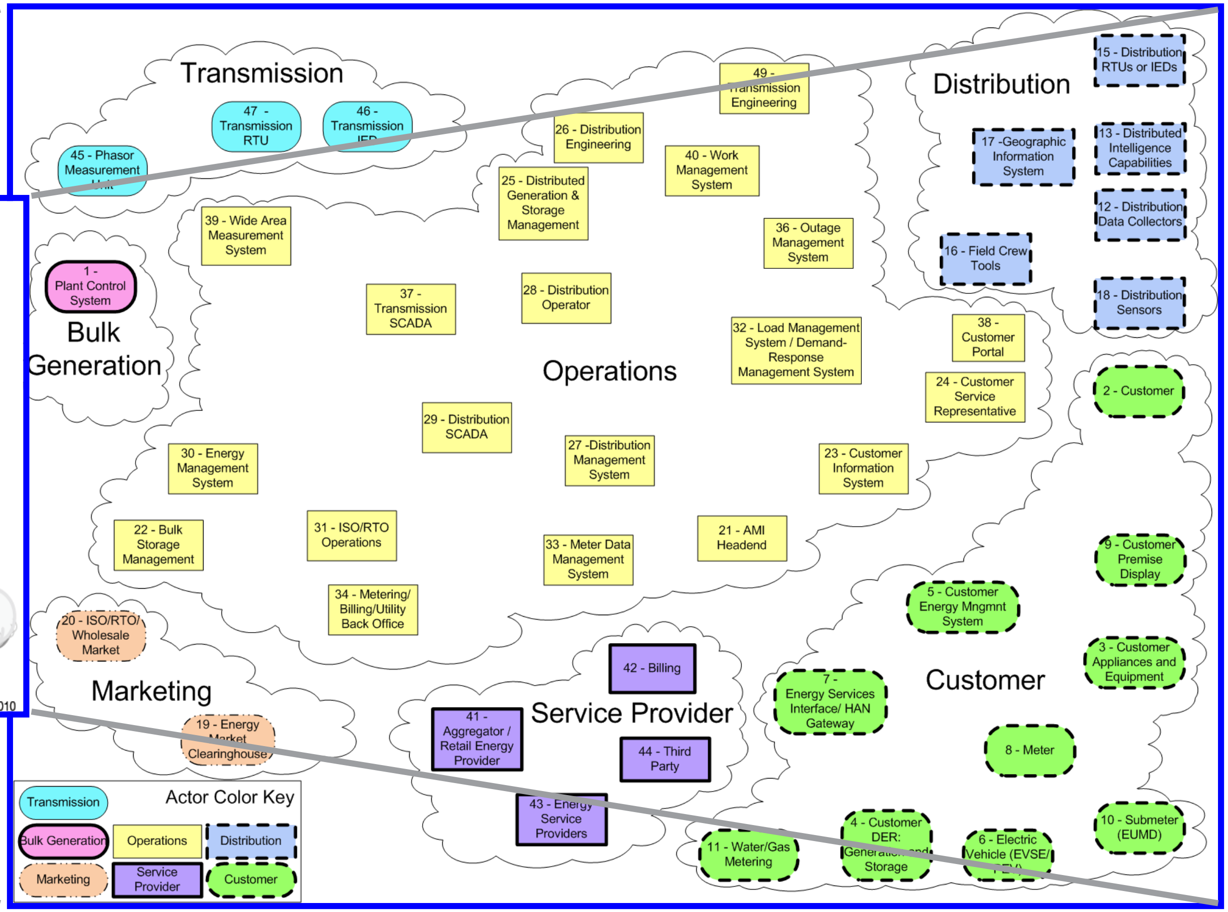
NISTIR[1] 7628, GUIDELINES FOR SMART GRID CYBER SECURITY

"NISTIR 7628 presents an analytical framework that organizations can use to develop effective cyber security strategies tailored to their particular combinations of Smart Grid-related characteristics, risks, and vulnerabilities."

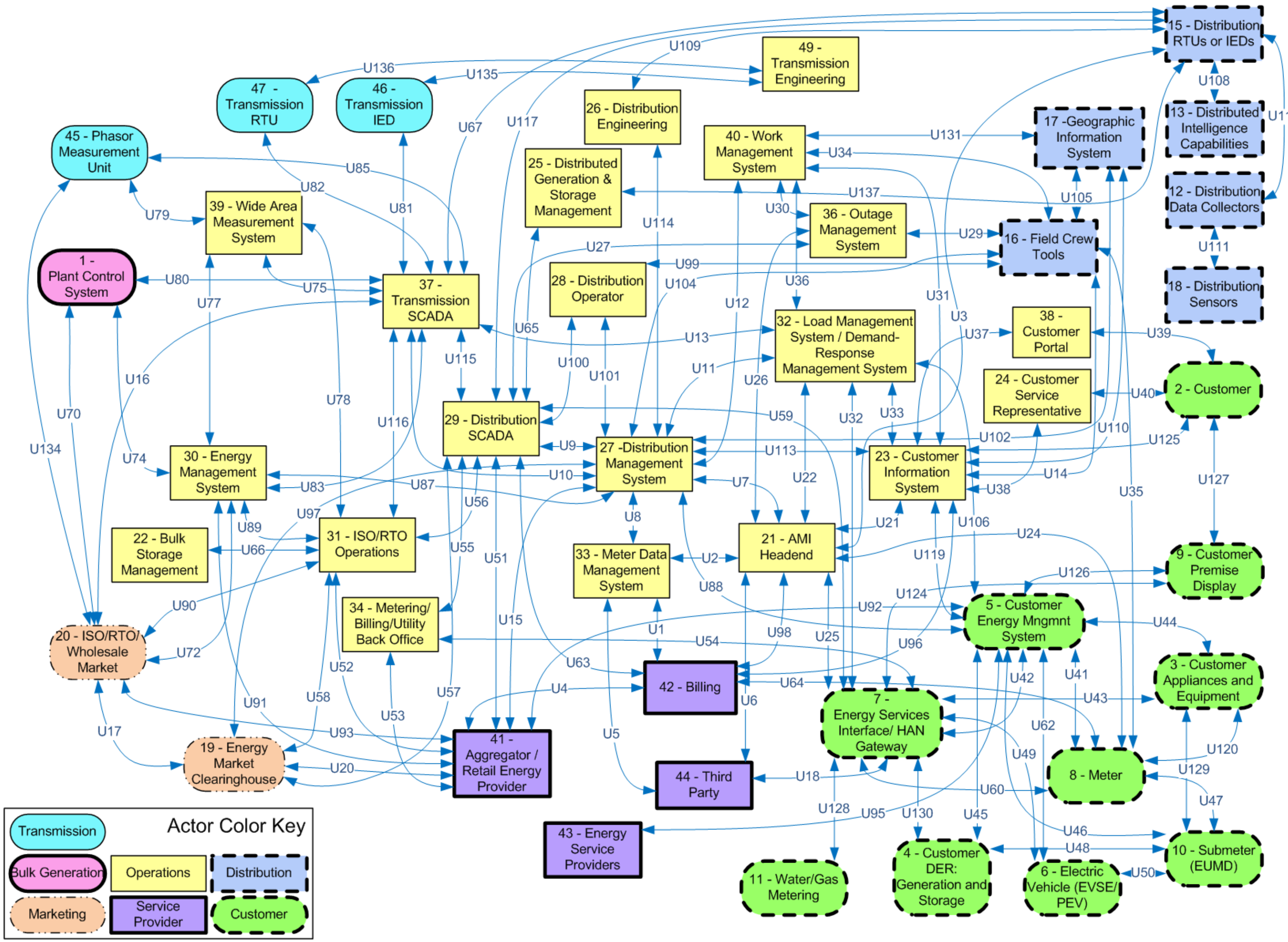
[1]NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY INTERAGENCY REPORT

NISTIR 7628 LOGICAL REFERENCE MODEL





NISTIR LOGICAL REFERENCE MODEL (CONT)



NISTIR LOGICAL INTERFACE CATEGORIES (CONT)

NISTIR 7628 Guidelines for Smart Grid Cyber Security v1.0 – Aug 2010

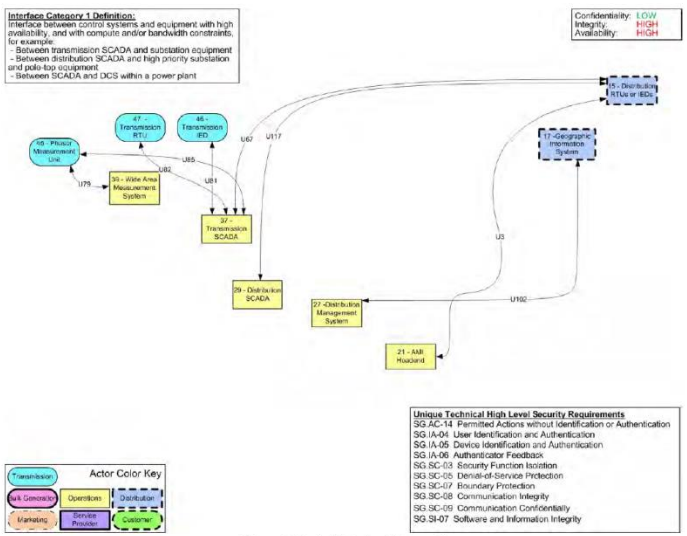


Figure 2-4 Logical Interface Category 1

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NISTIR 7628 Guidelines for Smart Grid Cyber Security v1.0 – Aug 2010

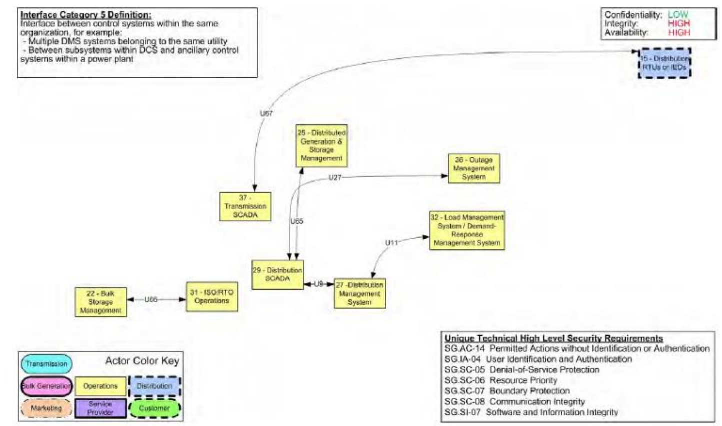

Figure 2-8 Logical Interface Category 5

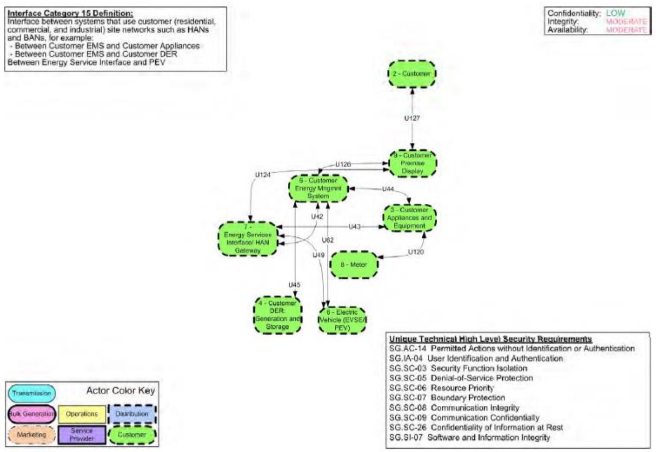

Figure 2-18 Logical Interface Category 15

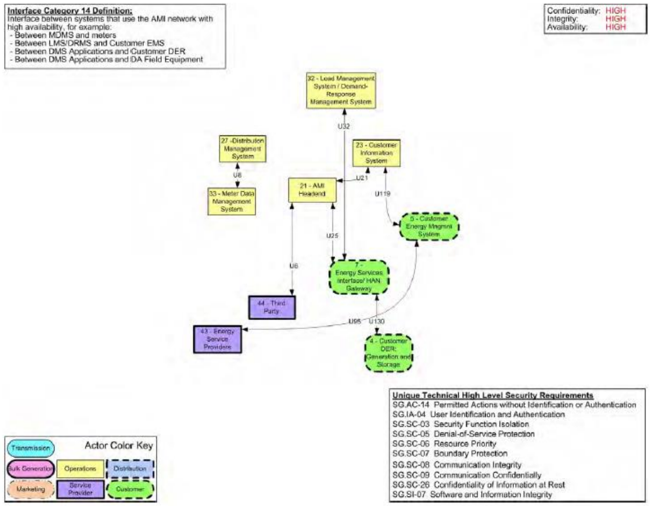

Figure 2-17 Logical Interface Category 14

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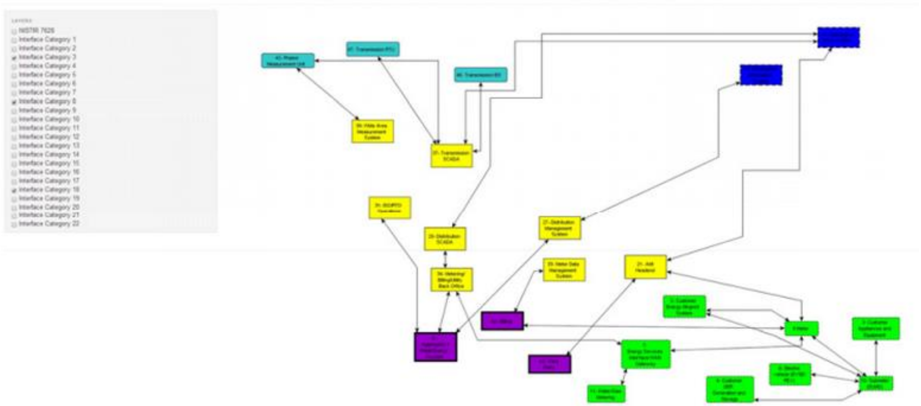
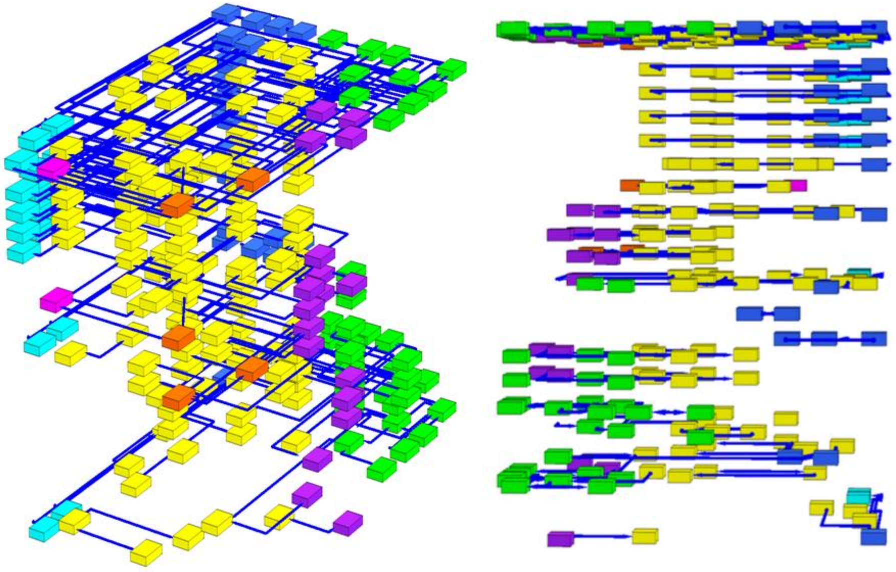
NISTIR REPRESENTATION

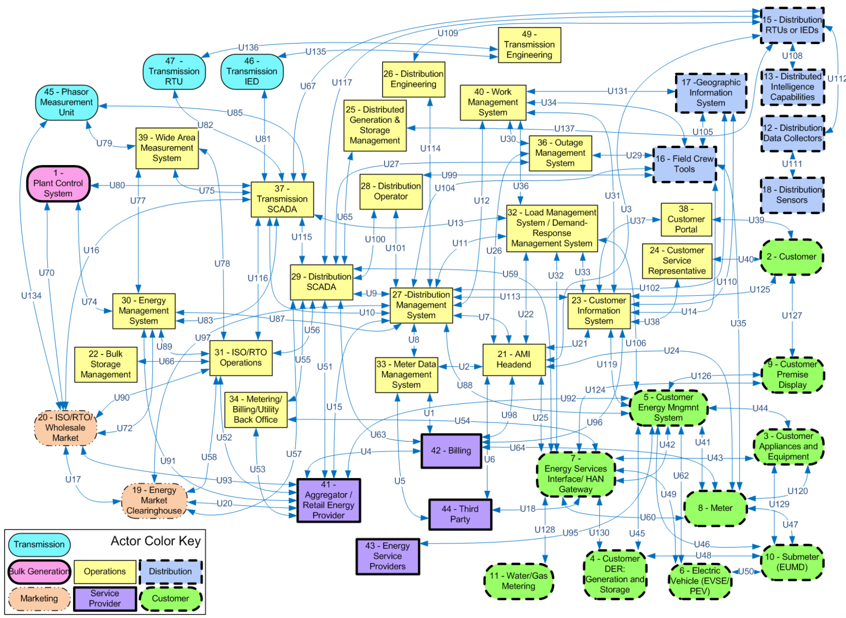


2D HTML Version

3D MATLAB Version



NISTIR 7628 VS TYPICAL CYBER NETWORK MAP



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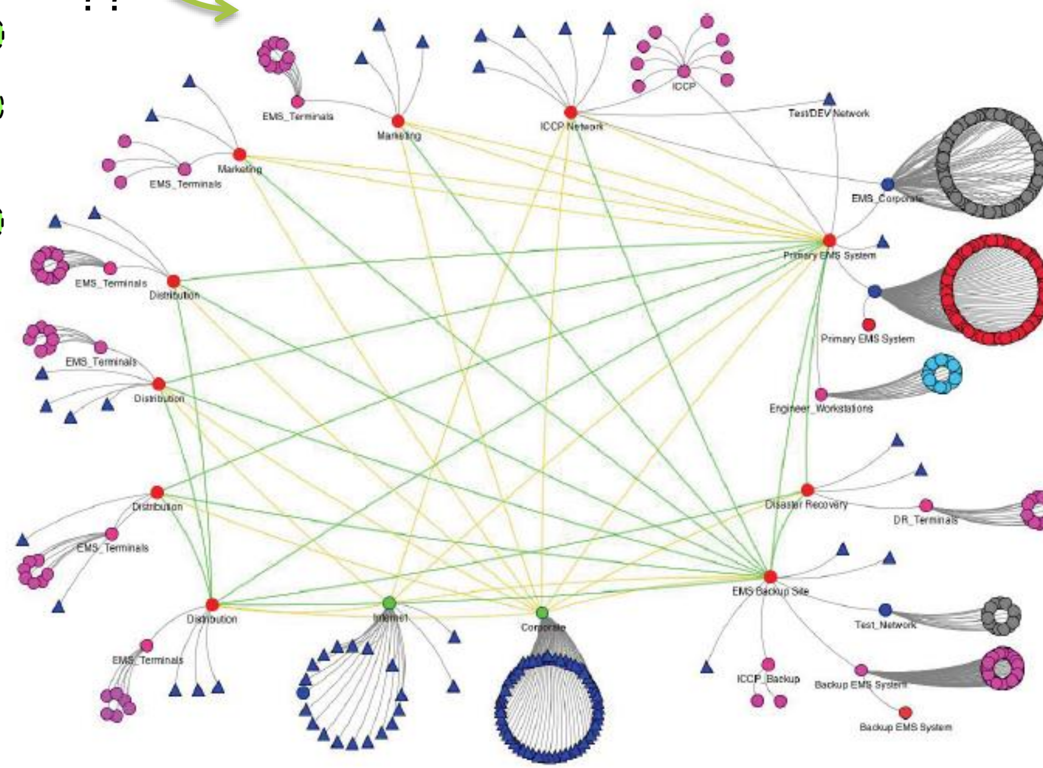
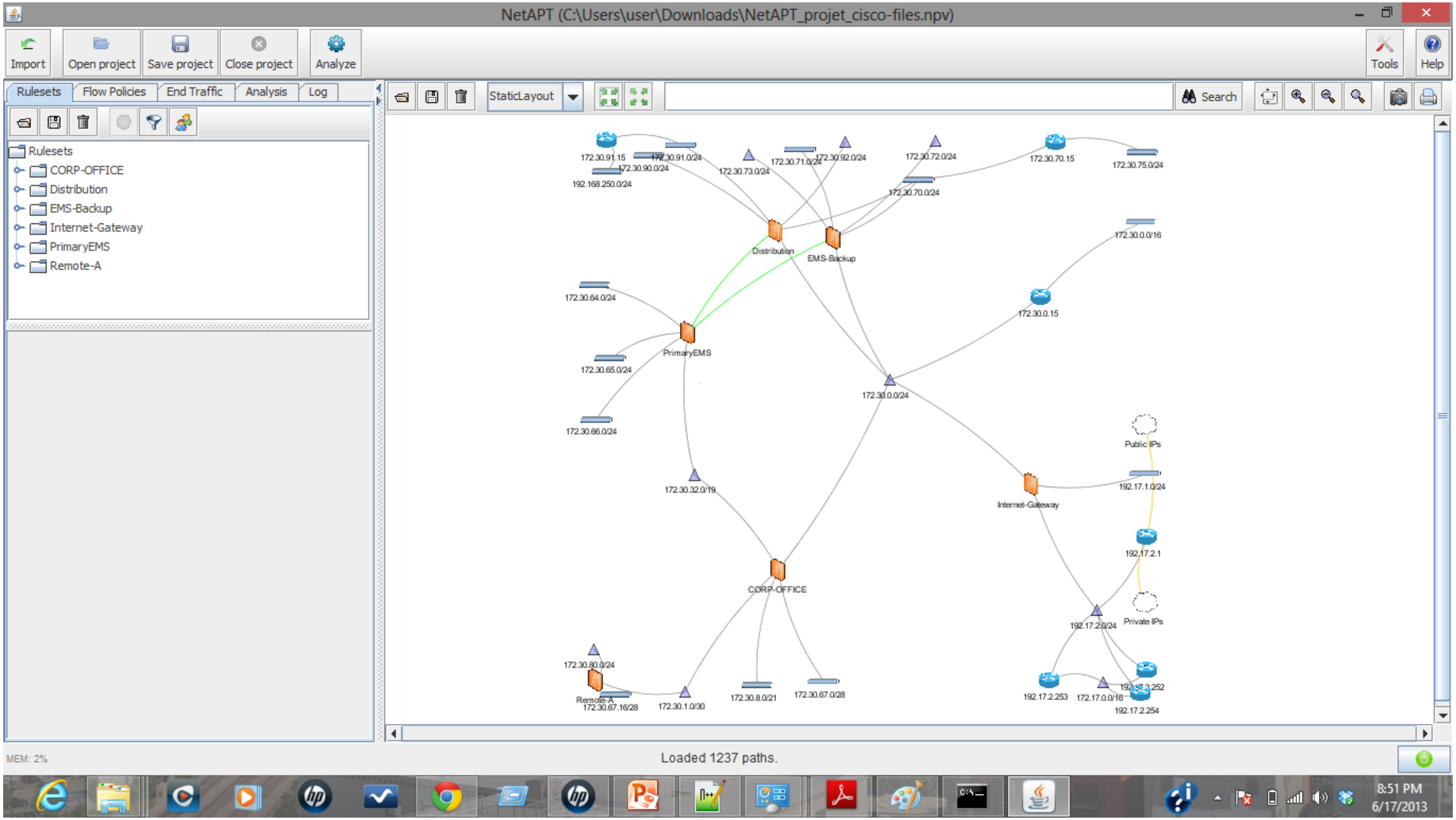


VISUALIZATION WITH NETAPT



Open Box Phasor Measurement Unit Development

MOTIVATION

- PMUs are one of the most important measuring devices in the future of power systems
- Ability to take synchronized measurements independent of location
- Key measurements:
  - Voltage: tells reactive power flow
  - Frequency: load-generation imbalance if not 60 Hz
  - Phase: direction of real power flow

OBJECTIVES

- Build / test an open-box PMU to understand the challenges of measuring, processing, synchronizing, and integrating synchrophasor data
- Investigate synchrophasor data quality issues – and identify remedies

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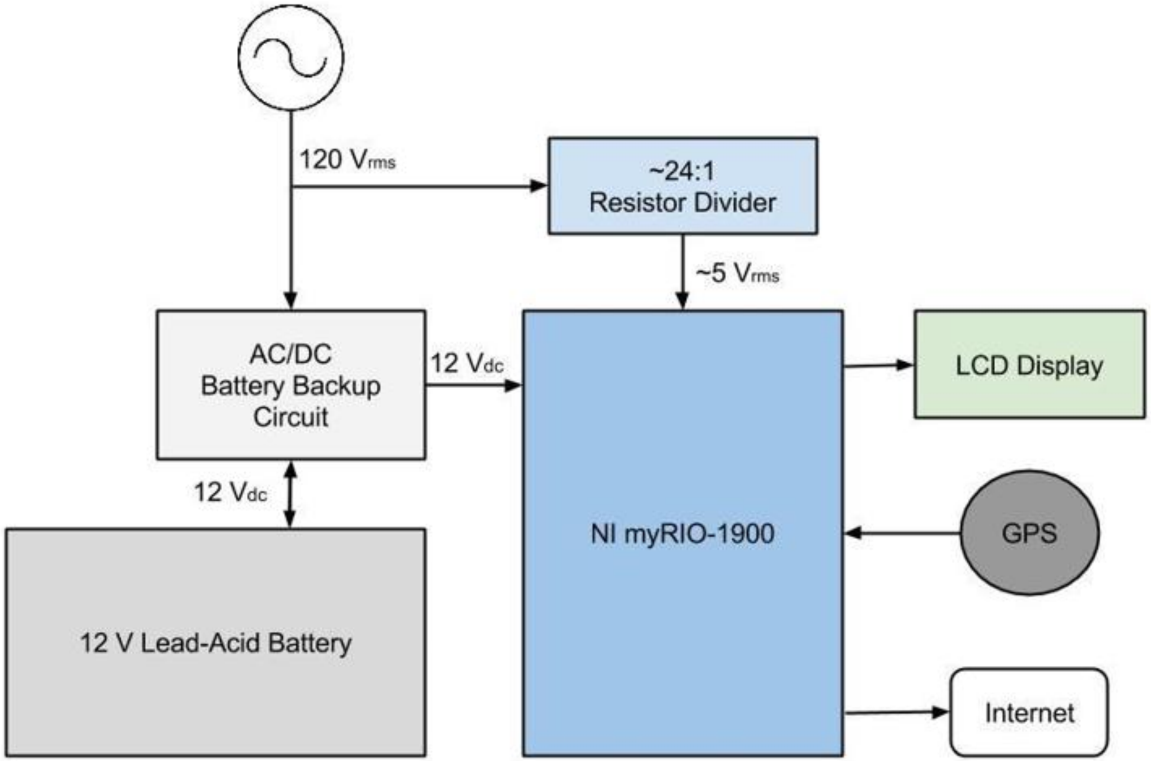
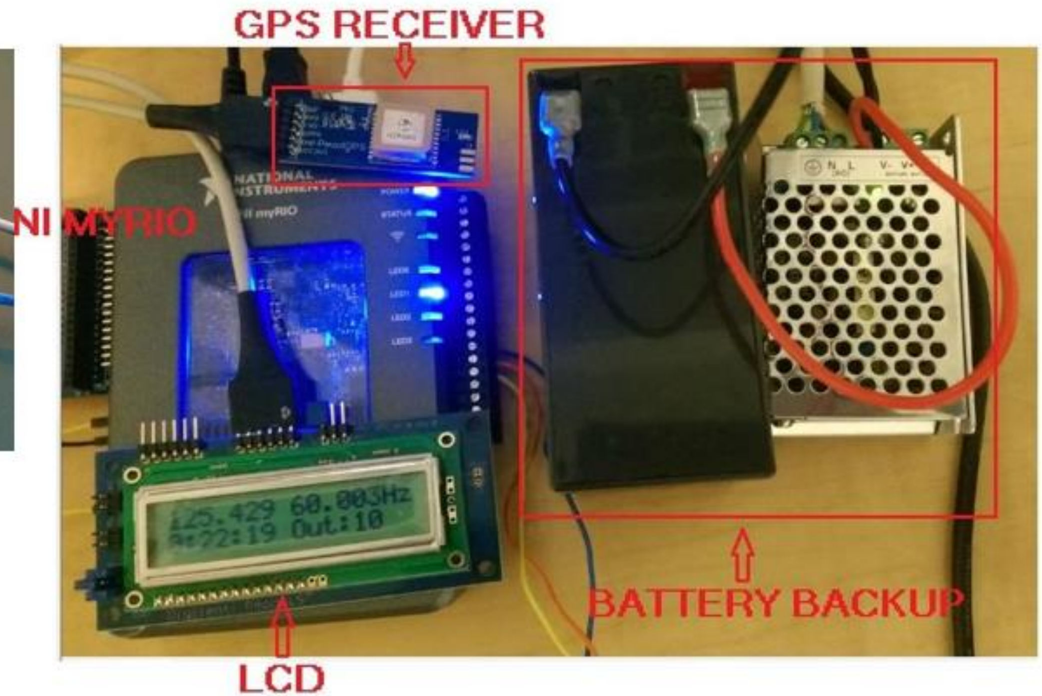
- Build a single phase, distribution level, open source PMU
  - Use UTC time from GPS to stamp the data
  - High sampling frequency (10 kS/s, may increase if desired)
  - User selectable report rate of 10 or 20 Hz
  - Back up power supply (~ 1 hour without power)
  - Low cost (~ $350)
- Deploy a network of PMUs across the Urbana-Champaign area

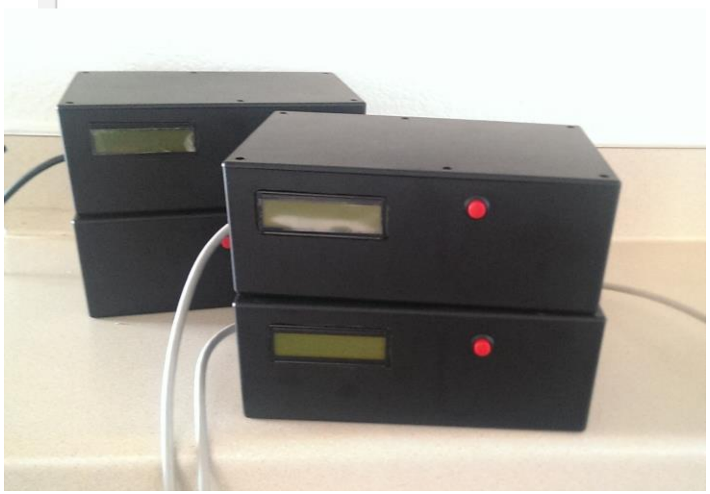
MICRO-PMU DESIGN

Part	Price (each)
Screw Terminal	$2.81
Plastic Enclosure	$13.52
USB to Ethernet	$8.99
GPS Receiver	$23.99
NI myRIO	$258.67
LCD	$16.31
12V/1.2Ah Battery	$8.66
UPS Converter	$23.88
TOTAL:	**$356.83**

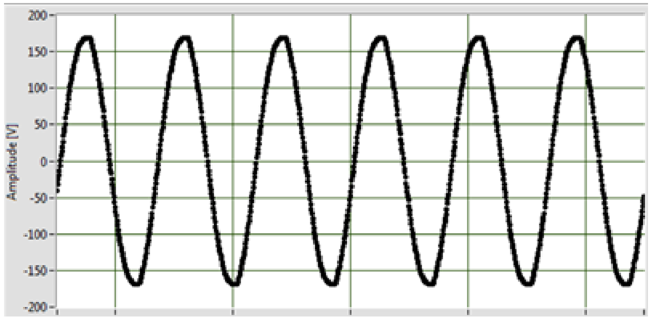


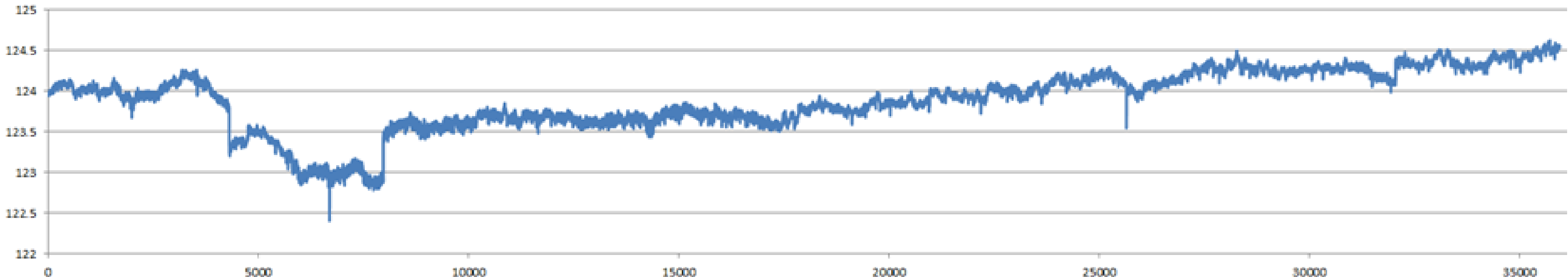
HARDWARE PROTOTYPE

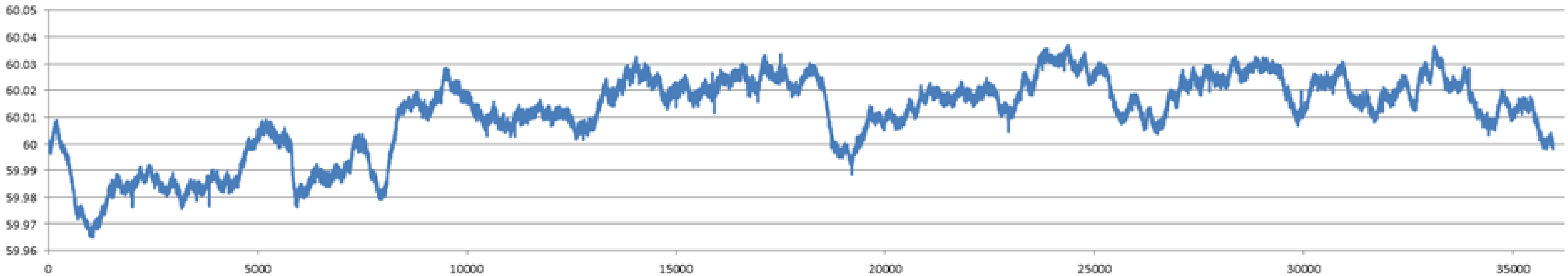




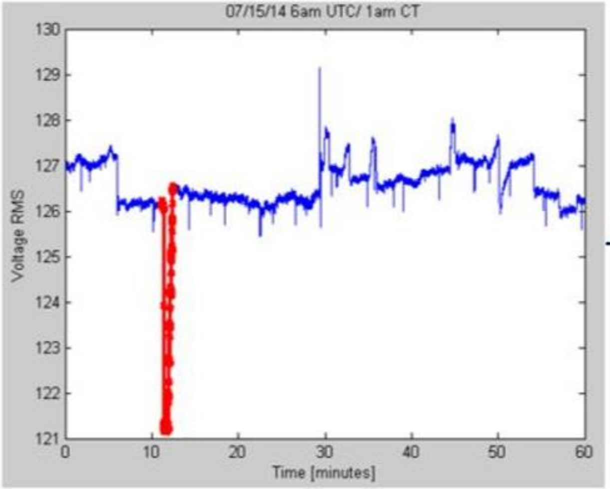
SOFTWARE OPERATION



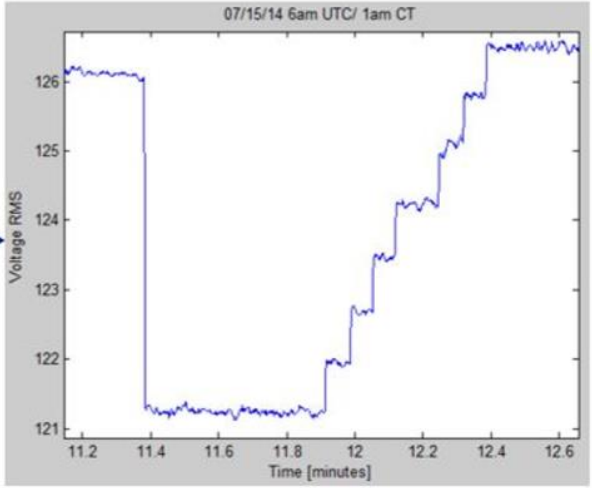




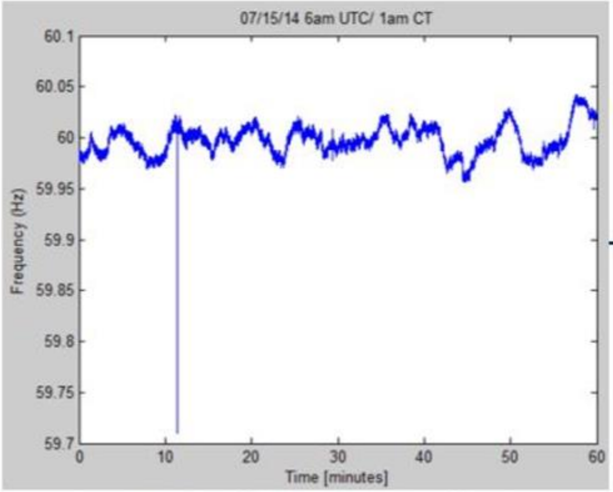
UNUSUAL EVENT DETECTED



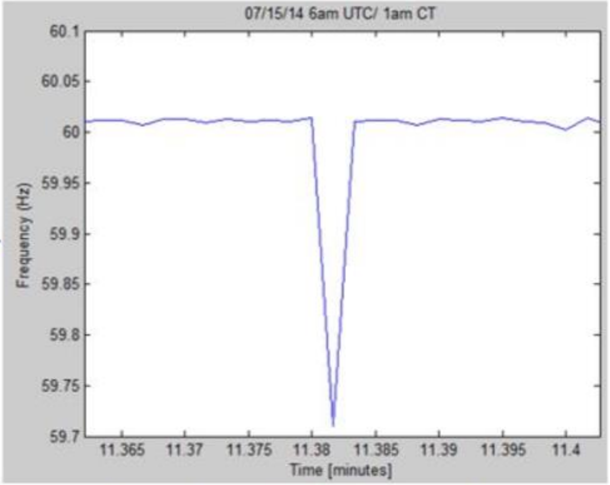
Sample hour long unusual voltage data



Zoom-in on the red voltage dip



Frequency during the same hour



Zoom-in on the frequency dip

CURRENT WORK

- Data Transmission & Storage
- Synchrophasor Latency & Accuracy
- Distibute Units Across Urbana/Champaign

DISCUSSION

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