Data & Network Management Task Team

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Agenda

- Synchrophasor History
  - American Reinvestment and Recovery Act (ARRA)
  - Western Interconnect Synchrophasor Program (WISP)
- Synchrophasor Data Delivery Architectures
  - Utility
  - Regional
- Synchrophasor Data Archive Architectures
  - Utility
  - Regional
- Synchrophasor Architectures to support specific use cases
  - Use cases
- Real World Synchrophasor Architectures
  - Issues and Lessons Learned
- NERC CIP

History

- 2006 – Eastern Interconnection Phasor Project renamed to the North American SynchroPhasor Initiative (NASPI). NERC began funding the project and hosting meetings
- Fewer than 200 research-grade PMUs on the grid
- 175 members total, 50 members attended meetings
- 2500+ production-grade PMUs in service
- 1900 members total, 200+ attendees per meeting
- Vision – Improve power system reliability through wide-area measurement, monitoring and control.
- Mission – Create a robust, widely available and secure synchronized data measurement infrastructure for the interconnected North American electric power system with associated analysis and monitoring tools for better planning and operation, and improved reliability.

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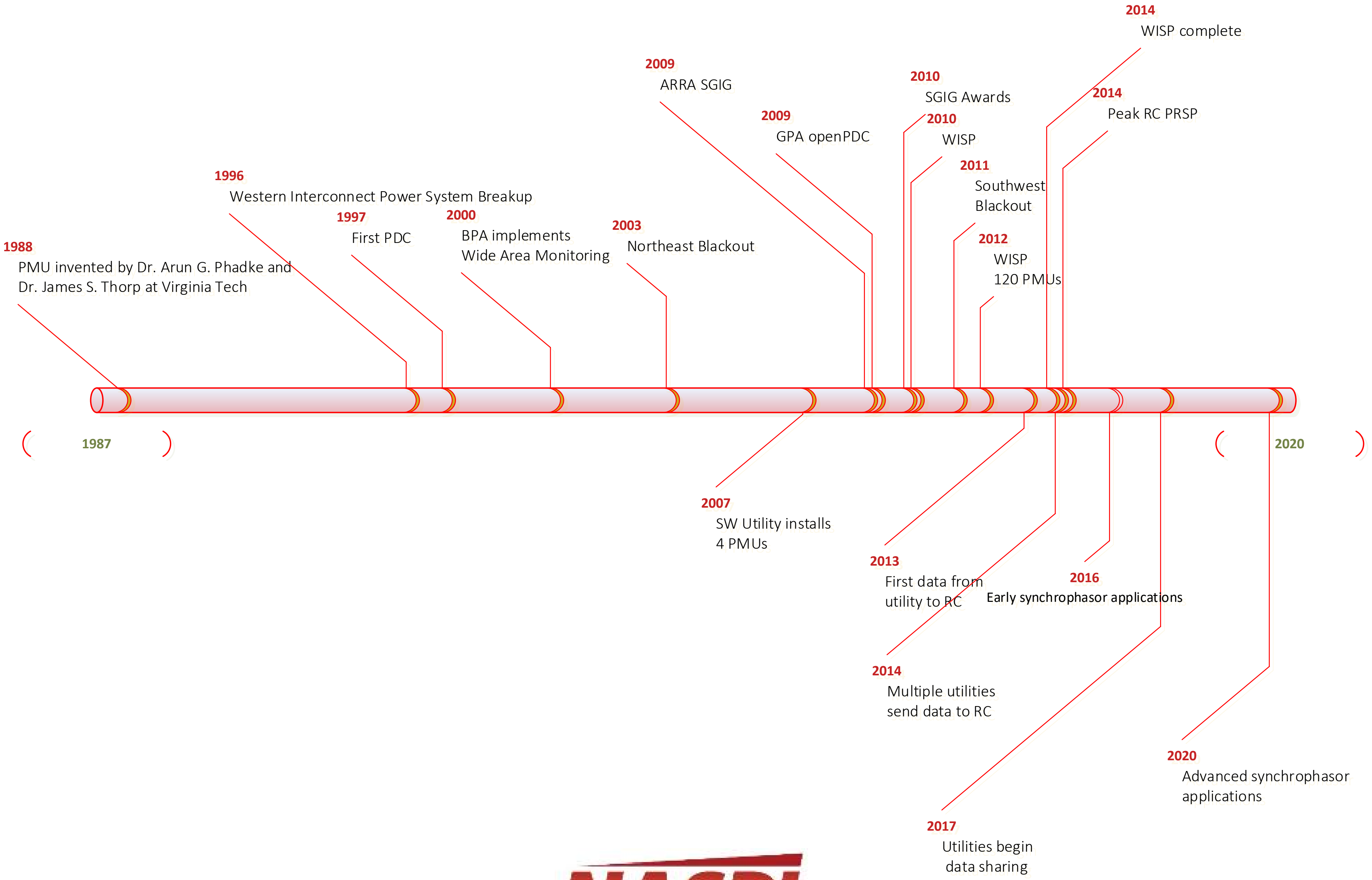

1988
PMU invented by Dr. Arun G. Phadke and Dr. James S. Thorp at Virginia Tech
1996
Western Interconnect Power System Breakup
1997
First PDC
2000
BPA implements Wide Area Monitoring
2003
Northeast Blackout
2009
ARRA SGIG
2009
GPA openPDC
2010
SGIG Awards
2010
WISP
2011
Southwest Blackout
2012
WISP 120 PMUs
2014
WISP complete
2014
Peak RC PRSP
1987
2020
2007
SW Utility installs 4 PMUs
2013
First data from utility to RC
2016
Early synchrophasor applications
2014
Multiple utilities send data to RC
2017
Utilities begin data sharing
2020
Advanced synchrophasor applications

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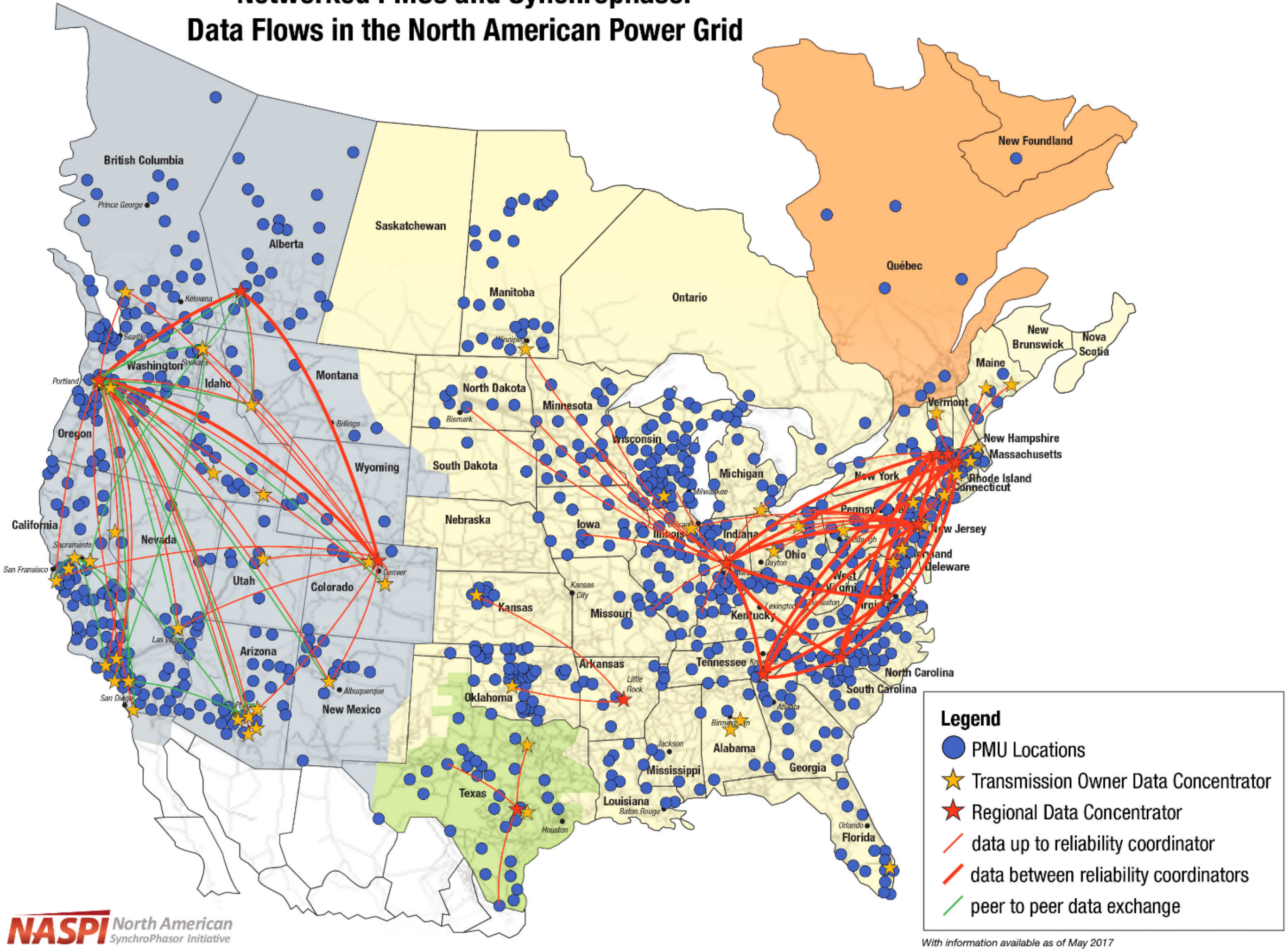
Networked PMUs and Synchrophasor Data Flows in the North American Power Grid



Major PMU Instillations in North America

ATC	102
CCET (ERCOT)	45
Duke Carolinas	104
Entergy	49
FPL	45
ISO-NE	77
MISO	365
NYISO	48
PJM	314
WECC	522
North America (Total)	>1,671

WISP Participants

- Cost Share Participants
- Bonneville Power Administration
- California ISO/California Energy Commission
- Idaho Power Corporation
- NV Energy
- Pacific Gas & Electric
- PacifiCorp
- Salt River Project
- Southern California Edison
- Peak RC

Additional Participants

- Alberta Electric System Operator
- Arizona Public Service
- British Columbia Transmission Company/BC Hydro
- Los Angeles Department of Water and Power
- Northwestern Energy
- Public Service of New Mexico
- San Diego Gas & Electric
- Tri-State G&T
- Tucson Electric Power
- Western Area Power Administration

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Real World Communication Issues

- 30 or 60 reports per second
  - Good: Easy to tell when there are communication issues
  - Not Good: Significant stress on existing communications networks

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Synchrophasor Communication Protocols

- IEEE C37.118-2011 P9 Update
  - Pro: Universal vendor support (mostly -2005 but 2011 moving up)
  - Con: Large data frames can cause delays or dropouts
- IEC 61850-90-5
  - Pro: 61850 in use in substations
  - Con: Limited vendor support for synchrophasor data, even larger data frames
- Grid Protection Alliance Secure Telemetry Transport Protocol (STTP)
  - Pro: Efficient use of communication bandwidth small data frames deliver higher data availability
  - Con: Limited vendor support, in the process of becoming am IEEE standard

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Troubleshoot Communications Issues

Just because the name is trouble *shooting* doesn't mean you should use the shotgun method

- Understand the terminology
- Take advantage of time stamps
- Build Dashboards

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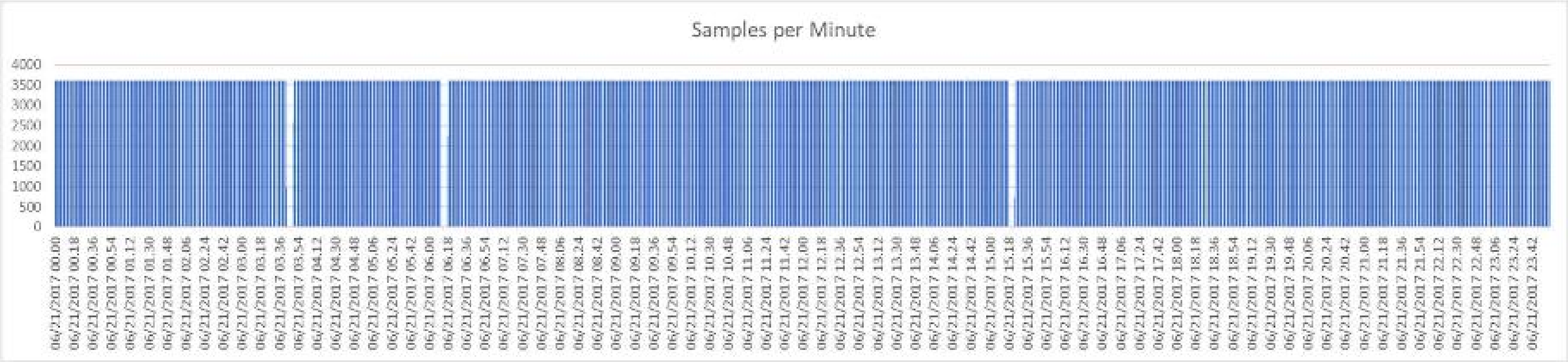

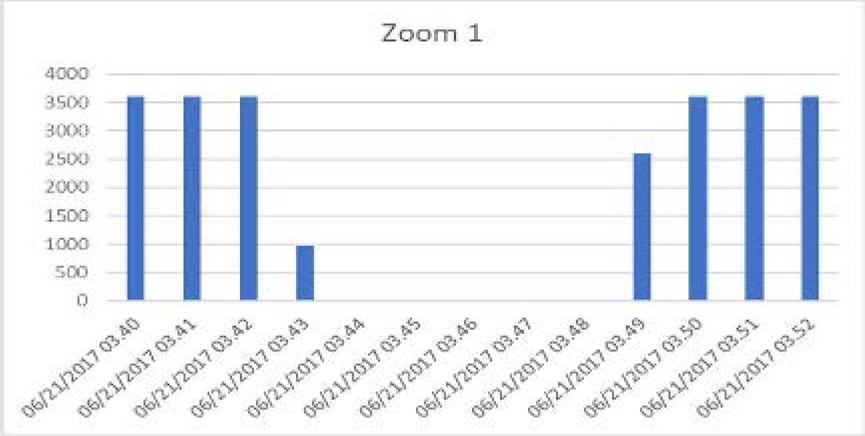

- Counting how many samples arrive every minute can help trouble shooting
- In this case it could indicate router issues or some timed process overloading the network

Data Dropouts Substation PDC to Control Center PDC

Typical of TCP/IP communication issues

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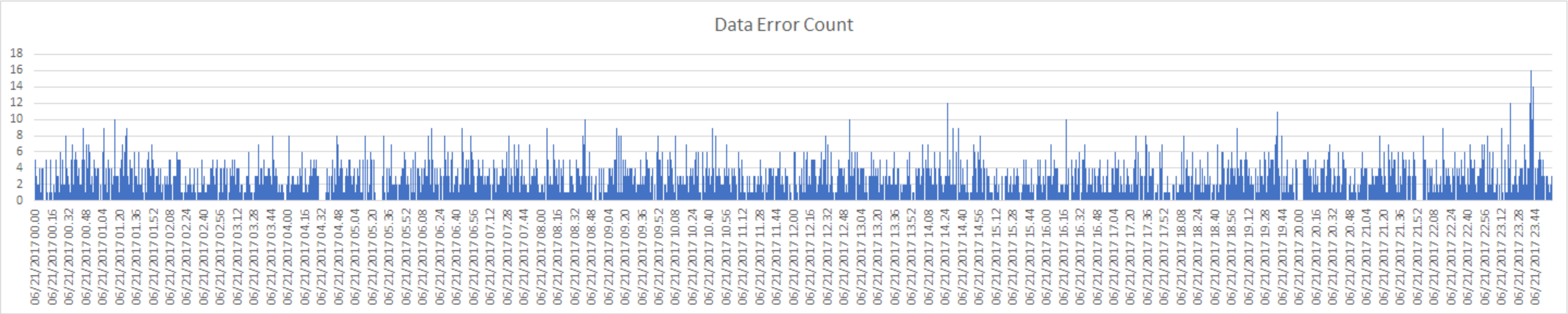
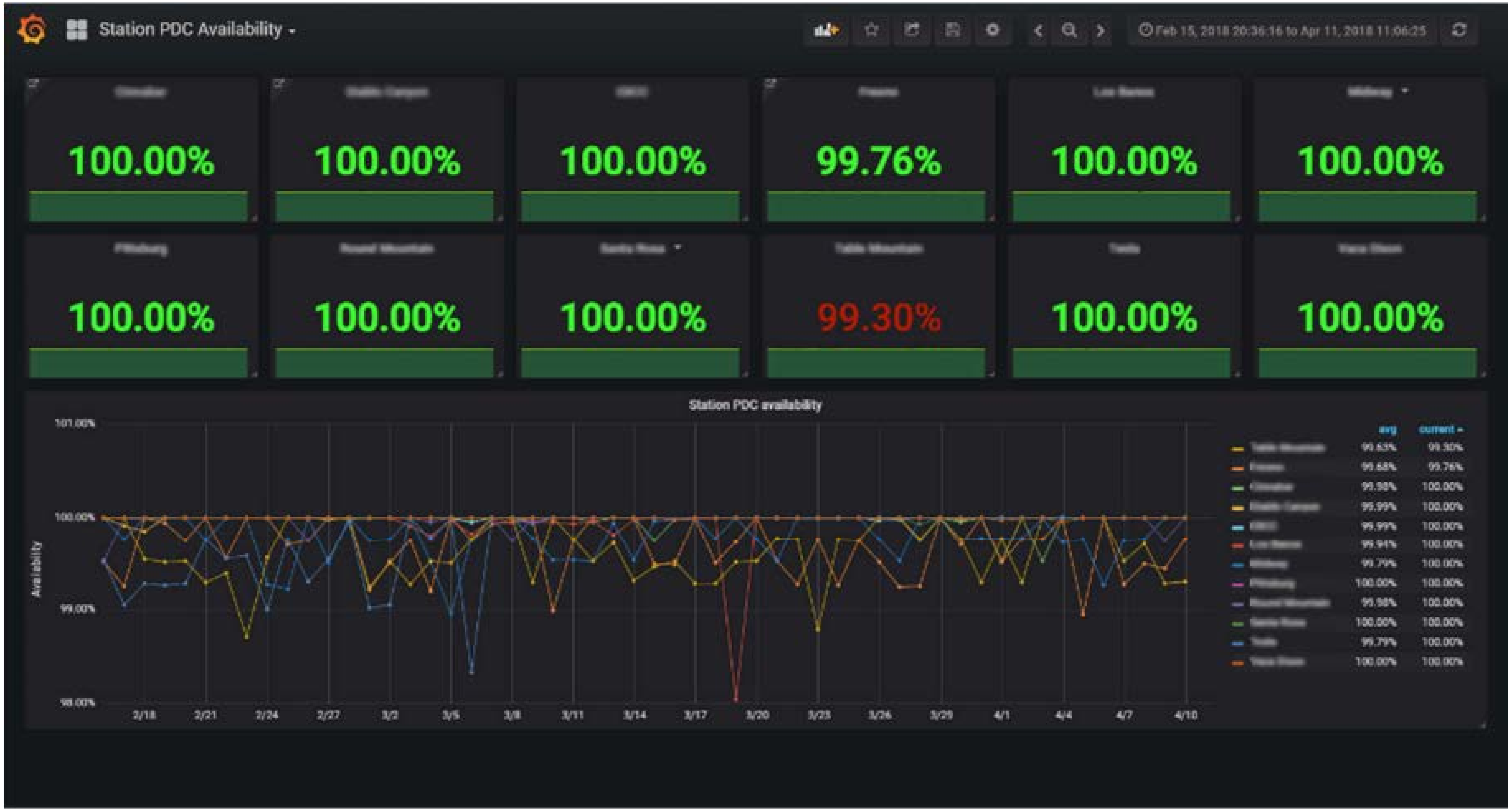


- PMU to PDC communication errors as seen on the output of the PDC
- Spread out over entire day (4407 data errors)
- Typical of UDP communication issues



TCP/IP does not guarantee 100% delivery

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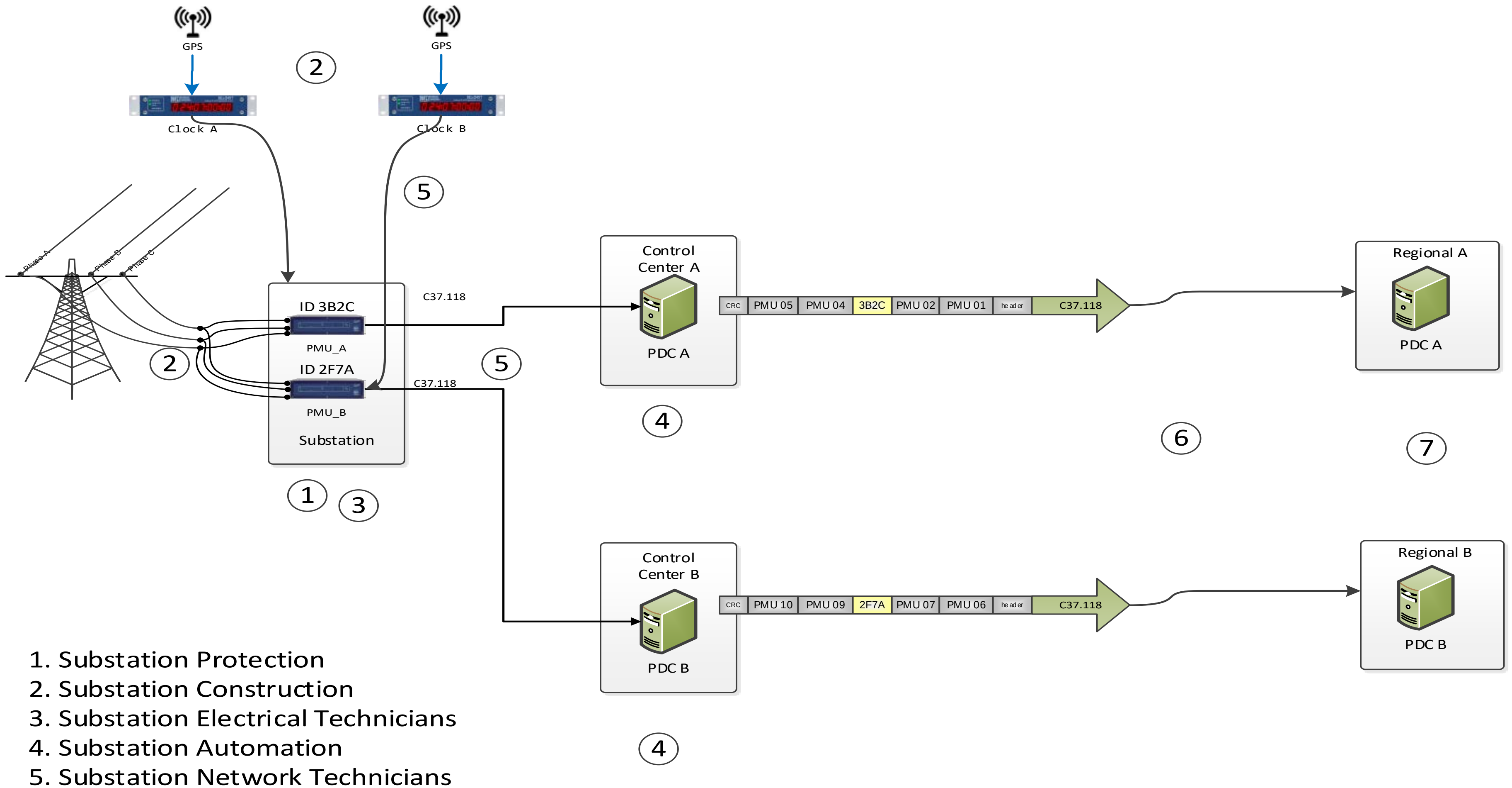
Many departments are required to make it all work



1. Substation Protection
2. Substation Construction
3. Substation Electrical Technicians
4. Substation Automation
5. Substation Network Technicians
6. WAN Communications Technicians
7. IT (Corporate and Operations)

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Naming Convention

- Develop and Adopt a naming convention as soon as possible
  - Avoid thinking it will easily be fixed later
- Leverage existing naming conventions
- Involve Engineers, Operators, and IT in the development of the naming convention
- While not technically either Data Archive or Networking issue using a naming convention can significantly improve data use
- PMU and Signal names require different organization for use inside a utility vs. use by an RC or ISO
- Original naming conventions were simple. Deployment was typically bus voltage and line current. Now other equipment is being monitored with PMUs e.g. SynCon, Reactors, etc.

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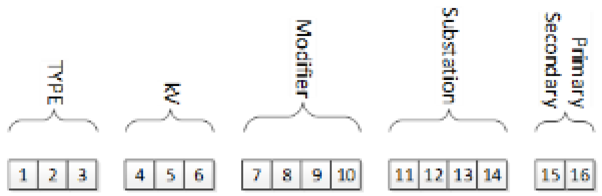
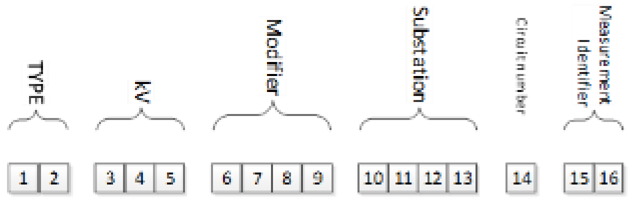
Naming Convention



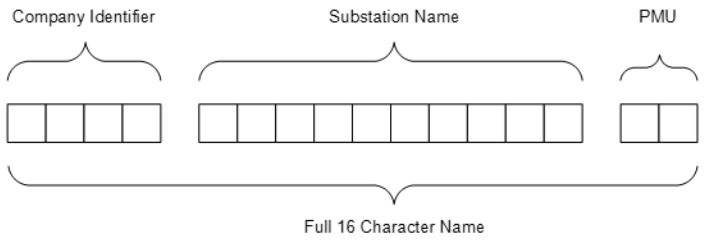
PMU Naming Convention



Signal Naming Convention

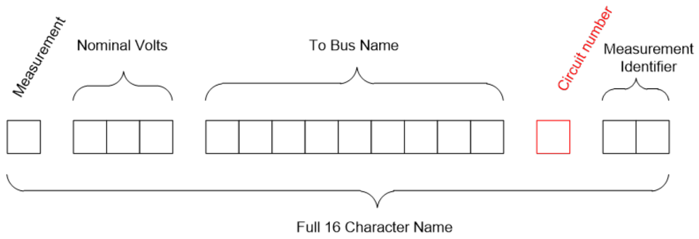
Utility internal naming convention

RC or ISO naming convention



PMU

Signal



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Archiving Strategies: Synchrophasor Application Advancement

Synchrophasor Application Progression Quandary

How did use cases start:

Time synchronized situational awareness

Data production, collection and delivery was built around a single network and archive architecture:

The Quandary Question:

Why is it taking so long to develop new synchrophasor applications?

The Quandary Answer:

We are working off of a decades old data management infrastructure and are archiving for single use cases which are, most often, siloed in single departments.

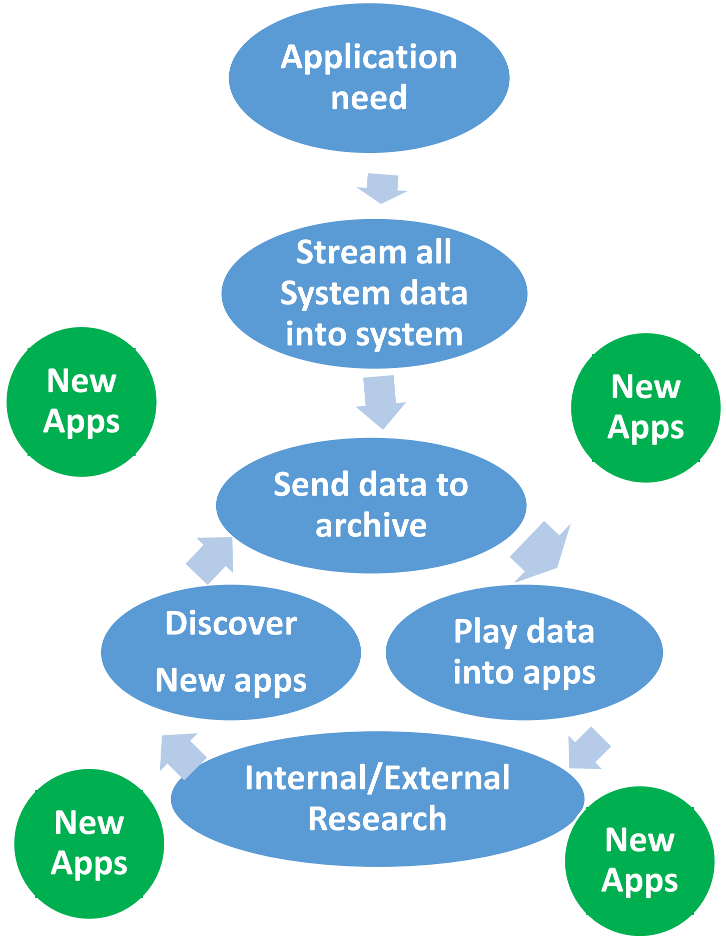
Security sensitive real-world applications – Research institutions cannot get real system data to adequately develop advanced analytics applications

Existing Application Development

<u>NEW VENDOR APPLICATION</u>
REPEAT(DUPLICATE)
REPEAT(DUPLICATE)
REPEAT(DUPLICATE)
APPLICATIONS TEND TO BE SILOED

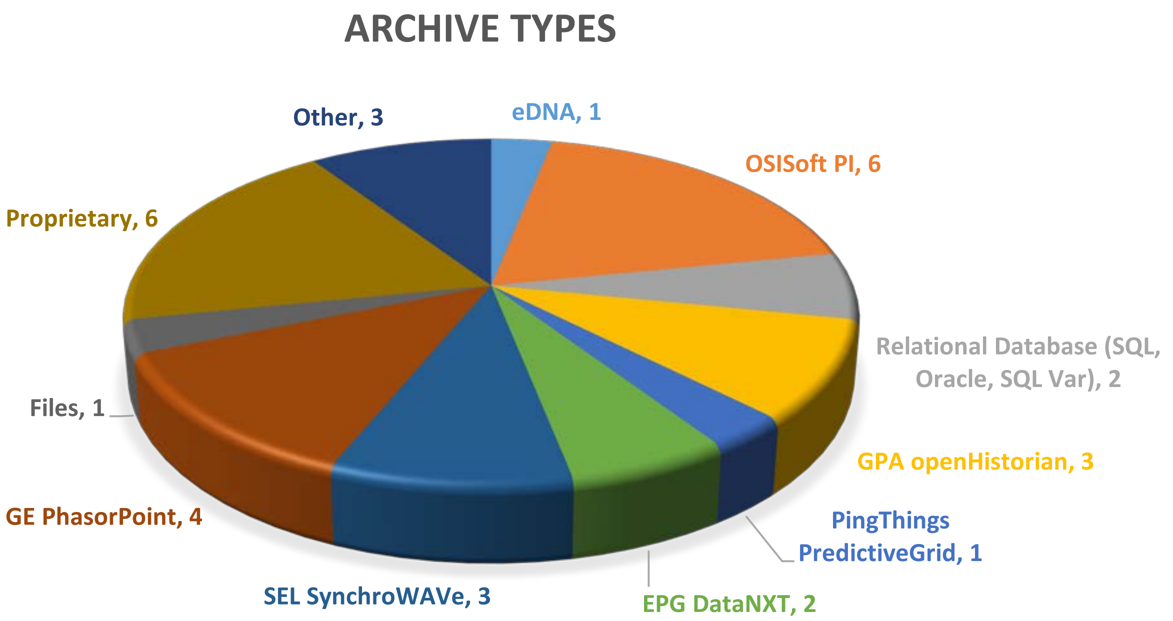
<u>NEW APPLIACATION DISCOVERY</u>
INTERNAL – TYPICALLY SPORADIC UNLESS DEDICATED GROUP
EXTERNAL – DATA SHARING LIMITED/DIFFICULT

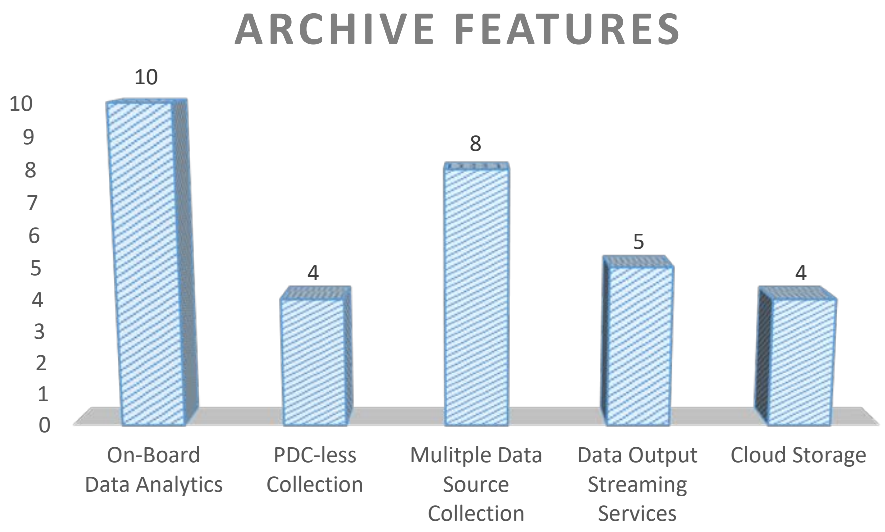
Future Application Development



Current Utility Archives Usage and Future Desires

- NASPI DNMTT survey of **18** synchrophasor data users shared their archive of choice and desires for future archive features.





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Data Collection and Archiving Issues today

What are the challenges we are facing?

Data Architecture for Short Term vs. Long Term Use – PDC based

- Short-term storage (7 days) in Gigabytes – Real Time Situational Awareness
  - Lends to Vendor specific archives on small physical servers
- Long-term storage (3 years) in Tera/Petabytes – Model Validation
  - Lends to Vendor specific archives on large physical servers or Cloud-based storage

- What are the existing problems?
  - High Data Management labor
    - PDC data routing
    - Data quality and conditioning (removal of dropouts, interpolation of data, stale data detection, etc.)
  - Duplicity of data – Copies of data across a utility
  - Data sources are siloed – Synchrophasor data, DFR data, PQ Data, relay data, SCADA data
  - Data storage limits are constantly being breached

SOLUTION: BRING THE APPLICATION TO THE DATA, ELIMINATE THE STORAGE SPACE BOUNDARY

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Three Questions Lead to Improvements

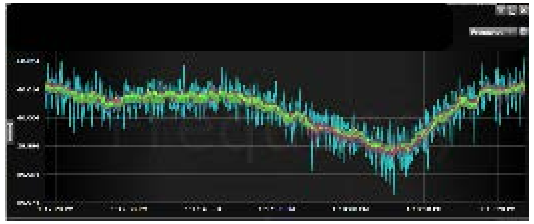
How is data used?

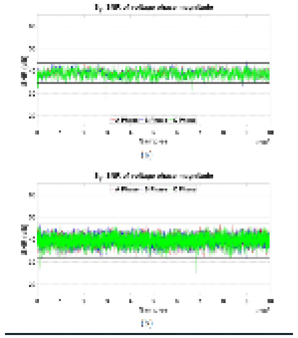
One siloed application or open for many? How do we harness the power of data?

What we see or what we don't see?

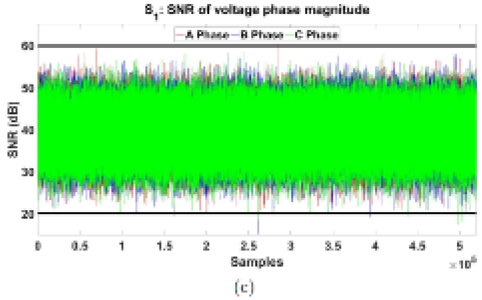
Situational awareness of top data to big data analytics deep dive of hidden data.

System Frequency



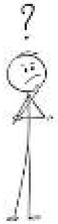


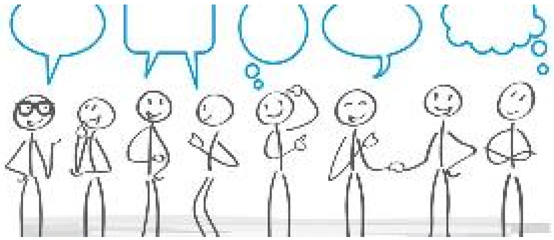
SNR Variation of voltage synchrophasor up to time of transformer failure *(Pal et. al)*



Who gets access to the data?

One department, the entire utility, internal researchers, external researchers?





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The Future is Already Here One Source to Rule them All

Local "cloud" based VM systems

- Local utility "cloud" based computing and storage (less limited than physical servers but still limited in cloud computing space)

External Cloud based systems

- Single-Source PDC-less system
  - Single Source – All data sources, not just synchrophasors, collected in one location
  - PDC Less – Sense data directly from field PMUs
  - Virtually unlimited storage
  - Highly vetted and experienced Cloud-based services to manage data continuity
- Advanced Data Collection and Alignment
  - Container technology allows for highly efficient data management, data quality and application segregation and ease of compute allocation
  - Provide time-synchronized alignment at the time of archiving
  - Minimize PMU stream pass through at the utility

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The Future is Already Here
One Source to Rule them All

- Universal Application development and Free-Form Analytic Research
  - Universal set of APIs to plug in many disparate applications
  - Create platform for researchers to develop and test new analytics against real data
- Open and secure data access
  - Internal utility analytics research access
  - Secured and isolated data access for external research opportunities

<u>Disparate sources pointer system</u>

- Separate sources (DFR, relay, PQ, POW, etc.)
- Central pointer system to disparate data archives

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SYNCHROPHASORS AT SALT RIVER PROJECT

- SRP first installed synchrophasors as participant in the WISP (Western Interconnect Synchrophasor Program) project in which utilities installed synchrophasor collection devices to send to a central hub real-time visibility and analytics of the WECC system.
- SRP expanded our fleet synchrophasor devices as part of the System Protection relay upgrade program which took advantage of synchrophasor technology built into the protection relays.
- SRP then installed SEL SynchroWAVe Central which provided a visualization tool for post-fault analysis.
- SEL SynchroWAVe Central also offered SRP a method to archive system data.

SRP SYNCHROPHASOR NETWORK AND ARCHIVE TIMELINE

WISP PROJECT ~2009

SRP joins WISP project

2010

SRP System Protection synchrophasor relay installation standard & install SEL SynchroWAVe Central with 5TB of archive space

2013

SRP System Protection begins evaluating and resolving network, PMU and PDC programming issues

2015

SRP System Protection resolves network issues by making standard synchrophasor programming, installation testing and signal routing

2017

SRP expands synchrophasor archive to 160TB

Now

SRP tests moving synchrophasor archiving to an SRP virtual platform and investigates off-site Cloud storage

SRP DATA NETWORK MANAGEMENT
A SERIES OF FAILURES TURNED INTO SUCCESSES

- As the SRP network was expanded it was discovered that there were three severe gaps in network and signal maintenance.
    1. PMU programming mistakes were rampant – Partially due to a lack of standards
    2. Network switches repeatedly disconnected inactive PMU links
    3. Network firewalls (central and substation) were not adequately allowing bi-directional flow from relays.
- SRP established the following to resolve these issues
    1. Build in synchrophasor PMU programming standards to all relay and DFR installations
    2. Network switches were set to maintain an always on configuration
    3. Firewall rules established for all PMU installations – relay communication uni-directional and PMU communication bi-directional.

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SRP DATA ARCHIVE STRATEGY

- SRPs data archive history of retention growth
  - SRPs initially experimented with synchrophasor archiving through the installation of SEL SynchroWAVe Central which was recorded on a 5TB application server.
  - Next SRP purchased 2 new servers to expand storage to 160TB to allow for longer term archiving of SynchroWAVe Central data. The need to retain data arose from SRP Transmission Planning initiatives to perform model validation.
- SRP future plans and initiatives
  - Experiment with a trial of moving synchrophasor archiving onto an SRP local virtual infrastructure for faster, cheaper and more efficient archive expansion.
  - Investigations being made into the feasibility and value of moving synchrophasor data archiving to a Cloud infrastructure.

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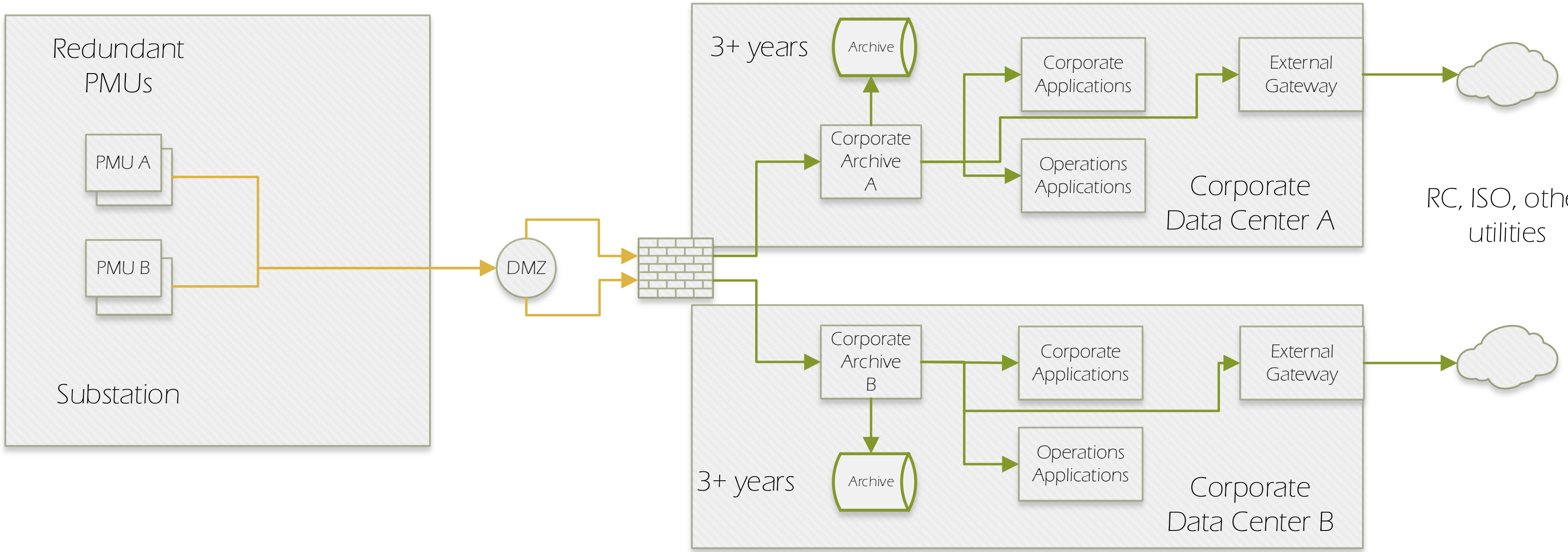
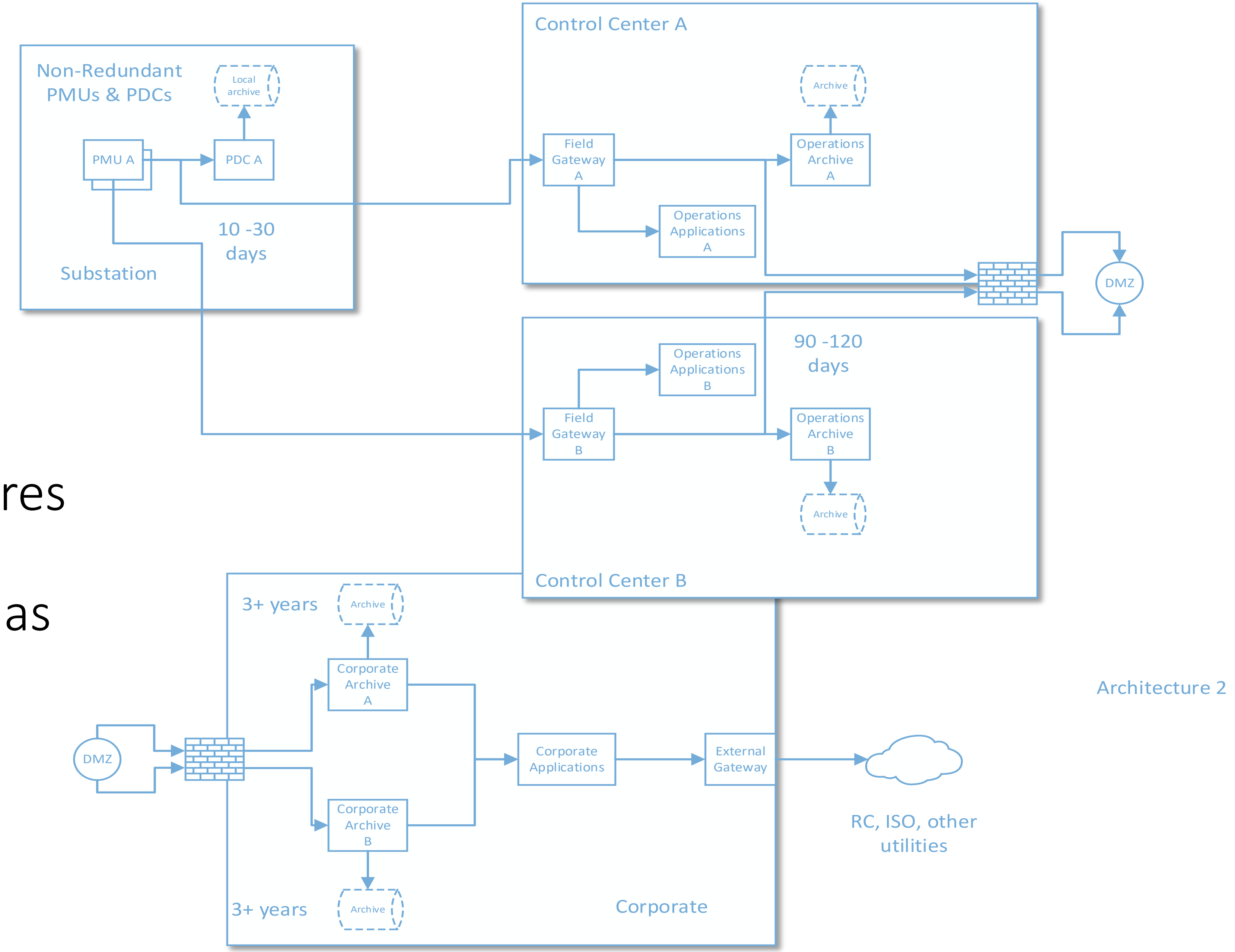
Example Utility Architectures for Synchrophasor Data



Architecture 1

Example Utility Architectures for Synchrophasor Data



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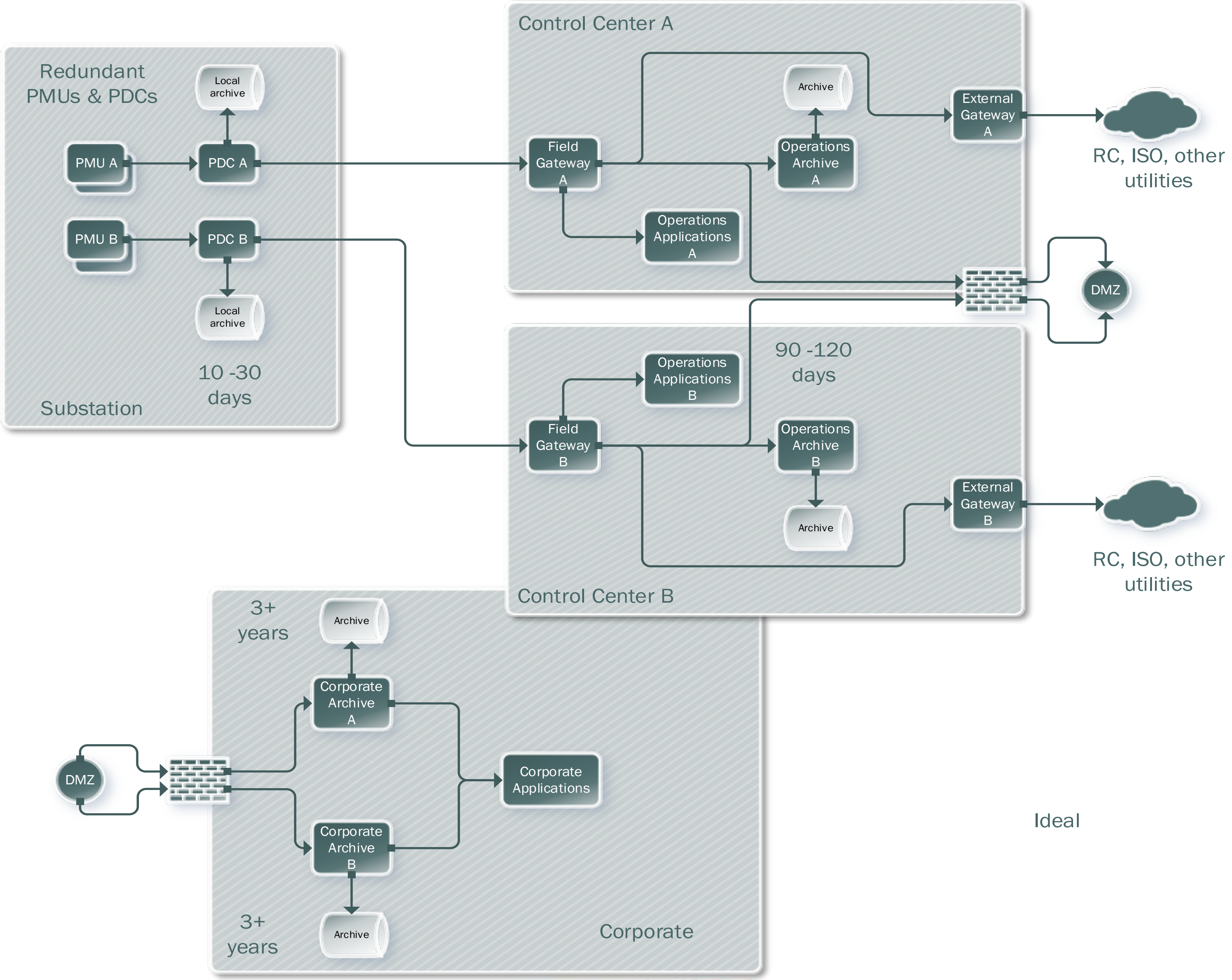

Ideal

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Why Archive

- NERC PRC 002-2
  - Deliver COMTRADE files after events
    - PSRC H8 Application of COMTRADE for Synchrophasor Data
- NERC MOD 27,27,33
  - Generator and System model validation
- Planning Engineers
- Post Event Analysis
- Asset Health
- Asset Condition Based Maintenance
- Baselining

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Synchrophasor data and NERC CIP compliance

It is difficult to discuss synchrophasor architectures without mentioning NERC CIP and the complications it may bring to deployment. Designing and deploying CIP compliant architectures is straightforward. It is the documentation and business change management policies and procedures that comprise the bulk of the effort. As time synchronized measurements become more useful for real-time decision making, the effort vs. value equation should tip in favor of value

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Synchrophasor Value Proposition

Synchrophasors have a strong history of providing exciting use cases to utilities initially advanced Situational Awareness, Oscillation Monitoring, State Estimation and Model Validation More recently, Machine Learning and Artificial Intelligence applications.
The underlying synchrophasor data network and archiving architectures have undergone significant improvements that have enabled and accelerated advanced application development. In this webinar, we will discuss the origins of synchrophasor networking from network architectures to synchrophasor stream protocols as well as advanced discussions of networking and protocol enhancements being developed. Also we will discuss how synchrophasor data archiving has come a long way from data availability for Post Event Analysis, to Wide Area Situational Awareness to cloud-based archiving for universal real-time application access
These new technologies set the stage for tremendous increases in synchrophasor application research and development. A utility example of networking and archiving challenges and advancement initiatives will demonstrate how these strategies manifest in a real-world setting.

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