Synchro-phasor Data Quality

North-American Synchro-Phasor Initiative
Technical Session
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Fort Worth, Texas

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- Jim Kleitsch, American Transmission Company
- Dmitry Kosterev, Bonneville Power Adm., PITT
- Jim McIntosh, California ISO
- Alison Silverstein, NASPI Manager

Session Overview

1. PMU data availability today
   - Eastern Interconnection
   - Western Interconnection
2. Synchro-phasor system design to maximize data availability and quality
   - Data quality issues
   - Best practices for system design
3. Synchro-phasor system performance metrics
4. Designing applications to deal with bad data

Part I:
PMU Data Availability Today

PMU Data Availability

- 99 % Availability
  - At 30 frames/sec – 25,920 lost frames per day
  - At 60 frames/sec – 51,840 lost frames per day
- 99.9 % Availability
  - At 30 frames/sec – 2,592 lost frames per day
  - At 60 frames/sec – 5,184 lost frames per day
- It is a lot of frames!

- Causes strain on applications, redundancy checks, event detection, control schemes

Context – Not all PMUs and Phasor Systems are the Same!

- Data quality and availability described below are from older, mostly R&D grade PMUs delivering data over analog or non-dedicated communications lines. The fact that they don't deliver high data quality and availability should not be viewed as an indictment of those older devices and systems.
- Data quality expectations have changed. Current phasor system projects are being designed with goal of production-grade data quality and availability, using faster PMUs, better device maintenance, and dedicated communications networks.

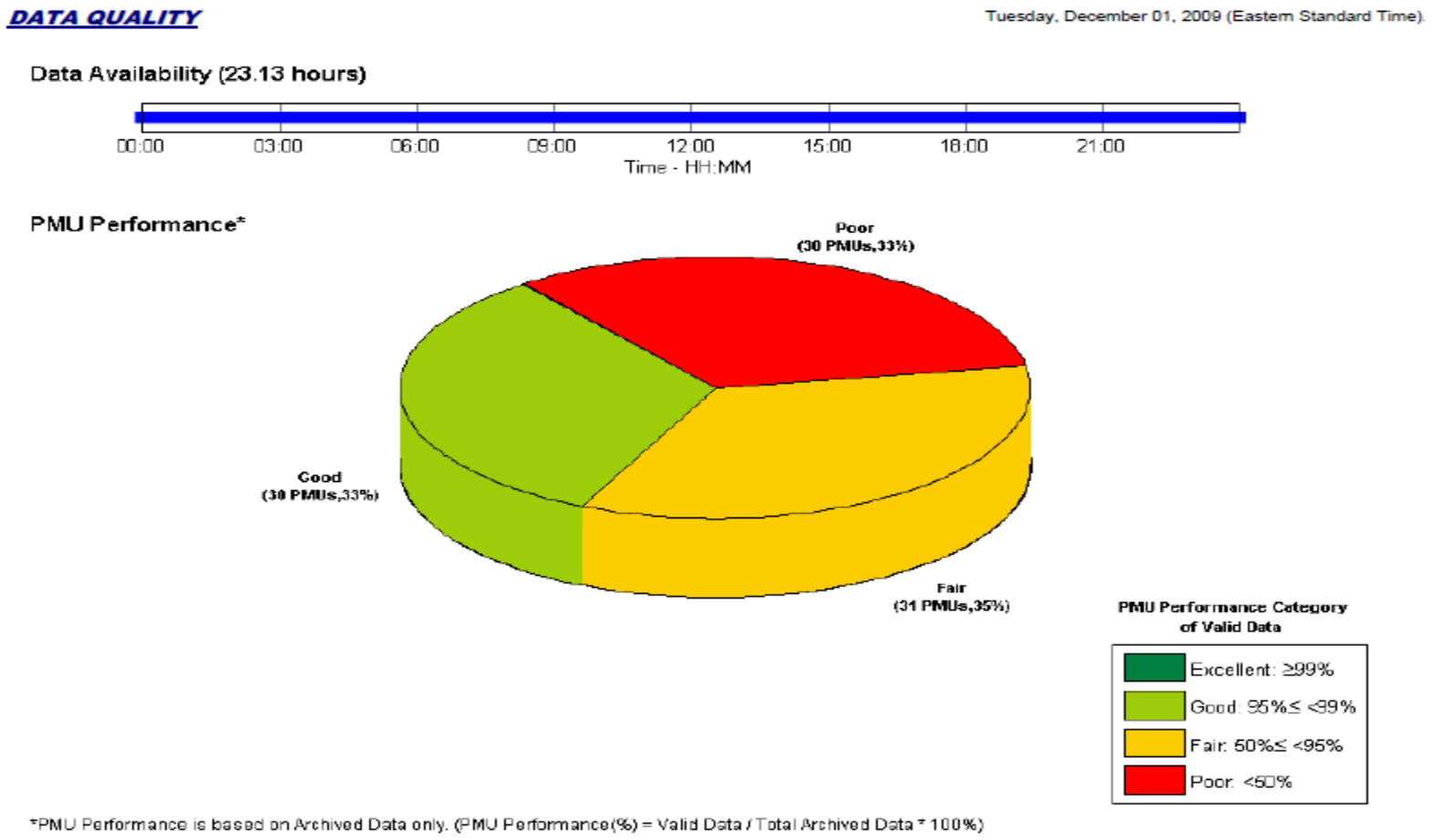
Eastern Interconnection

Ritchie Carroll
Grid Protection Alliance

Eastern Interconnection

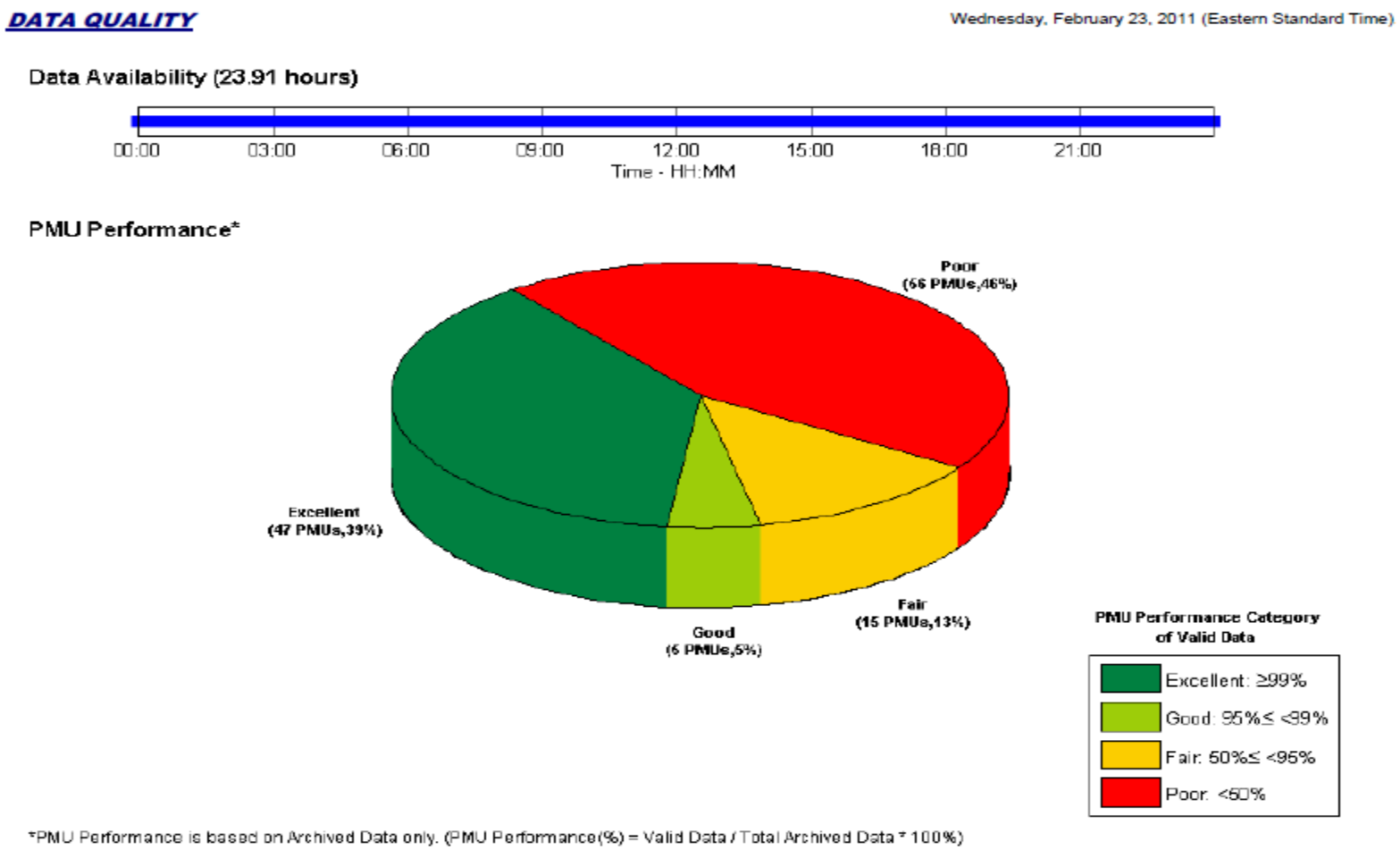
Phasor Measurement Units in the Eastern Interconnection

Data Quality on 12/01/2009



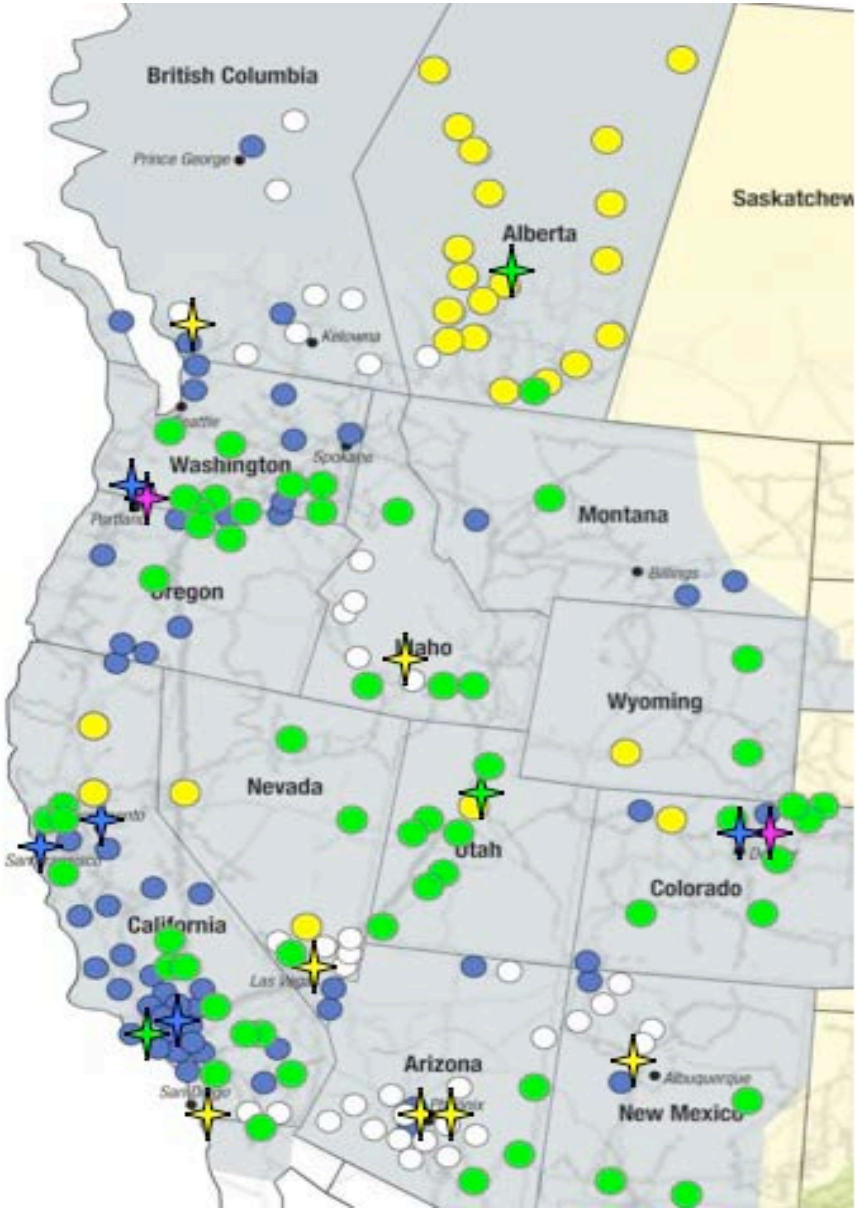
Note – 33% Good, 0% Excellent PMUs reporting in 2009

Data Quality on 02/23/2011



Note – 39% Excellent, 5% Good PMUs reporting

Western Interconnection



Phasor Measurement Units (PMU) in the Western Interconnection

Legend

- Phasor Data Concentrator (PDC)
- Networked PDC
- Desirable future PDC
- Desirable future Super PDC
- Networked PMU – Multiple PDC
- Networked PMU – Single PDC
- PMU Not Networked
- Desirable future PMU

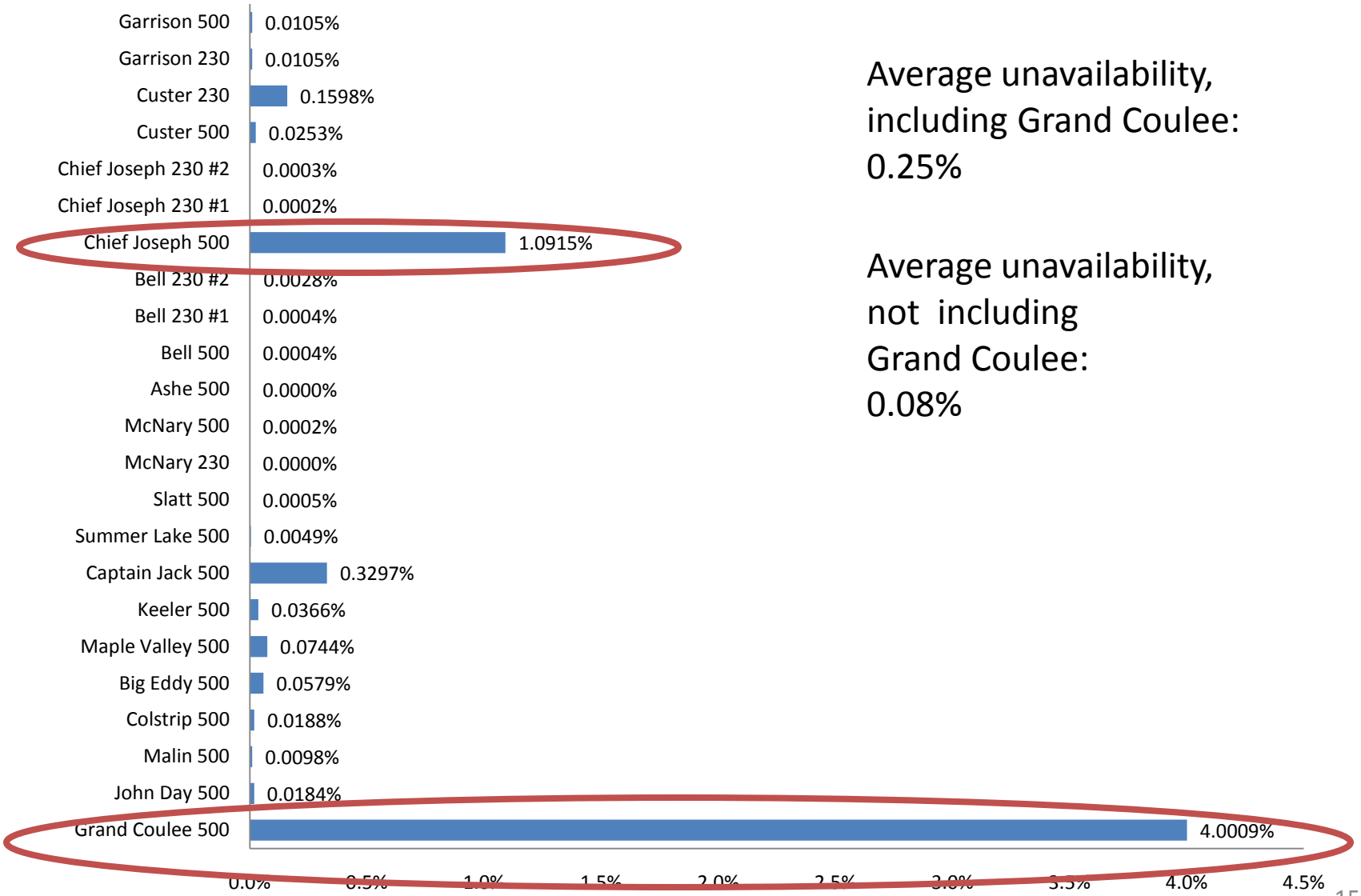
Bonneville Power Administration

Tony Faris, BPA

PMUs at BPA

- BPA today has 25 PMUs on its system
- BPA receives data from SCE, PG&E and WAPA PDCs
- BPA sends data to California ISO
- The data is used for:
  - Power plant performance monitoring and model validation
  - Oscillation analysis
  - System model validation
  - Phase angle alarm for operators

Unavailability of BPA PMU Data



Average unavailability, including Grand Coulee: 0.25%

Average unavailability, not including Grand Coulee: 0.08%

Unavailability of External PDC Data

PDC	Unavailability	# Lost Input*
SCE	19.06%	4227
WAPA	0.020%	9
PG&E	0.0038%	1

*PDC data loss for extended period of time

- One month period
- Yes, PDC to PDC communications can be reliable
- PDC to PDC data transfer, remote PDC may have data losses from its PMUs

Latency of PMU Data

- Latency today with mainly analog telecom:

PMU	Typical Latency (ms)
Grand Coulee	104.9
John Day	105.0
Malin	90.5
Colstrip	94.9
Big Eddy 230	51.0
PDC at SCE	171.4
Ault (PDC at WAPA)	192.5

- Communication latency for new digital PMU network within BPA is less than **40 ms** for any PMU

California ISO

Jim McIntosh, CAISO

CAISO PMU Data Availability

- Currently receive PMU data from 3 PDC streams:
  - BPA/WAPA (combined), SCE, PG&E
- Typically 10 out of 56 PMUs are failed or out-of-synch (about 18%)
- Network communications issues result in approximately 99.5% availability for the “good” PMUs due to frame losses, latency and data sorting problems (or sort by arrival issues)
- Obstacles to PMU data availability
  - Culture of R&D – robust infrastructure not always in place
  - PMUs may not be well understood
  - Utility maintenance priorities

PMU Data Availability and Its Effect On Control Room Applications

- PMU data quality/availability issues → inaccurate results → false positives → operators distrust the applications
- Control room apps catch many data quality problems
  - PMU errors – data is dropped out for entire PMU
  - Data spikes – dropped out or filtered
  - Difficult to catch all data quality issues
- How can we achieve our goal of acceptable phasor data quality and availability to use in Operations?
  - Well defined incentives for utilities to give higher priority to PMU and communication infrastructure – both installation and maintenance
  - Provide the same level of priority as SCADA

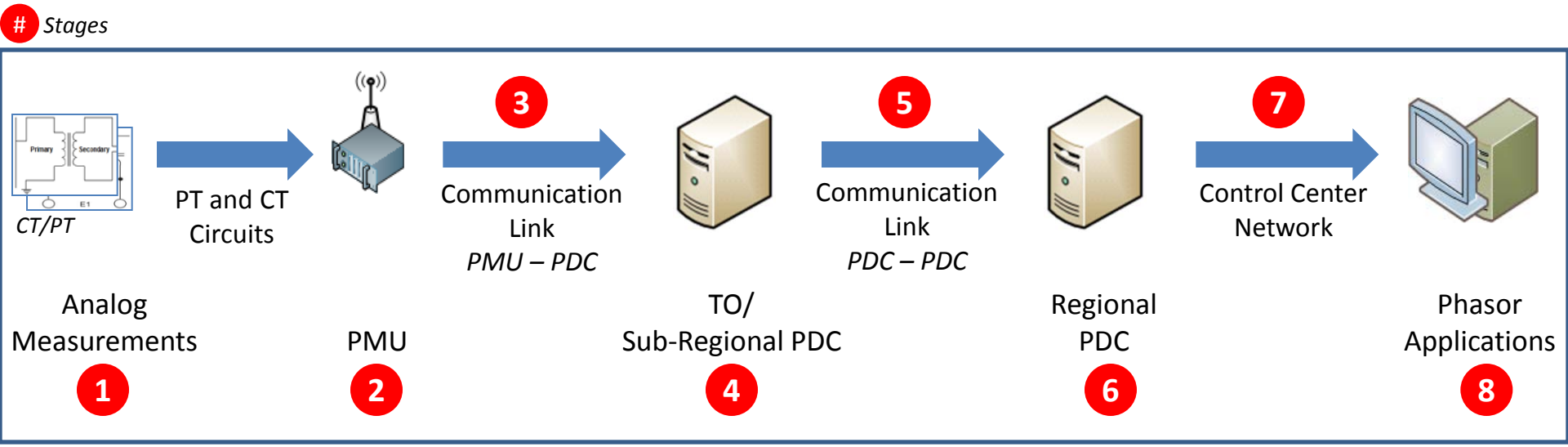
Moving Forward

- There is an expectation that availability and quality of PMU data will greatly improve with SGIG projects, when so called production-grade systems are deployed
- First, it is important to do “lessons learned” to share the best design and operational practices
- Second, it is important to develop performance metrics for the overall system and its components
- Third, it is important to design robust applications that can withstand data losses and bad data

Part II:
Design Practices

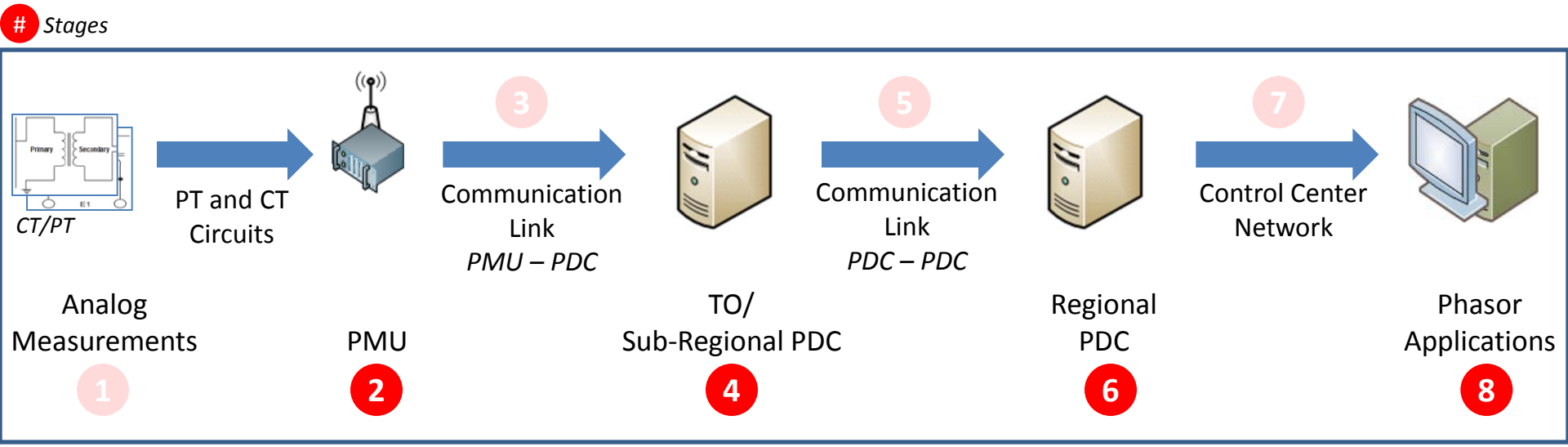
NASPI Synchrophasor Network Data Flow

Errors can originate at any of the following <u>8 stages</u> of data flow



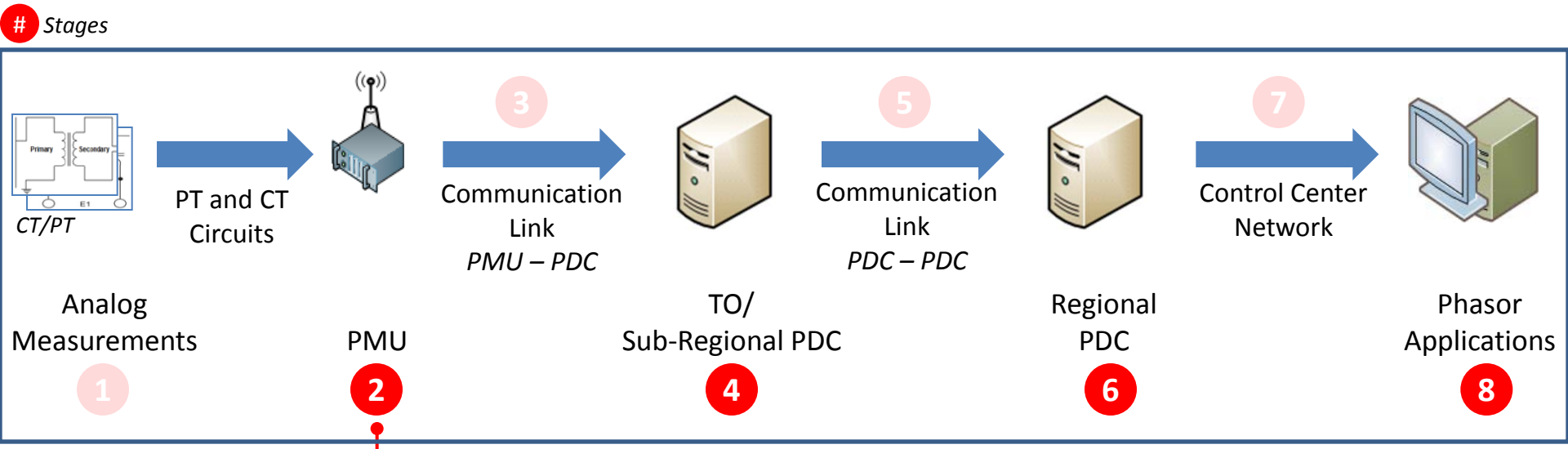
Stages of Error Detection and Flagging

Errors can be detected and flagged at any of the following <u>4 stages</u>



Errors Detected by PMUs

Errors that can be detected and flagged at <u>Stage 2</u>:

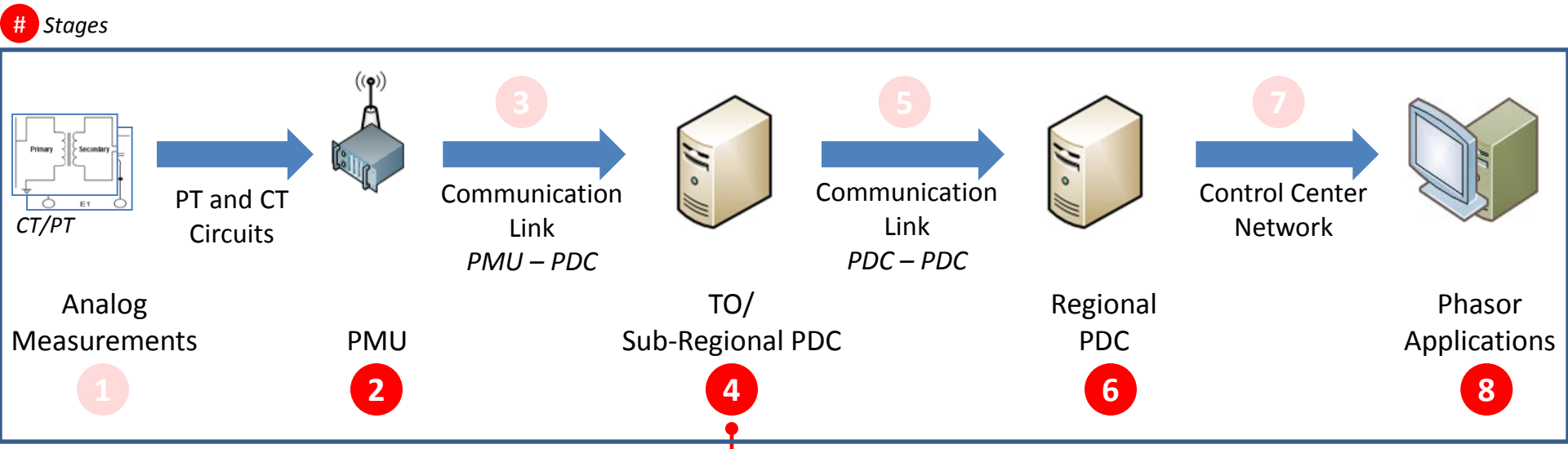


1. Data Invalid Error
2. PMU Error (e.g. PMU malfunction)
3. Synchronization Error
4. Time Alignment Error (Sort by Arrival)

These errors have been established as part of the C37.118 standard

Errors Detected by TO PDC

Errors that can be detected and flagged at <u>Stage 4</u>:



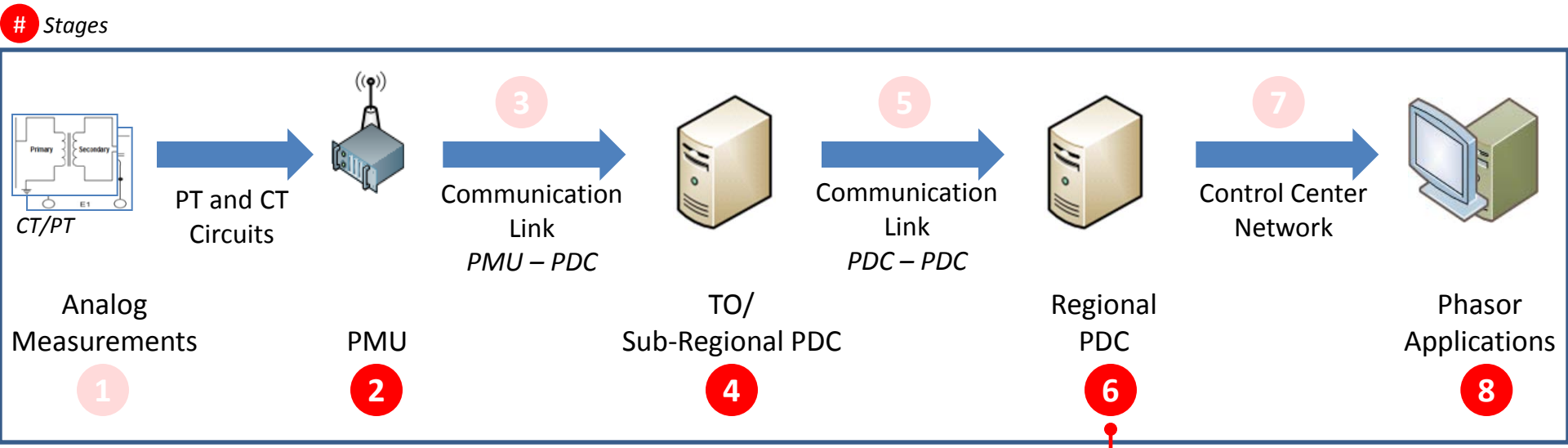
Errors flagged at Stage 2

+

1. PMU Data Dropout Error
2. PMU sends data to TO's PDC with invalid timestamp
3. PMU data arrives at TO's PDC later than acceptable latency
4. PMU does not send data to TO's PDC when expected
5. PMU sends data in invalid format to TO's PDC
6. CRC error

Errors Detected by Regional PDC

Errors that can be detected and flagged at <u>Stage 6</u>:

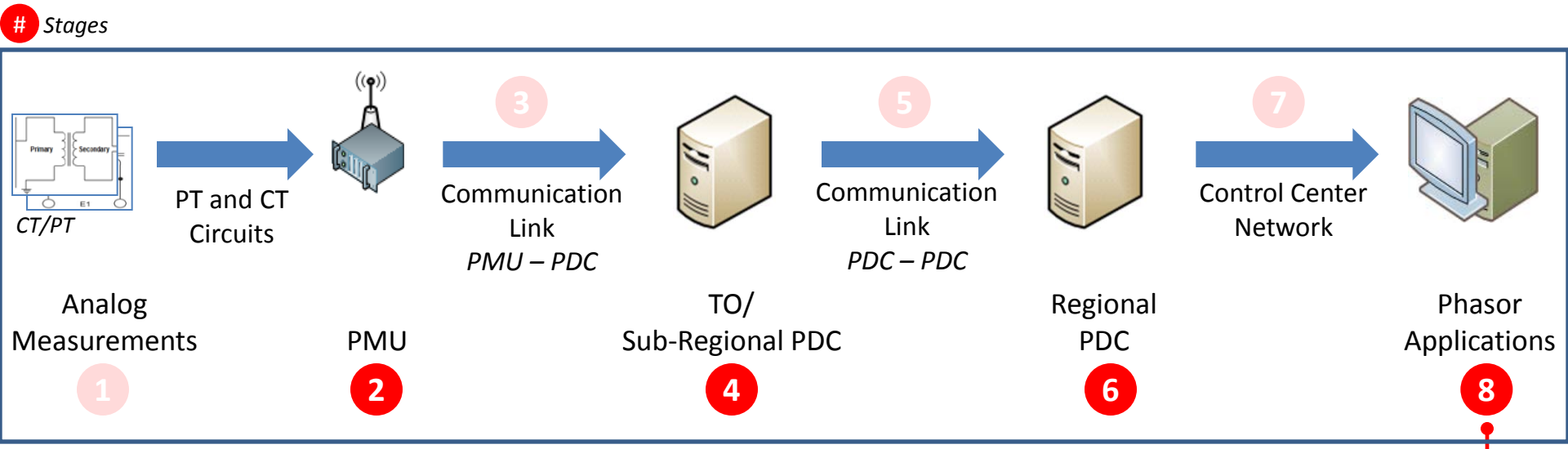


Errors flagged at Stage 2 + **Errors flagged at Stage 4** +

1. TO PDC Data Dropout Error
2. TO PDC sends data to Regional PDC with invalid timestamp
3. Data arrives at Regional PDC later than acceptable latency
4. TO PDC does not send data to Regional PDC when expected
5. TO PDC sends data in invalid format to Regional PDC
6. CRC error

Errors Detected by Phasor Applications

Errors that can be detected and flagged at <u>Stage 8</u>:



Errors flagged at Stage 2 + **Errors flagged at Stage 4** + **Errors flagged at Stage 6** +

PMUs reporting incorrect measurements but has not been flagged by PMUs or PDCs:

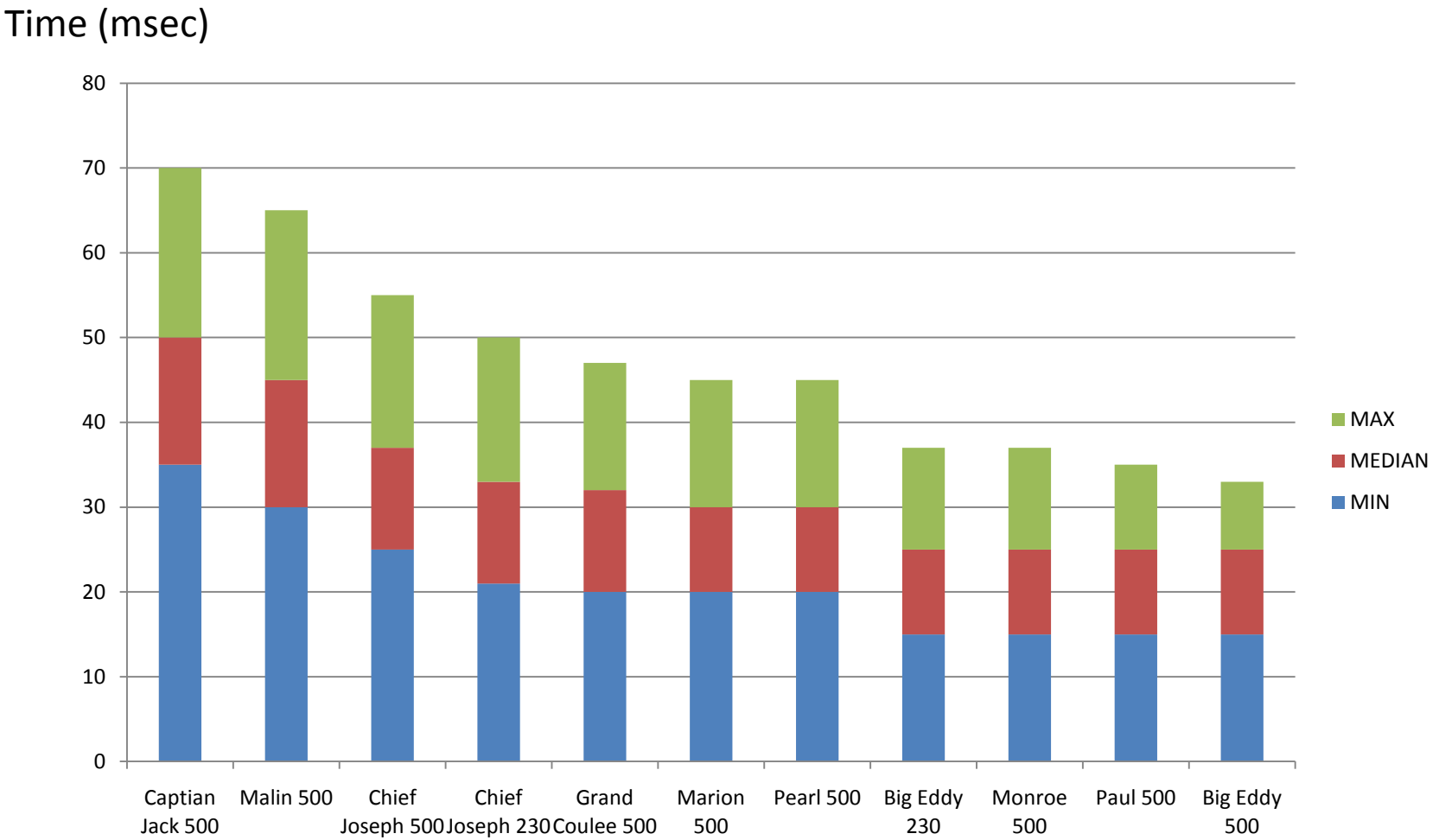
1. Sanity checks
2. Simple data checking against SCADA, SE, like signals
3. State confirmation

Part III
Performance Monitoring

PMU Statistics

- PMU statistics are collected at transmission owner's PDC over various periods of time
- Data quality:
  - Good data, out-synch data, lost data
- Latency (compare TO PDC GPS with PMU time stamp):
  - Minimum latency, maximum latency, distribution of latencies over a selected period
- NOTE – we should pay special attention to data quality and availability from "Reference PMUs" used for calculating phase angles for historical baselining

PMU Latency Statistics



TO PDC Statistics

- Data quality:
  - Good data, bad data, out-synch data, lost data
- Latency (compare Regional PDC GPS with TO PDC time stamp):
  - Minimum latency, maximum latency, distribution of latencies over a selected period
- TO PDC statistics are collected at Regional PDC

Part IV: Applications

Applications

- The data will get bad:
  - Missing data
  - Bad data, flagged by PMU
  - Corrupted data, not flagged by PMU
- An application must be designed:
  - To recognize bad data and alert tech staff
  - To continue operating correctly with partially bad data
  - To have intelligence to shunt down when the data quality is no longer adequate for correct decision making
- So, keep your applications simple and fail-safe
  - Do no harm, be inherently good

Applications

- Getting data quality flags is necessary, but not sufficient
- Measurements can be affected by
  - PT / CT issues
  - Single pole relaying used on 500-kV lines
- Data failure can look very similar to a disturbance that we are trying to protect against
- This is the benefit of Wide-Area Measurements, you can use many measurements for decision-making
  - Redundancy – measuring the same signals (from different sets of PTs and CTs)
  - Diversity – like signals measured at different locations (e.g. currents measured from both ends of a line, or phase angles at adjacent substations)

State Confirmation

- PMUs are directly measuring the system state
- If the network topology is known, a “state confirmation” application can be run to validate the measurements
- BPA will transmit the following in addition to phasors:
  - Individual phase quantities for voltages and currents
  - Breaker and disconnect status
- A pilot project on “state confirmation” will be very useful
- “State confirmation” is likely to be used as diagnostics tool first before using it for real-time operations and controls
- PITT prepared a statement of work for “state confirmation” prototype and demonstration project

“Simple” Checks

- Compare PMU measurements with SCADA measurements
- Compare PMU measurements with State Estimator model
  - Done successfully at AEP, ATC, PJM, CISO and BPA
  - Does the process need to be automated?
- Using PMU data only:
  - Compare several “like” measurements
    - Have many PMUs electrically close to each other
  - Make sure that all currents in a substation add to zero

Performance Measure for Applications

A. Percent of time application is functioning normally
B. Percent of time application is functioning at reduced capacity with incomplete information
C. Percent of time application is shut down due to bad or missing data
    - All PMUs and data received, v. reference PMUs?
    - Data quality dashboard within relevant applications?
D. The number of instances when an application took wrong action because of bad or missing data

Q&A

Background A

- PMU/Network performance statistics for 118 PMUs that feed data to RTDMS for NASPI at TVA (Eastern Interconnection) from 02/07/11 to 02/13/11
- Summary of PMU/Network performance:
  - PMUs with *0% data availability (i.e., not providing any data)*: 41% of the total 118 PMUs (on an average)

	2/7/2011	2/8/2011	2/9/2011	2/10/2011	2/11/2011	2/12/2011	2/13/2011
PMUs with 0% Availability (of 118 total PMUs)	48	48	46	47	47	50	50
	41%	41%	39%	40%	40%	42%	42%

  - PMUs with *>95% data availability*: 47% of the total 118 PMUs (on an average)

	2/7/2011	2/8/2011	2/9/2011	2/10/2011	2/11/2011	2/12/2011	2/13/2011
PMUs with > 95% Availability (of 118 total PMUs)	56	55	54	57	54	56	55
	47%	47%	46%	48%	46%	47%	47%

Background B

- PMUs from the same owner exhibit ***similar performance patterns*** – this can possibly be attributed to a communication/PDC issue instead of a PMU malfunction (see graphs in Appendix B for patterns) or company policies on data-sharing
- As of February 2011, PMUs from several companies were ***not reporting at all*** into Eastern Interconnection PDCs and applications:
  - Duke Energy *(3 PMUs)*
  - Entergy *(except 1 PMU that recently started reporting)*
  - ITC *(2 PMUs)*
  - Minnkota Power *(1 PMU)*

PMU/Network Performance Calculation Methodology

- PMU/network performance was determined based on the data status flags generated by the PMUs, TO PDCs and the TVA PDC (description of these status flags detailed on next page)
- PMU/network performance (or availability) is a measure of how much valid data is received compared to the total data received. The formula used is:

  *Valid Data / Total Data * 100%*

  Please note that the calculations are based on the total data that has been received and archived by RTDMS. The total data consists of both valid and invalid data.

  The statistics do not include data flowing during the following situations:

  - TVA PDC/RTDMS Server is down and not storing data to the RTDMS database
  - Dropouts/errors that may have occurred between TVA PDC and RTDMS

PMU Performance – Error Type & Description

Error Type	Error Description
Dropout	**Drop Outs:** The PDC, whether at a utility or at the central host site, synchronizes the received phasor data by sorting the data into an internal table based on their time stamps. The PDC has a nominal wait time (usually 1-2 seconds) for all the data to arrive so as not to miss any PMU's data. If, due to communication delays, the data from a PMU does not arrive within the wait time, then the PDC sends the synchronized data out without that PMUs data resulting in a data drop out for that PMU.
PMU Data Invalid	**PMU Data Invalid:** The individual PMUs have the ability to transmit data validity flags if the intelligence within this device construes the measurements to be unreliable. This direct information from the PMUs is preserved by the PDCs and is communicated within the real time stream.
Sync Error	**Synchronization Error:** PMUs use GPS clocks to provide precise timing reference to calculate phasor values and accurately time tag each of the phasor measurement samples. If the GPS synchronization signal to the PMU is lost for the PMU's time clock may no longer maintain its precision in which case the time tags could drift over time.
Time Alignment Error	**Time Alignment Error:** While short lapses in GPS synchronization signals may be tolerable, losing it permanently or for extended time periods make the time tags inaccurate. Logic within certain PDCs utilize the Synchronization flag status from the individual PMUs to identify such circumstances, in which case it sorts the data into the PDC table based on the time of arrival and sets an appropriate flag. In such cases, the phasor magnitude and frequency signals may still be dependable; however the phase angles are no longer reliable