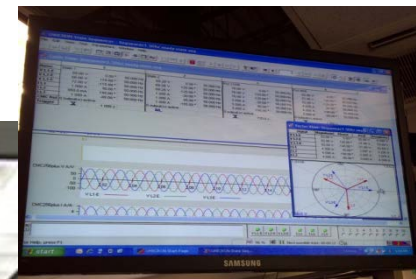# PG&E ARRA Synchrophasor Project

End-to-End Testing

June 9, 2011

Vahid Madani

Proof of Concept Testing – San Ramon

Proof of Concept Stage (POC)

POC is a smaller scale synchrophasor system used to test, validate, and demonstrate various functions, interoperability before field deployment. Also:

- Serves as a trouble shooting platform throughout the project
- Helps address life cycle support questions and requirements
- Provide initial training grounds for various disciplines
- Helps drive solutions both internal and the global standards (e.g: IEEE and IEC)
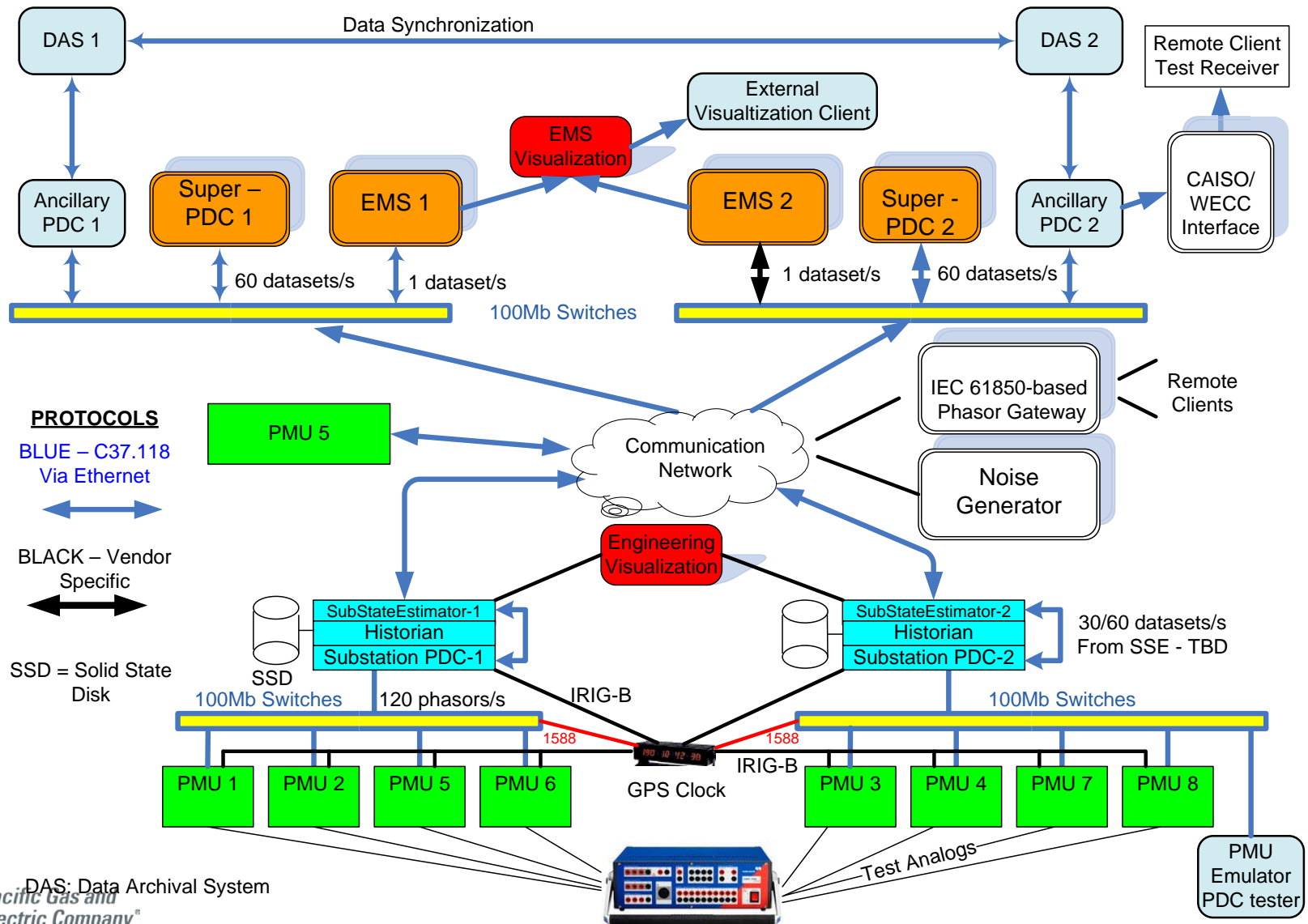
POC system includes:

- Minimum of 8 PMUs, 2 Aggregate PDCs, 2 Super PDCs (and EMS systems)
- A PMU Emulator (Generates over 40 PMU at 120 phasors/s, each stream 12 values)
- Digital Fault Recorder (DFR) and testing for PRC-002 recording
- Real Time Digital Simulation (RTDS) system
- COMTRADE file playback system
- GPS Clock with IRIG-B and IEEE-1588 time distribution protocols
- Additional series of test equipment capable of generating time-synched analog and digital signals
  - ✓ Five 3-phase voltage Sources
  - ✓ Ten 3-phase current sources
  - ✓ Synchronized test waveform generation
- Noise impairment Tools ologyand Tec
  - ✓ Communication routers, switches, delay line, as well as test equipment (e.g., traffic and error bit generators)

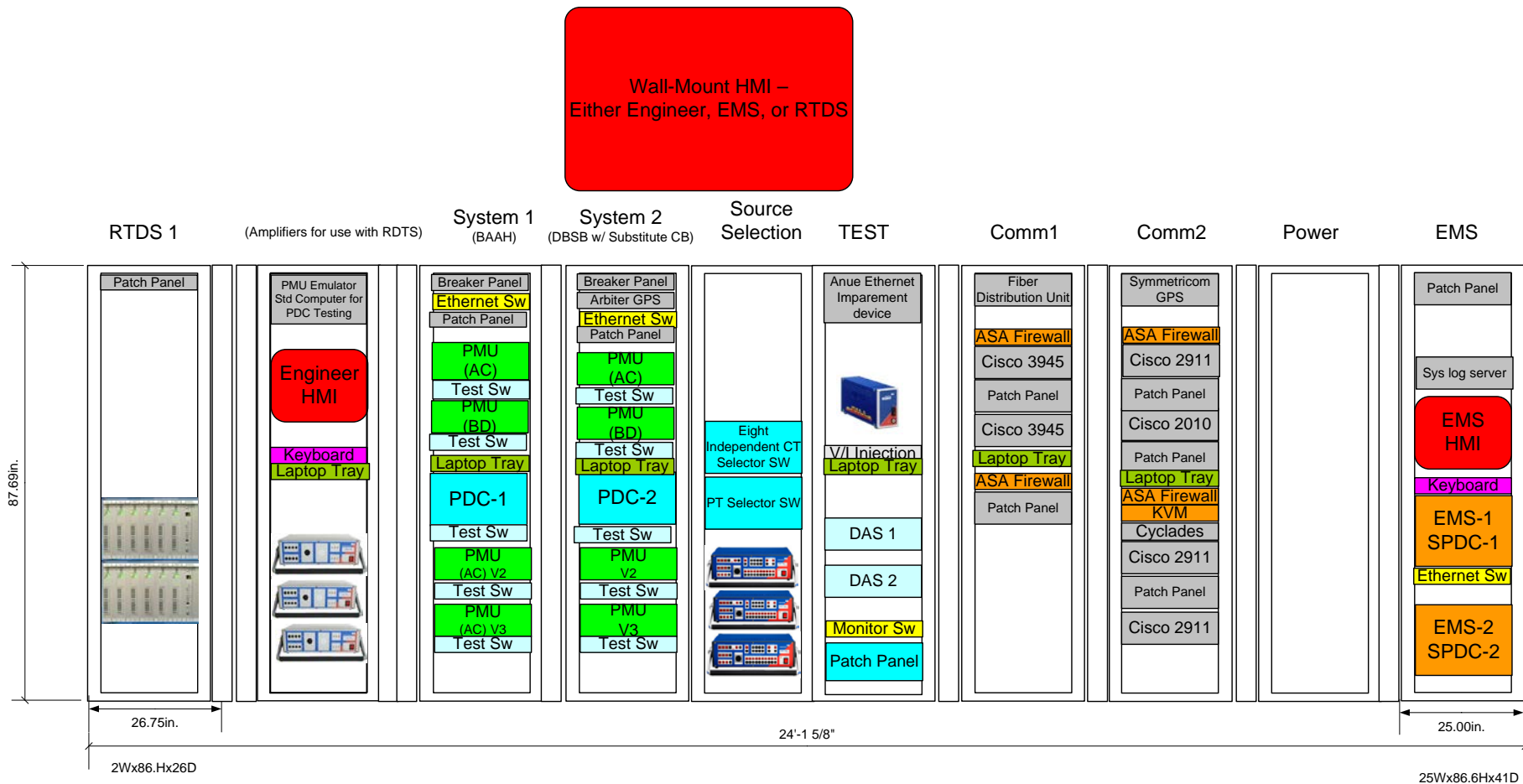Testing is well underway with significant results

Proof of Concept Testing - Architecture

PG&E Synchrophasor Project – Proof of Concept Architecture
C37.118 is used for interim testing while harmonization with IEC 61850 is demonstrated

PROTOCOLS

BLUE – C37.118
Via Ethernet

BLACK – Vendor Specific

SSD = Solid State Disk

DAS: Data Archival System

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Proof of Concept Testing - Rack-Layout

Hierarchical Layers of System Testing
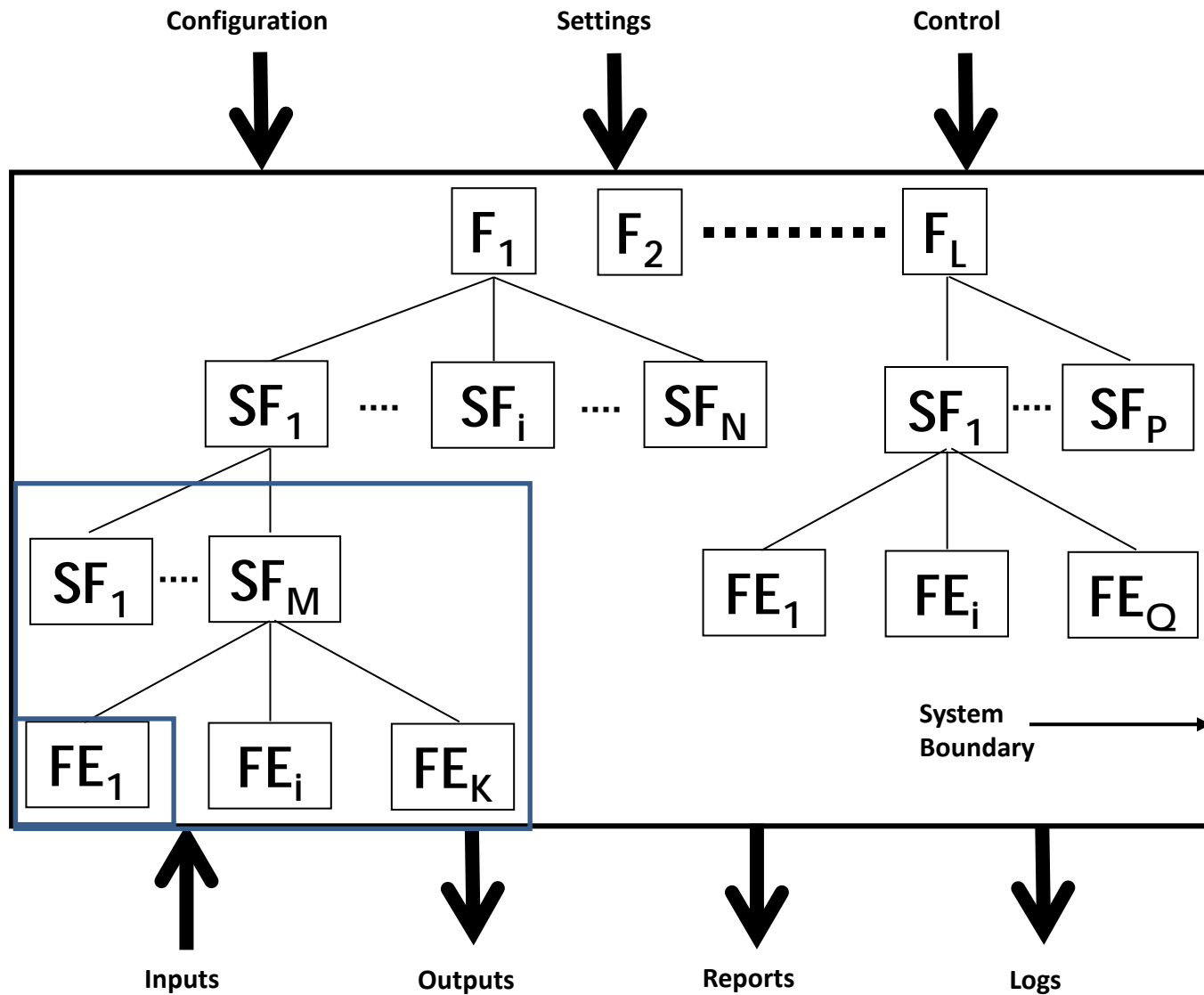
PMU and PDC Initial Key Test Considerations

- Port set-up and data framing / packets
- True "transparent" multicasting
- Data streaming - Records per second set point, and performance when multi-functions are assigned to the port
  - E.g: Protection functions vs. Synchrophasor data streaming
- Threshold set points for PDC processing
- Ramp and step responses
- PDC performance
- Impact of noise or data streaming impairment
- PMU data with momentary loss of synchronization
- Data reporting for different Classes of data ("P" and "M")
- Bandwidth and storage verification

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TCP / UDP Communication Observations -2

- Various combination of TCP/UDP protocols are available in products for communicating commands (from PDC to PMU), header and configuration files (from PMU to PDC), and data streams (to PDC).
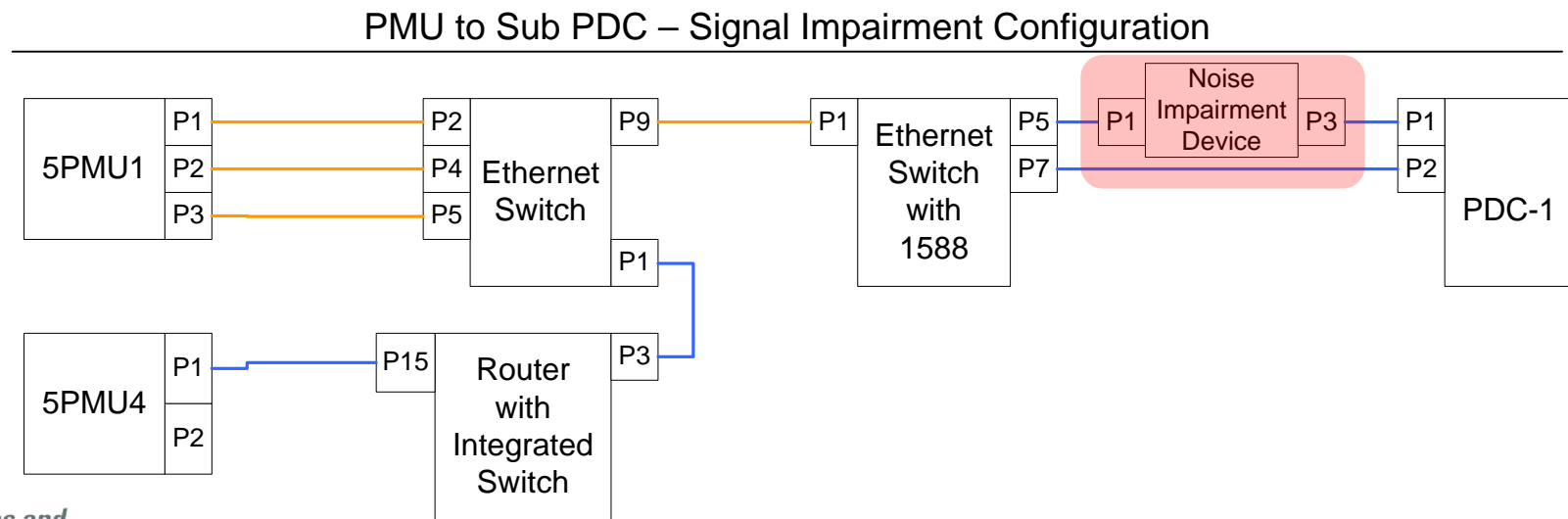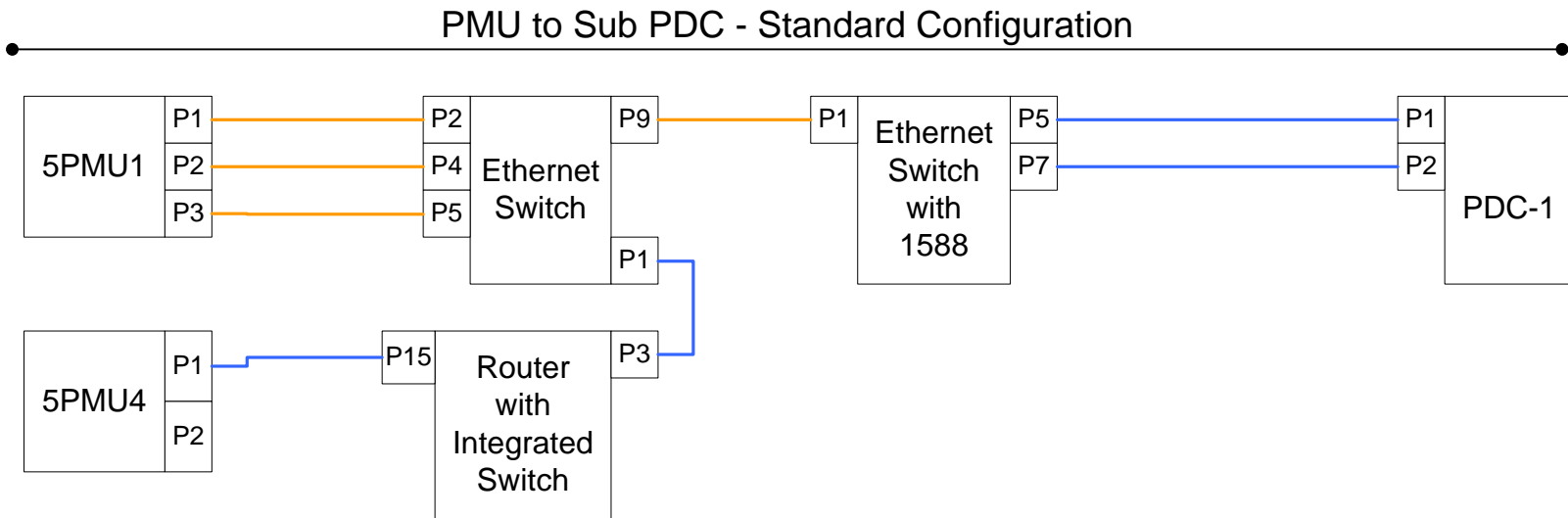
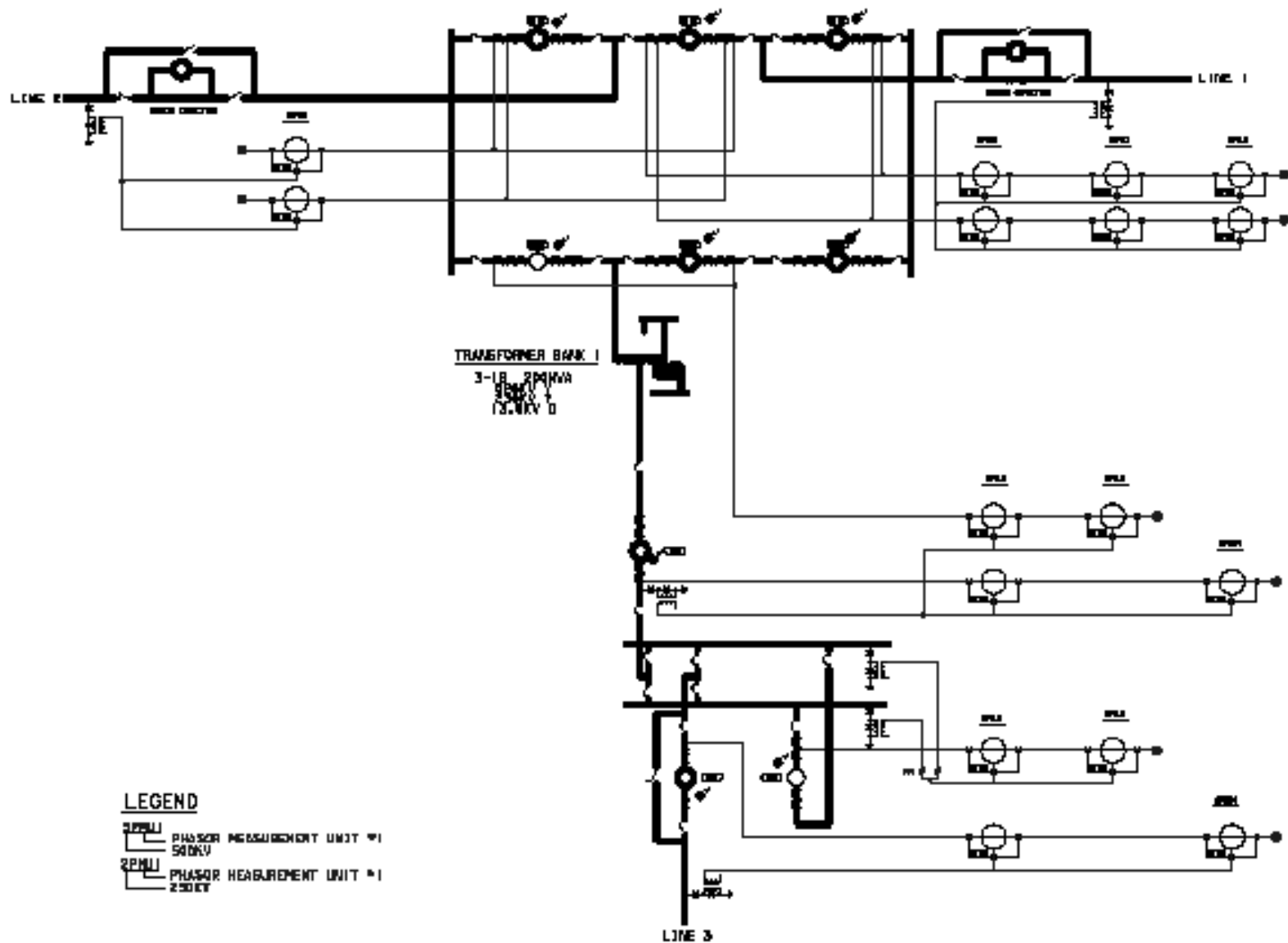| IP Combinations Available	Command (from PDC to PMU)	CFG / HEADER	Phasor Data
OPT-1	(Ignored)	UDP (periodic, unsolicited)	UDP
OPT-2	TCP	TCP	UDP
OPT-3	TCP	UDP	UDP
OPT-4	TCP	TCP	TCP

POC Observations – Continued

- Various set up and product interoperability
  - Verify various combinations of UDP and TCP protocols used in each product for
    - Command communications (e.g., start/stop)
    - Configuration communications (e.g., Config 1, Config2, and future Connfig 3)
    - Synchrophasor data streaming
  - Verify Config files (Config 1, 2, and 3)
  - Certain PMUs expect control bits in the IRIG clock to be set to send correct year. Without these, they use default year (2000). Other PMUs can use the IRIG clock without the control bits, and the use a local device clock setting as the date / year etc.
  - From end user perspective, the UTC time:
    - Should be transparent relative to the local time displayed in front of the clock
    - Real-time information should be in local time
    - COMTRADE file plots and other post mortem troubleshooting tools need to display in lcoal time with optional user conversion tool for UTC time.

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Noise Impairment Tests

- Noise Injection / IP Packet interference

PMU to Sub PDC - Standard Configuration

PMU to Sub PDC – Signal Impairment Configuration

# System Schematic - POC

Noise Impairment Test – Dropped Data Packets

- Noise Impairment tests – Missing/corrupted data packets
  - The PDC interpolated for the missing / corrupt data packets
  - Used a logarithmic signal pattern to test - network corrupting 1 phasor packet for every 13 packets
    - PDC Interpolates to replace missing data
    - PDC is required to flag data is interpolated
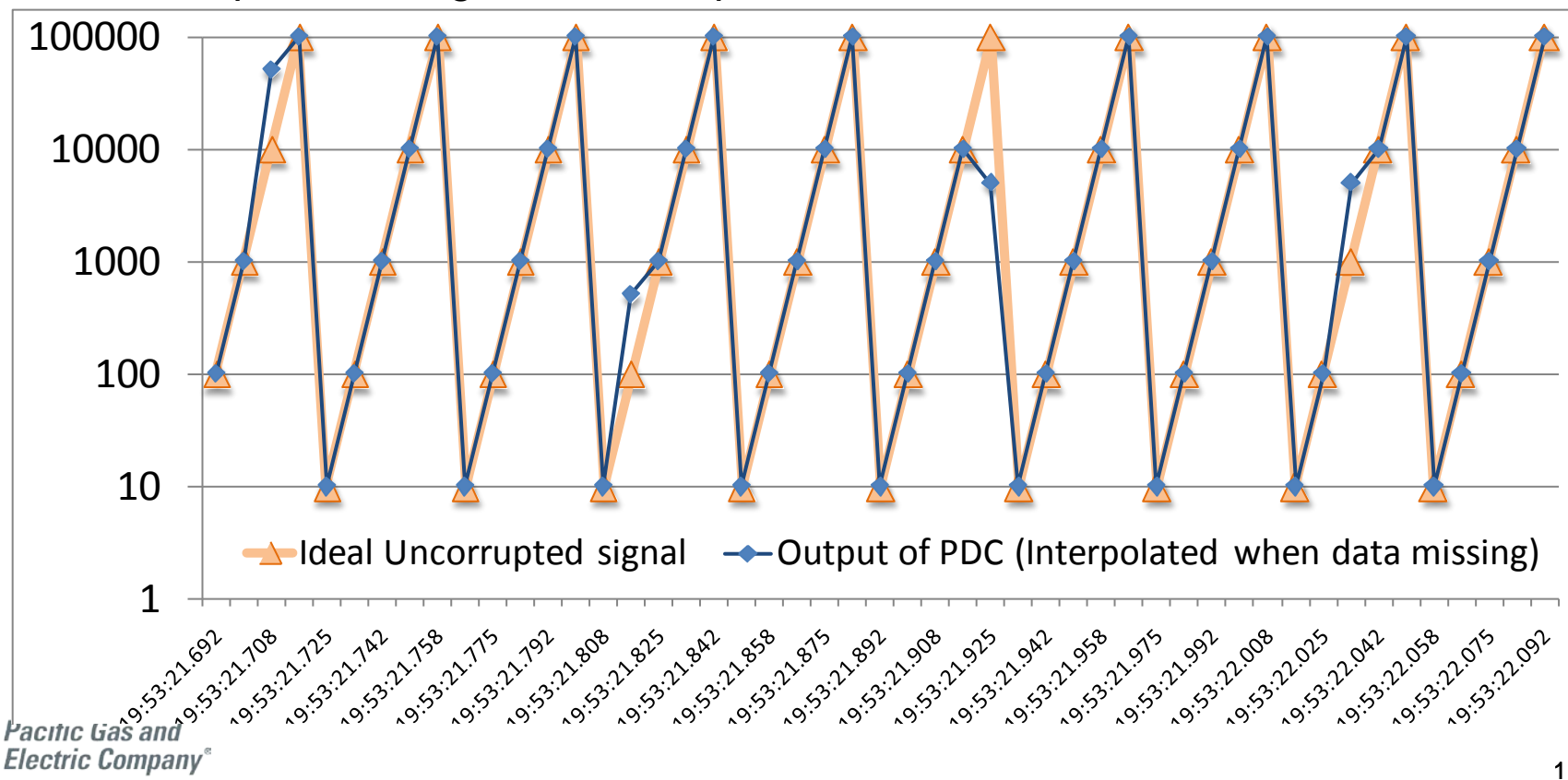
Noise Impairment Test – Corrupt Data Injection

- Noise Impairment tests – Frequent corrupt data packets
  - Data frame withheld and sent much later (20 frames later)

Before Noise Injection

Historian Trend

	Timestamp	Value	Quality
01.VM	5/26/2011 22:14:36.200	10000	Good
01.VM	5/26/2011 22:14:36.192	1000	Good
01.VM	5/26/2011 22:14:36.183	100	Good
01.VM	5/26/2011 22:14:36.175	10	Good
01.VM	5/26/2011 22:14:36.167	100000	Good
01.VM	5/26/2011 22:14:36.158	10000	Good
01.VM	5/26/2011 22:14:36.150	1000	Good
01.VM	5/26/2011 22:14:36.142	100	Good
01.VM	5/26/2011 22:14:36.133	10	Good
01.VM	5/26/2011 22:14:36.125	100000	Good

Noise Injection in Progess

Historian Trend

| Tagname	Timestamp	Value	Quality
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.592	99.17124	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.583	99.0959	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.575	99.02056	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.567	98.94522	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.558	98.86988	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.550	427.6677	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.542	511.2015	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.533	594.7354	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.525	678.2692	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:15:53.517	761.803	Good

After Noise Injection

Historian Trend

Tagname	Timestamp	Value	Quality
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.592	100	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.583	10	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.575	100000	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.567	10000	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.558	1000	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.550	100	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.542	10	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.533	100000	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.525	10000	Good
POC-EMT1.16.Phasor01.VM	5/26/2011 22:17:33.517	1000	Good

Additional points

- GOOSE message triggering
  - Use of GOOSE messaging –
    - The devices are programmed to perform a data record capture on receipt of a message
    - Adaptive protection application and visualization applications (DOE research project)
      - DOE Research Grant

- Power Cycle Testing
  - Verify PMU devices and aggregate PDCs able to re-establish connection on power cycling of individual devices.
  - Power cycling certain PMU devices did not result in re-establishment of connection (these PMUs happen to use TCP connection). The PDC had to be restarted for the connection to be established again.

- Measurements reported on low magnitudes
  - Some PMUs may zero out reported angles, when the magnitude is too low. Other PMUs may report whatever their calculations show (usually random variation of angles if magnitude is zero.)
  - Various set up and product interoperability verifications
  - Have seen variations among PMU measurements (within TVE of 1%)

Security/Dependability Balance - DOE Collaborative Research Grant with VT and MSU

Adaptive Protection Scheme
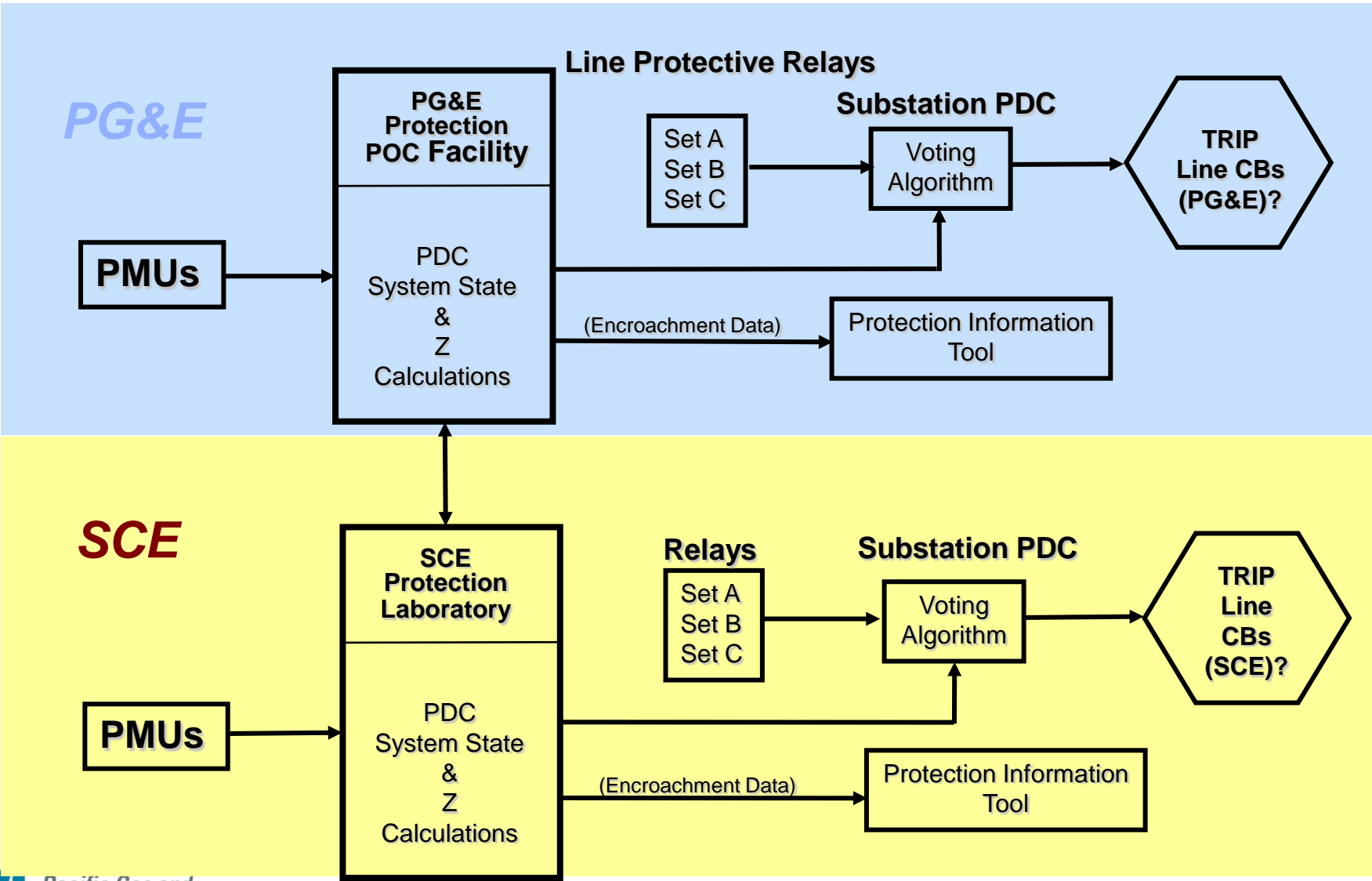
Expansion of IEC 61850 - Outside Substation Environments

- IEC 61850 as communication interface with EMS
  - Simplified Substation integration
- IEC 61850 as single substation model
  - Single IEC 61850/IEC 61850 Substation PDC used as single Substation interface
  - Single access for remote control, maintenance & asset management
  - Version management for Hardware, Software, Configuration and Setting
- IEC61850 as a fast automation back bone to support Wide Area Automation

Control & Asset Management Centers

IEC 61850

IEC 61850

PDC

IEC 61850

PMUs

PMUs

IEDs

Substation