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
  - 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

**PMU:** Phasor Measurement Unit

**EMS:** Energy Management System

**PDC:** Power Distribution Center

**CAISO/WECC:** California Independent System Operator/Western Electricity Coordinating Council

**IRIG-B:** International Recommmended Standard for the Exchange of Digital Timing and Timing-Related Information

---

**PMU 5**

SubStateEstimator-1

Historian

Substation PDC-1

SSD

100Mb Switches

120 phasors/s

**PMU 6**

**PMU 1**

**PMU 2**

**PMU 3**

**PMU 4**

**PMU 7**

**PMU 8**

GPS Clock

Test Analogs

PMU Emulator PDC tester

DAS 1

Super – PDC 1

EMS 1

EMS Visualization

EMS 2

Super - PDC 2

Ancillary PDC 2

DAS 2

Remote Client Test Receiver

Communication Network

IEC 61850-based Phasor Gateway

Remote Clients

30/60 datasets/s From SSE - TBD

**DAS:** Data Archival System

**GPS Clock:** Global Positioning System Clock

**IRIG-B:** International Recommmended Standard for the Exchange of Digital Timing and Timing-Related Information

**100Mb Switches:** Gigabit Ethernet Switch

**120 phasors/s:** 120 measurements per second

**60 datasets/s:** 60 datasets per second

**1 dataset/s:** 1 dataset per second

**100Mb Switches IRIG-B:** Gigabit Ethernet Switch with IRIG-B synchronization

---
Proof of Concept Testing - Rack-Layout

Wall-Mount HMI – Either Engineer, EMS, or RTDS

RTDS 1
(Amplifiers for use with RTDS)

System 1
(BAAH)

System 2
(DBSB w/ Substitute CB)

Source Selection

TEST

Comm1

Comm2

Power

EMS

26.75 in.

25.00 in.

24'-1 5/8"

2Wx86.8Hx26D

25Wx86.6Hx41D
Hierarchical Layers of System Testing

Configuration

Settings

Control

System Boundary

Inputs

Outputs

Reports

Logs
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
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).

<table>
<thead>
<tr>
<th>IP Combinations Available</th>
<th>Command (from PDC to PMU)</th>
<th>CFG / HEADER</th>
<th>Phasor Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPT-1</td>
<td>(Ignored)</td>
<td>UDP (periodic, unsolicited)</td>
<td>UDP</td>
</tr>
<tr>
<td>OPT-2</td>
<td>TCP</td>
<td>TCP</td>
<td>UDP</td>
</tr>
<tr>
<td>OPT-3</td>
<td>TCP</td>
<td>UDP</td>
<td>UDP</td>
</tr>
<tr>
<td>OPT-4</td>
<td>TCP</td>
<td>TCP</td>
<td>TCP</td>
</tr>
</tbody>
</table>
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, Config 2, and future Config 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 local time with optional user conversion tool for UTC time.
Noise Impairment Tests

- Noise Injection / IP Packet interference

**PMU to Sub PDC - Standard Configuration**

5PMU1

- P1
- P2
- P3

P2

- P4
- P5

P9

- P1

Ethernet Switch

P2

- Ethernet Switch with 1588

P1

P5

- P7

PDC-1

5PMU4

- P1
- P2

P15

- P3

Router with Integrated Switch

**PMU to Sub PDC – Signal Impairment Configuration**

5PMU1

- P1
- P2
- P3

P2

- P4
- P5

P9

- P1

Ethernet Switch

P2

- Ethernet Switch with 1588

P1

P5

- P7

PDC-1

5PMU4

- P1
- P2

P15

- P3

Router with Integrated Switch

Noise Impairment Device
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

<table>
<thead>
<tr>
<th>Tagname</th>
<th>Timestamp</th>
<th>Value</th>
<th>Quality</th>
</tr>
</thead>
</table>

After Noise Injection

<table>
<thead>
<tr>
<th>Tagname</th>
<th>Timestamp</th>
<th>Value</th>
<th>Quality</th>
</tr>
</thead>
</table>
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%)
Adaptive Protection Scheme

PG&E

PMUs

PG&E Protection POC Facility

Set A
Set B
Set C

Substation PDC

Voting Algorithm

TRIP Line CBs (PG&E)?

(Encroachment Data)

Protection Information Tool

Line Protective Relays

PDC System State & Z Calculations

SCE

PMUs

SCE Protection Laboratory

Set A
Set B
Set C

Substation PDC

Voting Algorithm

TRIP Line CBs (SCE)?

(Encroachment Data)

Protection Information Tool

PDC System State & Z Calculations
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